Universidade de Aveiro Departamento de Engenharia Mecânica
2020

Lucas Martins

Construção e teste de máquina de fabrico aditivo de metais

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Relatório de projeto apresentado à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia Mecânica, realizada sob orientação científica de António Manuel de Bastos Pereira, Professor Associado com Agregação do Departamento de Engenharia Mecânica da Universidade de Aveiro.

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Palavras-chave

Fabrico aditivo, DMLS, SLS, SLM, Impressão 3D de metais, Laser, Controlo de Motores.

Resumo

O Fabrico Aditivo está a revolucionar o desenvolvimento do produto e da sua produção. Esta tecnologia apresenta numerosas vantagens, em particular a enorme liberdade geométrica através do desenvolvimento de componentes com geometria complexa, orgânica e otimizada, quando comparada com peças produzidas através de processos convencionais. O trabalho desenvolvido neste projeto abrange uma breve descrição da tecnologia de Fabrico Aditivo direcionada para a sinterização direta de metais por laser (Direct Metal Laser Sintering - DMLS), onde é apresentado o processo, materiais usados e os fabricantes de máquinas disponíveis no mercado. O objetivo deste projeto visa a finalização de uma máquina de fabrico aditivo de metais desenvolvida no Departamento de Engenharia Mecânica da Universidade de Aveiro. Com o projeto inicial da máquina previamente definido e parcialmente construído, realizaram-se alterações e novas aplicações de modo a tornar a máquina funcional. Ao nível do comando da máquina, foram efetuadas alterações do esquema elétrico inicial e parametrizados alguns dos componentes integrados, de forma a ser possível controlar e realizar ensaios experimentais na máquina. Os resultados obtidos através dos testes efetuados permitiram concluir que todos os componentes integrantes da máquina se encontram funcionais.

Keywords Additive manufacturing, DMLS, SLS, SLM, 3D metal printing, Laser, Motor Control.

Abstract Additive Manufacturing is revolutionizing the Product Development industry and its production as this technology possesses numerous advantages. When compared to more usual production processes, Additive Manufacturing has proven to be able to achieve highly complex, organic and optimized geometries due to the great amount of geometric and shape freedom. This documents body of work encapsules a brief description of Additive Manufacturing and its technology applied to the Direct Metal Laser Sintering (DMLS), where the process, used materials and available machine and manufactorers are presented and discussed. The project produced for this document has the goal of developing and building an Additive Manufacturing machine for metals and was done in Departamento de Engenharia Mecânica of University of Aveiro. An existing project was used as a basis and some alterations and enhancments were made in order to make the machine functional. Some changes were also made to the machine's existing eletrical componentes and adjustments to its parts were also made in order to allow the control and execution of experimental tests for the project. After such tests the reliability of the machine was confirmed and it is possible to say that it is functioning and operational.

Conteúdo

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Lista de Abreviaturas

3D Tridimensional

ASTM *American Society for Testing and Materials*

BJ *Binder Jetting*

CAD *Computer Aided Design*

CJP *ColorJet Printing*

CNC *Computer Numeric Control*

DED *Directed Energy Deposition*

DEM Departamento de Engenharia Mecânica

DLP *Digital Light Processing*

DMLS *Direct Metal Laser Sintering*

DoD *Drop on Demand*

EBAM *Electron Beam*

EBM *Electron Beam Melting*

FA Fabrico Aditivo

FDM *Fused Deposition Modelling*

FFF *Fused Filament Fabrication*

FLM *Fused Layer Modelling*

LD *Laser Deposition*

LENS *Laser Engineered Net Shaping*

LOM *Laminated Object Manufacturing*

LS *Laser Sintering*

ME *Material Extrusion*

MJ *Material Jetting*

MJM *Multi Jet Modeling*

NF Normalmente Fechado

NI *National Instruments*

PBF *Powder Bed Fusion*

SL *Sheet Lamination*

SLA *Stereolithography*

SLM *Selective Laser Melting*

SLS *Selective Laser Sintering*

UC *Ultrasound Consolidation*

VP *VAT Photopolymerisation*

ZM Zero Máquina

Lista de Unidades

$	Dólar Americano
°C	Temperatura em graus *celsius*
A	Ampere
cm^3/h	Centímetro cúbico por hora
h	Hora
HRB	Dureza *Rockwell* pelo método B
HRC	Dureza *Rockwell* pelo método C
HV	Dureza *Vickers*
Hz	Hertz
g	Grama
GPa	Gigapascal
m	Metro
m/s^2	Metro por segundo quadrado
min	Minuto
MPa	Megapascal
N	*Newton*
$N.m$	*Newton* metro
Ohm	Ohm
Ra	Rugosidade média
rpm	Rotação por minuto
s	Segundo
V	*Volt*
W	*Watt*

Lista de Símbolos

$AlSi_{10}Mg$	Liga de Alumínio, Silício e Magnésio
$PTFE$	Politetrafluoretileno
Ti	Titânio
Yb	Itérbio

Parte I

Enquadramento

Capítulo 1

Introdução

O presente relatório de projeto insere-se no Mestrado Integrado em Engenharia Mecânica da Universidade de Aveiro, no Departamento de Engenharia Mecânica (DEM).

Este projeto tem como finalidade dar mais um passo na construção e teste de uma máquina de Fabrico Aditivo (FA) de metais, uma máquina de sinterização direta de metais por laser (*Direct Metal Laser Sintering* - DMLS). O desenvolvimento deste projeto permitiu solucionar alguns dos constrangimentos inerentes a este tipo de equipamento, nomeadamente os fins de curso e o controlo dos motores da máquina, de entre outros.

1.1 Âmbito do tema

Nos dias de hoje, a tecnologia de FA tem vindo a demonstrar uma forte eficácia na produção de componentes metálicos. Este tipo de tecnologia apresenta várias vantagens em relação a processos de fabrico subtrativos. Esta realidade tornou evidente a importância da investigação neste tipo de tecnologia de FA.

1.2 Organização geral do relatório de projeto

O relatório de projeto encontra-se dividido em quatro partes:

- A **Parte I - Enquadramento** é constituída pelos capítulos 1, 2 e 3, que apresentam o enquadramento do projeto. O capítulo 1 enquadra a introdução ao trabalho onde é destacada a pertinência do tema abordado e a estrutura geral do relatório de projeto. O capítulo 2 introduz os objetivos do projeto e, por fim, o capítulo 3 descreve e analisa, com fundamentação teórica, os conceitos relacionados com o FA, como por exemplo a sua evolução no mercado, bem como os processos e materiais usados no mesmo.

- A **Parte II - Métodos e Modelos** integra o capítulo 4 e 5. No capítulo 4 são apresentados os obstáculos que foram surgindo ao longo da construção da máquina. Para além disso, são propostas algumas das soluções viáveis para a resolução destes problemas, através do projeto das soluções. Já no capítulo 5 é abordado o controlo do equipamento, os *software* usados para tal e é apresentado ainda o desenvolvimento da preparação do ensaio experimental.

- A **Parte III - Resultados e Discussão** é composta pelos capítulos 6 e 7. O capítulo 6 mostra os modelos finais escolhidos no capítulo 4 e a sua aplicação real na máquina. Já no capítulo 7, são apresentados os resultados obtidos nos ensaios experimentais realizados.

- A **Parte IV - Conclusão** está organizada num único capítulo, o capítulo 8. Este capítulo apresenta as reflexões finais do autor sobre o projeto, bem como os possíveis desenvolvimentos que poderão ser realizados no futuro.

Capítulo 2

Objetivos

O principal objetivo deste projeto centra-se em concluir a construção segundo um projeto realizado em trabalhos anteriores e testar a máquina de DMLS que se encontra no laboratório de soldadura do DEM da Universidade de Aveiro. Para tal, o trabalho será dividido em duas componentes principais: a parte mecânica e a parte de comando da máquina.

- Na parte mecânica, encontrar-se-ão os problemas associados à mecânica da máquina, nomeadamente os fins de curso da varredora e o zero máquina dos elevadores, especificamente a forma de os fixar e definidos os componentes ou peças necessários.
- Na parte de comando elétrico, é explicado o controlo dos motores da máquina e do sistema de laser, assim como, são expostas as alterações realizadas no esquema elétrico e indicadas as parametrizações dos componentes integrados.

O objetivo final do projeto centra-se na realização de um ensaio experimental do controlo dos motores e do sistema de laser, bem como, a apreciação dos resultados.

Capítulo 3

Revisão do Estado da Arte

3.1 Fabrico Aditivo

A prototipagem rápida é conhecida como um processo de desenvolvimento de modelos físicos produzidos a partir de um *software Computer Aided Design* (CAD) e gerado por sucessivas camadas de material. Comparando a prototipagem rápida com processos de fabrico mais convencionais é possível concluir que esta permite uma produção de protótipos e modelos físicos mais rápida e rentável do ponto de vista económico (Relvas, 2018).

O processo evolutivo do desenvolvimento desta tecnologia evidenciou que a sua aplicação não se deveria restringir à produção de protótipos mas sim, avançar para o fabrico de produtos reais e, desta forma possuir um papel naquele que é o ciclo do produto. Desta forma, o desenvolvimento desta tecnologia, intitulada de FA, tornou evidente a sua praticidade (Gibson, Rosen e Stucker, 2010).

Assim sendo, em 1981 surge o FA, após a publicação de *Hideo Kodama* do *Nagoya Municipal Industrial Research Institute* acerca de um modelo físico impresso. Posteriormente, desenvolveu-se um modelo Tridimensional (3D) baseado na produção por meio da sobreposição de camadas poliméricas. Tal processo intitula-se de estereolitografia (*Stereolithography* - SLA) e é, ainda nos dias de hoje, utilizado na obtenção de peças. O SLA foi desenvolvido e patenteado por *Charles Hull*, nos Estados Unidos e é capaz de criar modelos a partir da polimerização de resina líquida fotossensível por ação de luz ultravioleta (Schotte, 2019).

3.1.1 A evolução do Fabrico Aditivo

Embora o FA (também conhecido por impressão 3D) seja uma tecnologia com forte desenvolvimento recente, a verdade é que esta se encontra no mercado desde 1987. O espectro de aplicação desta tecnologia restringia-se, inicialmente, à indústria, todavia recentemente alargou-se ao consumidor comum. O desvio existente entre a invenção e a aplicação pode ser facilmente explicado pela procura do consumidor e consequente crescimento da exposição desta tecnologia nos mídia (Relvas, 2018).

O SLA, em 1987, foi o primeiro processo de FA desenvolvido e comercializado pela empresa *3D Systems*. Desde essa época, foram realizados inúmeros estudos que culminaram no desenvolvimento notório da comercialização do processo de FA, nomeadamente sinterização seletiva a laser (*Selective Laser Sintering* - SLS) pela empresa *EOS* (*Elec-*

tro Optical Systems) (Wohlers Associates Inc., 2015; Grenda, 2005). Na Figura 3.1 é apresentado um cronograma da linha temporal das invenções de algumas tecnologias de FA.

Nos inícios do século *XXI* a tecnologia de FA apresentou um crescimento acentuado justificado pela evolução dos computadores e das suas capacidades gráficas, melhoria do CAD, materiais mais dotados, consolidação de processos e, por fim, pela globalização alcançada pela *internet*. O desenvolvimento de novos e acessíveis modelos de impressoras 3D foi impulsionado pelo vencimento de patentes mais antigas, nomeadamente, a deposição de filamentos fundidos (*Fused Deposition Modelling* - FDM). Para além disso, estes avanços na tecnologia de FA permitiram o desenvolvimento de comunidades virtuais onde são partilhadas peças de FA em *open source* (Chua e Leong, 2017).

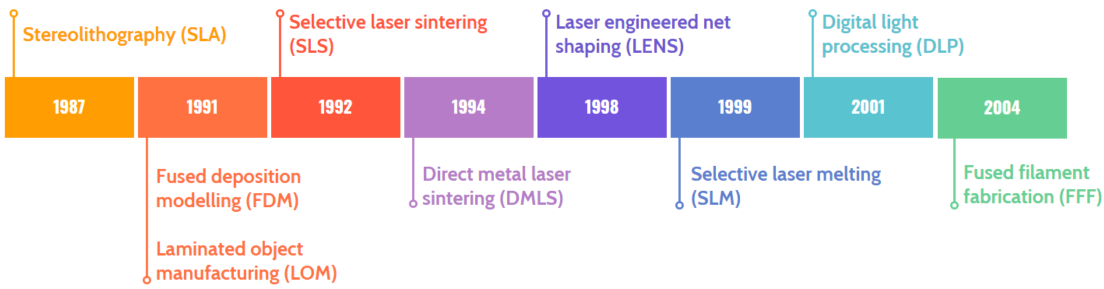


Figura 3.1: Cronograma do aparecimento das tecnologias de Fabrico Aditivo (FA) no mercado, adaptado de Gornet e Wohlers, 2014

A indústria do FA, em 2014, que inclui todos os produtos de FA e serviços a nível mundial, cresceu 35,2% (3.625 mil milhões de euros) em comparação com 2013. A tecnologia de FA de metais aumentaram a sua popularidade, uma vez que, se estima que quinhentos e quarenta e três máquinas de FA de metais foram vendidas em 2014, um crescimento de 54,7% em relação a 2013 (Wohlers Associates Inc., 2015).

O mercado do FA, mais recentemente, em 2019, atingiu a marca dos $10 mil milhões e as previsões até 2029 são de um crescimento contínuo com a possibilidade de atingir os $55 mil milhões. A Figura 3.2, apresenta as previsões de crescimento até 2029, onde o principal setor do mercado são os serviços associados ao FA, representado pelas barras cinzentas (Sher, 2020).

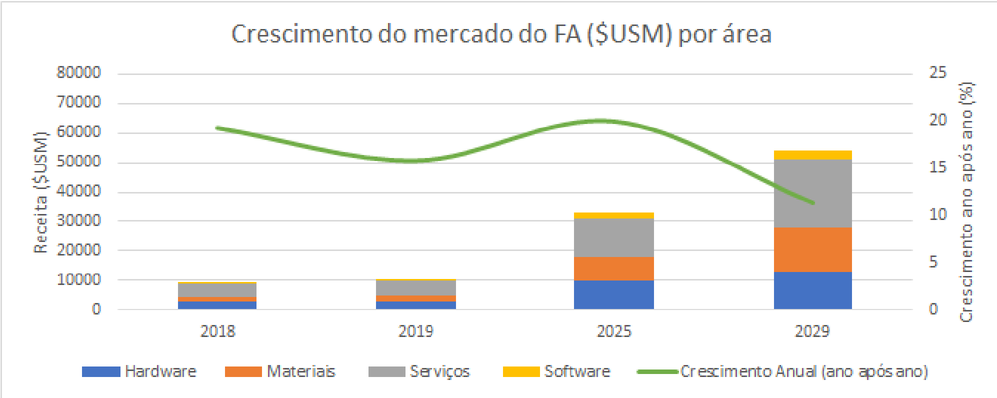


Figura 3.2: Crescimento total do mercado no FA, adaptado de Sher, 2020

3.1.2 Processos de Fabrico Aditivo e materiais

O FA incorpora diferentes processos e materiais com características distintas que resultam na obtenção de peças com propriedades funcionais diferenciadas. Desta forma, o produto final do FA está diretamente dependente da escolha do material e do processo de produção. Os diferentes processos de FA apresentam vantagens e desvantagens, relacionadas com os equipamentos e materiais associados, e permitem desenvolver peças em material polimérico, metálico, cerâmico, compósito e orgânico. É importante enaltecer que, o principio de sobreposição de camadas é comum a todos os processos de FA, o que os distingue entre si é o tipo de material, o endurecimento das camadas ligantes e o ligante entre cada uma (Warnier e Verbruggen, 2014).

Em 2009, com vista à normalização do FA, foi constituído o comité técnico F42 pela *American Society for Testing and Materials* (ASTM). De forma idêntica, também ao nível internacional há o comité ISO/TC 261 (ISO/TC, 2011). Ambos os grupos colaboram na construção de normas relacionadas com o FA, por exemplo as ISO 17296, ISO/ASTM 52900 e ISO/ASTM 52912 (ISO, 2015; ISO/ASTM, 2015; ISO/ASTM, 2020). Esta última norma define sete categorias de processamento em FA, que são: fotopolimerização em tina-estereolitografia (*VAT Photopolymerisation* - VP), jato de aglomerante (*Binder Jetting* - BJ), jato de material (*Material Jetting* - MJ), extrusão de material (*Material Extrusion* - ME), fusão de leito em pó (*Powder Bed Fusion* - PBF), laminagem de folhas (*Sheet Lamination* - SL) e deposição por energia direta (*Directed Energy Deposition* - DED). A Tabela 3.1 apresenta uma categorização dos processos aditivos, incluindo suas vantagens e limitações (Loughborough University, s.d.; Tofail et al., 2018; Relvas, 2018).

Tabela 3.1: As sete categorias da Fabrico Aditivo (FA) segundo o *American Society for Testing and Materials* (ASTM), processos e materiais, adaptado de Loughborough University, s.d.; Tofail et al., 2018; Relvas, 2018

ASTM/ tecnologias	**Processos de FA**	**Breve descrição**	**Materiais**	**Vantagens**	**Desvantagens**
Deposição por energia direta (Directed Energy Deposition - DED)	• Deposição a laser (Laser Deposition - LD) • Formação de pó a laser (Laser Engineered Net Shaping - LENS) • Feixe de elétrons (Electron beam - EBAM) • Fusão por arco de plasma (Plasma arc melting)	Depósito de partículas fundidas por um laser	• Cerâmicos • Híbridos • Metais	• É possível controlar a estrutura granular até um alto grau, o que permite a processos de reparação de alta qualidade, de peças funcionais; • Peças de alta qualidade.	• Material usado limitado; • Necessário por vezes pós- -processamento; • É necessário um equilíbrio entre qualidade de superfície e velocidade.
Extrusão de material (Material Extrusion - ME)	• Deposição de filamentos fundidos (Fused Deposition Modelling - FDM) • Fabricação de filamentos fundidos (Fused Filament Fabrication -FFF) • Modelagem de camada fundida (Fused Layer Modelling - FLM)	Extrusão de um filamento fundido através de um bocal aquecido	• Compósitos • Polímeros	• Processo globalizado e acessível; • Permite construir peças totalmente funcionais.	• O raio do bocal limita e reduz a qualidade final; • Efeito escada visível; • Anisotropia vertical.

Fotopolimerização em tina estereolitografia (VAT Photopoly-merisation - VP)	• Processamentos digital de luz (Digital Light Processing - DLP) • Estereolitografia (Stereolithography - SLA)	Solidificação de uma tina de material líquido fotossensível curada seletivamente através da luz ultravioleta	• Cerâmicos • Polímeros	• Bom acabamento e grande precisão; • Processo relativamente rápido; •Área de construção grande.	• Processo pouco económico; • Necessário pós processamento para a remoção de resina; • Material limitado a resina fotossensível; • Necessário o uso de suportes.
Fusão de leito em pó (Powder Bed Fusion - PBF)	• Sinterização direta de metais por laser (Direct Metal Laser Sintering - DMLS) • Fusão por feixe de elétrons (Electron Beam Melting -EBM) • Sinterização/ fusão seletiva a laser (Selective Laser Sintering/Melting - SLS/SLM)	Sinterização ou mesmo fundição seletiva de determinadas zonas da camada de pó através de feixe do laser	• Cerâmicos • Compósitos • Híbridos • Metais • Polímeros	• Económico; • Pó do tanque faz de suporte; • Grande variedade de materiais.	• Processo de baixa velocidade; • Limite de tamanho; • Grande consumo energético; • Acabamento superficial depende do tamanho do grão do pó.

Jato de aglutinante (Binder Jetting - BJ)	• Impressão por jato de tinta (ColorJet Printing - CJP) • Impressão por jato de aglomerante (Prometal)	Sobreposição de camadas de pó interpolado com um líquido aglutinante	• Biológicos • Cerâmicos • Compósitos • Híbridos • Metais • Polímeros	• Partes podem ter diferentes cores; • Processo rápido e económico; • Com a utilização de mistura de materiais é possível obter várias propriedades mecânicas diferentes; • Grande volume de impressão.	• Peças frágeis; • É necessário pós-processamento o que aumenta o tempo do processo.
Jato de material (Material Jetting - MJ)	• Modelação por multijatos de material (Multi Jet Modelling - MJM) • Deposição a pedido (Drop on Demand -DoD)	Deposição de gotas de material depositadas seletivamente	• Biológicos • Cerâmicos • Compósitos • Híbridos • Polímeros	• Elevada precisão na deposição de gotícula; • Baixo desperdício; • Múltiplos materiais e cores num único processo.	• É necessário material de suporte; • Materiais são limitados a polímeros e ceras.
Laminagem de folhas (Sheet Lamination - SL)	• Fabricação de objetos laminados (Laminated Object Manufacturing - LOM) • Consolidação ultrassônica (Ultrasound Consolidation - UC)	Justaposição de folhas recortadas e coladas	• Biológicos • Cerâmicos • Híbridos • Metais • Polímeros	• Processo rápido; • Baixo custo; • Simplicidade de manuseio dos materiais.	• Materiais são limitados; • Pode necessitar de pós-processamento; • Integridade dos objetos depende do adesivo usado.

3.1.3 Vantagens e desvantagens do Fabrico Aditivo

São diversos os autores que acreditam que a tecnologia de FA está a revolucionar o desenvolvimento e produção do produto. A vantagem que torna esta uma tecnologia de eleição centra-se no facto de permitir produzir peças com geometria complexa e orgânica, cuja forma seria difícil ou mesmo impossível de desenvolver recorrendo a processos ditos convencionais (Gibson et al., 2010). A Figura 3.3 apresenta um exemplo de uma otimização de topologia, peça esta que, só é possível produzir através de processos de FA.

As maiores desvantagens do FA, na atualidade são: o custo elevado, a baixa velocidade de produção, uma menor precisão dimensional, um pior acabamento superficial e possui uma limitação de tamanho das peças produzidas quando comparada com processos convencionais. A produção de peças com a tecnologia de FA, necessita numa fase posterior de acabamentos secundários, como por exemplo os tratamentos térmicos nas peças metálicas, a remoção de suportes ou acabamento superficial. Desta forma, a produção de grandes séries de peças encontra-se bastante restrita uma vez que, a produção em série para processos de FA envolve grandes custos e tempo (Gibson et al., 2010; Wohlers Associates Inc., 2015).

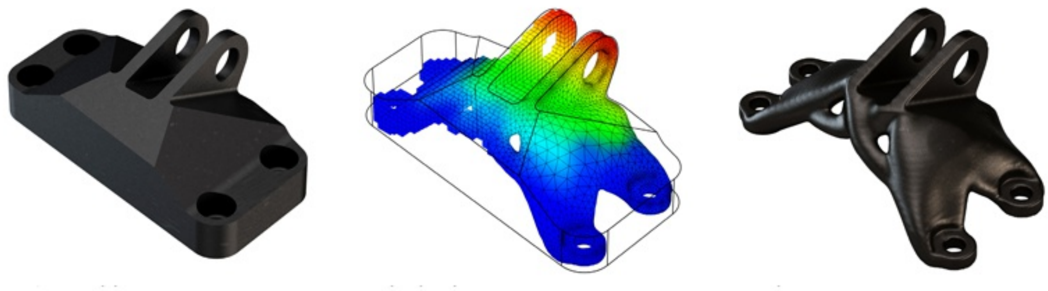


Figura 3.3: Otimização de topologia do suporte do motor *GE Aircraft* (3be, 2016)

Muitas das vezes, processos convencionais utilizam ferramentas auxiliares na produção de grandes lotes. Estas ferramentas têm um custo elevado, mas este custo é amortizado com a produção de grandes lotes, porém para lotes pequenos torna-se vantajoso monetariamente o uso de processos de FA. De facto, é possível sem qualquer recurso a ferramentas auxiliares a obtenção de um produto totalmente funcional, com a escolha do processo adequado e graças à liberdade de geometria da tecnologia. No entanto, algumas peças produzidas necessitam de operações de acabamento posteriores, dependendo da finalidade do produto (Grenda, 2005).

Uma máquina de FA tem a particularidade de uma vez iniciada, terminar a impressão de uma peça sem a necessidade de presença de um operador, possibilitando desta forma a redução da quantidade de operários necessários. Contudo, dependendo da máquina de FA, é necessário operários mais qualificados, aumentando desta forma os custos. Estes processos, trazem a possibilidade de remover ou até só simplificar vários estágios de produção, permitindo desta forma uma redução de custos (Gibson et al., 2010).

Os processos subtrativos, iniciam a produção de uma peça a partir de um bloco de material e retiram o excedente até chegar à peça desejada, o que se traduz num grande desperdício de material, ao contrário da tecnologia de FA que se trata de um processo aditivo de material e adiciona material unicamente no local da peça, implicando assim um desperdício de material mínimo. O desperdício de material da tecnologia de FA deve-se à necessidade de inclusão de suportes e acabamentos superficiais posteriores das peças, bem como a algum pó ou fio que não são utilizados na totalidade. Apesar destes processos serem aditivos, são necessários sempre grandes quantidades de *stocks* de material que provoca um aumento do preço do processo. Importa ainda referir, que o preço da matéria prima varia consoante o tipo material (Grenda, 2005).

Através da liberdade de geometria destes processos, é possível construir objetos inteiros com uma única peça, o que permite eliminar custos de montagem associados ao projeto e construção, ao contrário de processos convencionais que seriam necessários produzir objetos em parte separadas e posteriormente utilizar processos de montagem, posteriores (Relvas, 2018).

3.2 Sinterização direta de metais por laser (*Direct Metal Laser Sintering* - DMLS)

O processo de DMLS é um processo de FA desenvolvido em 1994 pela cooperação entre a empresa *Rapid Product Innovations*, originária da Finlândia e empresa *EOS GmbH*, proveniente da Alemanha (ASTM International, 2012). Esta cooperação deu origem a comercialização em 1995 da máquina *EOSINT M 250* e de uma nova mistura de pó baseado em bronze. Posteriormente, em 1998, foi desenvolvida uma nova mistura de pó baseado em aço, que revolucionou o mercado uma vez que, possibilitou a produção de ferramentas e moldes de injeção de peças poliméricas com formas geométricas difíceis ou impossíveis de conseguir com processos convencionais (Hänninen, 2001). A máquina *EOSINT M 250* é capaz de produzir moldes de injeção metálicos em alguns dias. Uma das características do pó baseado em bronze é que não necessita de uma atmosfera controlada para a produção de peças, ao contrário do pó baseado em aço que necessita de uma atmosfera de azoto (Khaing, Fuh e Lu, 2001).

3.2.1 Processo

O processo de DMLS pertence à categoria de PBF e consiste na sinterização de uma camada de espessura fina distribuída uniformemente numa plataforma através de um feixe laser. O processo de sinterização resume-se ao aquecimento de um pó de liga metálica até ao ponto de pré-fusão (só há fusão superficial dos pequenos grãos - habitualmente esferas - de pó) do material, que resulta numa massa coesa e não porosa. Após cada passagem do laser, a plataforma de construção desce, a plataforma de reserva de pó sobe e uma varredora espalha uma nova camada de pó de forma uniforme e deste modo, camada após camada, obtém-se a peça final (Ngo, Kashani, Imbalzano, Nguyen e Hui, 2018). Na Figura 3.4 é apresentado um esquema da construção de uma peça por um processo de DMLS.

O processo de funcionamento do DMLS e do SLS da *3D Systems* (ASTM International, 2012) são bastante similares. A principal diferença existente entre estes dois processos centra-se no facto de que, no DMLS é utilizado um pó metálico sem qualquer revestimento polimérico ao passo que, no SLS é utilizado um pó metálico revestido. Uma outra diferença é a necessidade de suportes no processo de DMLS devido às altas temperaturas de sinterização que aumenta o risco de distorção da peça, ao contrário do

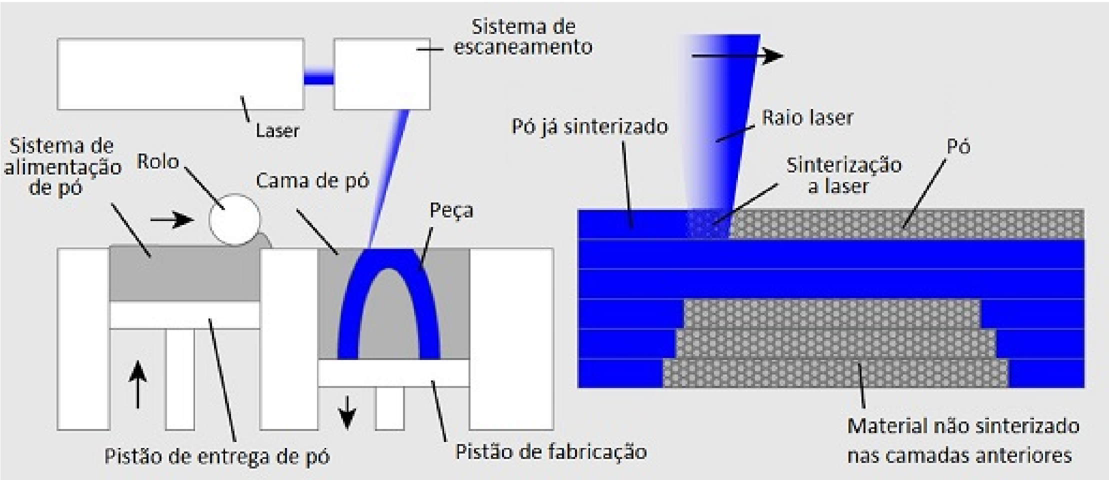


Figura 3.4: Esquema da construção de uma peça por um processo de sinterização direta de metais por laser (*Direct Metal Laser Sintering* - DMLS) (Roda, 2018)

processo de SLS que não carece de suportes uma vez que, o pó presente nas camadas antecedentes fornecem esse suporte (Bourell et al., 2017; Redwood, Schffer, Garret e Igor, 2017).

A tecnologia de DMLS sinteriza o pó através da utilização de um laser de alta potência, devido às altas temperaturas que são necessárias para atingir o ponto de pré-fusão do material. Após a finalização da impressão do objeto, este necessita de arrefecer e remover o excesso de pó presente na peça. Este excesso de pó é reutilizável numa próxima impressão (Umaras e Tsuzuki, 2017).

De referir ainda, que em 2015 a norma ASTM F2792-12a (ASTM International, 2012) foi retirada e substituída pela norma ISO/ASTM 52900:2015 (ISO/ASTM, 2015). Na norma antiga existia a expressão DMLS sendo esta uma marca registada pela empresa *EOS GmbH*, bem como o termo SLS, uma marca registada pela empresa *3D Systems*. Estas terminologias na norma em vigor (ISO/ASTM 52900:2015), deixaram de existir e passaram-se a intitular-se por sinterização laser ((*Laser Sintering* - LS)). Este termo contempla todas as tecnologias que utilizam um laser para fundir seletivamente, uma ou várias camadas de pó de qualquer tipo de material, no interior de uma câmara vedada (ISO/ASTM, 2015).

3.2.2 Tipos de materiais usados

O processo de DMLS é focalizado no FA de metais e existe um vasta gama de materiais possíveis de serem utilizados. Esta tecnologia permite produzir peças para aplicações em vários tipos de indústrias como por exemplo na indústria automóvel, aeroespacial, médica, entre outras (Relvas, 2018). Na Tabela 3.2 são apresentados alguns dos materiais produzidos pela *GE Additive*, acompanhado das suas propriedades e a indústria a que pode ser aplicado.

Tabela 3.2: Materiais, propriedades e aplicações, adaptado de GE Additive, s.d.

Material	Propriedades	Indústria
Aço inoxidável 316 L	• Adequado para temperaturas baixas • Altamente moldável • Elevada resistência à tração • Resistente à corrosão • Resistente até 300ºC em operações contínuas	• Aeroespacial • Automóvel • Joalheria • Médica
Aço inoxidável M300	• Adequado para temperaturas baixas • Baixa distorção • Elevada tenacidade	• Ferramentas • Moldes
Aço inoxidável 14-4 PH	• Elevada tenacidade • Resistente à corrosão	• Aeroespacial • Automóvel • Médica • Moldes
Liga de cobalto-cromo	• Biocompatibilidade • Elevada dureza • Elevada tenacidade • Resistente à corrosão	• Dentária
Liga de titânio	• Baixa condutividade térmica • Baixa expansão térmica • Boa fadiga • Biocompatibilidade • Elevada tenacidade • Resistente à corrosão	• Dentária

Os objetos fabricados por um processo de DMLS têm propriedades mecânicas equivalentes a objetos metálicos obtidos por fundição e podem atingir uma densidade de 99.5% (Stratasys Direct Manufacturing, 2020). Na Tabela 3.3 são apresentadas propriedades físicas de alguns dos materiais utilizados no processo de DMLS. De notar que este valores foram retirados diretamente de objetos logo após a sua fabricação. Estes valores são diferentes após as peças passarem por tratamentos térmicos.

Existem vários tipos de tratamento térmicos disponíveis. No que diz respeito ao aço inoxidável 17-4 PH existem quatro tipos distintos de tratamento térmico: o recozimento que consiste em aquecer um forno até 1040℃ durante duas horas em vácuo, o *H900* com o propósito de endurecer a peça a 480℃ durante uma hora em árgon, o *H1150* com o intuito de recozer a peça a 620℃ durante quatro horas em árgon e um último que conjuga os dois primeiros tratamentos térmicos. Existem outros tipos de tratamentos térmicos com base em pressão e temperaturas altas (Stratasys Direct Manufacturing, 2020). Outro exemplo, agora para o caso de liga de titânio (Teixeira, Silva, Ferreira e Atzeni, 2020).

Tabela 3.3: Propriedades físicas de materiais imediatamente após fabricação por um processo de sinterização direta de metais por laser (*Direct Metal Laser Sintering* - DMLS), adapatado de Stratasys Direct Manufacturing, 2020

Material	Tensão de cedência (MPa)	Tensão de rotura (MPa)	Alongamento (%)	Módulo de Young (GPa)	Dureza
Aço inoxidável 17-4 PH	731	1041	17	-	30 HRC
Aço inoxidável 316L	530	641	40	-	85 HRB
Alumínio AlSi10Mg	232	379	6.9	68.3	64 HRB
Liga de Níquel 625	669	1027	30	179.2	29 HRC
Liga de Níquel 718	772	875	30	179.2	-
Liga de Níquel K500	367	486	40.2	-	85 HRB
Titânio Ti64	1030	1150	11	110	44 HRC
Cobalto-cromo	750	1050	14	200	360 HV
Cobre C18150	152	207	31	103	90 HRB

3.2.3 Tipos de máquinas existentes

O FA de metais sofreu um crescimento exponencial, o que permitiu um aumento de impressoras 3D de metais no mercado. Cada máquina, independentemente da marca, tem as suas vantagens, desvantagens e diferentes aplicações na indústria. São exemplos de máquinas bem implementadas no mercado de DMLS a *RenAM250*, a *RenAM400*, a *RenAM 500Q* da empresa *Renishaw*, a *ProX DMP 100*, a *ProX DMP 200*, a *ProX DMP 300*, a *ProX DMP 320* da empresa *3D Systems* e a *EOS M100*, a *EOS M400*, a *EOS M400-4* e a *Precious M080* da empresa *EOS* (AMFG, 2018).

No que se refere à máquina *RenAM 500Q* da empresa *Renishaw*, esta apresenta um volume de construção de 250 mm x 250 mm x 350 mm, possui quatro lasers de 500 W cada, permite alcançar uma velocidade de impressão até 150 cm^3/h. Possui ainda um sistema de vácuo, baixo consumo de Árgon e tem um sistema integrado de peneirar e recircular o pó (AMFG, 2018);(Renishaw, 2020). Esta máquina é ideal para o ramo aeroespacial, automóvel, médico e metalúrgico. A Figura 3.6 mostra a máquina *RenAM 500Q* da empresa *Renishaw*.

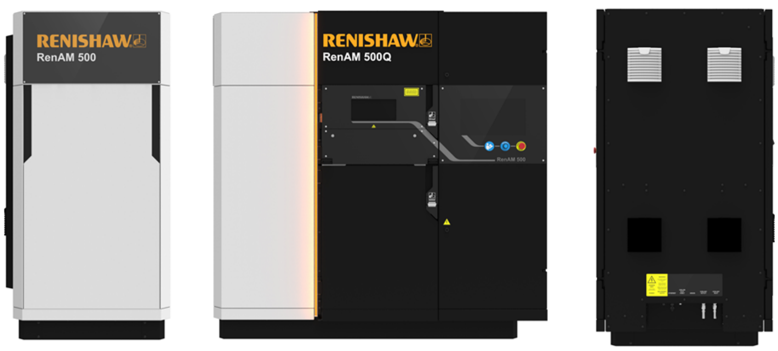


Figura 3.5: *RenAM 500Q* (Renishaw, 2020)

A empresa *3D Systems* apresenta também uma máquina de topo, a *ProX DMP 300*. Esta apresenta um volume de construção de 250 mm x 250 mm x 330 mm, produz peças muito densas e sem porosidade, tem uma precisão típica de 50 μm em peças pequenas, apresenta uma repetibilidade de aproximadamente 20 μm e acabamento superficial até 5 μm Ra. Possui ainda boas características de limpeza e segurança que permitem que o operador não entre em contacto direto com o pó, assim como um sistema integrado de reciclagem. Os ramos apropriados para a máquina são as próteses dentárias, implantes ortopédicos, moldes, aeronáutica, ferramentas e entre outros (AMFG, 2018);(3D Systems, 2020). Na Figura 3.6 é apresentada a máquina *ProX DMP 300* da empresa *3D Systems*.

Figura 3.6: *ProX DMP 300* (3D Systems, 2020)

Por último, a máquina *EOS M400* da empresa *EOS*. Esta dispõe de um volume de construção de 400 mm x 400 mm x 400 mm, um laser de fibra ótica com potência de 1 kW, tem uma precisão de aproximadamente 90 μm, possui a plataforma modular para facilitar a integração de inovações futuras, sistema de filtragem automático e duas plataformas de reservatório de pó de modo a minimizar tempo de produção (AMFG, 2018);(EOS, 2014). A Figura 3.7 mostra a máquina *EOS M400* da empresa *EOS*.

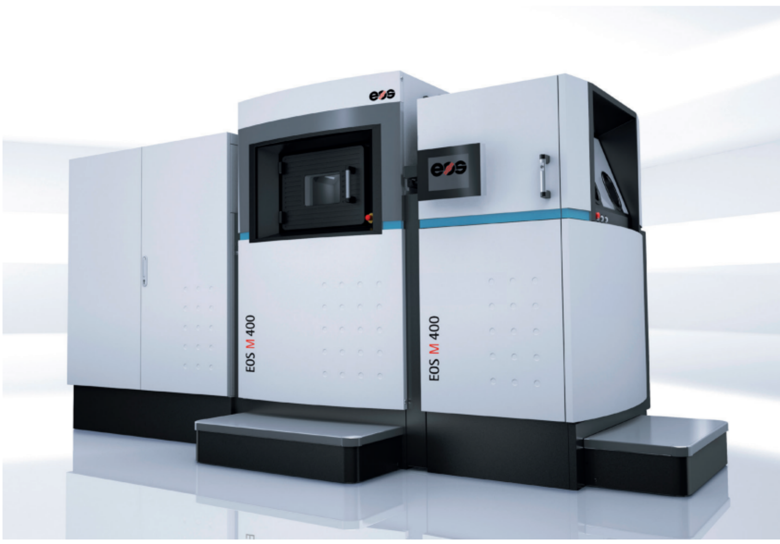


Figura 3.7: *EOS M400* (EOS, 2014)

Parte II

Métodos e Materiais

Capítulo 4

Descrição do equipamento e modelação 3D

No decorrer da construção da máquina foram surgindo alguns obstáculos. Neste capítulo, será apresentada uma descrição global do equipamento e ainda os problemas com algumas das possíveis soluções que podem ser implementadas. Seguem-se as soluções detalhadas e a modelação 3D das peças novas.

4.1 Descrição do equipamento

A máquina do projeto possui um volume de construção de 250 mm x 250 mm x 300 mm, um único reservatório de pó e a câmara de sinterização é isolada por uma parede dupla de chapa de aço com uma camada de 50 mm de lã de rocha no seu interior. O laser e o sistema de deflexão de laser são controlados por uma carta *SP-ICE-3* (Raylase, 2020b). O controlo de motores é feito por duas cartas da *National Instruments* (NI) através de um programa em *LabView*.

A máquina divide-se em cinco partes distintas (Figura 4.1). Na parte inferior direita da mesa de trabalho encontra-se o elevador de construção da peça e à esquerda o elevador do depósito de pó. Já na parte superior da mesa de trabalho encontra-se o sistema de transporte de pó, no caso uma varredora. Pousado na câmara de construção da máquina e acima do elevador de construção da peça encontra-se o sistema de deflexão do laser. Por fim, o laser encontra-se instalado sobre a estrutura da máquina.

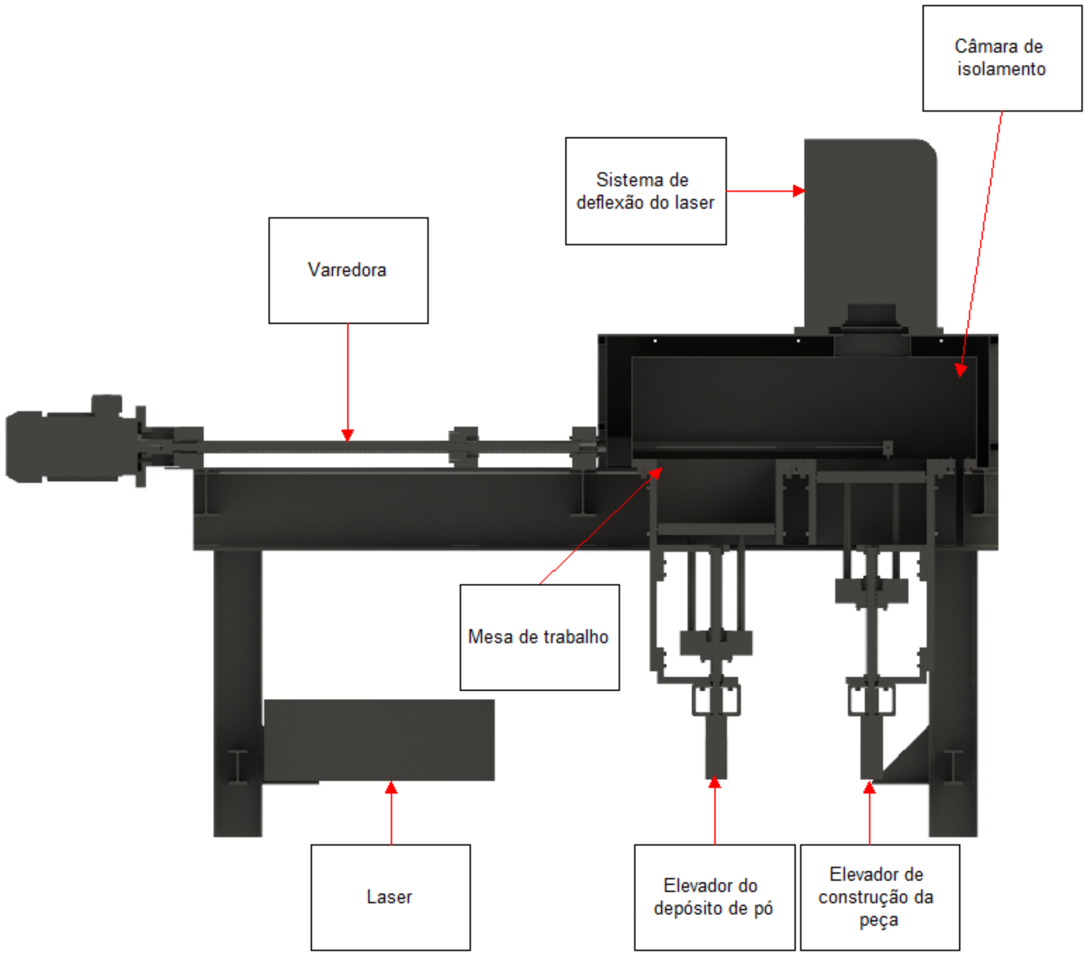


Figura 4.1: Identificação das partes da máquina

4.1.1 Elevadores

Cada elevador tem uma função própria, o elevador do depósito de pó tem a função de armazenar o pó e abastecer o outro elevador. Já o elevador da construção da peça tem como principal objetivo fornecer o eixo vertical do objeto, para tal, o movimento do elevador necessita de uma resolução melhor que os 50 μm (este foi o valor assumido como sendo o diâmetro máximo dos grãos de pó a utilizar na máquina). À cautela, considerou-se uma resolução de 10 μm.

Os elevadores são compostos por: 4 peças em forma de "L"que estão fixas à mesa de trabalho (1), um bloco móvel (2), um fuso trapezoidal com passo de 5 mm que não se encontra representado na Figura 4.2, duas guias com 30 mm de diâmetro (3), quatro varões que se fixam às plataformas de trabalho e ao bloco móvel (4), duas plataformas (5) (uma sobre a outra), para fixar nas extremidades tiras de $PTFE$ (6), que têm a função de vedar, para preservar o pó. Apresenta ainda peças mais pequenas, como rolamentos (7), casquilhos (8) e vários parafusos $M8$, $M6$, $M5$ e $M4$. Na Figura 4.2, é apresentada uma imagem do elevador da construção da peça.

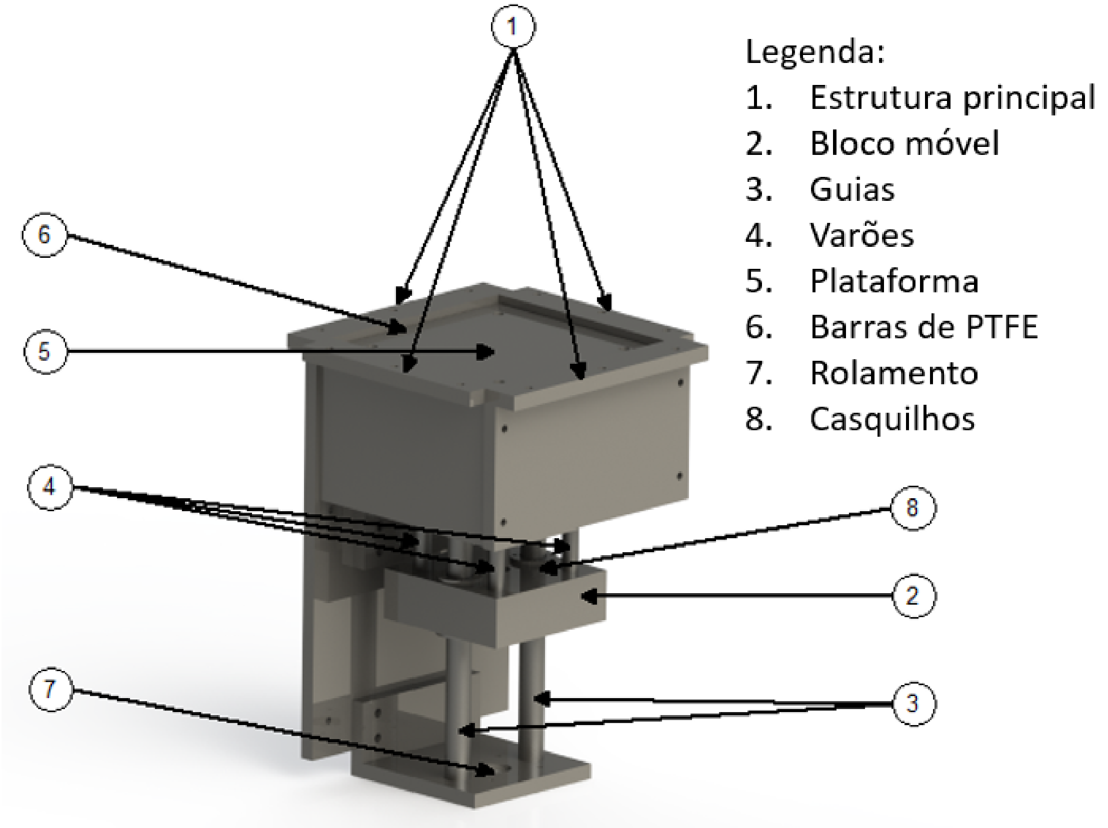


Figura 4.2: Elevador da construção da peça da máquina e identificação dos seus componentes

4.1.2 Varredora

A varredora possui como principal função arrastar o pó de forma uniforme para a zona de fabrico da peça.

Os componentes da varredora são dois blocos fixos (1), um bloco central móvel (2), quatro guias com 30 mm de diâmetro (3), das quais duas entre os blocos fixos e outras duas ligadas ao bloco central móvel e o final da varredora, um fuso trapezoidal com 900 mm de comprimento e passo de 5 mm (4) e peças mais pequenas, como rolamentos (5), casquilhos (6) e vários parafusos $M8$, $M6$ e $M4$. De referir, ainda a ponta da varredora composta por duas peças (7) que apertam uma tira de $PTFE$ (8) que irá empurrar o pó do depósito para a zona de sinterização. Na Figura 4.3 é exibida uma imagem da varredora do projeto.

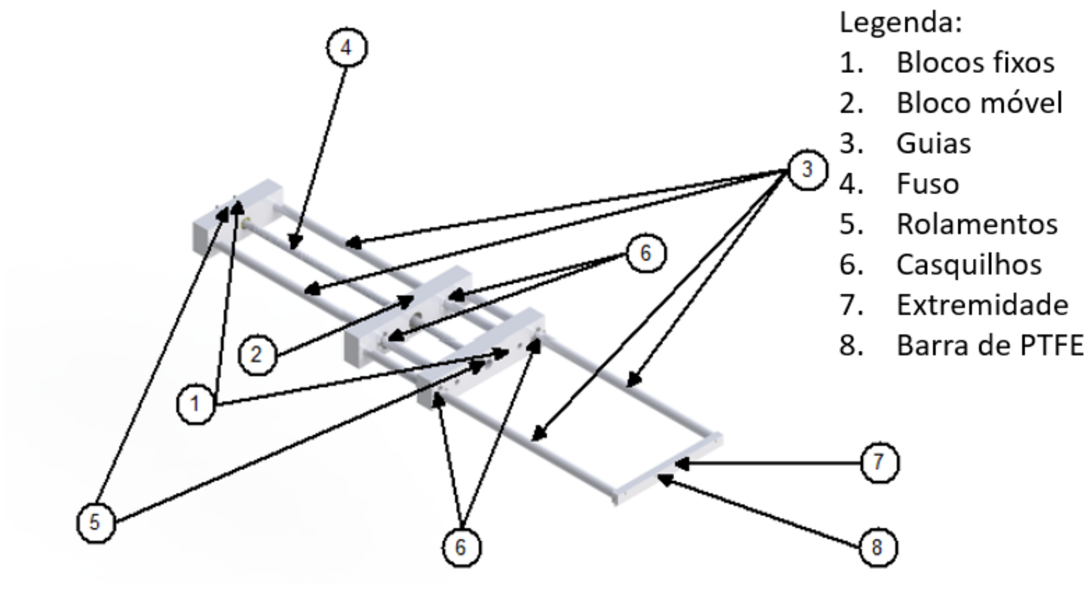


Figura 4.3: Varredora da máquina e identificação dos seus componentes

A velocidade de deslocamento da varredora é um parâmetro que necessita de ser definido. A varredora tem um curso útil de 800 mm, portanto, de modo a que este deslocamento seja realizado o fuso necessita de realizar 160 rotações. De modo a tirar o proveito máximo da máquina definiu-se que o tempo de deslocamento do curso útil da varredora seria no máximo de 7 segundos. Assim sendo, o fuso tem de rodar, no mínimo, a 1380 rpm. Utilizando este valor, teoricamente é possível imprimir uma peça com 50 mm de altura e espessura por camada de 50 μm num tempo total de aproximadamente quatro horas e 30 minutos, sem contar com o tempo de preparação da máquina. Este tempo total de impressão foi deduzido a partir das equações 4.1, 4.2 e 4.3.

O número de camadas de impressão foi calculado a partir da equação 4.1, em que N é número de camadas, h é a altura da peça a fabricar $[mm]$ e e a espessura da camada $[mm]$.

$$N = \frac{h}{e} \tag{4.1}$$

O tempo de varrimento por camada (T_v $[s]$) é calculado a partir da equação 4.2, em que d é curso útil da varredora $[mm]$, p é o passo do fuso da varredora $[mm]$ e n são as rotações do fuso da varredora $[rpm]$.

$$T_v = 2 \ . \ \frac{d \ . \ 60}{p \ . \ n} \quad [s] \tag{4.2}$$

O tempo total de impressão (T) é calculado a partir da equação 4.3, na qual T_l é o tempo da atuação do laser $[s]$ por camada. Este tempo de laser será uma estimativa média, uma vez que este varia segundo a área de impressão de cada camada e da otimização da trajetória de varrimento.

$$T = N \ . \ \sum (T_v + T_l) \quad [s] \tag{4.3}$$

Na Tabela 4.1 é possível observar, de forma sintetizada, os valores obtidos pelas equações anteriores.

Tabela 4.1: Resumo do tempo total teórico na impressão de uma peça com 50 mm de altura e espessura por camada de 50 μm

Curso útil da varredora [mm]	800
Passo do fuso da varredora [mm]	5
Altura da peça [mm]	50
Altura da camada [mm]	0,050
Velocidade do motor da varredora [rpm]	1380
Tempo de varrimento por camada [s]	13,9
Tempo de laser por camada [s]	2
Tempo Total [$h : min : s$]	04:25:13

4.1.3 Sistema de deflexão do laser

A *Raylase* é uma empresa alemã que possui sistemas de deflexão de laser de alta precisão e uma vasta gama de tecnologia laser adequada para corte por laser, soldadura a laser e FA. Um dos produtos da *Raylase* é o *AM-MODULE NEXT GEN* (Raylase, 2020a), Figura 4.4, um sistema de deflexão de laser potencializado para o FA, que fornece os dois eixos da peça, o longitudinal e o transversal. Este sistema está preparado para campos de trabalho de 250 mm x 250 mm até uma área de 600 mm x 600 mm e com um diâmetro do feixe do laser de 38 μm até 85 μm.

Figura 4.4: *AM-MODULE NEXT GEN* (Raylase, 2020a)

4.1.4 Laser

A *IPG Photonics* é uma empresa fundada em 1991 na Rússia e foi pioneira na área do laser de fibra ótica. O laser da máquina do projeto é proveniente desta empresa. O modelo do laser é o *YLR-200-AC* e possui uma potência de 200 W e comprimento de onda de 1070 nm. É um laser de onda contínua e de estado sólido que opera com Itérbio (Yb) como meio ativo (IPG Photonics, 2020). Na Figura 4.5 é apresentado o laser da máquina do projeto.

Figura 4.5: Modelo *YLR-200-AC* da *IPG Photonics* (IPG Photonics, 2010)

4.2 Motores da máquina

4.2.1 Motores dos elevadores

A necessidade de precisão aliada à baixa velocidade, ao baixo preço e a deslocamentos na ordem dos 50 μm levou à escolha de motores de passo para a movimentação dos elevadores. Os motores de passo são motores elétricos caracterizados pela rotação dos seus veios um pequeno ângulo de cada vez, isto é, executando um número fixo de graus de rotação e quando acompanhados por um *driver* podem executar micro-passos e alcançar uma elevada precisão posicional até aproximadamente os $0,007°$. Estes são usados em várias máquinas industriais (Fiore, 2020).

Os motores utilizados nos elevadores são motores de passo em malha fechada da *Stepperonline* do modelo *23HS22-2804D-PG15-E1000* (Figura 4.6) (Stepperonline, 2018a). Estes possuem um binário de $1,25$ $N.m$ e na sua saída têm integrado um redutor planetário com redução de $19:1$ com eficiência de 95%, traduzido num aumento linear do binário de saída para os $22,5$ $N.m$.

Os motores são controlados por *drivers CL57T* da *Stepperonline* configurados a 800 impulsos por revolução (Stepperonline, 2020). Na Figura 4.7 é mostrada uma fotografia do *driver* usado para o controlo dos elevadores.

Figura 4.6: Motorredutor de passo da *Stepperonline* utilizado nos elevadores (Stepperonline, 2018a)

Figura 4.7: *Driver* CL57T da *Stepperonline* (Stepperonline, 2020)

Teoricamente o conjunto motor de passo e *driver* permite atingir os requisitos de precisão e binário para o correto funcionamento dos elevadores. Para findar, na prática, houve a necessidade de realizar um teste com as condições extremas de trabalho do funcionamento dos elevadores.

4.2.2 Motor da varredora

A escolha do motor da varredora seguiu a mesma ordem de ideias dos motores dos elevadores e optou-se por usar um motor de passo (sem redutor) com o seu respetivo *driver*.

O motor inicial escolhido para a varredora foi o *34HS38-4204D-E1000* da *Stepperonline* e o seu *driver* o *CL86T* (Stepperonline, 2018b). Nos motores de passo, verifica-se na Figura 4.8, que o binário do motor decresce consideravelmente quando existe um aumento da velocidade de rotação.

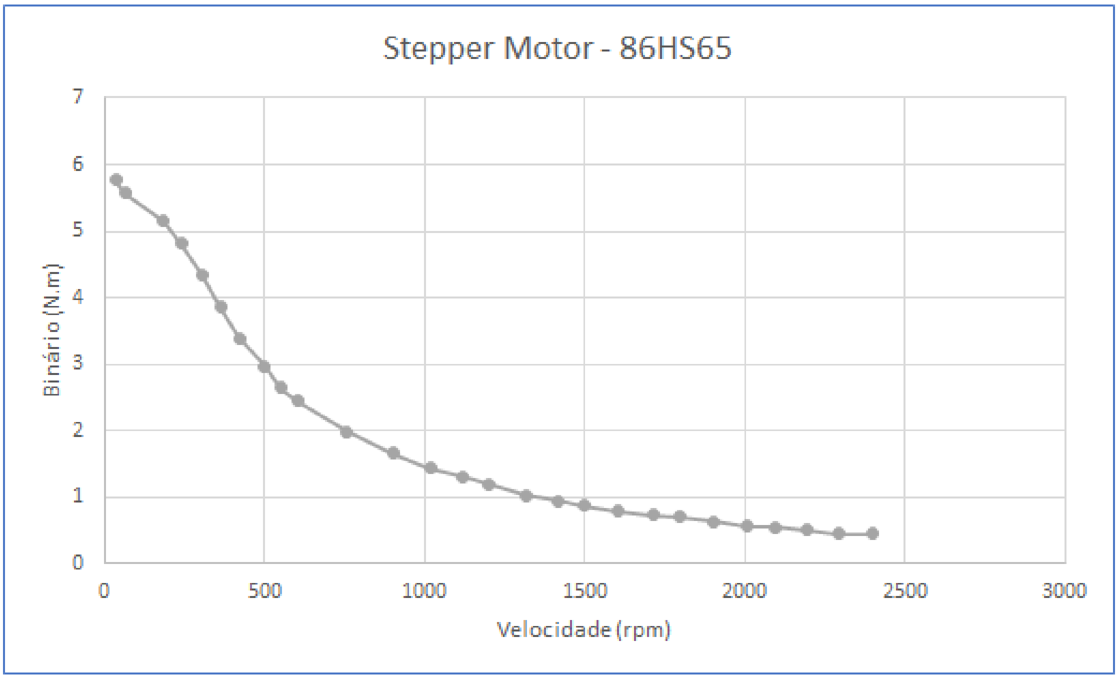


Figura 4.8: Gráfico de motores de passo de velocidade binário, adaptado de AMT, s.d.

Ao testar o motor, verificou-se que ao chegar às 500 rpm, este começava a saltar passos e deixava de funcionar, uma vez que o *driver* entrava em erro. Dado que a realidade permitiu fazer esta verificação, assumiu-se que a falha no cálculo estivesse na desconsideração do atrito que a varredora tem nos seus vários componentes, desde a raspagem do pó até às guias em casquilhos e até ao eventual desalinhamento do mecanismo. Feitas várias experiências, o problema permanecia e a limitação às 500 rpm mantinha-se. Foi então feita uma verificação prática sobre o binário efetivamente requerido para rodar o fuso. Para isso, colocou-se na extremidade do fuso um peso de 2 kg com um pequeno braço, o qual quando era superior a 125 mm o fazia rodar. Portanto, o binário requerido era de aproximadamente $2,5$ $N.m$, o que até está conforme a Figura 4.8 atendendo a que a experiência com o peso foi feita em modo estático e portanto desconsiderou a aceleração.

Através da equação 4.4, em que n são as rotações do motor em rpm, τ o binário do motor em $N.m$, tendo como coeficiente de segurança o valor de 2 e assumindo que se poderá querer colocar o motor a rodar até 3000 rpm para obter uma maior velocidade de trabalho, obtém um valor de $1,57$ kW. O motor escolhido foi um motor trifásico de corrente alternada de $1,5$ kW e 1500 rpm, acionado por um variador de frequência (Motor elétrico trifásico $1,5$ kW 4P B5 90L IE3) (Figura 4.9) (Inverter Drive, 2017).

$$P = \frac{2\ .\ \pi\ .\ \tau\ .\ n}{60\ .\ 1000} \quad (kW) \tag{4.4}$$

Figura 4.9: Motor elétrico trifásico $1,5\ kW$ 4P B5 90L IE3

A troca de motor levou à necessidade de fabricar uma peça com o propósito de fixar e alinhar o motor ao fuso da varredora. Esta peça é fixa por quatro parafusos $M8$ à varredora e por quatro parafusos e porca $M10$ para fixar o motor. Na Figura 4.10 é apresentada uma imagem da peça projetada. A peça foi maquinada no torno com Comando Numérico (*Computer Numeric Control* - CNC) do DEM, a partir de chapa de aço com espessura de 20 mm. No Apêndice A é exibido o desenho técnico da peça utilizado na sua maquinagem.

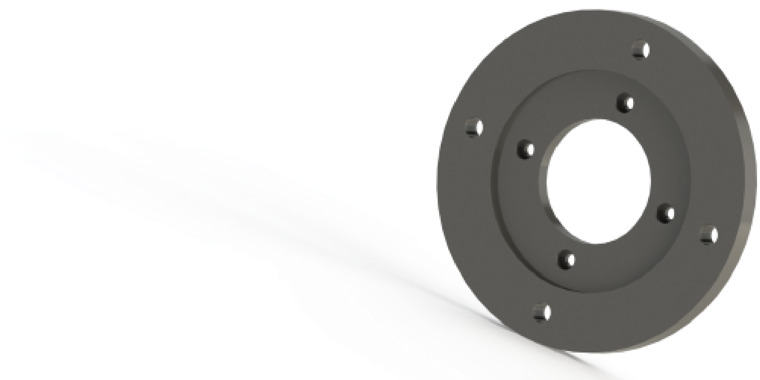
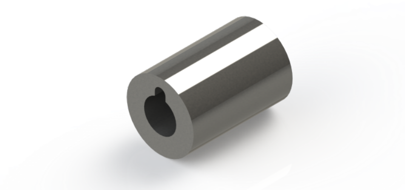
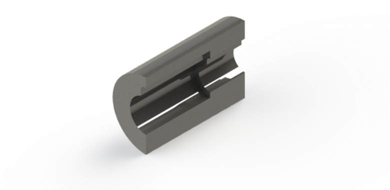


Figura 4.10: Flange do motor da varredora

A ligação entre o veio do motor e o fuso da varredora é feita através de um acoplador, com o propósito de os interligar mecanicamente. Na Figura 4.11, são apresentadas as imagens do acoplador projetado. O material eleito para o acoplador foi aço, que exibia inicialmente o formato de um varão com 50 mm de diâmetro. A transmissão do binário entre os veios é conseguida através de chavetas. O veio do motor possui uma Chaveta paralela A, ISO/R 773 8x7x40 - St e o fuso uma Chaveta paralela A, ISO/R 773 5x5x25. No Apêndice B é apresentado o desenho técnico da peça.



(a) Acoplador do motor



(b) Acoplador do motor cortado no plano longitudinal

Figura 4.11: Acoplador do motor projetado

4.3 Zero máquina dos elevadores

Os motores dos elevadores possuem *encoder's* incrementais. Os *encoder's* incrementais indicam apenas a mudança de posição, ao contrário dos *encoder's* absolutos que mantêm a informação da posição quando estes são desligados. Posto isto, uma vez que o tipo de *encoder* utilizado não tem informação da sua última posição foi necessário definir um ponto de referência denominado de Zero Máquina (ZM). Desta forma, o ZM é um ponto predefinido que é ativado através de toque ou eletronicamente. O *OPB830W55Z* foi o sensor utilizado na máquina. Este é um interruptor ótico com ranhura, compatível com as cartas da NI por possuir uma tensão de saída de 5 V (Apêndice C).

O ZM é ativado quando as plataformas estão na posição superior da máquina, como exposto na Figura 4.2. As peças para o ZM foram projetadas de modo a ser possível regular a altura do ponto. O interruptor é ativo quando deteta a passagem de um objeto pela sua ranhura. A fixação das peças do ZM foi feita através de furos das tampas que seguram os casquilhos, na parte inferior do bloco móvel e dos furos no L principal do elevador que tinham sido feitos para fixar a peça ao CNC aquando da sua maquinagem.

Foram concebidas quatro peças diferentes para cada elevador. A primeira peça é fixa ao bloco móvel do elevador e serve de suporte para a segunda peça que irá passar no interruptor ótico. A terceira peça é uma barra ligada ao L principal do elevador e permite fixar a quarta peça onde é aparafusado o interruptor ótico.

A peça fixa ao bloco móvel do elevador, também irá servir de substituição das tampas dos casquilhos do bloco móvel. É feita em aço galvanizado e segura a segunda peça que irá passar no *OPB830W55Z*. Os furos são feitos de modo a passar dois parafusos $M5$ e um $M4$ na extremidade (Figura 4.12).

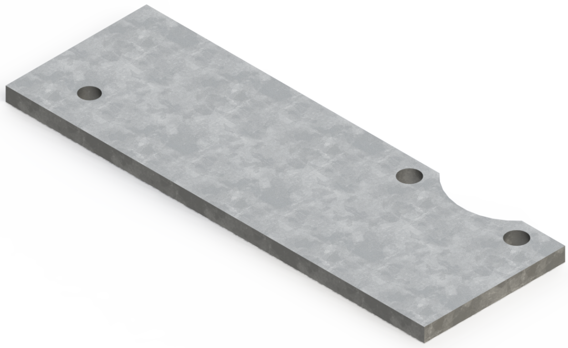


Figura 4.12: Peça 1 - Peça fixa ao bloco móvel

A peça que ativa o interruptor ótico é uma chapa de alumínio com 2 mm de espessura. Esta peça apresenta um rasgo maquinado no CNC e a sua geometria final foi obtida através do corte na serra de fita e da quinagem. O material escolhido foi uma liga de alumínio 6082 uma vez é facilmente maleável para o ajuste final. Esta peça é fixa por um parafuso $M4$. Na Figura 4.13 é exibida a imagem da peça final.

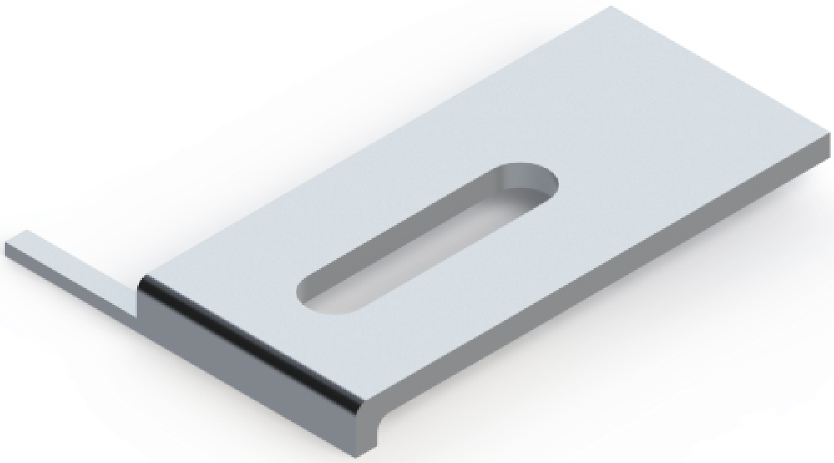


Figura 4.13: Peça 2 - Peça que ativa o interruptor ótico

A terceira peça foi r a partir de uma barra com 20 mm de espessura em aço. A escolha da espessura da barra teve em conta o material disponível no laboratório. A mesma é fixa ao L principal do elevador, através de dois parafusos $M8$ e as suas respetivas porcas. Na Figura 4.14 é mostrada uma imagem da peça final.

Figura 4.14: Peça 3 - Barra aparafusada ao L principal do elevador

Por último, a peça quatro em forma de L é fixa na barra laminada e segura o interruptor ótico através de dois parafusos $M3$. A peça possui um rasgo de modo a que seja possível ajustar a altura do ZM. O formato original da peça é uma chapa em aço galvanizado de 4 mm de espessura (material disponível no laboratório), que foi maquinada no CNC e posteriormente quinada. A Figura 4.15 retrata a imagem final da peça.

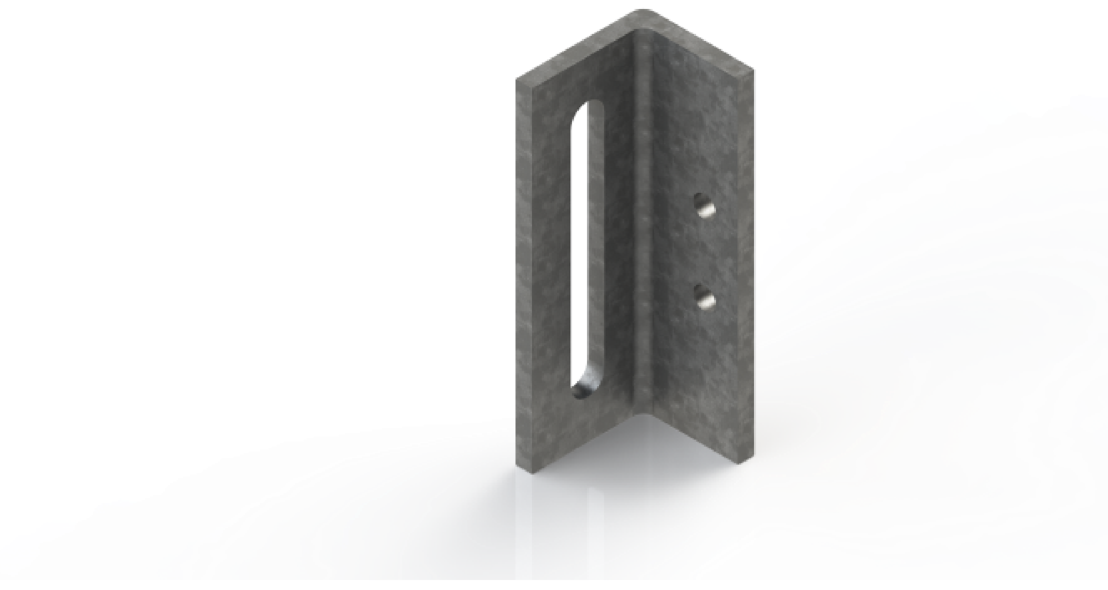


Figura 4.15: Peça 4 - Peça aparafusada à barra

A Figura 4.16 apresenta o conjunto das quatro peças e as suas interações. No Apêndice D, são apresentados os desenhos técnicos das peças pela mesma ordem acima dispostos.

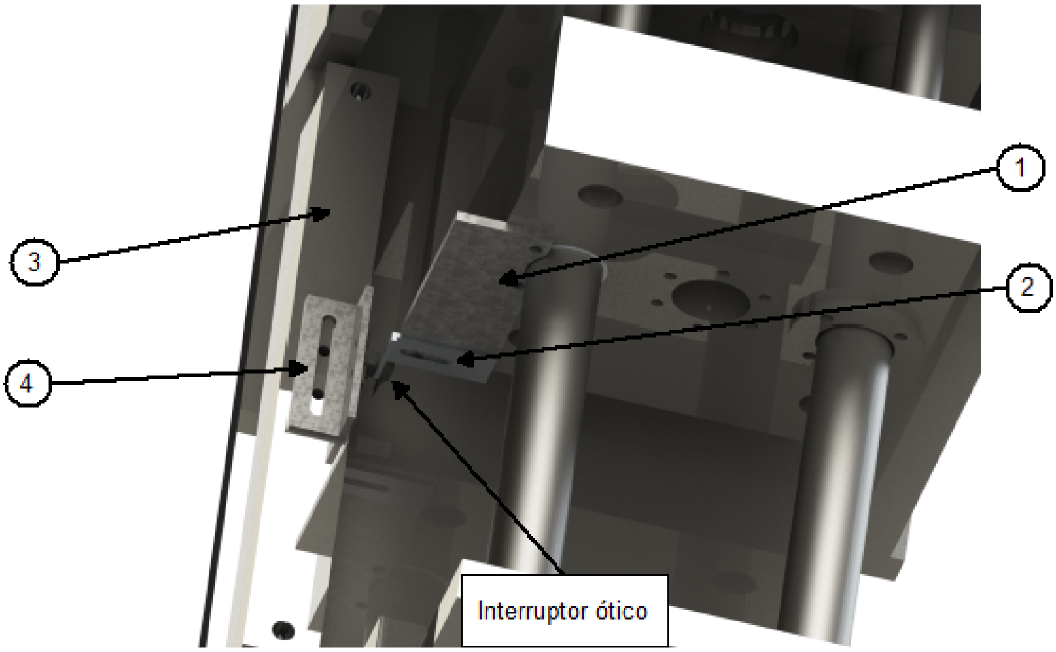


Figura 4.16: Peças projetadas do Zero Máquina (ZM) e respetiva identificação (ver Figuras 4.12, 4.13, 4.14 e 4.15)

4.4 Fins de curso da varredora

A varredora possui um motor de corrente alternada, e desta forma torna-se essencial o controlo da posição inicial e final do varrimento. Através deste controlo é possível delinear o curso útil da varredora. Para que tal fosse possível, existem três diferentes tipos de abordagens, acrescentar um *encoder* no fuso da varredora, utilizar um sensor indutivo ou utilizar um fim de curso mecânico.

Após a análise dos três diferentes cenários, conclui-se que, a primeira abordagem, não se demonstrou viável, uma vez que na extremidade do fuso oposta ao motor, não existe espaço suficiente para aplicar um *encoder* e por outro lado, o custo de aquisição desse componente é elevado.

No que se refere à segunda possível solução, verificou-se que esta seria uma abordagem viável. Na verdade, o bloco central móvel da varredora é um bloco de aço e os sensores indutivos permitirem detetar objetos metálicos dentro do seu campo magnético sem ter de entrar em contacto com os mesmos (PC Control, 2008). Desta forma, colocar em prática tal solução, seria de fácil execução, uma vez que só seria necessário colocar os sensores num suporte e fixá-lo na estrutura principal da máquina. No entanto, devido à incompatibilidade da tensão de alimentação dos sensores disponíveis com as fontes de alimentação da máquina, não seria fácil colocar em prática esta solução, por se tratar de uma abordagem que implicaria alterar o quadro elétrico já existente na máquina.

Por fim, a terceira hipótese demonstrou ser a mais exequível em comparação com as restantes. Esta solução consiste em utilizar fins de curso mecânicos que necessitam de uma pequena força mecânica para serem ativados. À semelhança dos sensores indutivos, este fim de curso mecânico é aplicado com recurso a um suporte fixo na estrutura principal da máquina.

O curso útil de varrimento, pode variar de acordo com o tipo de peça a produzir. Desta forma, os fins de curso possuem mobilidade de modo a serem ajustados de acordo com a necessidade. Assim sendo, o uso de um perfil *Bosch* 45 mm x 45 mm, com um comprimento de 900 mm, possibilitou a mobilidade dos fins de curso (Figura 4.17), através das ranhuras do perfil e o uso de um parafuso cabeça martelo $DIN186 - M8$. Este perfil é aparafusado na estrutura da máquina, com dois cantos em L em alumínio, que pertenciam ao conjunto do perfil (Figura 4.18). Na Figura 4.19 é apresentada a posição na qual o perfil *Bosch* é fixo.

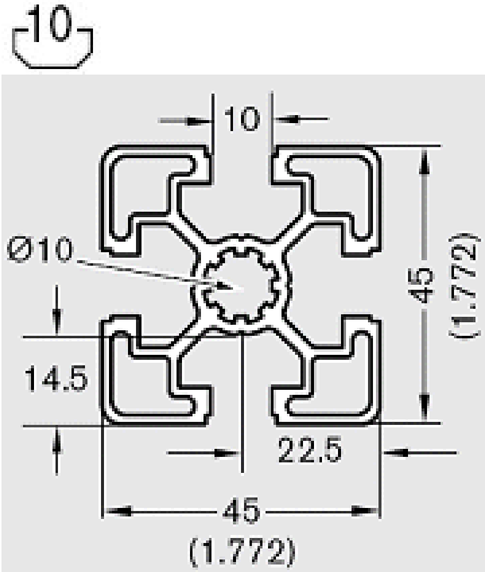


Figura 4.17: Perfil *Bosch* utilizado (Bosch Rexroth, s.d.)

Figura 4.18: Cantos usados para a fixação do perfil

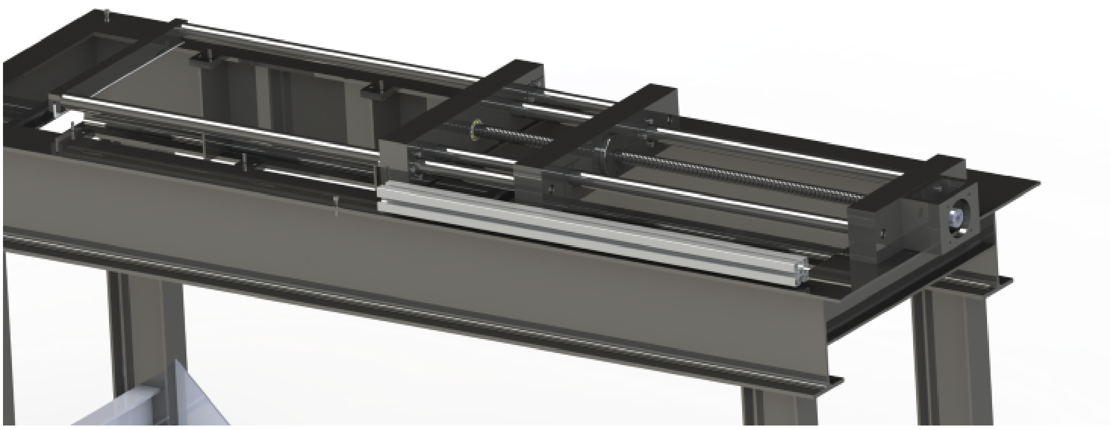


Figura 4.19: Perfil *Bosch* em posição

Os fins de cursos eleitos foram os *GLLA01A1B* (Honeywell, 2005). Posteriormente foi projetada a peça que faz a ligação entre o perfil e o fim de curso mecânico. Trata-se de uma peça simples em forma de ”L”, em aço galvanizado prevenindo assim a oxidação da peça. Esta peça possui dois rasgos que permitem a mobilidade transversal do fim de curso, de forma a possibilitar a regulação da distância entre o fim de curso e o bloco central móvel da varredora e apresenta ainda um furo com 10 mm de diâmetro com a finalidade de fixar a peça ao perfil. Na Figura 4.20 é exibida uma imagem da peça projetada e no Apêndice E é possível observar o desenho técnico da peça, que foi maquinada no CNC do DEM.

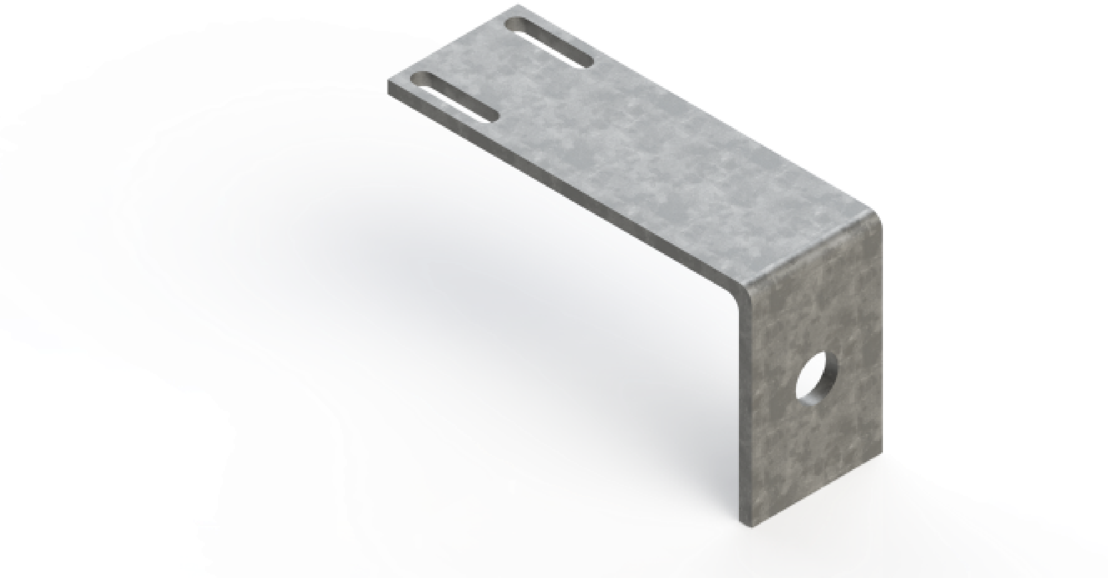


Figura 4.20: Peça em forma de L projetado para o suporte do fim de curso

A Figura 4.21 apresenta uma imagem da peça fixa ao perfil. A posição da peça foi escolhida de modo a que a troca de posição da mesma seja de fácil acesso, uma vez que toda a máquina terá uma cobertura.

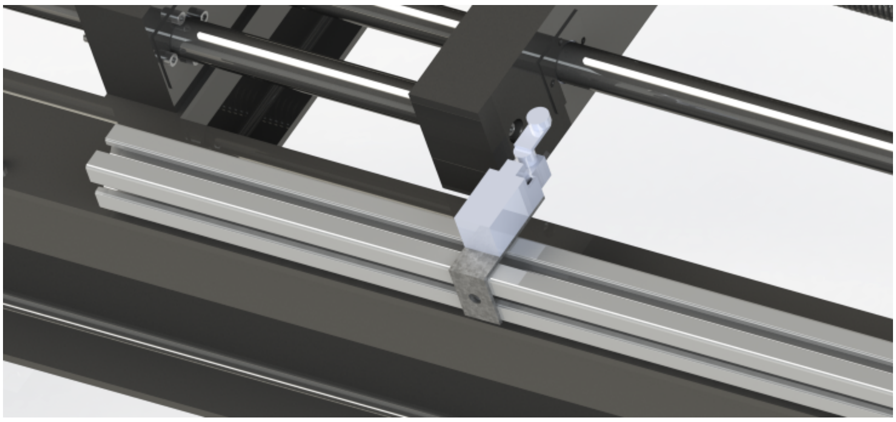


Figura 4.21: Peça na posição de trabalho

4.5 Acoplador entre a cabeça do laser e o *AM-MODULE NEXT GEN*

Ao analisar os componentes do laser escolhido, verificou-se a inexistência de um adaptador entre a cabeça do laser e o *AM-MODULE NEXT GEN*. Assim sendo, houve a necessidade de projetar uma peça que possibilita-se a ligação entre os dois componentes. Tendo em consideração a peça existente (Figura 4.22), foi projetado o acoplador, cuja fixação se realiza a partir de quatro parafusos $M5$ no *AM-MODULE NEXT GEN* e uma rosca $M32$x$0,5$, roscada à cabeça do laser (Figura 4.23).

O material escolhido para a peça foi o alumínio. Esta foi maquinada no torno convencional e no CNC do DEM. A peça possui uma gola na zona final da rosca que permite a inserção de um *O-ring*, que previne a entrada de pó na lente da cabeça do laser. No Apêndice F é apresentado o desenho técnico da peça.

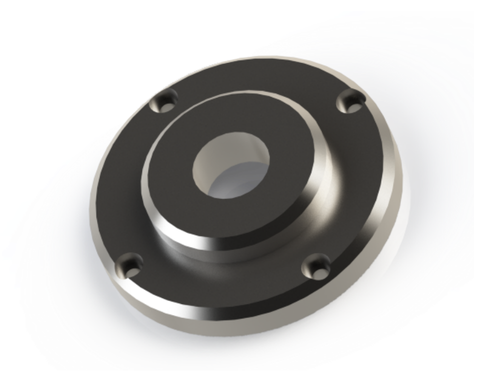


Figura 4.22: Peça existente do *AM-MODULE NEXT GEN*

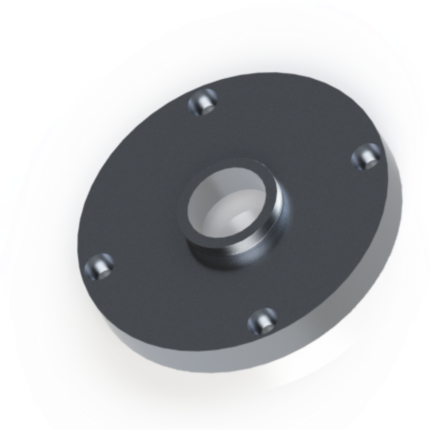


Figura 4.23: Peça maquinada para alojar a ligação por fibra ótica ao laser

4.6 Suporte do quadro elétrico da máquina

O quadro elétrico foi construído na empresa portuguesa *Quadtel* que produz material elétrico. O projeto inicial da máquina não possuía nenhum tipo de suporte para a fixação do quadro na máquina, uma vez que eram desconhecidas as dimensões do quadro elétrico. Surgiu então a necessidade de projetar um suporte para o quadro elétrico. Tendo em conta as dimensões dos furos de fixação do quadro, foi construído um caixilho com tubo quadrado de 20 mm em aço. Estes tubos foram cortados num ângulo de 45° de modo a facilitar a soldadura, permitindo desta forma uma harmonização dos aspeto visual. Na parte superior foram ainda soldadas duas chapas de aço com 10 mm de espessura com um furo cada com o propósito de fixar o suporte à estrutura principal da máquina com dois parafusos $M10$. Na Figura 4.24 é apresentada uma imagem do suporte projetado.

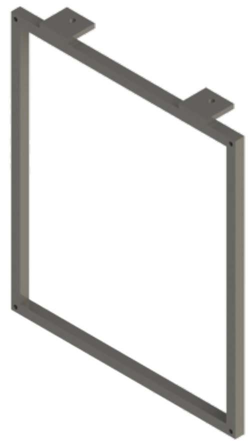


Figura 4.24: Suporte projetado do quadro elétrico

4.7 Conduta para a extração do pó em excesso

A mesa de trabalho da máquina possui um rasgo com 270 *mm* x 20 *mm* na sua parte final, de modo a que o pó em excesso não se acumule, mas que seja extraído por uma conduta. O projeto desta conduta teve em conta as ferramentas disponíveis e o desperdício mínimo de matéria prima. Posto isto, chegou-se à conclusão que a estratégia mais eficaz seria a separação da conduta em duas peças sensivelmente simétricas, com uma geometria como a representada na Figura 4.25.

Figura 4.25: Peça de extração do pó

Produzidas as peças, é possível uni-las, como demonstrado na Figura 4.26, sendo estas encaixadas uma no interior da outra, de forma a que as abas laterais fiquem coincidentes. Para tal, uma das peças possui uma dimensão inferior de 2 *mm* em relação à outra. Na Figura 4.27 é apresentado o pormenor da junção de ambas as peças.

Após o encaixe das peças, estas são soldadas, de maneira a criar uma ligação permanente e resistente. O material usado para a realização das peças é uma chapa de aço EN S235 com 1 *mm* de espessura. A chapa inicial, de forma a minimizar o desperdício de material, tem dimensões de 518 *mm* x 221 *mm*. Na Figura 4.28 é apresentada a planificação das peças da conduta com as suas dimensões.

Figura 4.26: Peças unidas

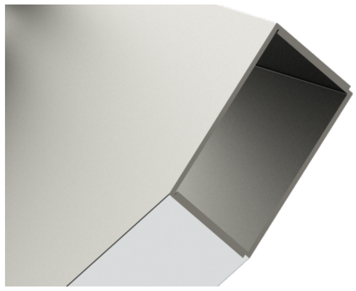


Figura 4.27: Pormenor da união

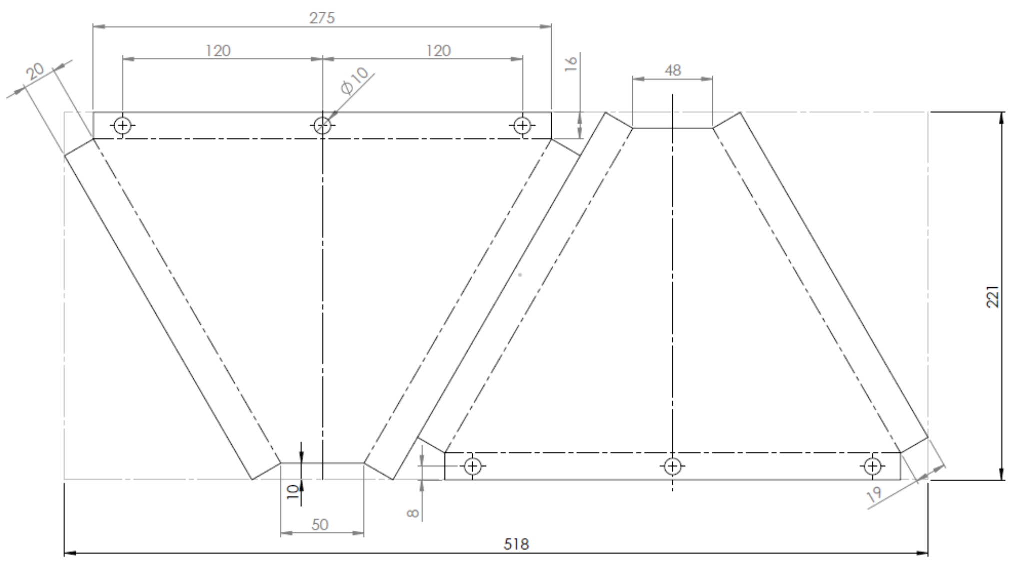


Figura 4.28: Planificação das chapas da conduta

Na parte mais estreita da conduta foi acoplado um tubo, de modo a facilitar a colocação de sacos para a recolha do pó e não existirem perdas. A parte estreita da conduta apresenta um perfil retangular com dimensões máximas de 55 mm x 22 mm, as quais se devem ter em conta para selecionar o perfil do tubo. O tubo escolhido tem um perfil retangular com dimensões de 70 mm x 40 mm e espessura de 3 mm. Este tubo é soldado à restante conduta, sendo esta fixa à mesa de trabalho da máquina através de seis parafusos $M8$.

4.8 Cobertura da máquina

O projeto inicial da máquina não possuía nenhum tipo de cobertura para além da zona do laser. De forma a garantir a segurança do utilizador, houve a necessidade de projetar uma cobertura, uma vez que, a varredora apresenta peças móveis e trabalha a altas rotações. A cobertura permite que nenhuma parte móvel da máquina tenha acesso direto ao operador. Para além disso a cobertura tem uma vantagem estética acrescida. Na Figura 4.29 é apresentada uma imagem da máquina sem cobertura.

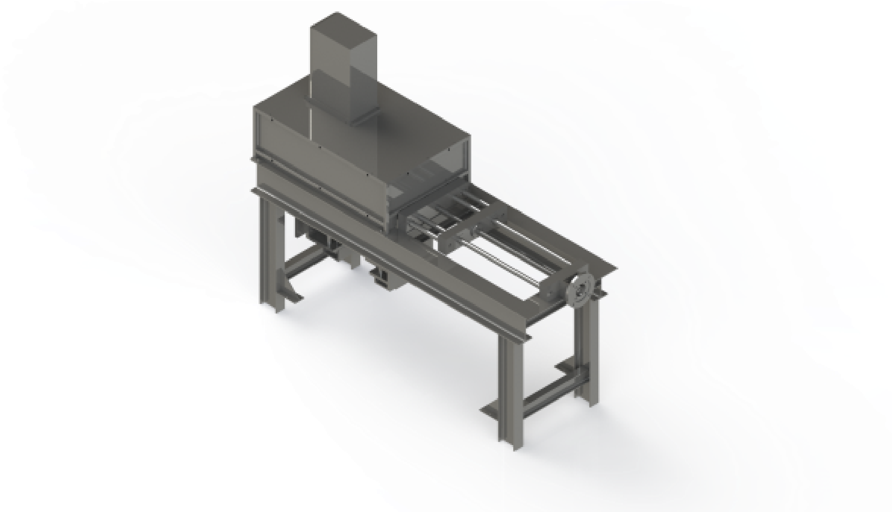


Figura 4.29: Máquina antes do projeto de cobertura

O conceito base para projeto de cobertura foi a simplicidade e eficácia de proteção do utilizador. Com essa linha de pensamento surgiram dois conceitos, onde, na Figura 4.30 é apresentado o conceito 1 da cobertura e na Figura 4.31 está exposto o conceito 2 da mesma. O modelo 1 é simples e tem formas retangulares, ao contrário do modelo 2 que possui uma forma mais complexa. Os dois desenhos têm em comum o uso de chapa galvanizada com $1,5$ mm de espessura, onde as quatro chapas são independentes, permitindo remover apenas aquela que cobre a área que se pretende aceder. As chapas também são unicamente pousadas na parte inferior sobre a estrutura da máquina e restringidas na parte superior utilizando furos que já se encontram feitos. Cada conceito tem as suas próprias vantagens e desvantagens em comparação com o outro. Na Tabela 4.2 é apresentada uma comparação entre ambos os conceitos.

Mediante as vantagens e desvantagens de cada conceito, foi escolhido o conceito 1, onde o principal fator de escolha foi a facilidade de produção, com menor gasto de mate-

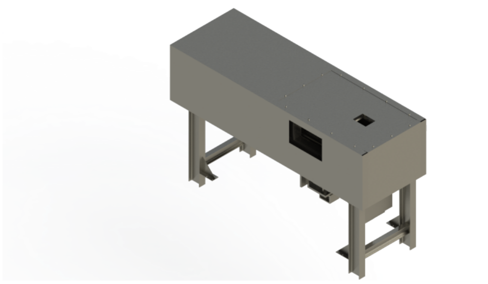


Figura 4.30: Conceito 1

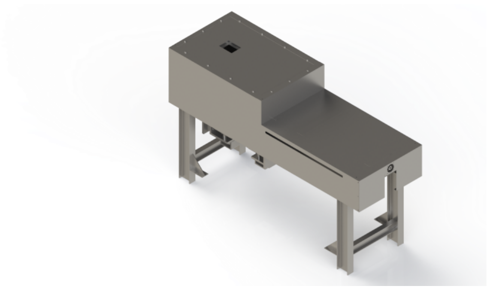
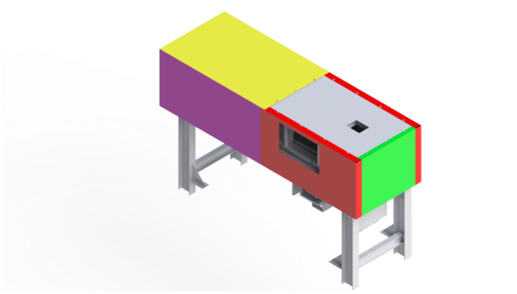


Figura 4.31: Conceito 2

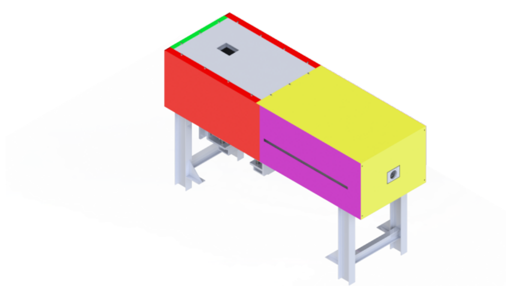
Tabela 4.2: Vantagens e desvantagens de cada conceito

Conceito 1		**Conceito 2**	
Vantagens	**Desvantagens**	**Vantagens**	**Desvantagens**
• Maior facilidade de produção; • Aspeto minimalista; • Necessita de menos material (chapa metálica).	• Ocupa mais espaço; • Não possui zona de mesa de trabalho.	• Mais compacta; • Zona da varredora pode funcionar como mesa de trabalho.	• Maior dificuldade de produção; • Necessita de mais material (chapa metálica); • Maior desperdício de chapa metálica.

rial. As duas partes laterais possuem um comprimento de aproximadamente 2100 mm, o que se tornou um problema uma vez que a quinadora disponível na Universidade de Aveiro possui apenas um comprimento útil de trabalho de 1200 mm. Desta forma, foi necessário separar as laterais em duas partes distintas que posteriormente foram ligadas por parafusos. Na Figura 4.32 é apresentado o resultado final da cobertura onde as cores das chapas servem unicamente para identificação e distinção das chapas da cobertura. Toda a chapa usada para a cobertura é chapa galvanizada com 1 mm de espessura que se encontrava disponível no DEM.



(a) Parte da frente com o pormenor do rasgo da porta



(b) Parte de trás com o pormenor do rasgo do fim de curso

Figura 4.32: Conceito 1 com as alterações finais

Foram utilizadas seis chapas, duas peças simétricas vermelhas e roxas, uma amarela e outra verde. As chapas foram cortadas na guilhotina em forma retangular com as dimensões máximas de cada chapa, sendo posteriormente cortadas as esquinas das chapas com uma tesoura de cortar chapa. De seguida, as chapas foram quinadas e por fim feita a furação para fixar as chapas à estrutura da máquina. No Apêndice G encontram-se os desenhos com as dimensões das chapas e a traço interrompido estão as zonas onde as chapas foram quinadas. A direção para qual a chapa é quinada é inversa nas duas chapas vermelhas e roxas, uma vez que são simétricas. Assim como, só uma delas tem os rasgos para a porta e para o fim de curso. Todas as ligações aparafusadas necessárias entre as chapas são por parafuso $M4$x8 e a sua respetiva porca. A chapa verde é aparafusada três vezes a cada chapa vermelha, a chapa vermelha por sua vez é aparafusada três vezes à chapa roxa e uma vez na chapa amarela, no que diz respeito à chapa roxa esta é aparafusada três vezes na parte superior e duas vezes na lateral à chapa amarela.

Capítulo 5

Controlo do equipamento e desenvolvimento do ensaio experimental

O controlo da máquina pode dividir-se em duas partes distintas: o controlo do sistema de laser e o controlo dos motores da varredora e elevadores. O sistema de laser é controlado pelo *software weldMARK® 3* da *Raylase* (Raylase, 2020c), já o controlo dos motores é realizado por um programa em *LabView* da NI. A interação entre os dois programas é feita por uma entrada e saída digital. A primeira é ativada quando o laser termina a impressão de cada camada e é emitida pelo *SP-ICE 3* e o outro sinal é ativado pela carta da NI assim que uma nova camada de pó está pronta para sinterizar. A Figura 5.1 sintetiza as interações entre os componentes que necessitam de controlo.

5.1 Controlo dos motores da máquina

Os motores são uma das partes mais importantes de uma máquina de DMLS. De facto, são estes que em sincronia com o laser permitem a construção 3D da peça. Na parte esquerda da Figura 5.1 é apresentado o controlo relativo aos motores da máquina. O *NI cDAQ-9174* é um *chassis* com capacidade máxima de quatro cartas da NI (Apêndice H). Este *chassis* permite ligar as duas cartas da NI e controlar as suas entradas e saídas em simultâneo. A carta *NI 9403* possui um total de 32 entradas ou saídas digitais e tem a função de controlar vários componentes, alarmes e a interação entre o programa do controlo do sistema de laser (Apêndice I). Por último a carta *NI 9401* tem à sua disposição 8 entradas/saídas digitais ou entradas/saídas analógicas programáveis (Apêndice J).

5.1.1 Controlo dos motores dos elevadores

O conjunto motor de passo e *driver* abordados em 4.2.1 são controlados pela carta *NI 9401*, uma vez que esta carta permite criar saídas físicas necessárias para a criação de um sinal pulsado. Os *drivers* são controlados por três pares de sinais distintos, o par *PUL+/PUL-*, o par *DIR+/DIR-* e o par *EN+/EN-*. No par *PUL+/PUL-* são aplicados os impulsos necessários para a rotação do motor. Já no par *DIR+/DIR-* é controlado, via sinal digital, o sentido da rotação do motor. Por último o par *EN+/EN-* permite

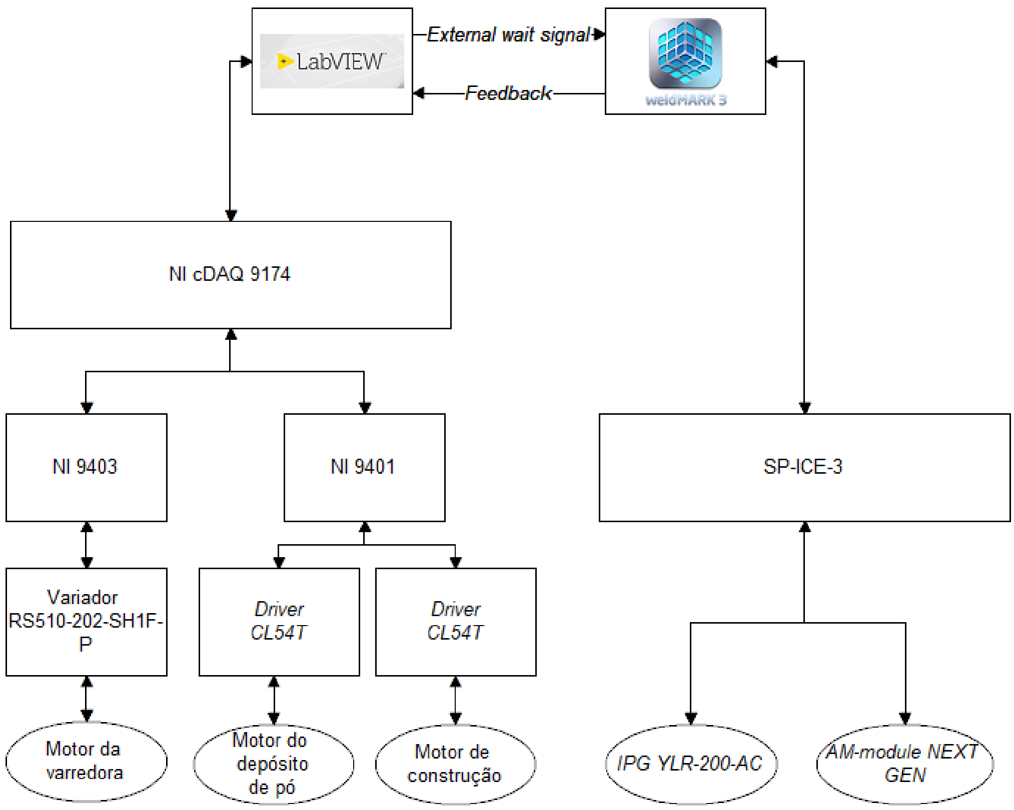


Figura 5.1: Diagrama de interação dos componentes

ativar a rotação do motor. O *driver* possui ainda uma saída digital de alarme que indica se existe alguma irregularidade no posicionamento ou no motor.

É possível parametrizar o *driver* através de *dip switch*. Na Tabela 5.1 é apresentada a parametrização utilizada para a máquina. No *switch SW1:SW4* é configurado o número de impulsos necessários para a realização de uma rotação do motor, sendo que o número varia entre os 800 impulsos por rotação até um máximo de 51200 impulsos por rotação. Para a máquina foi selecionada a posição de 800 impulsos por rotação, uma vez que este número já fornece a precisão de posicionamento necessário. O *SW5* permite alterar o sentido de rotação, já o *SW6* quando se encontra em *Off* permite ligar o *Auto Tuning*, função esta que permite identificar o motor conetado. Em seguida, o *SW7* controla o modo de impulso. Por fim, o *SW8* define o tipo de impulso (Stepperonline, 2020).

Tabela 5.1: Parametrização usada para o *dip switch* do *driver*

Switch	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8
On/Off	Off	On	On	On	Off	Off	Off	Off

Na fase inicial do projeto elétrico da máquina estava previsto controlar todos os componentes apenas pela carta *NI 9403*. Porém a carta *NI 9403* não permite criar entradas ou saídas sob a forma de impulsos, ao contrário da carta *NI 9401* que permite esta possibilidade. Este tipo de entradas ou saídas físicas são necessárias para a criação de impulsos necessárias para o controlo dos *drivers* dos motores dos elevadores. De modo a melhorar a organização do controlo dos *drivers* e utilizar uma única carta, no caso a *NI 9401*, houve a necessidade de alterar os terminais dos fios 5.11, 5.12, 5.13, 5.15, 5.16 e 5.17 do esquema elétrico (Apêndice K). Na Tabela 5.2 são apresentadas as alterações das ligações no esquema elétrico da carta *NI 9401* (Figura 5.2).

Tabela 5.2: Quadro resumo das ligações realizadas no *NI 9401* (Ver Figura 5.2)

Sinal	**Identificação do fio**	**Nome da porta do *NI 9401***	**Pino do *NI 9401***	**Tipo de saída**
***Driver* do elevador do depósito do pó**				
PUL+	5.11	PF7	25	Física
DIR+	5.12	P0.4	20	Digital
EN+	5.13	P0.5	22	Digital
***Driver* do elevador de construção da peça**				
PUL+	5.15	PF3	19	Física
DIR+	5.16	P0.1	16	Digital
EN+	5.17	P0.2	17	Digital

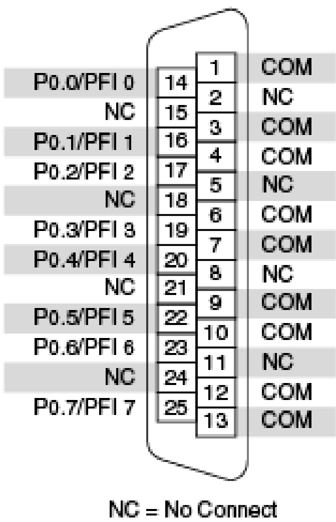


Figura 5.2: *NI 9401 pinout* (NI, 2020)

5.1.2 Controlo do motor da varredora

O controlo do motor da varredora é feito por um variador de frequência. O variador de frequência tem como principal função variar a frequência da rede que alimenta o motor. Assim sendo, o motor funciona a uma frequência diferente da fornecida pela rede (50 Hz, em Portugal). Desta forma é possível controlar facilmente a velocidade de rotação do motor (Lino, 2017).

O variador de frequência escolhido para a máquina é da empresa *RS Components*, do modelo *RS510-202-SH1F-P*. Este variador é alimentado a 230 V e tem uma potência de $1,5\ kW$. O variador de frequência necessita de uma parametrização inicial, para tal, o variador de frequência possuía um guia para facilitar a parametrização (Apêndice N). Na Tabela 5.3 são expostos os parâmetros alterados em relação aos valores de fábrica. O manual do variador encontra-se no Apêndice O.

Tabela 5.3: Parametrização do variador de frequência

Parâmetro	**Valor de fábrica**	**Valor alterado**
13-08	1250/1360	1250
02-07	0	1
00-05	2	0
00-06	0	1
00-10	0	2
00-11	0	12
00-13	0	5
00-14	10	1.5
00-15	10	1.5

O aumento da durabilidade do mecanismo é uma outra vantagem do uso de variador de frequência, uma vez que é possível parametrizar uma rampa de aceleração e desaceleração do motor, fazendo com que o arranque ou a paragem seja suavizada e deste modo poupar o choque entre o acoplador e o veio do motor. No caso, o valor possível de parametrizar é o tempo que o motor chega à sua velocidade máxima, no caso da aceleração e o mesmo acontece para o tempo de desaceleração. O tempo definido para os dois parâmetros foi de $1,5\ s$. Na Figura 5.3 é possível observar um gráfico exemplo da velocidade de varrimento, com o variador a uma frequência de 50 Hz. A área a verde representa a zona de aceleração, a área a azul indica a zona de velocidade máxima e a região a vermelho assinala a zona de desaceleração do motor.

Em modo automático, a varredora a cada camada irá percorrer um curso total de 800 mm para cada lado e os seus fins de curso são ativos uma vez que a varredora entra em contacto com eles, entrando assim o variador na zona de desaceleração. Uma vez que a paragem do motor não é imediata, mas sim, só no final de $1,5\ s$, a varredora irá percorrer uma distância de travagem representada pela área a vermelho da Figura 5.3. Em termos numéricos, com o variador a funcionar a uma frequência de 50 Hz a distância percorrida de travagem será de 75 mm, valor este superior ao espaço disponível no bloco móvel da varredora que entra em contacto com os fins de curso, o qual possui apenas uma largura de 55 mm. Esta distância de travagem pode vir a danificar a máquina mecanicamente, uma vez que o bloco móvel irá passar o fim de curso sem parar completamente. De modo a evitar esta situação é obviamente necessário tomar o devido cuidado de ter os fins de curso corretamente posicionados caso seja alterada a frequência do variador. Naturalmente, para obter o curso total é imperativo que os fins de curso estejam no interior do percurso total a vencer.

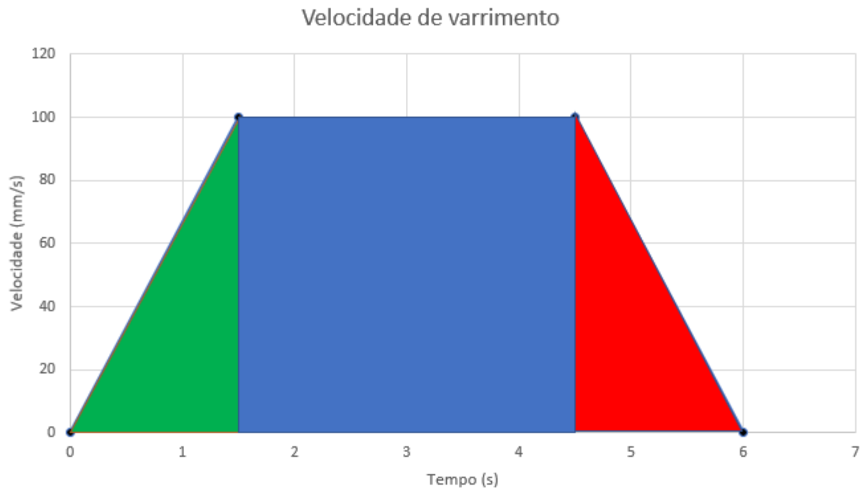


Figura 5.3: Gráfico exemplo da velocidade da varredora a 50 Hz

5.2 Controlo do sistema de laser

O sistema de laser da máquina permite sinterizar as camadas de pó metálico, processo este vital para a construção 3D da peça. Na parte direita da Figura 5.1 é apresentado o controlo relativo ao sistema de laser. Este sistema é controlado por uma carta de controlo *SP-ICE-3* da *Raylase*, carta esta, que permite o controlo em simultâneo do laser e do *AM-MODULE NEXT GEN*. Esta carta é ligada a um computador via placa *PCI-Express* e é alimentada a 12 V com 5 A. O *software weldMARK® 3* controla esta carta, onde o utilizador tem a possibilidade de definir múltiplos parâmetros de controlo. Na Figura 5.4 são apresentadas as ligações ao *SP-ICE-3* (Raylase, 2020b)

O *AM-MODULE NEXT GEN* comunica com o *SP-ICE-3* a partir do conector X904 pelo protocolo RL3-100 com uma resolução de 20 bits. Já o laser comunica com o *SP-ICE-3* a partir do conector *X907* através de uma interface com 15 pinos com duas saídas analógicas (Raylase, 2020b). O conector do laser possui um terminal com 24 pinos. O cabo referente ao módulo e o conector X904 foi fornecido, ao contrário do cabo entre o laser e o conector *X907*, que necessitou de ser fabricado. Este cabo de modo a identificar cada terminal dispõe de fios elétrico com cores diferentes, onde alguns deles têm uma única cor e outro têm uma cor principal e uma outra secundária. Na Tabela 5.5 é apresentado o mapa de cores do conector *X907* do *SP-ICE-3*. A identificação dos fios do cabo ligado ao conector do laser encontra-se numericamente identificado, ou seja, o fio com identificação 1 está ligado ao terminal 1 e assim por diante até ao terminal 24. A ligação entre este dois cabos é feita através do circuito que se encontra no esquema elétrico da máquina no Apêndice K. A ficha técnica e teste do laser são apresentados nos Apêndice L e Apêndice M, respetivamente.

O *software weldMARK® 3* é uma ferramenta eficiente para o controlo de sistemas de laser graças à sua interface amigável. Este *software* permite importar ficheiros com a informação do modelo 3D no formato DXF ou STL que contém a geometria do objeto ou, importar ficheiros *txt* que contêm as coordenadas de processamento 3D (Raylase, 2020c). Na Figura 5.5 é apresentada a página incial do *software weldMARK® 3*, onde

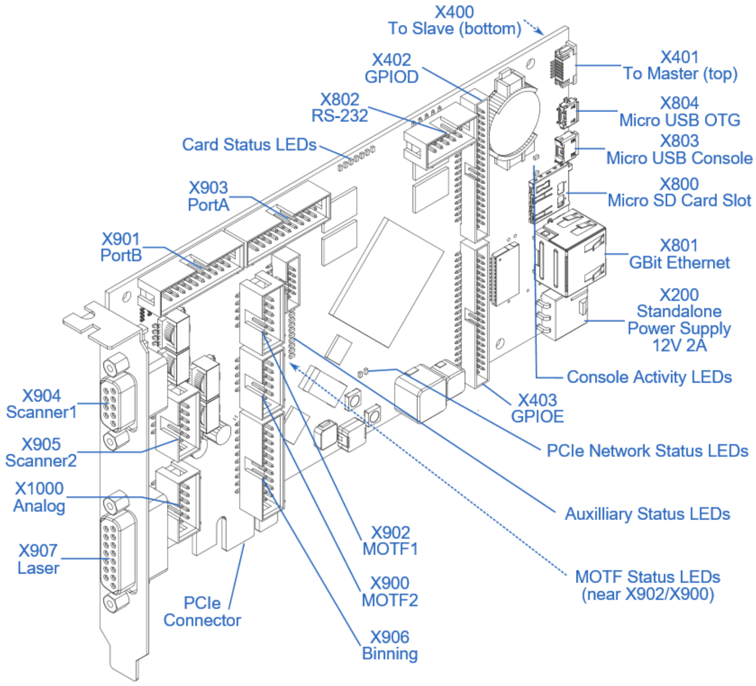


Figura 5.4: Conetores e portas do *SP-ICE-3* (Raylase, 2020b)

Tabela 5.4: Mapa de cores do cabo da saída *X907* do *SP-ICE-3*

Pino	Cor Primária	Cor Secundária	Pino	Cor Primária	Cor Secundária
1	Vermelho	-	9	Verde	Preto
2	Azul	-	10	Branco	-
3	Preto	-	11	Rosa	Verde
4	Rosa	-	12	Amarelo	Cinzento
5	Cinzento	-	13	Roxo	-
6	Verde	-	14	Branco	Preto
7	Amarelo	-	15	Castanho	Preto
8	Castanho	-	-	-	-

é feito o controlo de todos os parâmetros do programa.

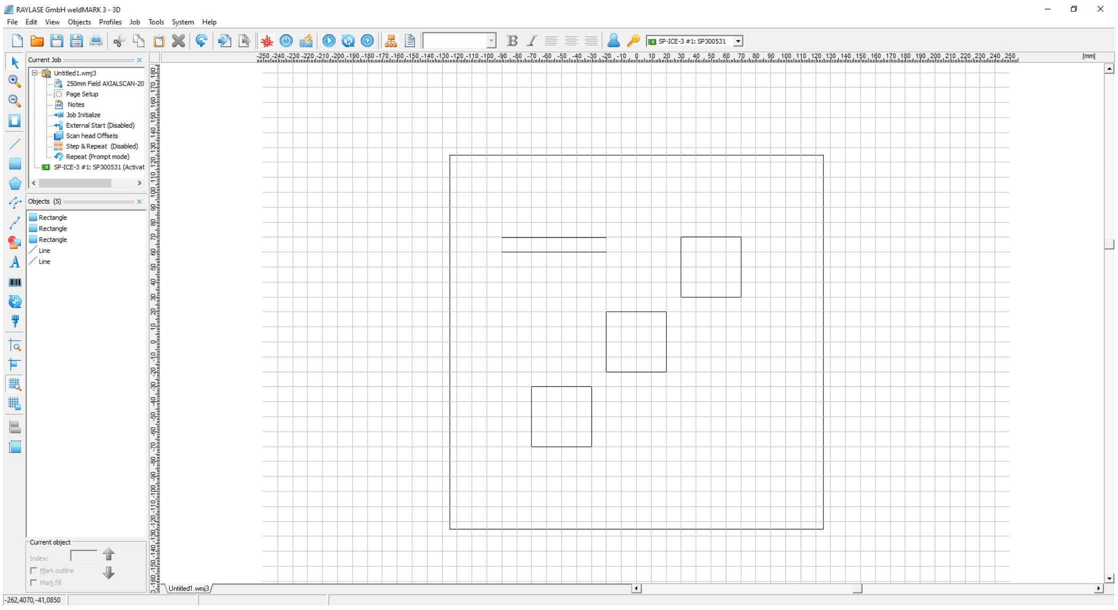


Figura 5.5: *Software weldMARK® 3* da *Raylase*

No *software weldMARK® 3* cada *Objects* (Figura 5.6) representa um diferente objeto ou camada. O controlo em modo automático da máquina necessita que a cada *Objects* diferente, o qual, neste caso, representa uma camada da peça, seja inserido um *Wait for External Signal*, na opção *Automation Object* que se encontra na barra lateral esquerda do programa, para que o sistema de laser espere pelo sinal do *NI 9403* quando este acabar de colocar uma nova camada de pó (Figura 5.7). As diferentes camadas da peça são importadas através da opção *Import*. Resumindo, a cada camada importada, é necessário inserir de seguida um *Wait for External Signal*, exceto na última camada.

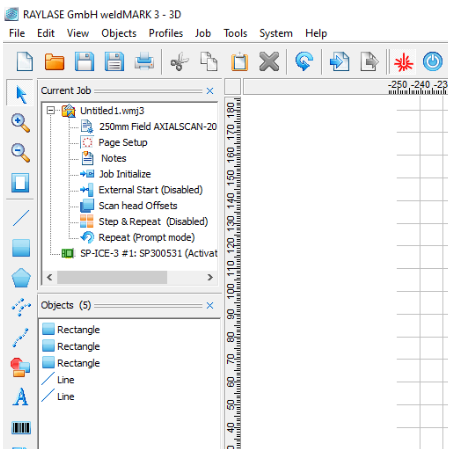


Figura 5.6: Árvore da trabalho do *software weldMARK® 3*

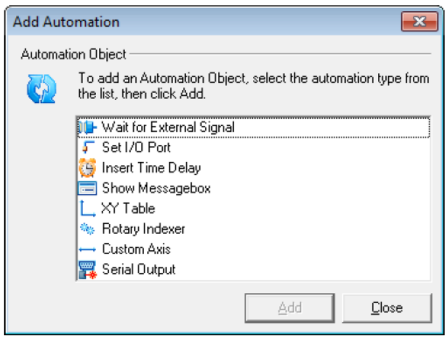


Figura 5.7: Janela *Add Automation*

5.3 Controlo dos sensores e fins de curso da máquina

O controlo da posição dos elevadores e da varredora é feita através de sensores óticos e fins de curso mecânicos, respetivamente. Este controlo é realizado por entradas digitais do *NI 9403* nos terminais 4 e 5 para os interruptores óticos e nos terminais 6 e 7 para os fins de curso. Este conjunto de sensores é alimentado por 5 V.

De modo a que seja possível utilizar os interruptores óticos de forma digital, surgiu a necessidade de realizar um circuito. Na Figura 5.8 é possível observar o circuito necessário realizar onde as alterações se encontram destacadas a vermelho. Também é possível constatar que os fins de curso são contactos Normalmente Fechado (NF) de modo a melhorar a segurança da máquina, uma vez que caso os fins de curso sofram qualquer tipo de anomalia como por exemplo, a fonte de alimentação estar desligada, fio partido ou mal conectado, o variador de frequência não será ativo.

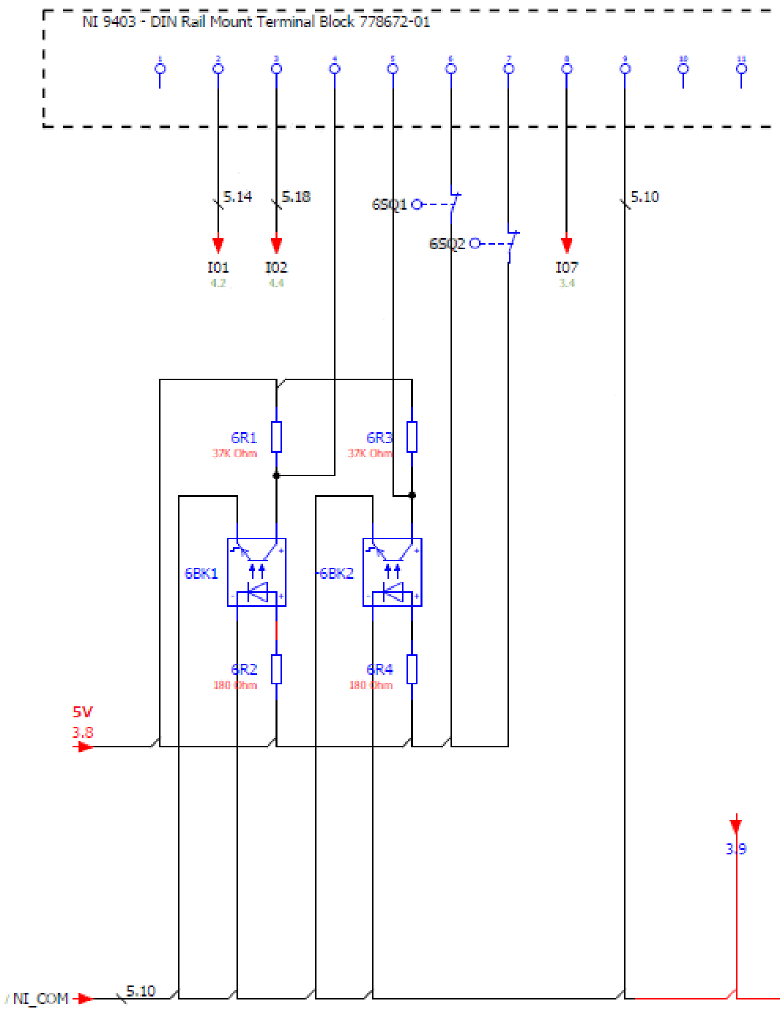


Figura 5.8: Circuito do esquema elétrico com alterações

O valor das resistências foi alterado de 40k Ohm para 37k Ohm e de 270 Ohm para 180 Ohm, devido do facto de resistências com valor de 37k Ohm e 180 Ohm serem valores mais comuns e encontravam-se em *stock* nos armazéns do DEM. Esta alteração do valor das resistência não altera em nada o desempenho dos interruptores óticos.

Uma vez que os interruptores óticos possuem fios com ligações frágeis, houve a necessidade de melhorar a resistência dos fios, dada a necessidade de realizar um circuito com resistências soldadas a esse cabo. O circuito foi realizado segundo o esquema elétrico com as resistências isoladas com mangas termoretráteis (Figura 5.9 (a)). O resultado final do cabo dos interruptores tem forma de Y com comprimento suficiente para os terminais entrarem no quadro elétrico da máquina (Figura 5.9 (b)).

(a) Circuito elétrico com resistências devidamente isoladas

(b) Resultado final

Figura 5.9: Cabo fabricados dos interruptores óticos

A identificação de fios e cabos é importante, uma vez que, sem ela é impossível saber qual a função de cada cabo ou fio. É possível identificar fios e cabos através da sua cor, etiquetas ou marcações. Assim sendo, o cabo produzido dos interruptores óticos foi identificado através da cor dos fios, neste caso pares de cores. Na Tabela 5.5 é apresentada uma descrição para cada sinal, assim como a cor dos fios usados, já na Figura 5.10 é exibida a régua de bornes utilizada para organizar os fios antes de conetar ao terminais do *NI 9403*.

O esquema elétrico inicialmente tinha projetado que uma saída digital no terminal 1 do *NI 9403* iria alimentar os 5 V dos interruptores e fins de curso, contudo esta alimentação foi substituída, como é possível observar, na Figura 5.8. O *NI 9403* possui saídas digitais com tensão de 5 V e intensidade de corrente de 2 mA, o que é insuficiente uma vez que cada interruptor ótico necessita no mínimo de 6 mA para o seu correto funcionamento. De modo a solucionar este problema foi utilizada uma fonte de tensão externa de 5 V com $2,5$ A, como fonte de alimentação do conjunto de sensores.

O utilizador do programa de controlo da máquina verifica o ZM dos elevadores através do *LED* que se encontra nas abas do modo Manual e do Modo automático. Na Figura 5.11 é possível perceber a diferença entre o interruptor ótico quando este está a detetar ou não o objeto através do *LED* estar vermelho ou branco, respetivamente. No momento em que o *LED* passa a vermelho o interruptor ótico está a detetar o objeto e a plataforma

Tabela 5.5: Quadro de cores dos fios da alimentação do conjunto de sensores da máquina

Sinal	**Cor**	**Descrição**
5 V	Vermelho/Laranja	Alimentação
COM	Preto/Castanho	Comum
Sinal do sensor do depósito do pó	Azul/Roxo	Entrada digital do sensor no terminal 4
Sinal do sensor de contrução	Verde/Amarelo	Entrada digital do sensor no terminal 5
Fim de curso da direita (frente) +	Castanho	5 V e possui identificação com fita isoladora vermelha
Fim de curso da direita (frente) -	Azul	Entrada digital do terminal 7
Fim de curso da esquerda (trás) +	Castanho	5 V e não possui identificação
Fim de curso da esquerda (trás) -	Azul	Entrada digital do terminal 6

encontra-se na posição de ZM. Na Figura 5.12 é observado o objeto a passar pela ranhura do interruptor ótico e o programa fica com o *LED* a vermelho, já na Figura 5.13 o interruptor ótico não deteta nenhum objeto e o *LED* do programa permanece a branco.

A calibração da altura das plataformas em relação à superfície da mesa de trabalho foi realizada por último. Os interruptores ótico foram fixos de forma a que as plataformas estejam a uma altura de 25 mm no elevador do depósito de pó e 30 mm no elevador de construção da peça. A escolha altura da plataforma do depósito de pó é derivado a esta ser a altura máxima sem danificar as barras de $PTFE$, que garantem a estanqueidade do depósito. Já a altura da plataforma de construção da peça é maior de modo a que seja possível adicionar uma chapa perdida que tem a função de servir de base da peça produzida. Na Figura 5.14 é apresentada a altura da plataforma quando esta se encontra no ponto ZM.

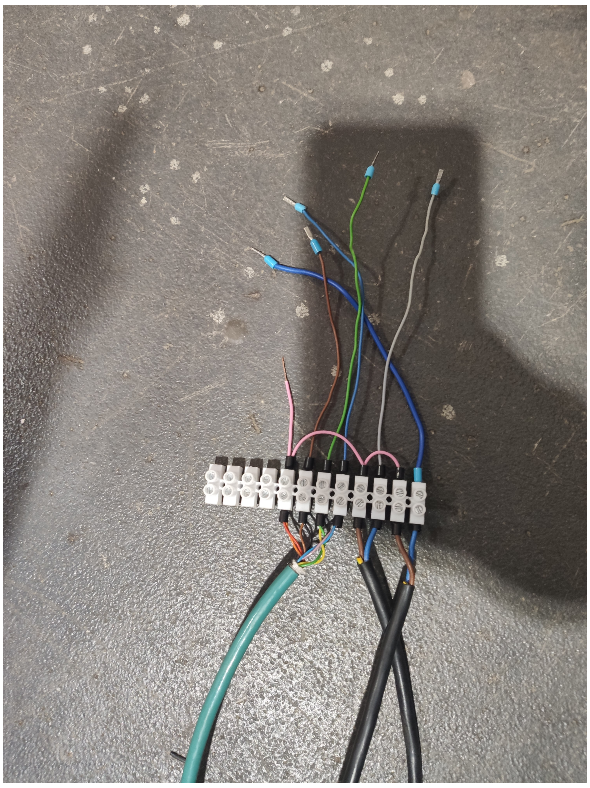
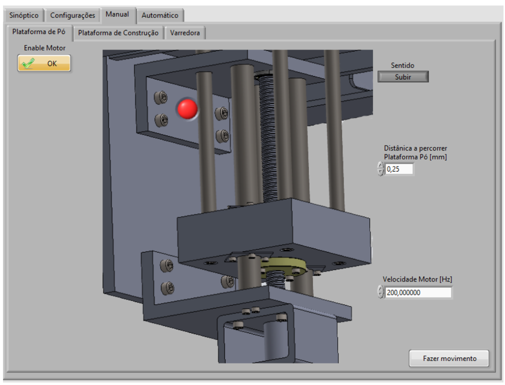
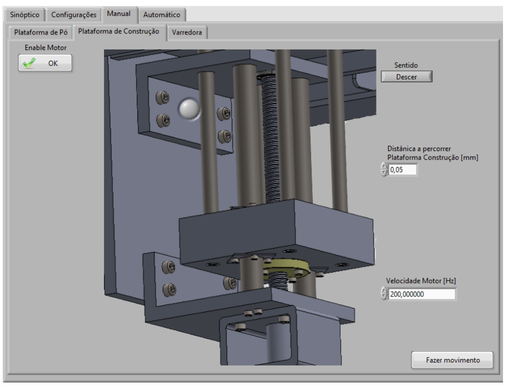


Figura 5.10: Régua de bornes final do circuito da Figura 5.8



(a) Programa a detetar o objeto



(b) Programa a não detetar o objeto

Figura 5.11: Programa de controlo da máquina em *LabView*

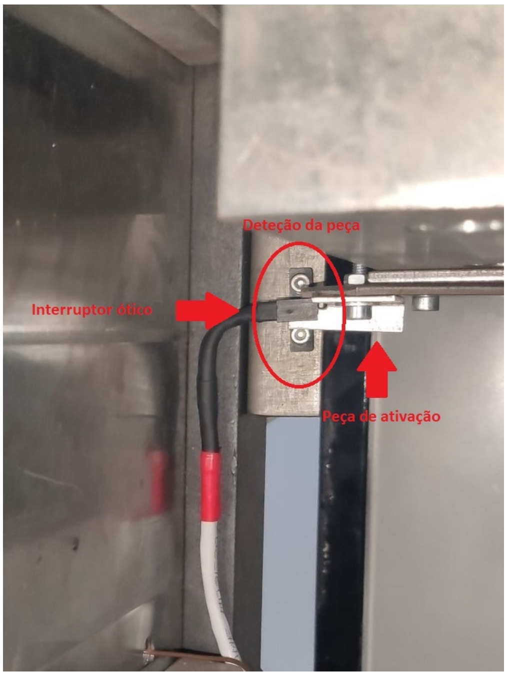


Figura 5.12: Interruptor ótico a detetar o objeto

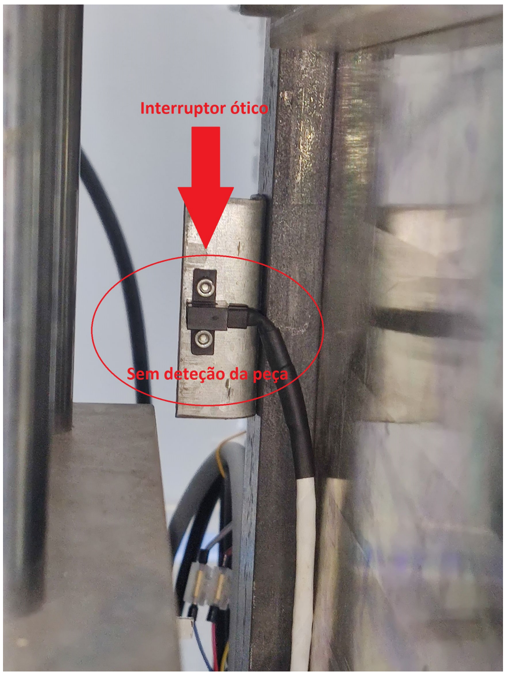


Figura 5.13: Interruptor ótico a não detetar o objeto

Figura 5.14: Altura da plataforma do depósito de pó quando se encontra no ponto ZM

Parte III

Resultados e Discussão

Capítulo 6

Resultados do projeto mecânico

O presente Capítulo tem por objetivo apresentar os resultados do projeto desenvolvido no Capítulo 4 através da exposição das peças produzidas.

6.1 Motores da máquina

6.1.1 Motores dos elevadores

Os motores dos elevadores encontravam-se funcionais, pelo que não foi necessário efetuar nenhuma mudança. No que se refere ao acoplador entre o veio do motor de passo e o fuso do elevador da construção da peça, houve a necessidade de aplicar um espaçador entre o motor e o acoplador, de forma a evitar o desgaste do rolamento do motor, uma vez que existia uma folga entre eles. Já o acoplador entre o veio do motor de passo e o fuso do elevador do depósito de pó, não necessitou de nenhum espaçador, dado que o veio estava alojado com aperto no acoplador. Na Figura 6.1 é possível observar os motores de passo devidamente montados com os acopladores em posição.

6.1.2 Motor da varredora

O motor da varredora, após estar devidamente montado e alinhado em relação ao fuso da varredora, foi testado de modo a garantir a sua funcionalidade. Os resultados deste teste permitiram concluir que o motor possui binário suficiente quando o variador funciona a uma frequência de 50 Hz. Na Figura 6.2 e 6.3 é apresentada, a peça maquinada para a fixação do motor da varredora e o acoplador entre o motor e o fuso da varredora, respetivamente. Por fim, na Figura 6.4 é exposto o motor fixo na máquina em posição de trabalho.

6.2 Zero máquina dos elevadores

O ZM de cada elevador necessitou de quatro peças, que resulta num total de 8 peças distintas. A simetria dos elevadores, levou a que houvesse a necessidade de produzir peças simétricas de forma a garantir a funcionalidade de cada ZM (Figura 6.5). A exceção desta característica de simetria das peças é a barra que se encontra fixa ao elevador (Figura 6.6).

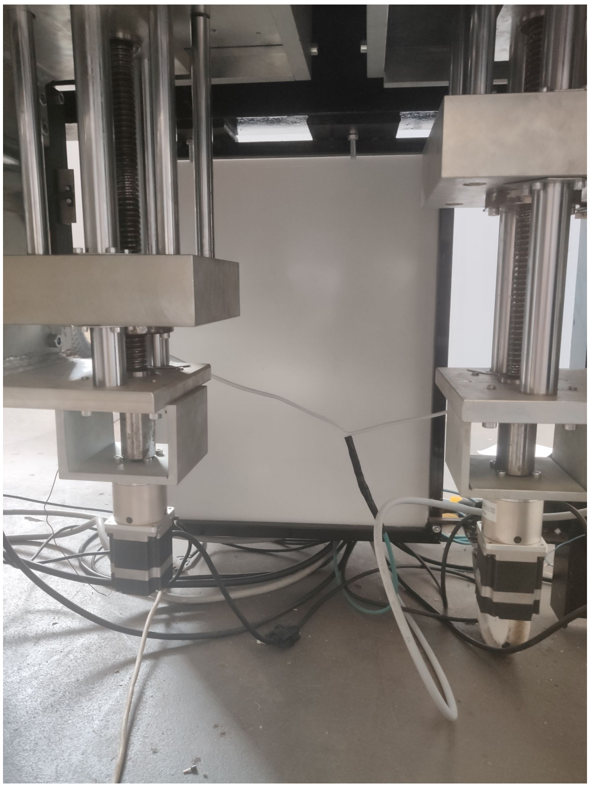


Figura 6.1: Motores dos elevadores

Figura 6.2: Peça de fixação para o motor da varredora

Figura 6.3: Acoplador do motor da varredora

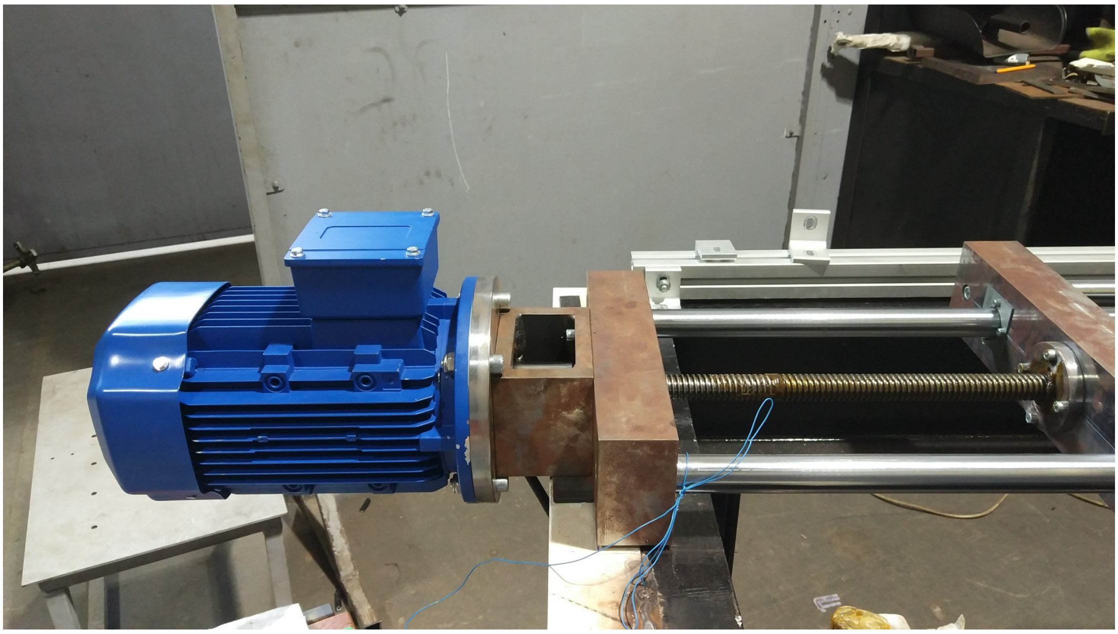


Figura 6.4: Motor da varredora montado na máquina

(a) Peças fixas ao bloco móvel do elevador

(b) Peças que ativam o interruptor ótico

(c) Calibrador da altura do interruptor ótico

Figura 6.5: Peças simétricas do ZM

Por fim, a montagem das peças do ZM foi bem sucedida, garantindo desta forma a função de trabalho dos interruptores óticos. Na Figura 6.7 é possível observar o resultado final do ZM.

Figura 6.6: Barra laminada fixa ao elevador

Figura 6.7: Peças no ZM montadas na máquina

6.3 Fins de curso da varredora

O fim de curso mecânico, nomeadamente o *GLLA01A1B* (Honeywell, 2005), foi o eleito para delimitar o curso da varredora. Nas Figuras 6.8 e 6.9 são exibidas as duas peças produzidas para a fixação dos fins de curso mecânicos no perfil *Bosch* e as peças já na sua posição final de trabalho, respetivamente.

Figura 6.8: Peças usadas para a fixação dos fins de curso mecânicos ao perfil

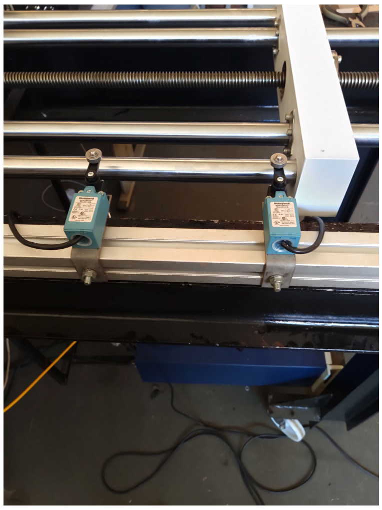


Figura 6.9: Fins de curso mecânicos montados no perfil

6.4 Acoplador entre a cabeça do laser e o *AM-MODULE NEXT GEN*

O pequeno comprimento de rosca dificultou a produção do acoplador entre a cabeça do laser e o *AM-MODULE NEXT GEN*. Desta forma, após a maquinagem do acoplador, houve a necessidade de ajustar o encaixe da rosca na cabeça do laser. Na Figura 6.10 é apresentada a peça maquinada e na Figura 6.11 a peça fixa no módulo.

Figura 6.10: Adaptador fabricado

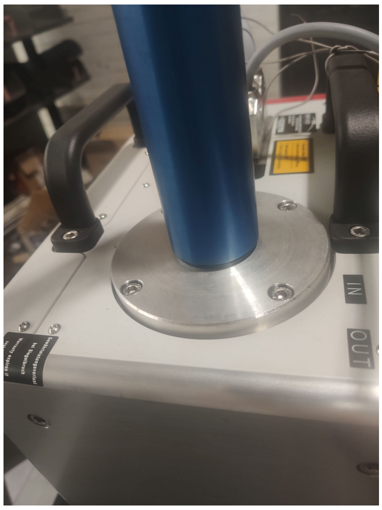


Figura 6.11: Peça fixa ao módulo

6.5 Suporte do quadro elétrico da máquina

O suporte do quadro elétrico encontrava-se bem projetado, uma vez que o quadro foi aparafusado ao suporte sem necessitar de qualquer tipo de alteração dimensional. Foram efetuadas roscas $M8$ nos quatro furos de fixação do quadro, através do uso de um macho de roscar. O suporte foi posteriormente pintado com primário anticorrosivo e esmalte de acabamento de modo a proteger da oxidação natural do material. Na Figura 6.12 é possível observar ligação a soldada entre os tubos e a chapa e entre os tubos em si. Na Figura 6.13 é apresentado o suporte antes da aplicação da tinta e na Figura 6.14 é possível constatar o quadro fixo no suporte, sendo este fixo à estrutura da máquina. Ao fixar o suporte à estrutura da máquina verificou-se que este se encontrava instável quando era necessário manipular o interior do quadro, assim sendo, foi adicionado uma chapa fixa às rodas da máquina, para fixar o suporte na sua parte inferior (Figura 6.15).

6.6 Conduta para a extração do pó em excesso

A conduta para a extração do pó em excesso foi fabricada consoante as dimensões do projeto e fixo na parte inferior da mesa de trabalho da máquina através de seis parafusos $M8$. A conduta é funcional, uma vez que todo o rasgo da mesa de trabalho da máquina para a extração do pó em excesso se encontra coberto pela conduta. Na Figura 6.16 é possível observar a conduta aplicada na máquina.

Figura 6.12: Pormenor da soldadura do quadro

Figura 6.13: Suporte do quadro antes da aplicação da tinta

Figura 6.14: Quadro fixo ao suporte na posição final

Figura 6.15: Pormenor para fixar o quadro

Figura 6.16: Conduta fabricada em posição

6.7 Cobertura da máquina

A cobertura da máquina foi fabricada segundo o projeto e as dimensões da máquina. As peças sofreram algumas alterações em relação aos pontos de fixação uma vez que, alguns destes pontos no projeto, eram diferentes na máquina real. Também foram necessários adicionar alguns pontos de fixação na estrutura da máquina na zona em que as peças eram apenas pousadas, uma vez que as chapas possuem uma espessura de 1 mm e as peças inicialmente foram projetadas com chapa de $1,5$ mm de espessura. Estes novos pontos de fixação melhoraram a firmeza global da cobertura, ponto este importante na proteção do utilizador. Em termos de estética, os novos pontos de fixação não pioraram em nada a aparência da máquina, dado que estes pontos são todos interiores e não visíveis na parte exterior da máquina. Em termos de acessibilidade e facilidade de remoção de qualquer peça independente, esta vantagem deixou de existir, apesar de não se tornar um problema, uma vez que é possível aceder a todas as zonas da máquina pela parte inferior da estrutura.

Nas Figuras 6.17 e 6.18 é possível observar um panorama global da cobertura visto de frente e trás, respetivamente. Nas Figuras 6.19 e 6.20 são apresentados alguns pormenores do encaixe harmonioso da cobertura e fixação.

Foi colocado um perfil plástico na chapa, em zonas que necessitam de manipulação, de forma a proteger o utilizador, uma vez que a cobertura é construída a partir de chapa fina. Estas zonas são a porta da câmara de impressão da máquina (Figura 6.21) e o perfil dos fins de curso da varredora (Figura 6.22).

Figura 6.17: Cobertura da máquina visto da frente

Figura 6.18: Cobertura da máquina visto de trás

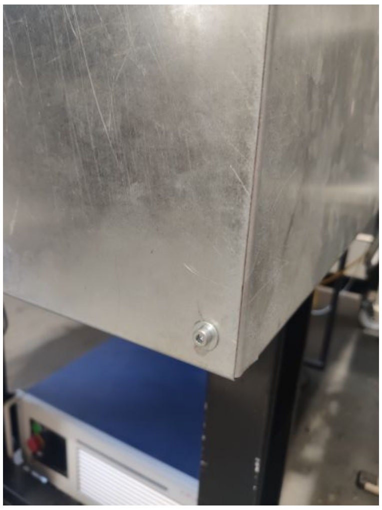


Figura 6.19: Pormenor da encaixa das chapas na parte inferior

Figura 6.20: Pormenor da encaixa das chapas na parte superior

Figura 6.21: Perfil de plástico de proteção da chapa da porta

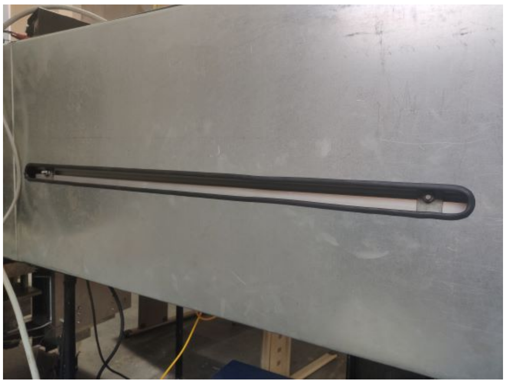


Figura 6.22: Perfil de plástico de proteção da chapa do rasgo dos fins de curso

A fibra ótica do laser percorre a máquina pelo interior da cobertura até ao módulo de deflexão. Na Figura 6.18 é possível observar a fibra ótica a passar pelo interior da cobertura, já na Figura 6.23 é apresentado a forma como a fibra ótica atravessa a máquina e é fixa na parte inferior da estrutura.

Figura 6.23: Percurso da fibra ótica na parte inferior da estrutura da máquina

Capítulo 7

Resultados experimentais e Discussão

O capítulo 7 irá abordar as alterações realizadas no programa de controlo de motores da máquina, assim como os resultados do sistema de laser, a sua calibração e por fim, a discussão dos resultados dos ensaios experimentais.

7.1 Programa de controlo dos motores da máquina

O esquema elétrico da máquina é a representação gráfica dos circuitos elétricos. Estes circuitos encontram-se dentro do quadro elétrico, devidamente identificado com etiquetas. O esquema elétrico da máquina (Apêndice K), sofreu algumas alterações que se encontram representadas a vermelho. Estas alterações ocorreram com a finalidade de adicionar novos componentes, fazer ligações entre componentes ou alterar ligações devido a alguma razão explicita em capítulos anteriores.

Em consequência das alterações realizadas nos terminais das saídas do controlo dos motores dos elevadores, a configuração do programa de controlo em *LabView*, também sofreu modificações. Na Figura 7.1 é apresentada a aba *Configurações* do programa com a configuração de entradas e saídas antes das alterações. Já na Figura 7.2 é exposta a nova configuração, onde as alterações se encontram destacadas a vermelho. Estas alterações foram realizadas nos sinais *PUL+*, *DIR+* e *EN+* de cada *driver* dos motores de passo dos elevadores.

Através das alterações realizadas no quadro elétrico, foi possível testar cada motor em segurança, através do programa em *LabView* da máquina. Ao realizar o teste do motor da varredora e dos fins de curso em funcionamento, foi possível constatar que a lógica da ativação dos fins de curso para a travagem da varredora, encontrava-se trocada. Ao trocar a lógica pelo inverso, o motor da varredora funcionou de maneira correta. Posto isto, o motor foi colocado na varredora, assim como, o fuso foi inteiramente lubrificado com massa consistente, para a realização do teste em modo de funcionamento real. O teste foi realizado com o variador a funcionar a uma frequência de 50 Hz e a varredora comportou-se como o expectável.

Ao realizar o teste dos motores de passo dos elevadores, a uma frequência de impulso mínima de 200 Hz e máxima de 3000 Hz, os elevadores com os seus fusos devidamente lubrificados com massa consistente, funcionaram corretamente, uma vez que, nenhum

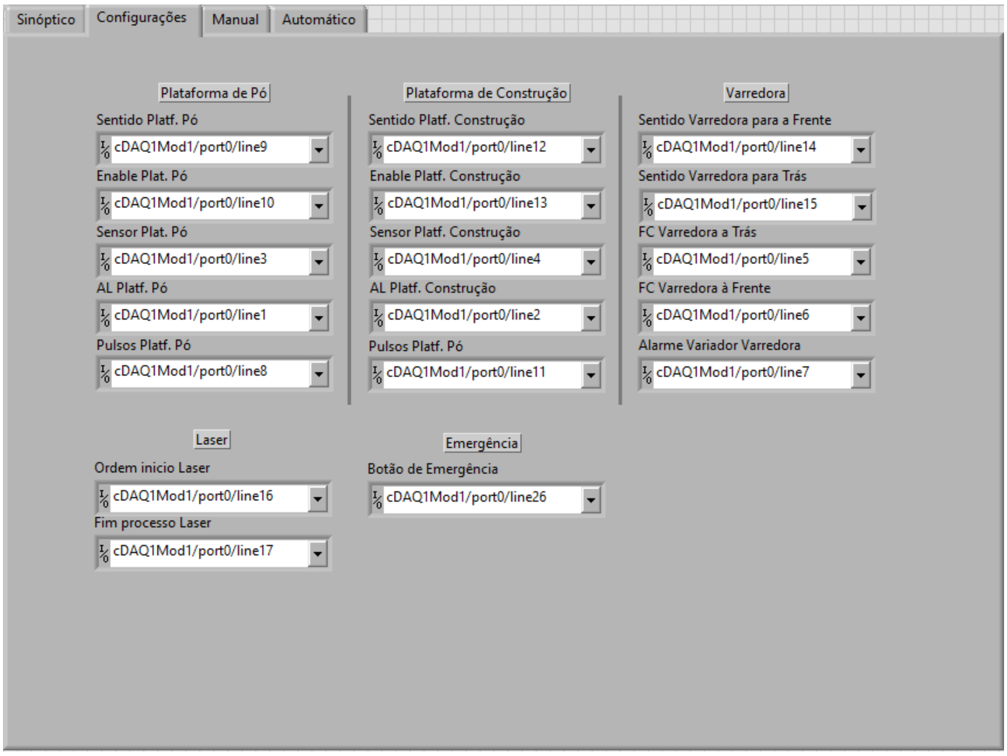


Figura 7.1: Configuração antiga do programa em *LabView* (Miranda, 2020)

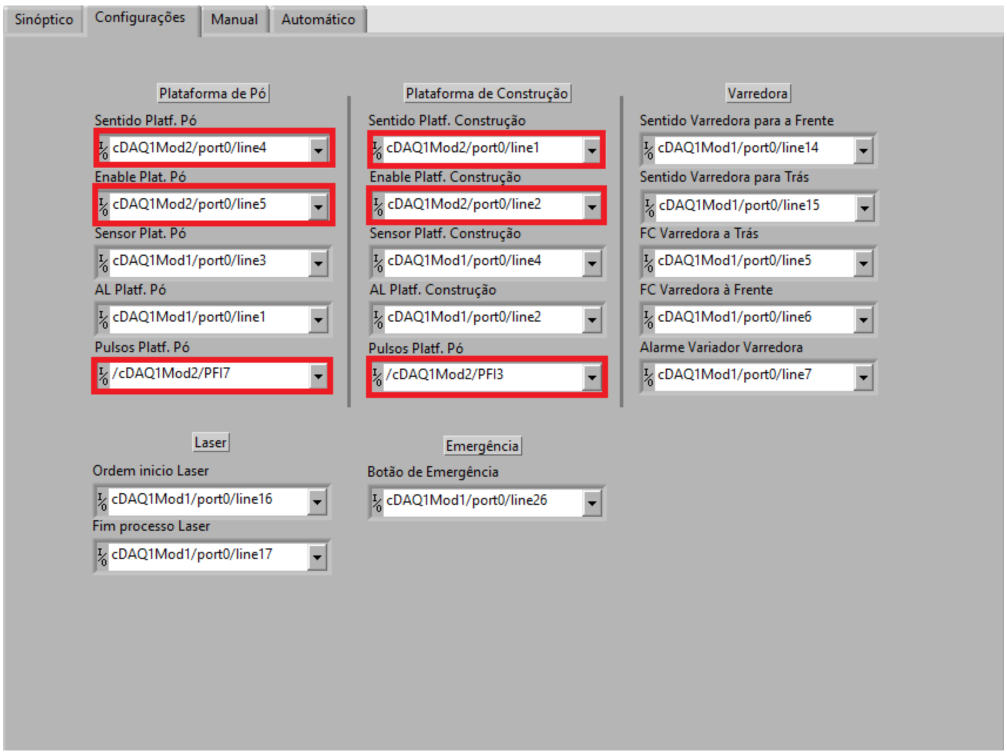


Figura 7.2: Configuração nova do programa em *LabView*

dos *drivers* entraram em erro de posição.

De concluir que, todos os motores e componentes controlados pelo programa em *LabView* encontram-se funcionais e devidamente testados.

7.2 Ensaio do sistema de laser

O sistema de laser tem na sua posse várias medidas de segurança, que têm de ser verificadas de modo a garantir a proteção do utilizador aquando da manipulação do equipamento. Estas medidas de seguranças são, por exemplo, a implementação da paragem da emergência do laser, a utilização de óculos de segurança, a verificação da vedação completa da câmara de impressão e a não manipulação da cabeça do laser quando este se encontra ativo. Todos os ensaios do sistema de laser foram realizados segundo estas normas de segurança, que se encontram presentes no manual do laser (Apêndice L).

Para a realização do primeiro ensaio do sistema de laser, foi utilizado como base de incidência uma chapa de aço com $1,5$ mm de espessura posicionada à altura da mesa de trabalho. Este primeiro ensaio, foi realizado sem nenhum tipo de configuração de *software* do *weldMARK® 3* (modo *default* do *software*) e a ordem de trabalho foi a realização de um quadrado com 20 mm de lado, centrado e a uma velocidade de 10 mm/s. As dimensões escolhidas para o quadrado permitiram que, o feixe do laser não ultrapassasse a área de impressão da máquina e que por sua vez, não danificasse a mesa de trabalho ou qualquer outro componente da máquina.

Nas Figuras 7.3 e 7.4, é possível observar os resultados do primeiro ensaio experimental e verificar que este teve como resultado um retângulo com dimensões de $52,60$ mm x $49,45$ mm. Após a análise do resultado do primeiro ensaio experimental, foi possível concluir que o módulo de deflexão se encontrava totalmente descalibrado, dado que os resultados têm dimensões de aproximadamente $2,6$ vezes superiores à ordem de trabalho enviada. Nos testes posteriores, foram utilizados quadrados com dimensões de 40 mm de lado, de forma a facilitar as medições dos resultados obtidos na impressão, sem comprometer a mesa de trabalho e outros componentes da máquina.

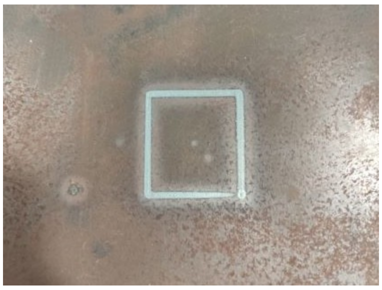


Figura 7.3: Resultado do primeiro ensaio experimental

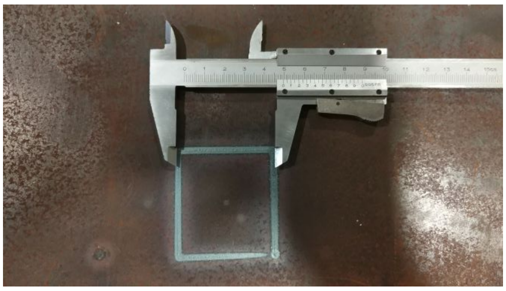


Figura 7.4: Resultado do primeiro ensaio experimental com dimensões

Através do resultado do primeiro ensaio experimental, foi possível calibrar o módulo de deflexão do laser através da importação das suas características para o *software* e configurar o ficheiro de correção do módulo. O processo de calibração do *hardware*, consiste na escolha do ficheiro de correção, onde se segue uma sequência de calibração, cujo laser imprime uma grelha de 3 x 3, 5 x 5 ou 9 x 9 (fator à escolha do operador), posteriormente o operador importa as medidas obtidas para o *software* e o programa realiza a calibração automaticamente, no caso é alterada a razão do ganho em X e Y. Na Figura 7.5 é apresentada a calibração final do laser, no qual o ganho de X é de $0,763$ e em Y de $0,748$, utilizado no segundo ensaio experimental do sistema de laser.

O segundo ensaio experimental foi realizado numa chapa de aço com $1,5$ mm de espessura, posicionada à altura da mesa de trabalho. A ordem de trabalho foi a realização de um quadrado com 40 mm de lado, centrado e a uma velocidade de 10 mm/s.

Nas Figuras 7.6 e 7.7 é possível apreciar os resultados do segundo ensaio, onde foi obtido um quadrado centrado com 40 mm de lado. A averiguação do resultado do segundo ensaio experimental permitiu concluir que o sistema de laser se encontra agora devidamente calibrado, quando testado com formas centradas.

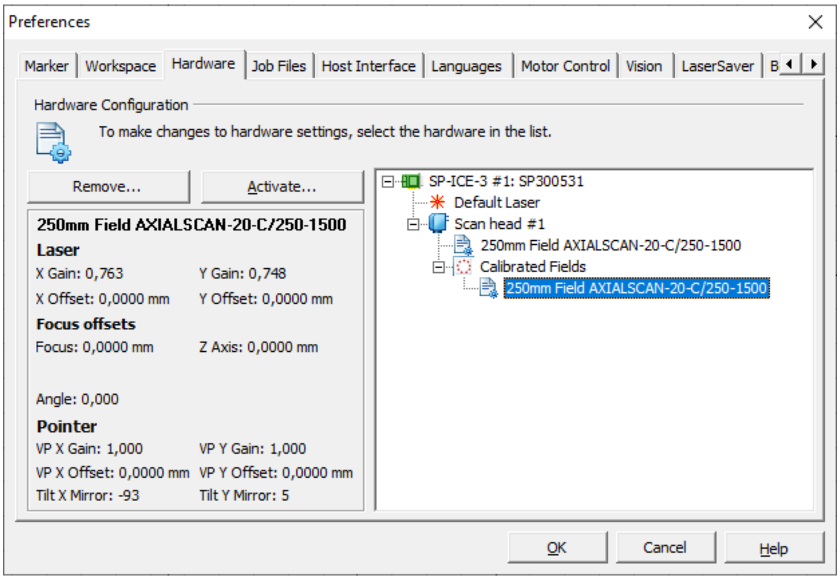


Figura 7.5: Calibração do módulo de deflexão do laser

Os ficheiros de correção têm como função corrigir o valor do eixo Z do campo de impressão do módulo de deflexão. O valor do eixo Z sofre um maior desvio quando a ordem de trabalho se trata de uma forma mais desviada do centro (Figura 7.8). De forma a validar o ficheiro de correção, foi realizado um último ensaio numa chapa de aço com 30 mm de espessura, posicionada à altura da mesa de trabalho. A ordem de trabalho continha quatro quadrados com 40 mm de lado e uma linha a atravessar um dos quadrados.

Na Figura 7.9 é apresentado o resultado do ensaio e é possível observar que foram obtidos quatro quadrados e uma linha reta perfeita. Estes resultados validam o ficheiro de correção e a calibração do *hardware*.

O último ensaio foi realizado numa chapa de maior espessura, uma vez que, com as dimensões utilizadas nos ensaios anteriores, a chapa apresentava-se completamente deformada quando retirada da câmara de impressão. Esta deformação provocou uma descontinuidade no último segmento de cada quadrado, devido ao facto do laser sair do seu ponto focal (Figuras 7.3 e 7.6).

Em suma, a partir desta sequência de ensaios experimentais foi possível concluir que a calibração do sistema de laser foi bem sucedida uma vez que, todas as ordens de

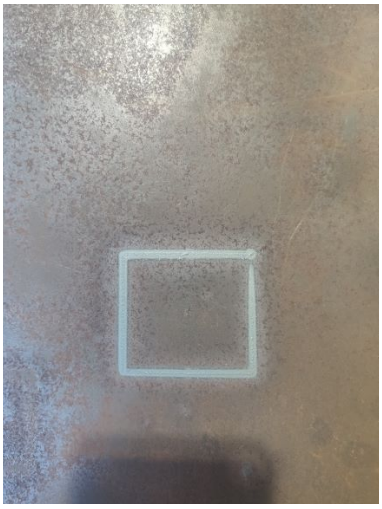


Figura 7.6: Resultado do segundo ensaio experimental

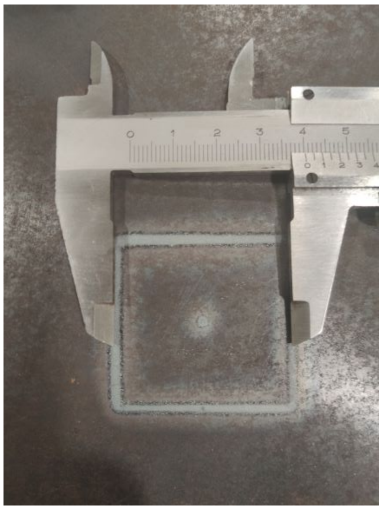


Figura 7.7: Resultado do segundo ensaio experimental com dimensões

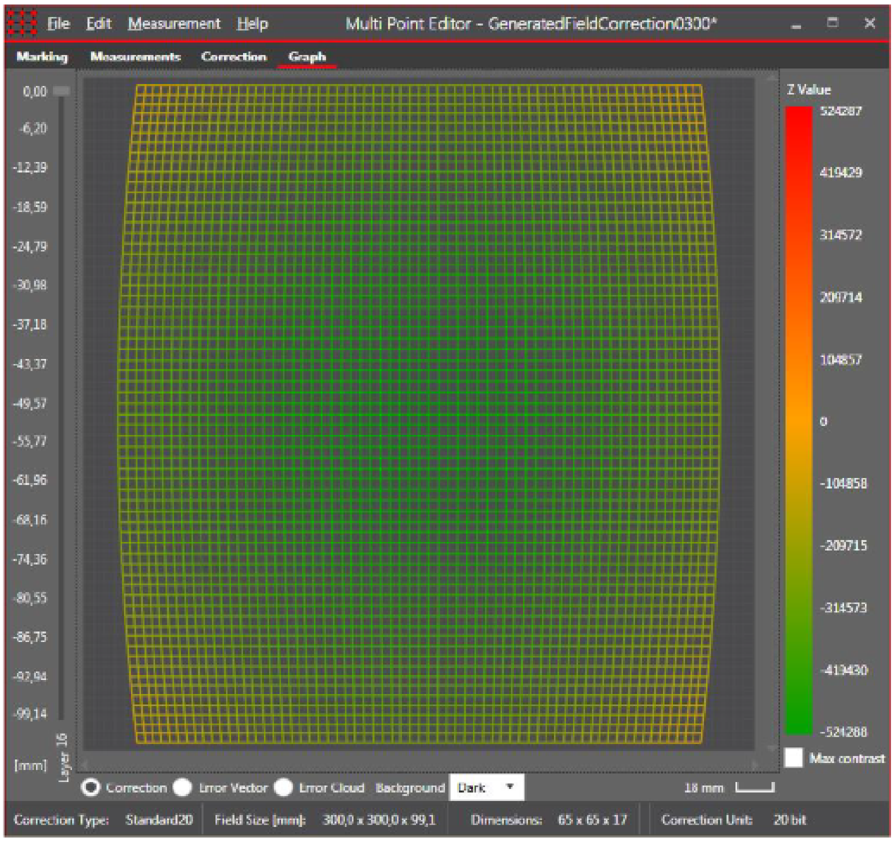


Figura 7.8: Exemplo de campo de campo de correção (Raylase, 2020c)

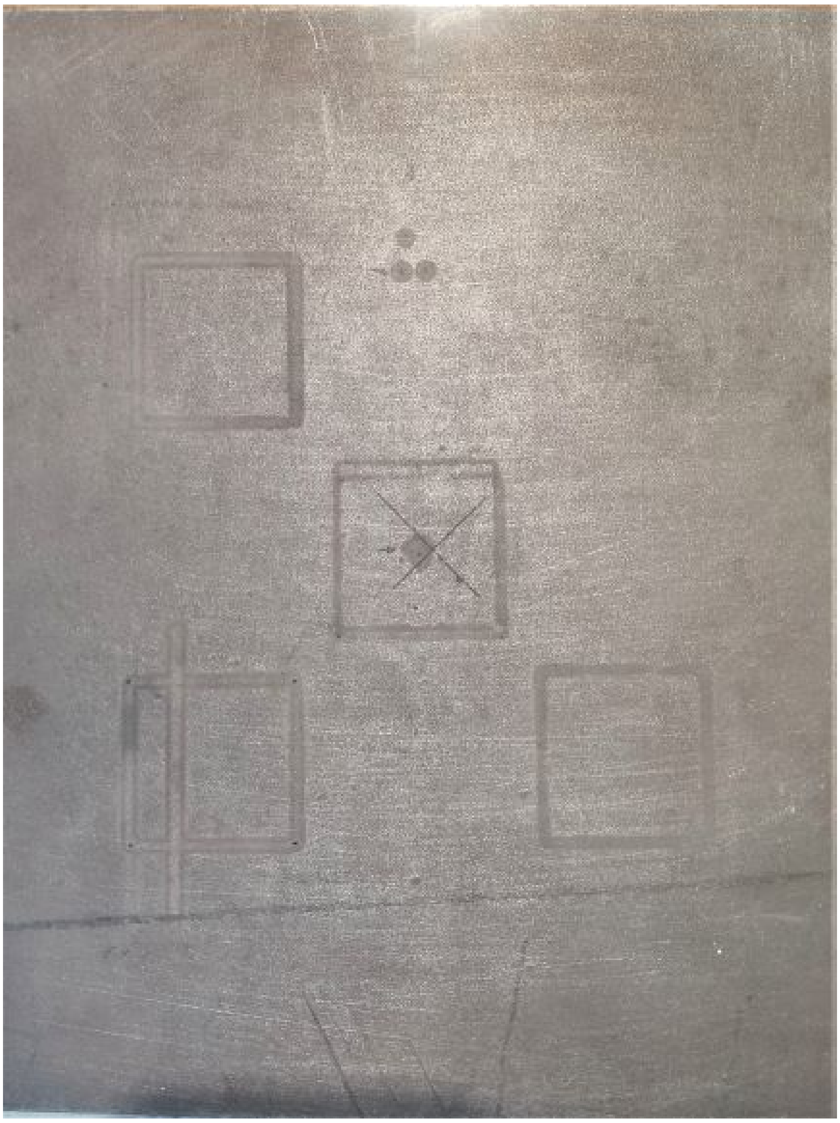


Figura 7.9: Resultado do ensaio experimental final

trabalho foram realizadas de forma correta no ensaio experimental final. No entanto, pelas imagens apresentadas nas figuras anteriores é possível verificar que o diâmetro do feixe laser está excessivamente largo. Esse facto foi reportado à empresa *Raylase*, fabricante da cabeça defletora, a qual informou que há, com certeza, uma avaria ou que a mesma se encontra a uma distância incorreta da mesa de trabalho. De facto, verificou-se que a cabeça galvanométrica presente neste equipamento deveria situar-se a 580 mm da mesa de trabalho. Essa é a distância à qual o laser está focado e apresenta o diâmetro de feixe de 58 μm. Na instalação atual a distância é de 300 mm, portanto, torna-se obrigatório colocar um calço de separação entre a cabeça e a mesa de trabalho da máquina (trabalhos futuros, a decorrer).

Parte IV

Conclusão

Capítulo 8

Reflexão final

O FA tem sido um motor de mudança na indústria, no que diz respeito a novas possibilidades de produção. Esta tecnologia apresenta inúmeras vantagens em relação a processos de fabrico convencionais, tornando-a num mercado em crescimento exponencial. Desta forma, o DEM projetou e iniciou a construção de uma máquina de DMLS, para além disso, propôs um projeto de mestrado, tendo como principal objetivo finalizar a construção da máquina de FA de metais, bem como realizar ensaios experimentais.

O presente relatório de projeto, apresenta inicialmente uma breve descrição da tecnologia de FA existente no mercado atual, assim como, de forma mais aprofundada a tecnologia de DMLS. Segue-se uma descrição da máquina do projeto, bem como, os seus componentes a integrar. Posteriormente, foram apresentados os problemas existentes e projetadas as suas soluções. Em seguida, é explicado o controlo da máquina e as alterações realizadas, por fim, são expostos os resultados do projeto e dos ensaios experimentais da máquina.

O desenvolvimento do projeto envolveu uma revisão bibliográfica da teoria conceptual que se revelou essencial para o entendimento dos processos envolvidos. De forma a realizar um estudo holístico da tecnologia de FA, foi adotada uma abordagem histórica, contendo desde o conceito inicial até à sua padronização, sendo ainda apresentada a previsão do crescimento do mercado. Para além disso, foram ainda analisados os tipos de tecnologia de FA existentes, assim como a sua normalização e enumeradas as suas vantagens e desvantagens em comparação com processos de fabrico convencionais. Posteriormente, optou-se por uma abordagem da tecnologia envolvida na máquina do projeto, o DMLS, onde é explicado o conceito do processo, os diferentes tipos de materiais usados, bem como, as suas propriedades físicas e aplicações na indústria.

Seguida da apresentação da descrição dos equipamentos da máquina, surge a resolução de vários problemas associados à finalização da máquina, onde foram apresentadas várias soluções e conceitos de forma a resolver estes obstáculos. Assim, a cada problema, está associada uma solução ou conceito devidamente justificado.

Numa fase seguinte, foi realizada a conclusão da eletrificação do quadro elétrico da máquina e efetuada a parametrização dos componentes, assim como expostas as alterações do esquema elétrico da máquina. Por fim, foi desenvolvida a preparação dos ensaios experimentais da máquina.

Logo após à preparação dos ensaios experimentais da máquina, são apresentados os resultados dos projetos mecânicos, já aplicados na máquina real. Após a análise destes mesmos resultados, foi possível concluir que a máquina não necessita nenhuma adição de componentes mecânicos para o ensaio experimental.

Finalmente, foram apresentados os resultados do controlo dos motores da máquina, da qual foi possível concluir que, todos os componentes controlados pelo programa em *LabView* se encontravam funcionais e devidamente testados. Em seguida, foram expostos os resultados dos ensaios do sistema de laser, onde foi apresentada uma sequência de resultados e uma calibração do *hardware*, de modo a obter um resultado final igual à ordem de trabalho enviada no *software*. Dado que, durante o ano letivo ocorreu uma crise pandémica que impôs o confinamento social, não foi possível concluir os trabalhos experimentais que necessitavam de ser realizados em contexto de laboratório. Ainda assim, foi possível concluir a parte mecânica e de controlo dos componentes da máquina.

No que se refere a projetos futuros, naturalmente, o próximo passo seria construir o separador para colocar a cabeça galvanométrica na nova cota agora indicada pelo fabricante, testar, e realizar os ensaios experimentais com pó metálico e proceder à impressão de provetes, de modo a fazer ensaios e obter resultados das propriedades físicas do material impresso.

Em modo de conclusão, acredito que consegui cumprir os objetivos que inicialmente me propus. Numa visão retrospetiva, este projeto contribuiu para o desenvolvimento das minhas capacidades ao nível do pensamento crítico e reflexivo que resultaram numa enaltecimento profissional e pessoal. Superei todas as dificuldades e problemas que necessitaram de solução, de forma a que nesta incursão de aluno finalista de mestrado, ocasionou momentos de descoberta, de partilha de conhecimento e aprendizagem de uma área emergente, fulcral para a prática do engenheiro.

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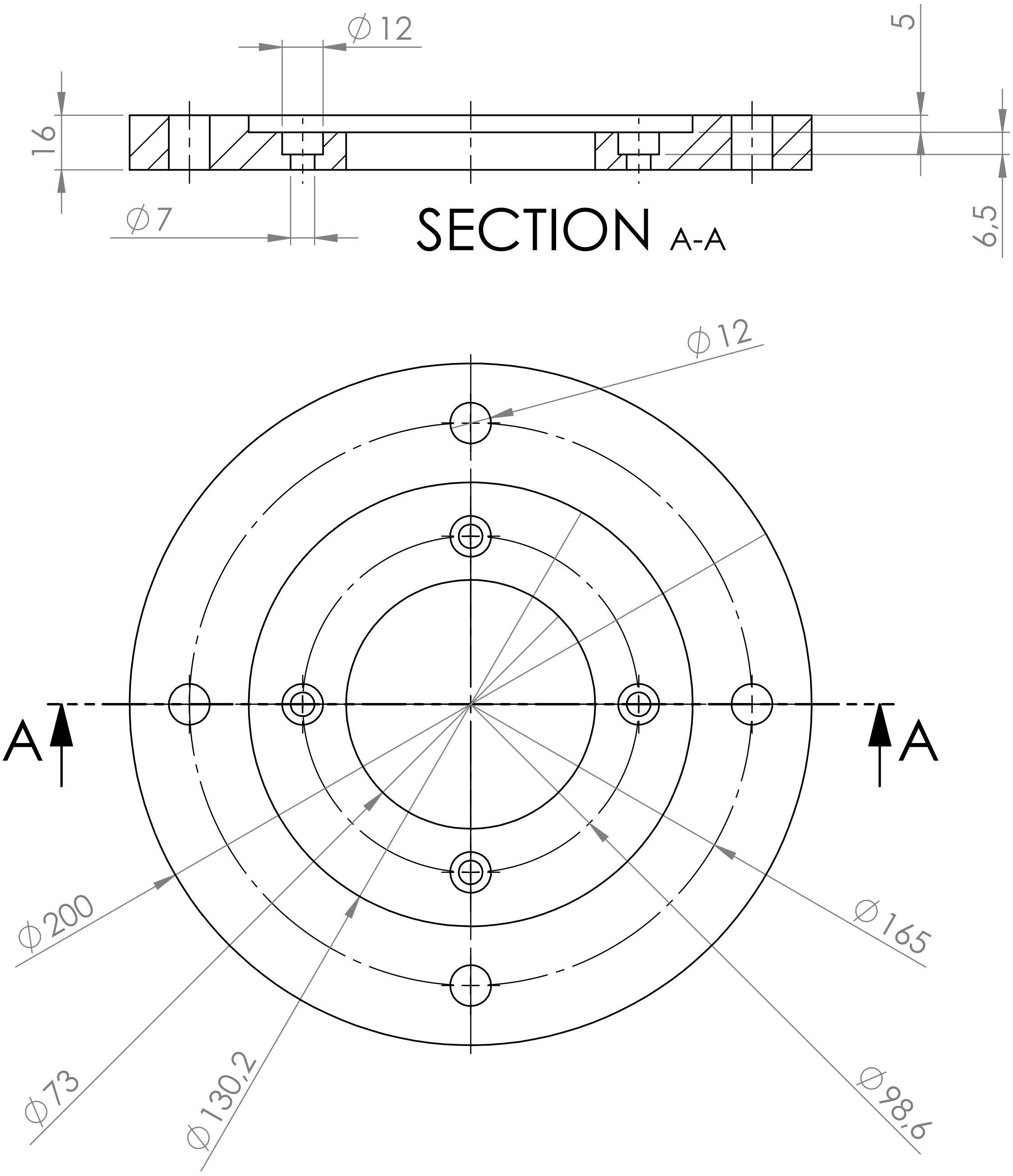
APÊNDICES

Apêndice A

Desenho técnico do suporte do motor final da varredora



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

Tolerâncias:
ISO 8015
ISO 2768-mK

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Lucas Martins		
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:
Aço EN c45

DWG NO.
Suporte do motor

A4

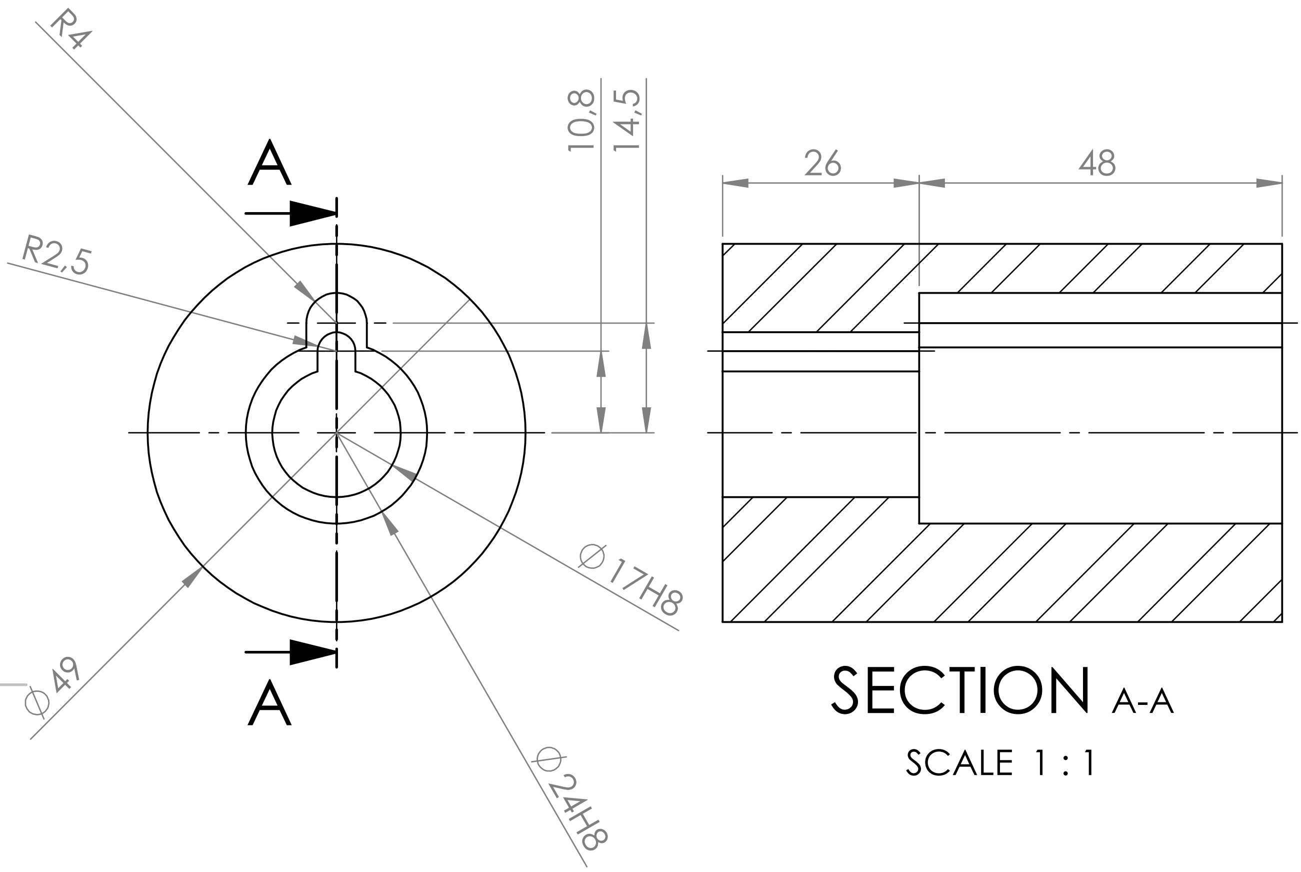
WEIGHT:

SCALE:1:2

SHEET 1 OF 1

Apêndice B

Desenho técnico do acoplador do motor final da varredora



SECTION A-A

SCALE 1 : 1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

Tolerâncias:
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BREAK SHARP
EDGES

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REVISION

	NAME	SIGNATURE	DATE
DRAWN	Lucas Martins		
CHK'D			
APPV'D			
MFG			
Q.A	1		

TITLE:

MATERIAL:
Aço EN c45

WEIGHT:

DWG NO.
Acoplador Motor

A4

SCALE:1:2

SHEET 1 OF 1

Apêndice C

Datasheet do interruptor ótico *OPB830W55Z*

https://docs.rs-online.com/cc69/0900766b814a6886.pdf

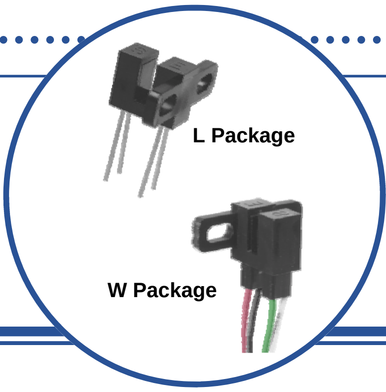
Slotted Optical Switch

OPB830 and OPB840 Series (L & W)

TT electronics
OPTEK Technology

Features:

- 0.125" (3.18 mm) wide slot
- Choice of electrical output parameters
- Choice of aperture
- Choice of opaque or IR transmissive shell material
- Side mount configuration
- Choice of lead spacing (L Series)
- 24" [610 mm] 26 AWG wire leads (W Series)



Description:

OPB830 and **OPB840 series** provide the design engineer with the flexibility of a custom device from a standard product line. The **L Series** offers a choice of PCBoard mount lead spacing, while the **W Series** offers 24" (610mm) 26AWG wire leads.

Building from a standard housing that utilizes a .375" (9.5 mm) wide slot, a user can specify the electrical output parameters, choice of aperture, discrete shell material, side mount configuration, and a choice of lead spacing (for the L Series) or 24" [610 mm] UL approved 26 AWG wire leads (W Series).

Housings are made from an opaque grade of injection-molded plastic that minimizes the assembly's sensitivity to visible and near-infrared ambient radiation. Discrete shells (exposed on the parallel faces inside the device throat) are made of either IR transmissive plastic (for applications where aperture contamination may occur) or of opaque plastic with aperture openings (for maximum protection against ambient light).

Switching of the phototransistor occurs whenever an opaque object passes through the slot and interrupts the beam.

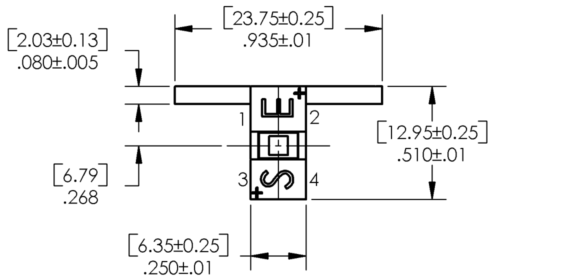
Custom electrical, wire and cabling and connectors are available. Contact your local representative or OPTEK for

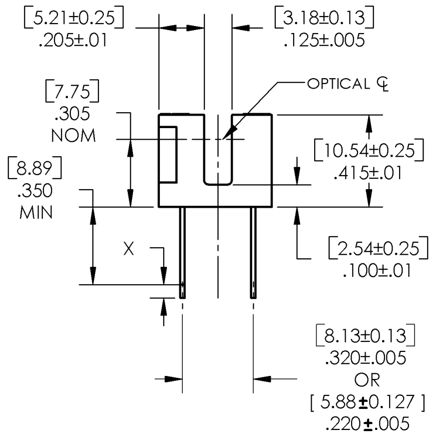
Applications:

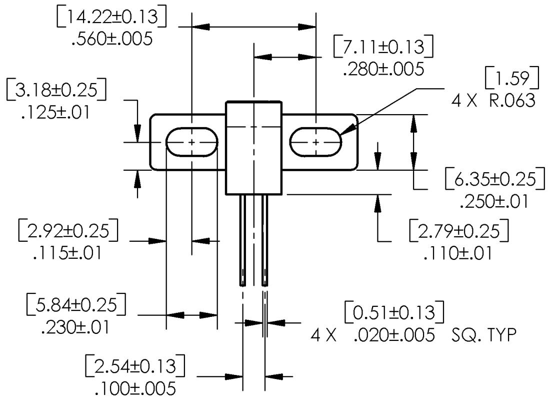
- Non-contact interruptive object sensing
- Assembly line automation
- Machine automation
- Equipment security
- Machine safety

RoHS

OPB830/840L Series







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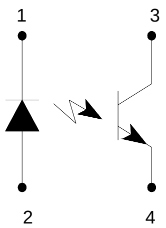
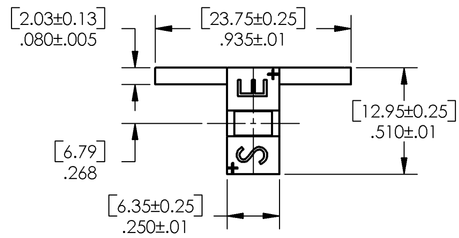
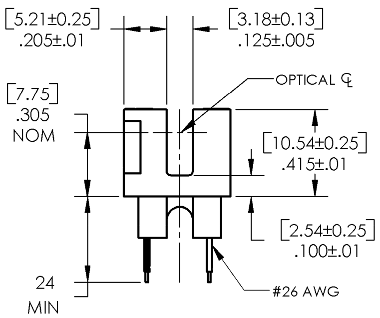
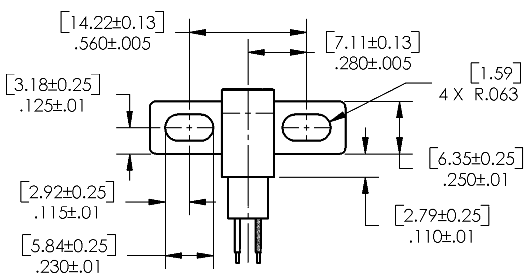


Pin # / Color	Description
1 / Black	Cathode
2 / Red	Anode
3 / White	Collector
4 / Green	Emitter

OPB830/840W Series







DIMENSIONS ARE IN INCHES AND [MILLIMETERS].

DIMENSIONS ARE IN: [MILLIMETERS] INCHES

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Phone: (972) 323-2200 or (800) 341-4747 FAX: (972) 323-2396 sensors@optekinc.com www.optekinc.com

Part Number Guide — OPB8XX

OPB 8 X X L X X

- **Optek Assembly** — OPB
- **Phototransistor Output Family** — 8
- **Discrete Shell Material:**
  - **3** — Side mount IR transmissive Plastic discrete shell
  - **4** — Side mount opaque Plastic discrete shell
- **Electrical Specification Variations:**
  - **0** = Electrical Parameter A - (0.320" lead spacing)
  - **1** = Electrical Parameter B - (0.320" lead spacing)
  - **2** = Electrical Parameter C - (0.320" lead spacing)
  - **5** = Electrical Parameter A - (0.220" lead spacing)
  - **6** = Electrical Parameter B - (0.220" lead spacing)
  - **7** = Electrical Parameter C - (0.220" lead spacing)
- **Mounting configurations:**
  - **L** — Solder lead termination
- **Emitter Aperture:**
  - **1** — 0.010" (0.25 mm)
  - **5** — 0.050" (1.27 mm)
- **Sensor Aperture:**
  - **1** — 0.010" (0.25 mm)
  - **5** — 0.050" (1.27 mm)

Notes:

- Assemblies with dual 0.010" apertures are currently available with electrical parameter "A" only.

Part Number Guide — OPB8XX

OPB 8 X X W X X Z

- **Optek Assembly** — OPB
- **Phototransistor Output Family** — 8
- **Discrete Shell Material:**
  - **3** — Side mount IR transmissive Plastic discrete shell
  - **4** — Side mount opaque Plastic discrete shell
- **Electrical Specification Variations:**
  - **0** = Electrical Parameter A
  - **1** = Electrical Parameter B
  - **2** = Electrical Parameter C
- **Mounting configurations:**
  - **W** — Wire termination
    - Parts ending with "Z" meet RoHS requirements
    - Wires = 26 AWG—24" Long
- **Emitter Aperture:**
  - **1** — 0.010" (0.25 mm)
  - **5** — 0.050" (1.27 mm)
- **Sensor Aperture:**
  - **1** — 0.010" (0.25 mm)
  - **5** — 0.050" (1.27 mm)

Notes:

- Assemblies with dual 0.010" apertures are currently available with electrical parameter "A" only.

Absolute Maximum Ratings (T_A=25°C unless otherwise noted)

Storage and Operating Temperature L Series(1) W Series(1)	 -40° C to +85°C -40° C to +80°C
Lead Soldering Temperature [1/16 inch (1.6mm) from the case for 5 sec. with soldering iron](2)	260°C

Input Diode

Forward DC Current	50 mA
Peak Forward Current (1 µs pulse width, 300 pps)	1 A
Reverse DC Voltage	2 V
Power Dissipation(1)	100 mW

Output Phototransistor

Collector-Emitter Voltage	30 V
Emitter-Collector Voltage	5 V
Collector DC Current	30 mA
Power Dissipation(1)	100 mW

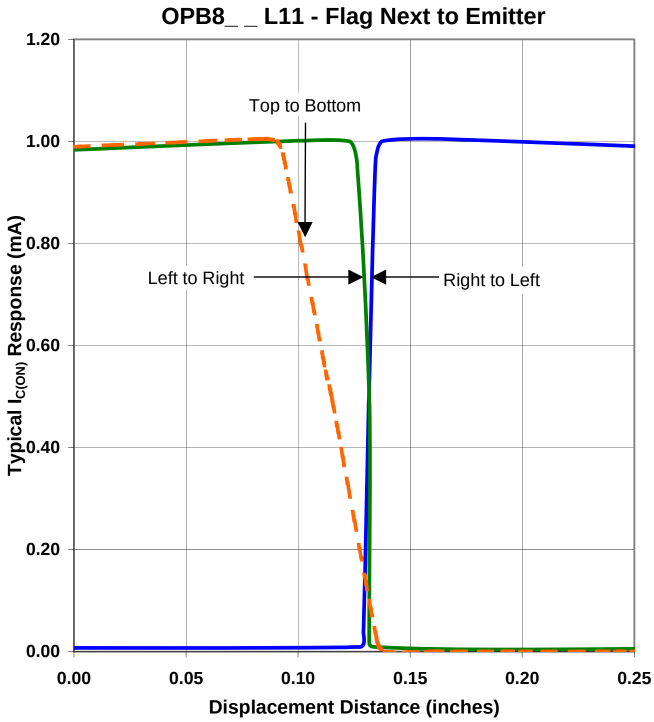
Electrical Characteristics (T_A = 25°C unless otherwise noted)

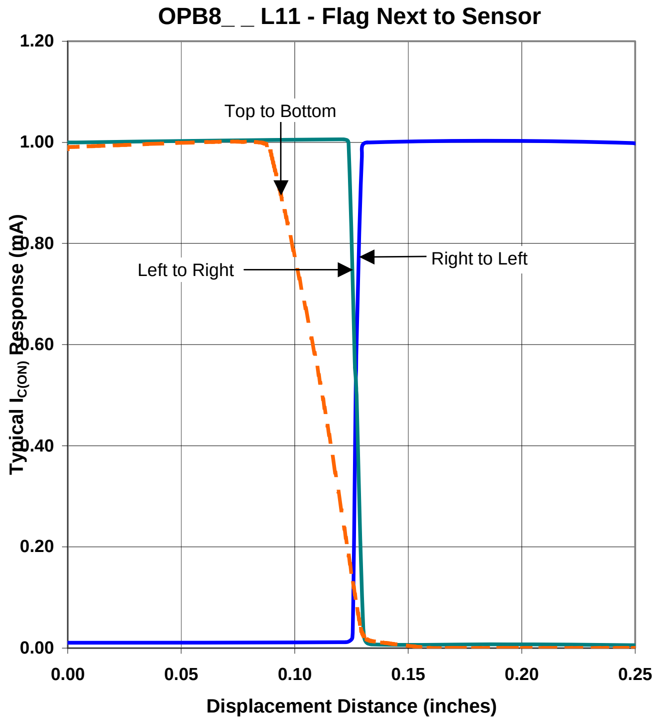
SYMBOL	PARAMETER	MIN	TYP	MAX	UNITS	TEST CONDITIONS
Input Diode LED (See OP240 for additional information—for reference only)						
V_F	Forward Voltage	-	-	1.7	V	I_F = 20 mA
I_R	Reverse Current	-	-	100	µA	V_R = 2 V
Output Transistor (See OP550 for additional information—for reference only)						
$V_{(BR)CEO}$	Collector-Emitter Breakdown Voltage	30	-	-	V	I_C = 1 mA
$V_{(BR)ECO}$	Emitter-Collector Breakdown Voltage	5	-	-	V	I_E = 100 µA
I_{CEO}	Collector-Emitter Dark Current	-	-	100	nA	V_{CE} = 10 V

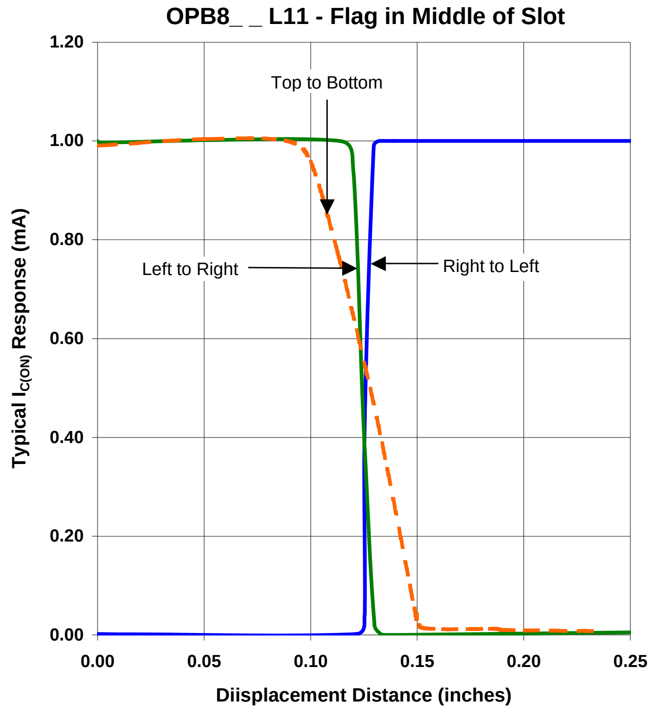
Notes:
(1) Derate linearly 1.67 mW/° C above 25° C for L Series.
(2) RMA flux is recommended. Duration can be extended to 10 seconds maximum when flow soldering.
(3) Methanol or isopropanol are recommended as cleaning agents. Plastic housing is soluble in chlorinated hydrocarbons and ketones.
(4) The W Series includes wire terminations of 24" (610 mm) 7-strand, 26 AWG UL insulated wire on each terminal. Each device incorporates a wire strain relief at the housing surface. The insulation functions and colors are: anode (red), cathode (black), phototransistor collector (white) and phototransistor emitter (green).
(5) All parameters tested using pulse technique.

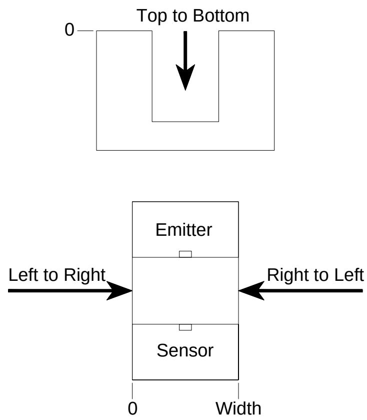
Electrical Characteristics (T_A = 25°C unless otherwise noted)

SYMBOL	PARAMETER	MIN	TYP	MAX	UNITS	TEST CONDITIONS
Combined						
$V_{CE(SAT)}$	Collector-Emitter Saturation Voltage Parameter A (OPB830L,OPB840L) (OPB835L, OPB845L) (OPB830W,OPB840W) (OPB835W, OPB845W)	-	-	0.4	V	I_C = 400 µA, I_F = 20 mA
	Parameter B (OPB831L,OPB841L) (OPB836L,OPB846L) (OPB831W,OPB841W) (OPB836W,OPB846W)	-	-	0.4	V	I_C = 800 µA, I_F = 10 mA
	Parameter C (OPB832L,OPB842L) (OPB837L,OPB847L) (OPB832W,OPB842W) (OPB837W,OPB847W)	-	-	0.6	V	I_C = 1800 µA, I_F = 20 mA
$I_{C(ON)}$	On-State Collector Current Parameter A (OPB830L,OPB840L) (OPB835L, OPB845L) (OPB830W,OPB840W) (OPB835W, OPB845W)	0.625	-	-	mA	V_{CE} = 10 V, I_F = 20 mA
	Parameter B (OPB831L,OPB841L) (OPB836L,OPB846L) (OPB831W,OPB841W) (OPB836W,OPB846W)	1.250	-	-	mA	V_{CE} = 5 V, I_F = 10 mA
	Parameter C (OPB832L,OPB842L) (OPB837L,OPB847L) (OPB832W,OPB842W) (OPB837W,OPB847W)	2.250	-	-	mA	V_{CE} = .6 V, I_F = 20 mA

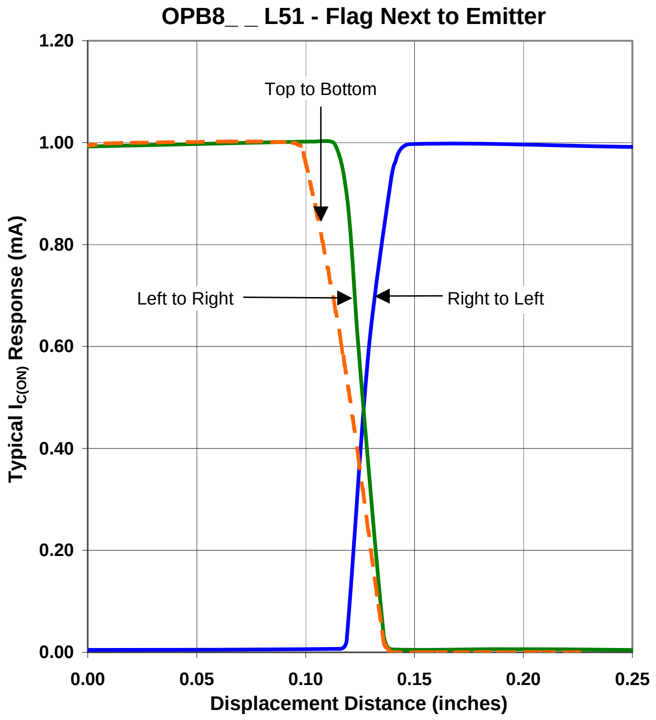




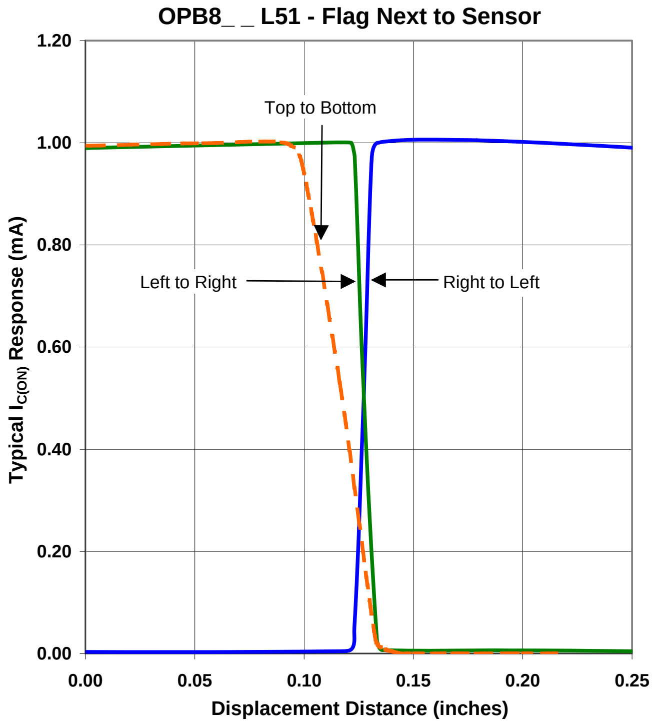




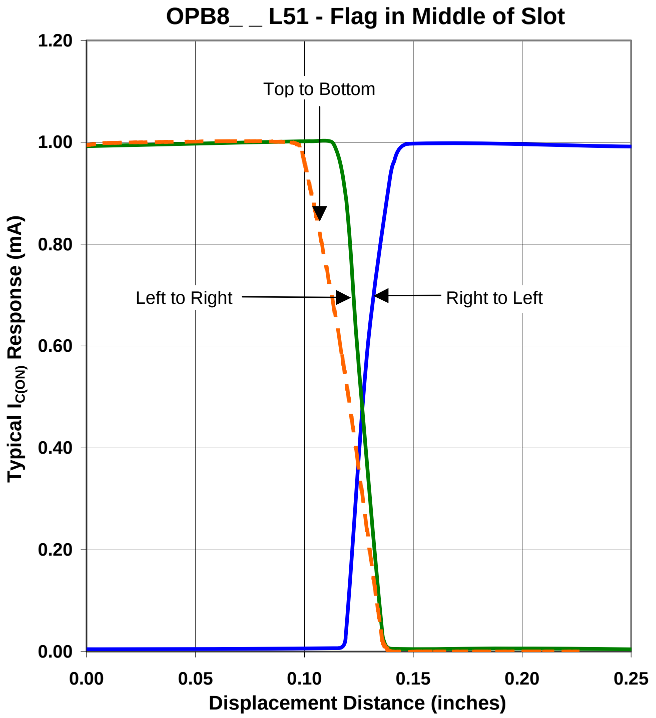
OPTEK reserves the right to make changes at any time in order to improve design and to supply the best product possible.



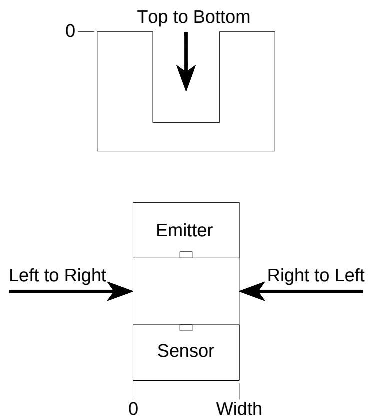
OPB8_ _ L51 - Flag Next to Emitter
Typical $I_{C(ON)}$ Response (mA)
Displacement Distance (inches)
Top to Bottom
Left to Right
Right to Left
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
0.05
0.10
0.15
0.20
0.25



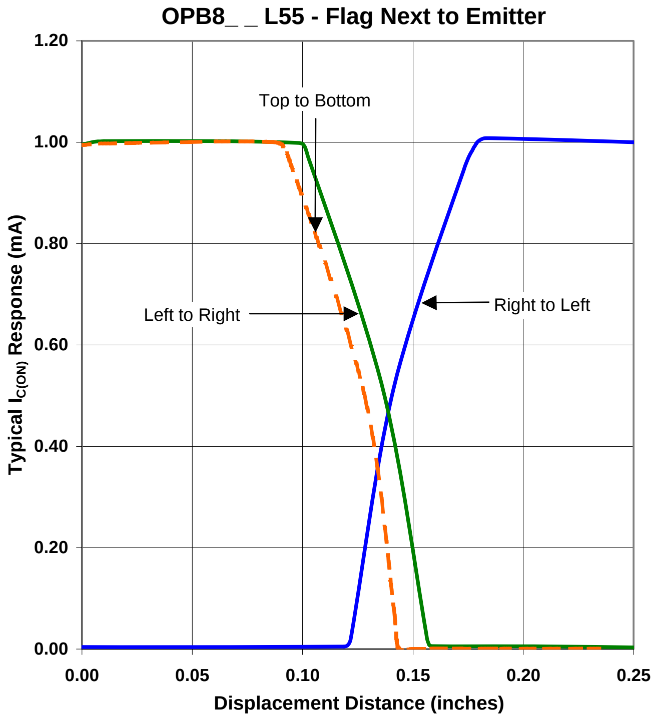
OPB8_ _ L51 - Flag Next to Sensor
Typical $I_{C(ON)}$ Response (mA)
Displacement Distance (inches)
Top to Bottom
Left to Right
Right to Left
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
0.05
0.10
0.15
0.20
0.25

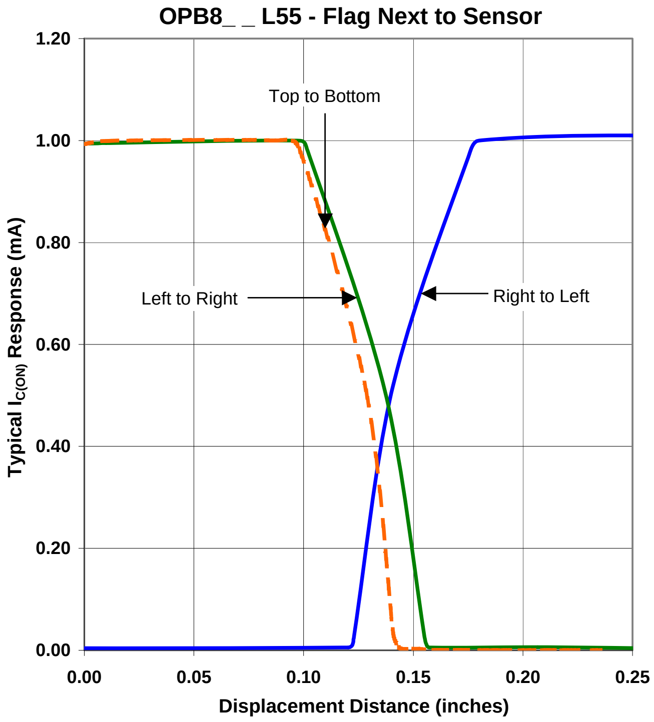


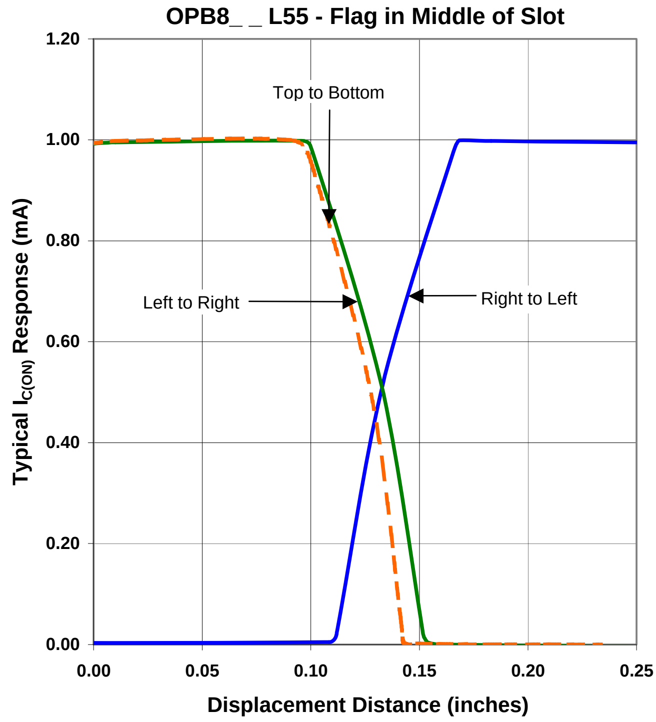
OPB8_ _ L51 - Flag in Middle of Slot
Typical $I_{C(ON)}$ Response (mA)
Displacement Distance (inches)
Top to Bottom
Left to Right
Right to Left
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.00
0.05
0.10
0.15
0.20
0.25

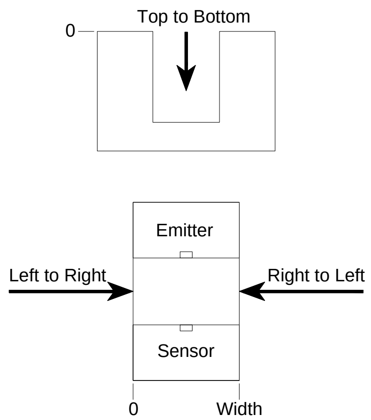


0
Top to Bottom
Emitter
Left to Right
Right to Left
Sensor
0
Width









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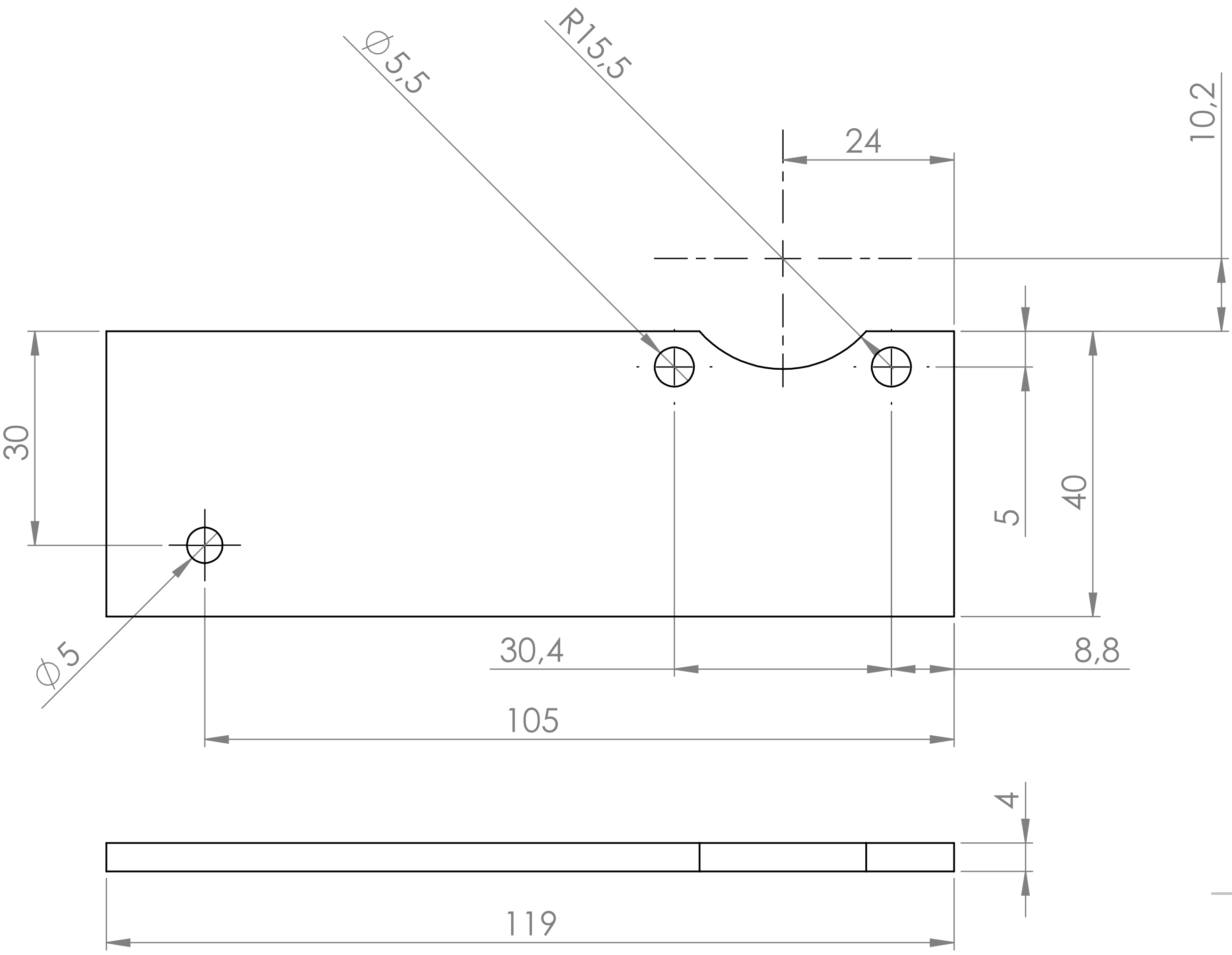
Apêndice D

Desenho técnico das peças para o Zero Máquina



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

Tolerâncias:
ISO 8015
ISO 2768-cL

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	LUCAS MARTINS		
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:
Aço EN S235 galvanizado

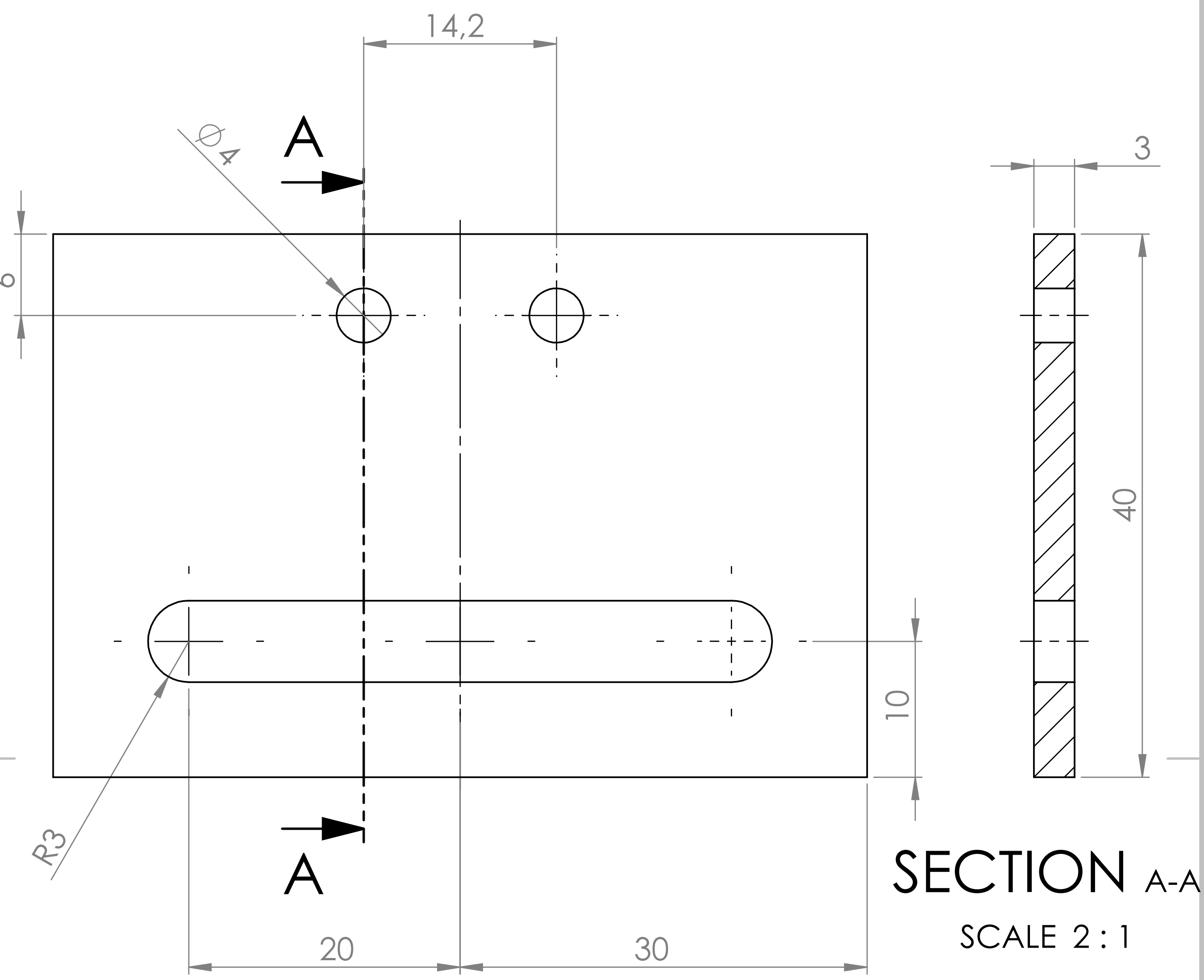
DWG NO.
peça do bloco

A4

WEIGHT:

SCALE:1:2

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
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Tolerâncias:
ISO 8015
ISO 2768-cL

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Lucas Martins		
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:
Aço EN S235 galvanizado

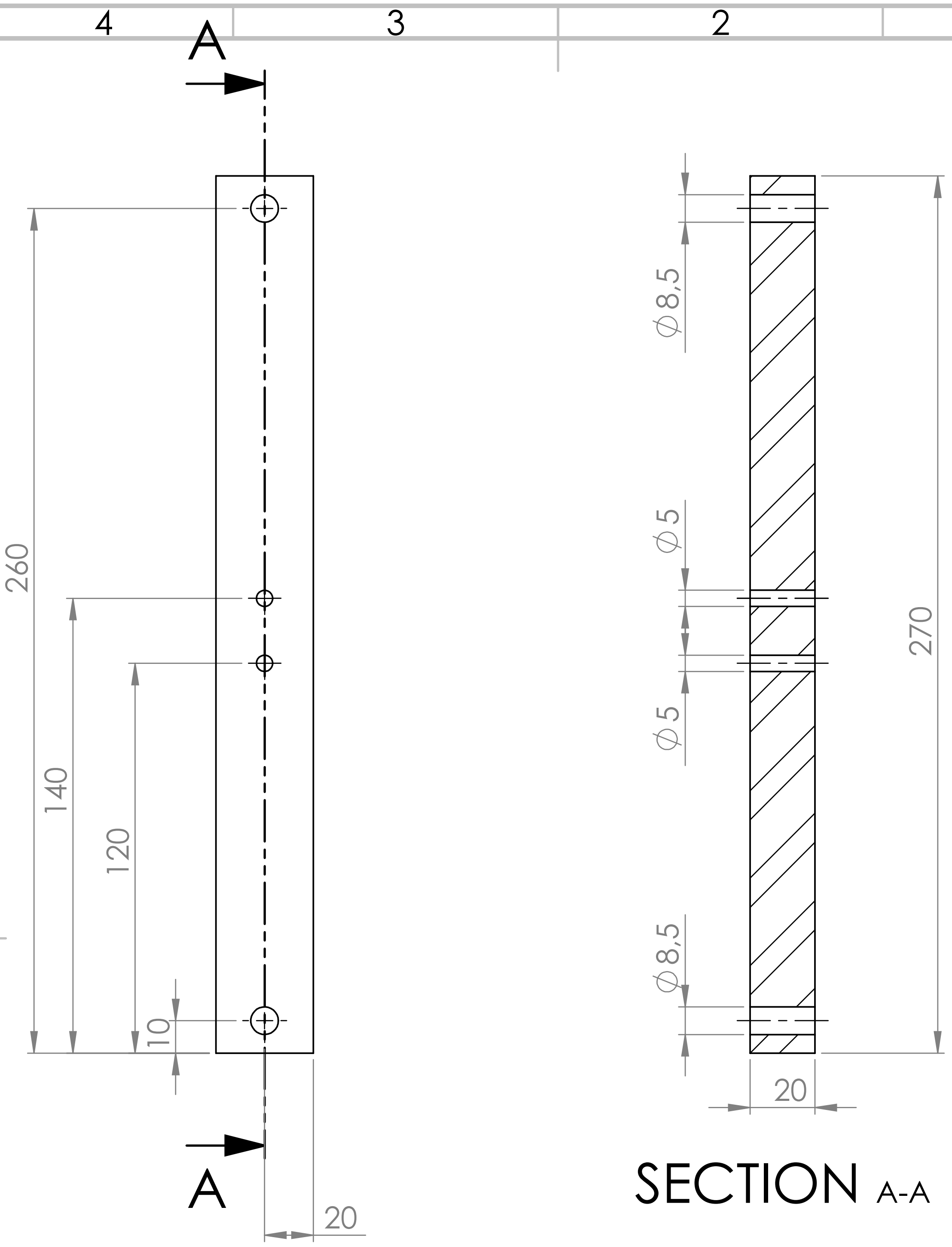
DWG NO.
L do ZM

A4

WEIGHT:

SCALE:1:1

SHEET 1 OF 1



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LINEAR:
ANGULAR:

Tolerâncias:
ISO 8015
ISO 2768-cL

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Lucas Martins		
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:
Aço EN S235

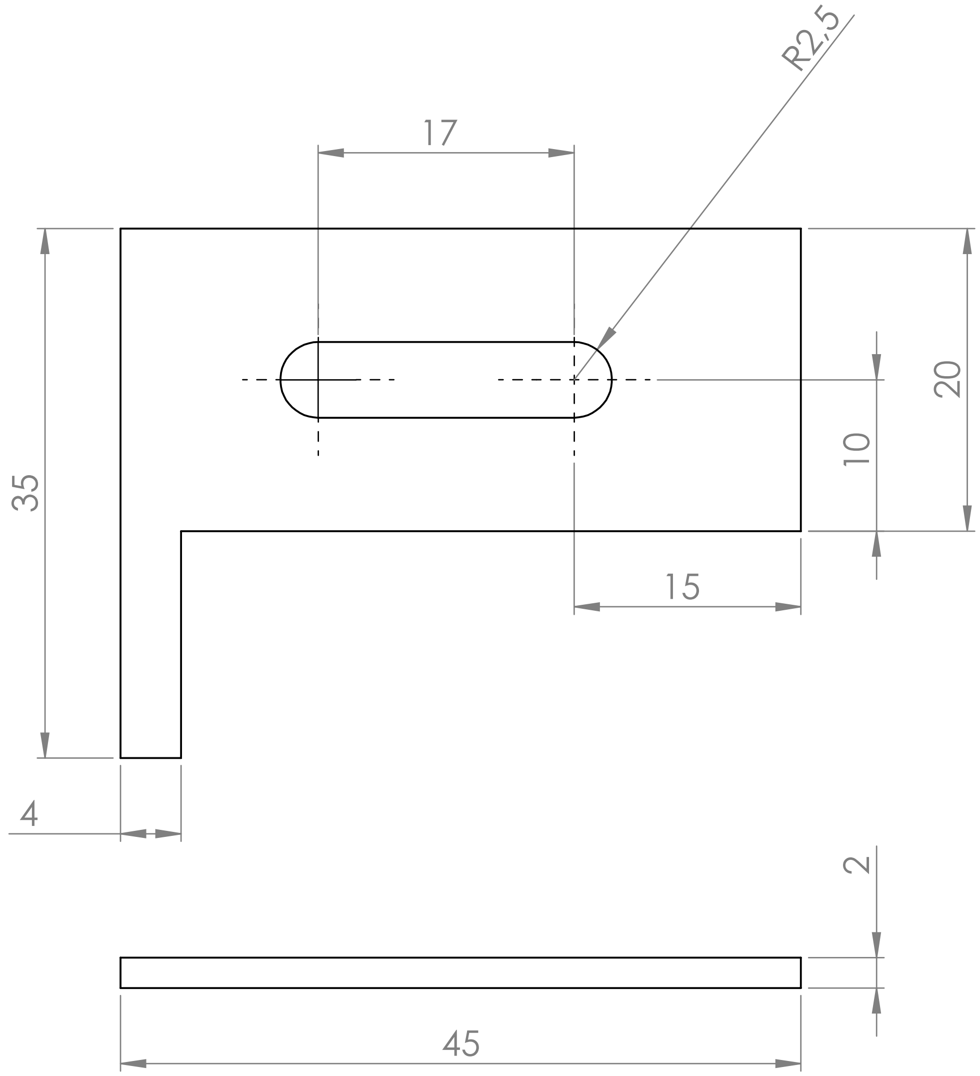
DWG NO.
Barra de suporte

A4

WEIGHT:

SCALE:1:2

SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
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Tolerâncias:
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ISO 2768-cL

DEBURR AND BREAK SHARP EDGES

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REVISION

	NAME	SIGNATURE	DATE
DRAWN	Lucas Martins		
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:
Liga de Alumínio 6082

WEIGHT:

DWG NO.
Passa sensor

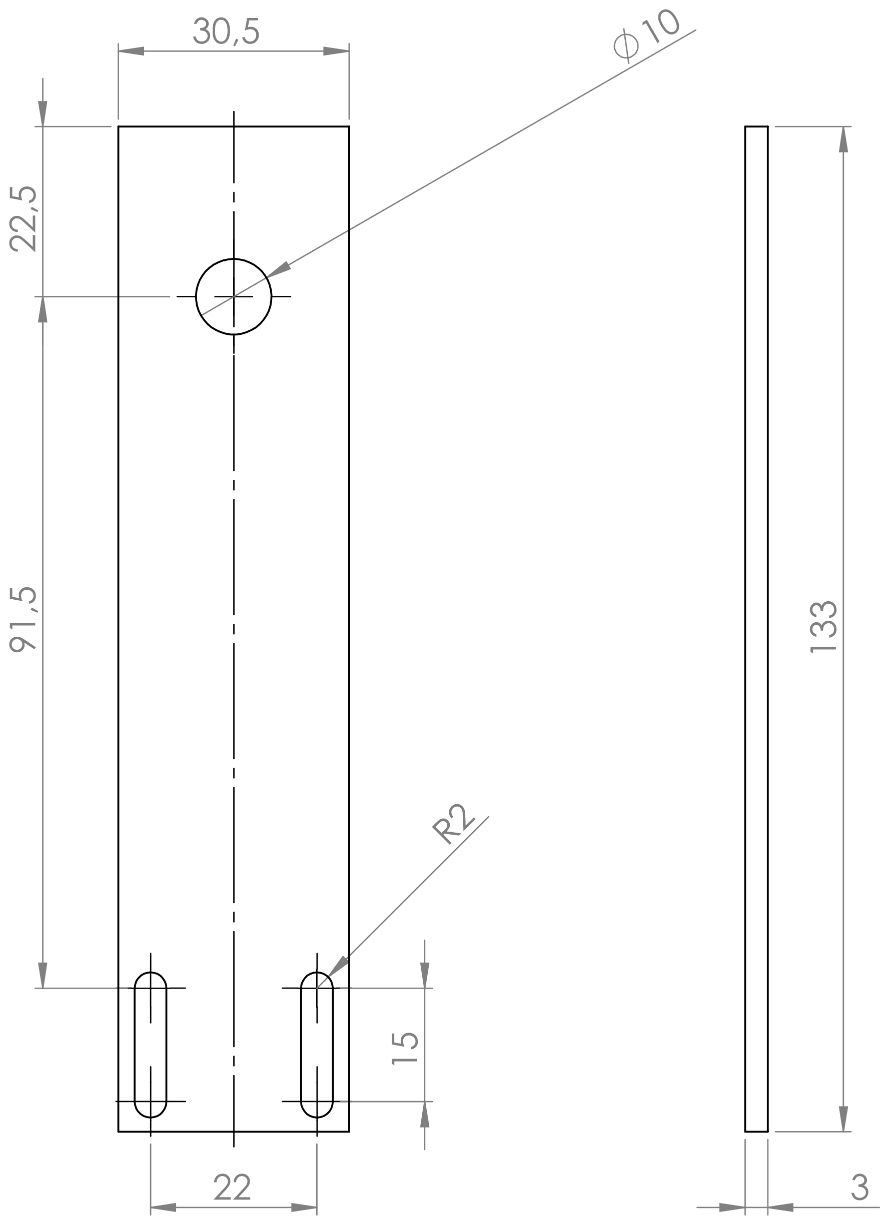
A4

SCALE:2:1

SHEET 1 OF 1

Apêndice E

Desenho técnico do *L* de fim curso



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

Tolerâncias:
ISO 8015
ISO 2768-cL

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:
Aço EN S235 galvanizado

DWG NO.
Fim de curso

A4

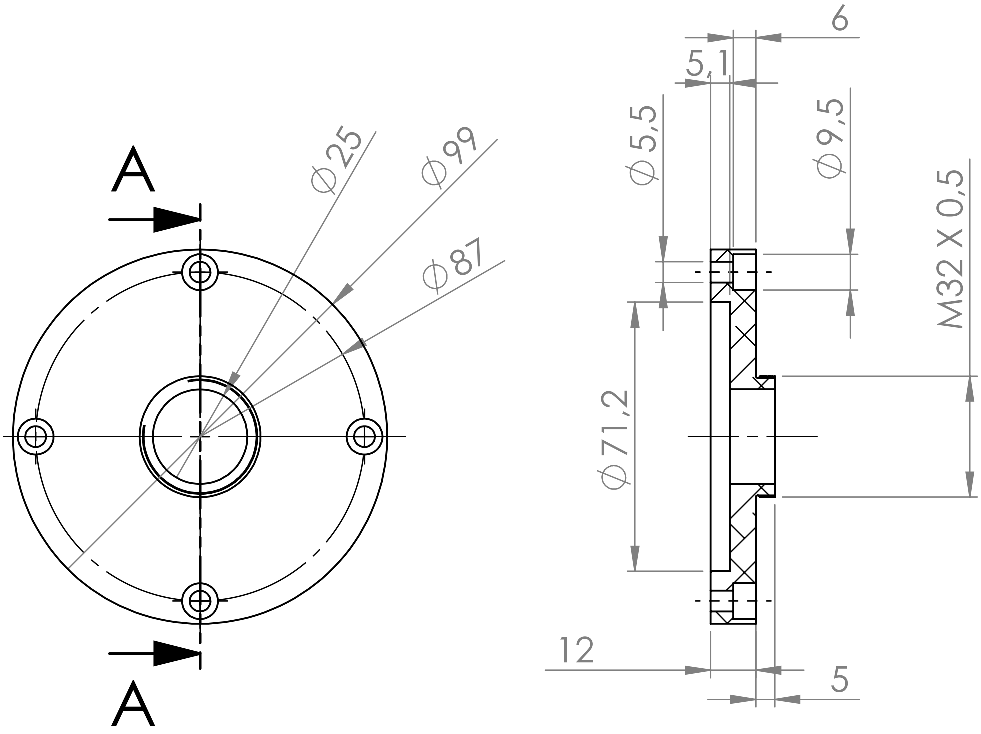
WEIGHT:

SCALE:1:2

SHEET 1 OF 1

Apêndice F

Desenho técnico do acoplador do laser



SECTION A-A

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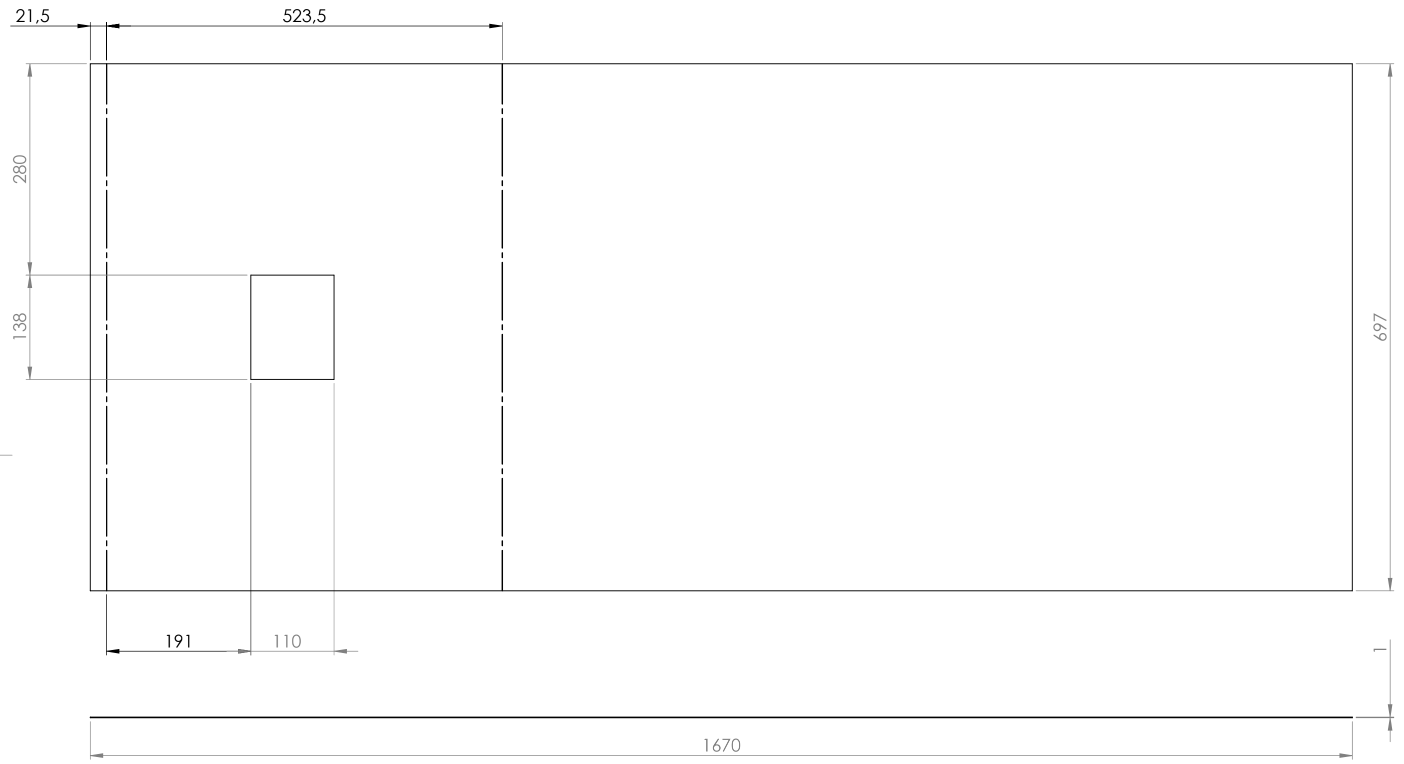
	NAME	SIGNATURE	DATE		TITLE:	
DRAWN	Lucas Martins					
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL: Alumínio 6082 T6	DWG NO. Acoplador laser	A4
				WEIGHT:	SCALE:1:2	SHEET 1 OF 1

Apêndice G

Chapas da cobertura da máquina



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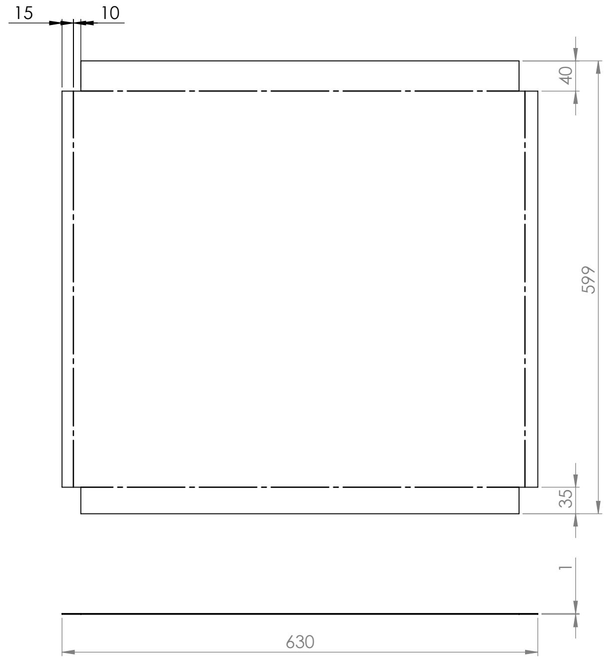
	NAME	SIGNATURE	DATE		TITLE:	
DRAWN	Lucas Martins					
CHK'D						
APPV'D						
MFG						
Q.A	1			MATERIAL: Aço EN S235 galvanizado	DWG NO. Chapa amarelo	A3
				WEIGHT:	SCALE:1:10	SHEET 1 OF 1



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DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Lucas Martins		
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:
Aço EN S235 galvanizado

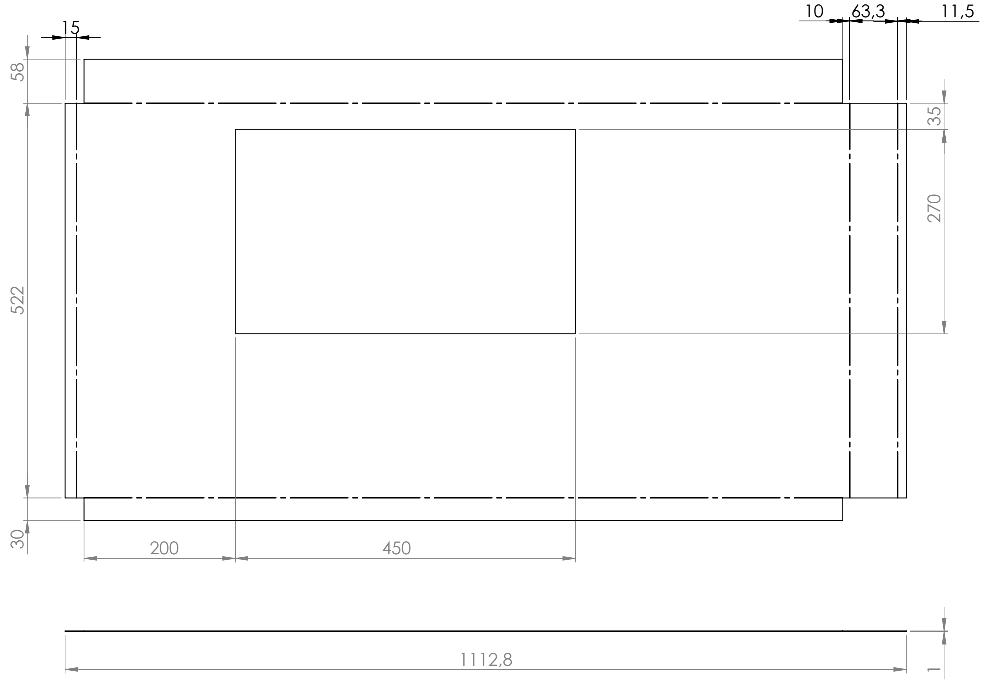
DWG NO.
Chapa verde

A3

WEIGHT:

SCALE:1:5

SHEET 1 OF 1



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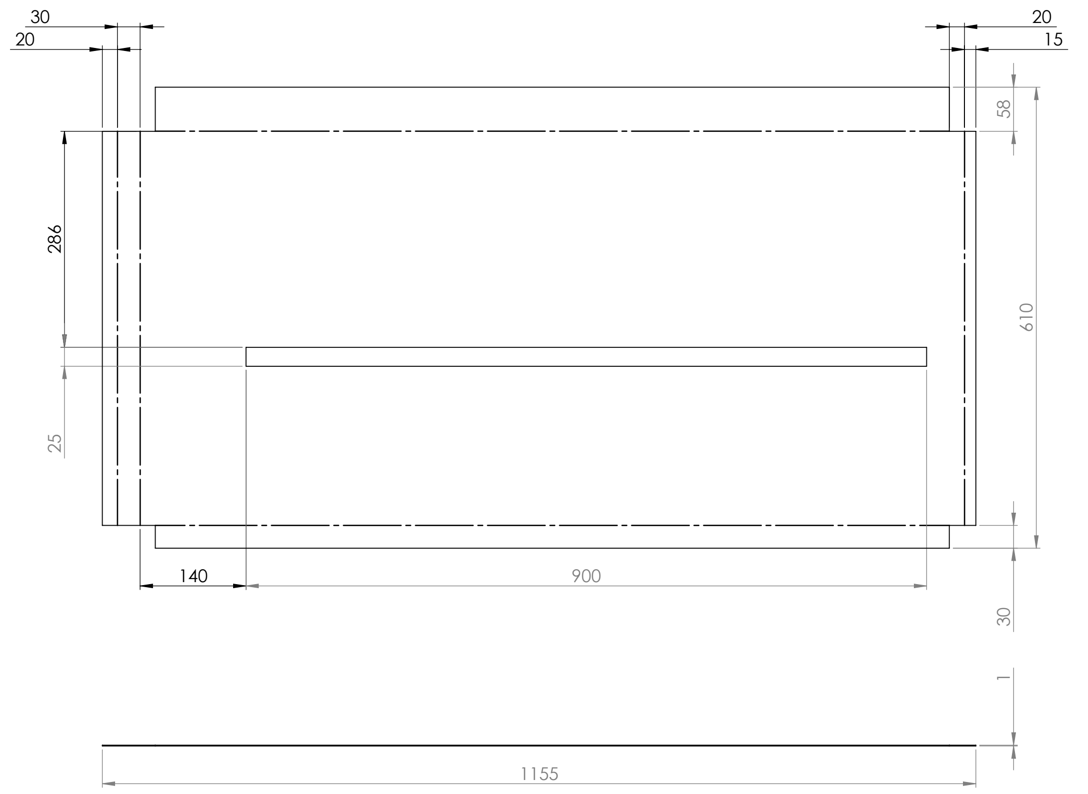
	NAME	SIGNATURE	DATE			TITLE:	
DRAWN	Lucas Martins						
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL: Aço EN S235 galvanizado		DWG NO. chapa vermelho	A3
				WEIGHT:		SCALE:1:5	SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
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LINEAR:
ANGULAR:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	Lucas Martins		
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

MATERIAL:
Aço EN S235 galvanizado

DWG NO.
chapa roxo

A3

WEIGHT:

SCALE:1:10

SHEET 1 OF 1

Apêndice H

Datasheet NI cDAQ-9174

https://www.ni.com/pdf/manuals/374045a.pdf

SPECIFICATIONS

NI cDAQ™-9174

NI CompactDAQ Four-Slot USB Chassis

These specifications are for the National Instruments CompactDAQ 9174 chassis only. These specifications are typical at 25 °C unless otherwise noted. For the C Series I/O module specifications, refer to the documentation for the C Series I/O module you are using.

Analog Input

Input FIFO size...127 samples per slot

Maximum sample rate[1]......................................Determined by the C Series I/O module or modules

Timing accuracy[2]...50 ppm of sample rate

Timing resolution[3]..12.5 ns

Number of channels supported..........................Determined by the C Series I/O module or modules

Analog Output

Number of channels supported

Hardware-timed task

Onboard regeneration........................16

Non-regeneration...............................Determined by the C Series I/O module or modules

---

1 Performance dependent on type of installed C Series I/O module and number of channels in the task.

2 Does not include group delay. For more information, refer to the documentation for each C Series I/O module.

3 Does not include group delay. For more information, refer to the documentation for each C Series I/O module.

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Non-hardware-timed task .... Determined by the C Series I/O module or modules

Maximum update rate

Onboard regeneration .... 1.6 MS/s (multi-channel, aggregate)

Non-regeneration .... Determined by the C Series I/O module or modules

Timing accuracy .... 50 ppm of sample rate

Timing resolution .... 12.5 ns

Output FIFO size

Onboard regeneration .... 8,191 samples shared among channels used

Non-regeneration .... 127 samples per slot

AO waveform modes .... Non-periodic waveform, periodic waveform regeneration mode from onboard memory, periodic waveform regeneration from host buffer including dynamic update

Digital Waveform Characteristics

Waveform acquisition (DI) FIFO .... 127 samples per slot

Waveform generation (DO) FIFO .... 2,047 samples

Digital input sample clock frequency

Streaming to application memory .... System-dependent

Finite .... 0 to 10 MHz

Digital output sample clock frequency

Streaming from application memory .... System-dependent

Regeneration from FIFO .... 0 to 10 MHz

Finite .... 0 to 10 MHz

Timing accuracy .... 50 ppm

General-Purpose Counters/Timers

Number of counters/timers	4
Resolution	32 bits
Counter measurements	Edge counting, pulse, semi-period, period, two-edge separation, pulse width
Position measurements	X1, X2, X4 quadrature encoding with Channel Z reloading; two-pulse encoding
Output applications	Pulse, pulse train with dynamic updates, frequency division, equivalent time sampling
Internal base clocks	80 MHz, 20 MHz, 100 kHz
External base clock frequency	0 to 20 MHz
Base clock accuracy	50 ppm
Output frequency	0 to 20 MHz
Inputs	Gate, Source, HW_Arm, Aux, A, B, Z, Up_Down
Routing options for inputs	Any module PFI, analog trigger, many internal signals
FIFO	Dedicated 127-sample FIFO

Frequency Generator

Number of channels	1
Base clocks	20 MHz, 10 MHz, 100 kHz
Divisors	1 to 16 (integers)
Base clock accuracy	50 ppm
Output	Any module PFI terminal

Module PFI Characteristics

Functionality	Static digital input, static digital output, timing input, and timing output
Timing output sources[4]	Many analog input, analog output, counter, digital input, and digital output timing signals
Timing input frequency	0 to 20 MHz
Timing output frequency	0 to 20 MHz

Digital Triggers

Source	Any module PFI terminal
Polarity	Software-selectable for most signals
Analog input function	Start Trigger, Reference Trigger, Pause Trigger, Sample Clock, Sample Clock Timebase
Analog output function	Start Trigger, Pause Trigger, Sample Clock, Sample Clock Timebase
Counter/timer function	Gate, Source, HW_Arm, Aux, A, B, Z, Up_Down

Module I/O States

At power-on	Module-dependent. Refer to the documentation for each C Series I/O module.

Note The chassis may revert the input/output of the modules to their power-on state when the USB cable is removed.

4 Actual signals available dependent on type of installed C Series I/O module.

Power Requirements

Caution You must use a National Electric Code (NEC) Class 2 power source with the NI cDAQ-9174 chassis.

Note Some C Series I/O modules have additional power requirements. For more information about C Series I/O module power requirements, refer to the documentation for each C Series I/O module.

Note Sleep mode for C Series I/O modules is not supported in the NI cDAQ-9174.

Input voltage range	9 to 30 V
Maximum required input power[5]	15 W
Power input connector	2 positions 3.5 mm pitch pluggable screw terminal with screw locks similar to Sauro CTMH020F8-0N001
Power input mating connector	Sauro CTF020V8, Phoenix Contact 1714977, or equivalent
Power consumption from USB, 4.10 to 5.25 V	500 µA maximum

Bus Interface

USB specification	USB 2.0 Hi-Speed
High-performance data streams	7
Data stream types available	Analog input, analog output, digital input, digital output, counter/timer input, counter/timer output, NI-XNET[6]

Note If you are connecting the NI cDAQ-9174 chassis to a USB hub, the hub must be externally powered.

5 Includes maximum 1 W module load per slot across rated temperature and product variations.

6 When a session is active, CAN or LIN (NI-XNET) C Series modules use a total of two data streams regardless of the number of NI-XNET modules in the chassis.

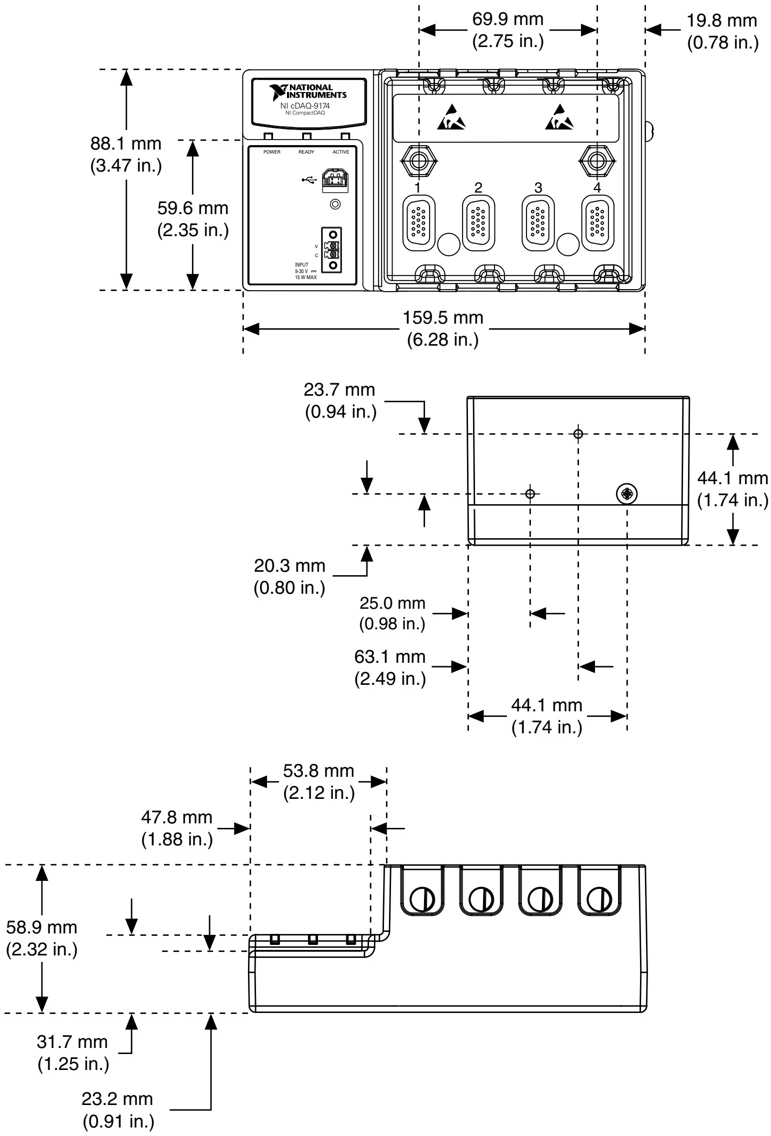
Physical Characteristics

Weight (unloaded)..Approx. 574 g (20.2 oz)

Dimensions (unloaded)......................................159.5 mm × 88.1 mm × 58.9 mm (6.28 in. × 3.47 in. × 2.3 in.) Refer to the following figure.

If you need to clean the chassis, wipe it with a dry towel.

Figure 1. NI cDAQ-9174 Dimensions



Environmental

Operating temperature[7] .... -20 °C to 55 °C (IEC-60068-2-1 and IEC-60068-2-2)

Storage temperature .... -40 °C to 85 °C (IEC-600068-2-1 and IEC-60068-2-2)

Ingress protection .... IP 30

Operating humidity .... 10 to 90% RH, noncondensing (IEC-60068-2-56)

Storage humidity .... 5 to 95% RH, noncondensing (IEC-60068-2-56)

Pollution Degree (IEC 60664) 2

Maximum altitude .... 5,000 m

Indoor use only.

Shock and Vibration

To meet these specifications, you must panel mount the NI cDAQ-9174 system, use an NI locking USB cable, and affix ferrules to the ends of the terminal lines.

Operational shock .... 30 g peak, half-sine, 11 ms pulse (Tested in accordance with IEC 60068-2-27. Test profile developed in accordance with MIL-PRF-28800F.)

Random vibration

- Operating .... 5 to 500 Hz, 0.3 g_{rms}
- Non-operating .... 5 to 500 Hz, 2.4 g_{rms} (Tested in accordance with IEC 60068-2-64. Non-operating test profile exceeds the requirements of MIL PRF-28800F, Class 3.)

7 When operating the NI cDAQ-9174 in temperatures below 0 °C, you must use the PS-15 power supply or another power supply rated for below 0 °C.

Safety

This product meets the requirements of the following standards of safety for electrical equipment for measurement, control, and laboratory use:

- IEC 61010-1, EN 61010-1
- UL 61010-1, CSA 61010-1

Note For UL and other safety certifications, refer to the product label or the *Online Product Certification* section.

Electromagnetic Compatibility

This product meets the requirements of the following EMC standards for electrical equipment for measurement, control, and laboratory use:

- EN 61326-1 (IEC 61326-1): Class A emissions; Basic immunity
- EN 55011 (CISPR 11): Group 1, Class A emissions
- AS/NZS CISPR 11: Group 1, Class A emissions
- FCC 47 CFR Part 15B: Class A emissions
- ICES-001: Class A emissions

Note In the United States (per FCC 47 CFR), Class A equipment is intended for use in commercial, light-industrial, and heavy-industrial locations. In Europe, Canada, Australia, and New Zealand (per CISPR 11) Class A equipment is intended for use only in heavy-industrial locations.

Note Group 1 equipment (per CISPR 11) is any industrial, scientific, or medical equipment that does not intentionally generate radio frequency energy for the treatment of material or inspection/analysis purposes.

Note For EMC declarations and certifications, refer to the *Online Product Certification* section.

CE Compliance

This product meets the essential requirements of applicable European Directives as follows:

- 2006/95/EC; Low-Voltage Directive (safety)
- 2004/108/EC; Electromagnetic Compatibility Directive (EMC)

Online Product Certification

To obtain product certifications and the DoC for this product, visit *ni.com/certification*, search by model number or product line, and click the appropriate link in the Certification column.

Environmental Management

NI is committed to designing and manufacturing products in an environmentally responsible manner. NI recognizes that eliminating certain hazardous substances from our products is beneficial not only to the environment but also to NI customers.

For additional environmental information, refer to the *Minimize Our Environmental Impact* web page at *ni.com/environment*. This page contains the environmental regulations and directives with which NI complies, as well as other environmental information not included in this document.

Waste Electrical and Electronic Equipment (WEEE)

EU Customers At the end of the product life cycle, all products must be sent to a WEEE recycling center. For more information about WEEE recycling centers, National Instruments WEEE initiatives, and compliance with WEEE Directive 2002/96/EC on Waste Electrical and Electronic Equipment, visit *ni.com/environment/weee*.

电子信息产品污染控制管理办法（中国 RoHS）

中国客户 National Instruments 符合中国电子信息产品中限制使用某些有害物质指令(RoHS)。关于 National Instruments 中国 RoHS 合规性信息，请登录 ni.com/environment/rohs_china。(For information about China RoHS compliance, go to ni.com/environment/rohs_china.)

374045A-01 May13

Apêndice I

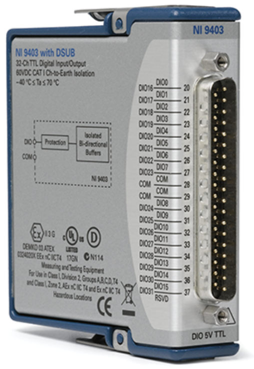
Datasheet NI 9403

https://www.ni.com/pdf/manuals/374069a_02.pdf

DATASHEET

NI 9403

32 DIO, 5 V/TTL, Bidirectional, 7 μs



- 5 V/TTL, sinking/sourcing digital I/O
- Bidirectional, configurable by line with shift-on-the-fly capability
- 60 VDC, CAT I isolation
- Industry-standard 37-pin DSUB connector
- -40 °C to 70 °C operating, 5 g vibration, 50 g shock

The NI 9403 is a 32-channel, 7 μs bidirectional digital I/O module for any NI CompactDAQ or CompactRIO chassis. You can configure the direction of each digital line on the NI 9403 for input or output. Each channel is compatible with 5 V/TTL signals and features 60 VDC, CAT I isolation. The NI 9403 also features ±30 V overvoltage protection and can source up to 2 mA output current per channel.

In an NI CompactDAQ chassis, you can use the NI 9403 as only a static (software-timed) digital I/O module. Due to the serial transfer of data, you cannot use these modules to route timing or triggering signals. With the NI 9403 in a CompactRIO chassis, you can use LabVIEW FPGA to program the NI 9403 for implementing custom counter/timers, pulse generation, and much more.

C SERIES DIGITAL INPUT/OUTPUT MODULE COMPARISON

Product Name	Signal Levels	Channels	Update Rate	Direction	Connectivity	Isolation Continuous
NI 9381	LVTTL	4	1 μs	Bidirectional	DSUB	None
NI 9401	5 V/TTL	8	100 ns	Bidirectional	DSUB	60 VDC Ch-Earth
NI 9402	LVTTL	4	55 ns	Bidirectional	BNC	None
NI 9403	5 V/TTL	32	7 μs	Bidirectional	DSUB	60 VDC Ch-Earth

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Kit Contents	• NI 9403 • NI 9403 Getting Started Guide
Accessories	**Front-Mount** • NI 9923 Screw-Terminal Block (780179-01)
	Cable • DSUB Cable, 1 m (778621-01) • Din-Rail Spring-Terminal Block (778676-01)

NI C Series Overview

NI provides more than 100 C Series modules for measurement, control, and communication applications. C Series modules can connect to any sensor or bus and allow for high-accuracy measurements that meet the demands of advanced data acquisition and control applications.

- Measurement-specific signal conditioning that connects to an array of sensors and signals
- Isolation options such as bank-to-bank, channel-to-channel, and channel-to-earth ground
- -40 °C to 70 °C temperature range to meet a variety of application and environmental needs
- Hot-swappable

The majority of C Series modules are supported in both CompactRIO and CompactDAQ platforms and you can move modules from one platform to the other with no modification.

CompactRIO

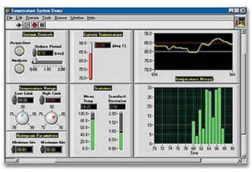
CompactRIO combines an open-embedded architecture with small size, extreme ruggedness, and C Series modules in a platform powered by the NI LabVIEW reconfigurable I/O (RIO) architecture. Each system contains an FPGA for custom timing, triggering, and processing with a wide array of available modular I/O to meet any embedded application requirement.

CompactDAQ

CompactDAQ is a portable, rugged data acquisition platform that integrates connectivity, data acquisition, and signal conditioning into modular I/O for directly interfacing to any sensor or signal. Using CompactDAQ with LabVIEW, you can easily customize how you acquire, analyze, visualize, and manage your measurement data.

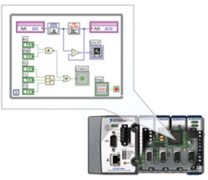
Software

LabVIEW Professional Development System for Windows



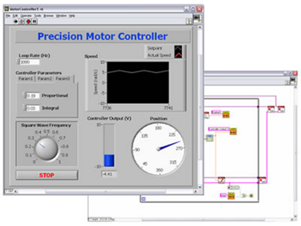
- Use advanced software tools for large project development
- Generate code automatically using DAQ Assistant and Instrument I/O Assistant
- Use advanced measurement analysis and digital signal processing
- Take advantage of open connectivity with DLLs, ActiveX, and .NET objects
- Build DLLs, executables, and MSI installers

NI LabVIEW FPGA Module



- Design FPGA applications for NI RIO hardware
- Program with the same graphical environment used for desktop and real-time applications
- Execute control algorithms with loop rates up to 300 MHz
- Implement custom timing and triggering logic, digital protocols, and DSP algorithms
- Incorporate existing HDL code and third-party IP including Xilinx IP generator functions
- Purchase as part of the LabVIEW Embedded Control and Monitoring Suite

NI LabVIEW Real-Time Module

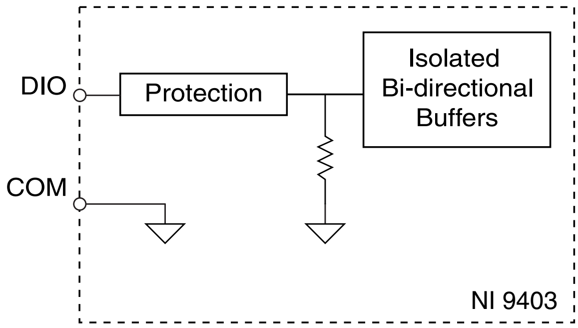


- Design deterministic real-time applications with LabVIEW graphical programming
- Download to dedicated NI or third-party hardware for reliable execution and a wide selection of I/O
- Take advantage of built-in PID control, signal processing, and analysis functions
- Automatically take advantage of multicore CPUs or set processor affinity manually
- Take advantage of real-time OS, development and debugging support, and board support
- Purchase individually or as part of a LabVIEW suite

Circuitry

The NI 9403 provides overvoltage, overcurrent, and short-circuit protection and isolated bi-directional buffers for each DIO channel.

Figure 1. NI 9403 Circuitry



The DIO channels have Schmitt trigger inputs and are compatible with 5 V/TTL logic devices. Each input channel has hysteresis for improved performance with noisy and non-monotonic input signals. Each channel also has a pull-down resistor.

NI 9403 Specifications

The following specifications are typical for the range -40 °C to 70 °C unless otherwise noted. All voltages are relative to COM unless otherwise noted.

Caution To ensure the specified EMC performance, operate this product only with shielded cables and accessories.

Caution Do not operate the NI 9403 in a manner not specified in this document. Product misuse can result in a hazard. You can compromise the safety protection built into the product if the product is damaged in any way. If the product is damaged, return it to NI for repair.

Input/Output Characteristics

Number of channels	32 digital input/output channels
Input/output type	TTL, single-ended
Default power-on line direction	Input
Input Current (0 V $\leq V_{in} \leq$ 4.5 V)	±250 µA maximum
Module output current[1]	64 mA maximum
Input capacitance	30 pF
Timing	
Input	
Setup time[2]	10 ns minimum
Hold time[3]	60 ns minimum
Output	
Propagation delay[4]	330 ns maximum
Channel-to-channel skew[5]	265 ns maximum
Update/transfer time[6]	
cRIO-9151 R Series Expansion chassis	8 µS maximum
All other chassis	7 µS maximum
Direction change time	18 µS maximum
Overvoltage protection Channel-to-COM	±30 V maximum on up to 8 channels at a time; however, continued use at this level will degrade the life of the module.
MTBF	763,325 hours at 25 °C; Bellcore Issue 2, Method 1, Case 3, Limited Part Stress Method

1 Module output current is the maximum guaranteed current that the module can drive from all the I/O lines without going into an overcurrent state.
2 *Setup time* is the amount of time input signals must be stable before reading from the module.
3 *Hold time* is the amount of time input signals must be stable after initiating a read from the module.
4 *Propagation delay* is the amount of time after writing to the module that the output signals become valid.
5 *Channel-to-channel skew* is the amount of time between the first output signal updating and the last output signal updating.
6 The update/transfer and direction change times are valid when the module is used in a CompactRIO system. When used in other systems, driver software and system latencies impact these times.

Digital Logic Levels

Input	
Voltage	-0.25 V to 5.25 V
High, V_{IH}	2.2 V minimum
Low, V_{IL}	0.8 V maximum
Hysteresis, V_H	0.2 V minimum
Output	
High, V_{OH} (5.2 V maximum)	
Sourcing 100 μA	4.75 V minimum
Sourcing 2 mA	4.4 V minimum
Low, V_{OL}	
Sinking 100 μA	0.1 V maximum
Sinking 2 mA	0.26 V maximum

Power Requirements

Power consumption from chassis	
Active mode	1 W maximum
Sleep mode	25 μW maximum
Thermal dissipation (at 70 °C)	
Active mode	1 W maximum
Sleep mode	25 μW maximum

Physical Characteristics

If you need to clean the module, wipe it with a dry towel.

Tip For two-dimensional drawings and three-dimensional models of the C Series module and connectors, visit *ni.com/dimensions* and search by module number.

Weight	150 g (5.3 oz)

Safety Voltages

Connect only voltages that are within the following limits:

Channel-to-COM	±30 V maximum on up to 8 channels at a time, Measurement Category I
Isolation	
Channel-to-channel	None

Channel-to-earth ground	
Continuous	60 VDC, Measurement Category I
Withstand	
up to 3,000 m altitude	1,000 Vrms, verified by a 5 s dielectric withstand test
up to 5,000 m altitude	860 Vrms, verified by a 5 s dielectric withstand test

Measurement Category I is for measurements performed on circuits not directly connected to the electrical distribution system referred to as *MAINS* voltage. MAINS is a hazardous live electrical supply system that powers equipment. This category is for measurements of voltages from specially protected secondary circuits. Such voltage measurements include signal levels, special equipment, limited-energy parts of equipment, circuits powered by regulated low-voltage sources, and electronics.

Caution Do not connect the NI 9403 to signals or use for measurements within Measurement Categories II, III, or IV.

Hazardous Locations

U.S. (UL)	Class I, Division 2, Groups A, B, C, D, T4; Class I, Zone 2, AEx nA IIC T4
Canada (C-UL)	Class I, Division 2, Groups A, B, C, D, T4; Class I, Zone 2, Ex nA IIC T4
Europe (ATEX) and International (IECEx)	Ex nA IIC T4 Gc

Safety and Hazardous Locations Standards

This product is designed to meet the requirements of the following electrical equipment safety standards for measurement, control, and laboratory use:

- IEC 61010-1, EN 61010-1
- UL 61010-1, CSA 61010-1
- EN 60079-0:2012, EN 60079-15:2010
- IEC 60079-0: Ed 6, IEC 60079-15; Ed 4
- UL 60079-0; Ed 5, UL 60079-15; Ed 3
- CSA 60079-0:2011, CSA 60079-15:2012

Note For UL and other safety certifications, refer to the product label or the *Online Product Certification* section.

Electromagnetic Compatibility

This product is designed to meet the requirements of the following standards of EMC for electrical equipment for measurement, control, and laboratory use:

- EN 61326 EMC requirements; Industrial Immunity
- EN 55011 Emissions; Group 1, Class A
- CE, C-Tick, ICES, and FCC Part 15 Emissions; Class A

Note For EMC compliance, operate this device with shielded cabling.

CE Compliance CE

This product meets the essential requirements of applicable European Directives, as follows:

- 2014/35/EU; Low-Voltage Directive (safety)
- 2014/30/EU; Electromagnetic Compatibility Directive (EMC)
- 94/9/EC; Potentially Explosive Atmospheres (ATEX)

Online Product Certification

Refer to the product Declaration of Conformity (DoC) for additional regulatory compliance information. To obtain product certifications and the DoC for this product, visit *ni.com/certification*, search by model number or product line, and click the appropriate link in the Certification column.

Shock and Vibration

To meet these specifications, you must panel mount the system.

Operating vibration	
Random (IEC 60068-2-64)	5 g_{rms}, 10 Hz to 500 Hz
Sinusoidal (IEC 60068-2-6)	5 g, 10 Hz to 500 Hz
Operating shock (IEC 60068-2-27)	30 g, 11 ms half sine; 50 g, 3 ms half sine; 18 shocks at 6 orientations

Environmental

Refer to the manual for the chassis you are using for more information about meeting these specifications.

Operating temperature (IEC 60068-2-1, IEC 60068-2-2)	-40 °C to 70 °C
Storage temperature (IEC 60068-2-1, IEC 60068-2-2)	-40 °C to 85 °C

Ingress protection	IP40
Operating humidity (IEC 60068-2-78)	10% RH to 90% RH, noncondensing
Storage humidity (IEC 60068-2-78)	5% RH to 95% RH, noncondensing
Pollution Degree	2
Maximum altitude	5,000 m

Indoor use only.

Environmental Management

NI is committed to designing and manufacturing products in an environmentally responsible manner. NI recognizes that eliminating certain hazardous substances from our products is beneficial to the environment and to NI customers.

For additional environmental information, refer to the *Minimize Our Environmental Impact* web page at *ni.com/environment*. This page contains the environmental regulations and directives with which NI complies, as well as other environmental information not included in this document.

Waste Electrical and Electronic Equipment (WEEE)

EU Customers At the end of the product life cycle, all NI products must be disposed of according to local laws and regulations. For more information about how to recycle NI products in your region, visit *ni.com/environment/weee*.

电子信息产品污染控制管理办法（中国 RoHS）

中国客户 National Instruments 符合中国电子信息产品中限制使用某些有害物质指令（RoHS）。关于 National Instruments 中国 RoHS 合规性信息，请登录 `ni.com/environment/rohs_china`。（For information about China RoHS compliance, go to `ni.com/environment/rohs_china`.）

374069A-02 Oct15

Apêndice J

Datasheet NI 9401

https://www.ni.com/pdf/manuals/374068a_02.pdf

DATASHEET

NI 9401

8 DIO, 5 V/TTL, Bidirectional, 100 ns

- DSUB connectivity
- CompactDAQ counter compatibility
- 60 VDC, CAT I, channel-to-earth isolation

The NI 9401 is a bidirectional digital module for any NI CompactDAQ or CompactRIO chassis. The eight DIO channels are grouped in two ports that you can configure independently for input or output. You can use the NI 9401 to implement custom digital systems such as counters/timers, digital communication protocols, pulse generation, and beyond.

Kit Contents	• NI 9401 • NI 9401 Getting Started Guide
Accessories	**Front-Mount** • NI 9924 Screw-Terminal Block (781922-01)
	Cable • DSUB Cable, 1 m (192568-01) • DIN Rail Screw-Terminal Block (781081-01)
	EMC Compliance • EMI Noise-Suppression Ferrite (782803-01)

C SERIES DIGITAL INPUT/OUTPUT MODULE COMPARISON						
Product Name	Signal Levels	Channels	Update Rate	Direction	Connectivity	Isolation Continuous
NI 9381	LVTTL	4	1 µs	Bidirectional	DSUB	None
NI 9401	5 V/TTL	8	100 ns	Bidirectional	DSUB	60 VDC Ch-Earth
NI 9402	LVTTL	4	55 ns	Bidirectional	BNC	None
NI 9403	5 V/TTL	32	7 µs	Bidirectional	DSUB	60 VDC Ch-Earth

NI C Series Overview

NI provides more than 100 C Series modules for measurement, control, and communication applications. C Series modules can connect to any sensor or bus and allow for high-accuracy measurements that meet the demands of advanced data acquisition and control applications.

- Measurement-specific signal conditioning that connects to an array of sensors and signals
- Isolation options such as bank-to-bank, channel-to-channel, and channel-to-earth ground
- -40 °C to 70 °C temperature range to meet a variety of application and environmental needs
- Hot-swappable

The majority of C Series modules are supported in both CompactRIO and CompactDAQ platforms and you can move modules from one platform to the other with no modification.

CompactRIO

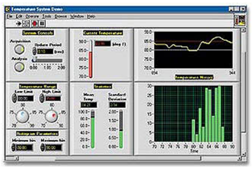
CompactRIO combines an open-embedded architecture with small size, extreme ruggedness, and C Series modules in a platform powered by the NI LabVIEW reconfigurable I/O (RIO) architecture. Each system contains an FPGA for custom timing, triggering, and processing with a wide array of available modular I/O to meet any embedded application requirement.

CompactDAQ

CompactDAQ is a portable, rugged data acquisition platform that integrates connectivity, data acquisition, and signal conditioning into modular I/O for directly interfacing to any sensor or signal. Using CompactDAQ with LabVIEW, you can easily customize how you acquire, analyze, visualize, and manage your measurement data.

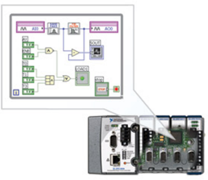
Software

LabVIEW Professional Development System for Windows



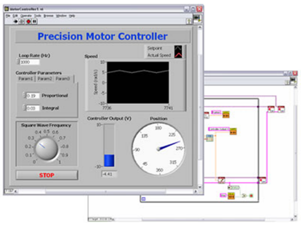
- Use advanced software tools for large project development
- Generate code automatically using DAQ Assistant and Instrument I/O Assistant
- Use advanced measurement analysis and digital signal processing
- Take advantage of open connectivity with DLLs, ActiveX, and .NET objects
- Build DLLs, executables, and MSI installers

NI LabVIEW FPGA Module



- Design FPGA applications for NI RIO hardware
- Program with the same graphical environment used for desktop and real-time applications
- Execute control algorithms with loop rates up to 300 MHz
- Implement custom timing and triggering logic, digital protocols, and DSP algorithms
- Incorporate existing HDL code and third-party IP including Xilinx IP generator functions
- Purchase as part of the LabVIEW Embedded Control and Monitoring Suite

NI LabVIEW Real-Time Module

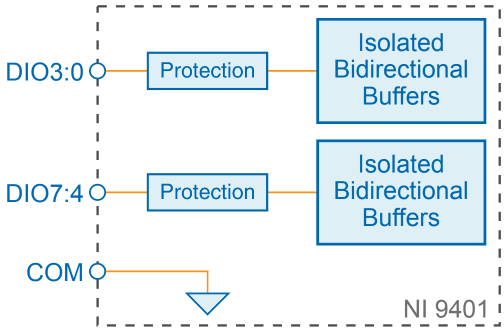


- Design deterministic real-time applications with LabVIEW graphical programming
- Download to dedicated NI or third-party hardware for reliable execution and a wide selection of I/O
- Take advantage of built-in PID control, signal processing, and analysis functions
- Automatically take advantage of multicore CPUs or set processor affinity manually
- Take advantage of real-time OS, development and debugging support, and board support
- Purchase individually or as part of a LabVIEW suite

Input/Output Circuitry

The eight DIO channels are internally referenced to COM, so you can use any of the nine COM lines as a reference for the external signal.

Figure 1. NI 9401 Input/Output Circuitry



NI 9401 Specifications

The following specifications are typical for the range -40 °C to 70 °C unless otherwise noted. All voltages are relative to COM unless otherwise noted.

Caution Do not operate the NI 9401 in a manner not specified in this document. Product misuse can result in a hazard. You can compromise the safety protection built into the product if the product is damaged in any way. If the product is damaged, return it to NI for repair.

Input/Output Characteristics

Number of channels	8 DIO channels
Default power-on line direction	Input

Input/output type	TTL, single-ended
Digital logic levels	
Input	
Voltage	5.25 V maximum
High, V_{IH}	2 V minimum
Low, V_{IL}	0.8 V maximum
Output High, V_{OH} (5.25 V maximum)	
Sourcing 100 µA	4.7 V minimum
Sourcing 2 mA	4.3 V minimum
Output Low, V_{OL}	
Sinking 100 µA	0.1 V maximum
Sinking 2 mA	0.4 V maximum
Maximum signal switching frequency, per channel	
Input	
8 input channels	9 MHz
4 input channels	16 MHz
2 input channels	30 MHz
Output[1]	
8 output channels	5 MHz
4 output channels	10 MHz
2 output channels	20 MHz
I/O propagation delay	100 ns maximum
I/O pulse width distortion	10 ns
Input current (0 V ≤ V_{IN} ≤ 4.5 V)	±250 µA
Input capacitance	30 pF
Input rise/fall time	500 ns maximum
Overvoltage protection, channel-to-COM[2]	±30 V maximum on one channel at a time
MTBF	1,244,763 hours at 25 °C; Bellcore Issue 2, Method 1, Case 3, Limited Part Stress Method

[1] By number of output channels with an output load of 1 mA, 50 pF

[2] Continued use at this level will degrade the life of the module.

Power Requirements

Power consumption from chassis	
Active mode	580 mW maximum
Sleep mode	1 mW maximum
Thermal dissipation (at 70 °C)	
Active mode	580 mW maximum
Sleep mode	1 mW maximum

Physical Characteristics

If you need to clean the module, wipe it with a dry towel.

Tip For two-dimensional drawings and three-dimensional models of the C Series module and connectors, visit *ni.com/dimensions* and search by module number.

Weight	145 g (5.1 oz)

Safety Voltages

Connect only voltages that are within the following limits:

Maximum voltage[3]	
Channel-to-COM	±30 V maximum on one channel at a time, Measurement Category I
Isolation voltages	
Channel-to-channel	None
Channel-to-earth ground	
Continuous	60 VDC, Measurement Category I
Withstand	1,000 Vrms, verified by a 5 s dielectric withstand test

Measurement Category I is for measurements performed on circuits not directly connected to the electrical distribution system referred to as *MAINS* voltage. MAINS is a hazardous live electrical supply system that powers equipment. This category is for measurements of voltages from specially protected secondary circuits. Such voltage measurements include signal levels, special equipment, limited-energy parts of equipment, circuits powered by regulated low-voltage sources, and electronics.

[3] The maximum voltage that can be applied or output between any channel and COM without damaging the module or other devices.

Caution Do not connect the NI 9401 to signals or use for measurements within Measurement Categories II, III, or IV.

Note Measurement Categories CAT I and CAT O are equivalent. These test and measurement circuits are not intended for direct connection to the MAINS building installations of Measurement Categories CAT II, CAT III, or CAT IV.

Hazardous Locations

U.S. (UL)	Class I, Division 2, Groups A, B, C, D, T4; Class I, Zone 2, AEx nA IIC T4
Canada (C-UL)	Class I, Division 2, Groups A, B, C, D, T4; Class I, Zone 2, Ex nA IIC T4
Europe (ATEX) and International (IECEx)	Ex nA IIC T4 Gc

Safety and Hazardous Locations Standards

This product is designed to meet the requirements of the following electrical equipment safety standards for measurement, control, and laboratory use:

- IEC 61010-1, EN 61010-1
- UL 61010-1, CSA 61010-1
- EN 60079-0:2012, EN 60079-15:2010
- IEC 60079-0: Ed 6, IEC 60079-15; Ed 4
- UL 60079-0; Ed 5, UL 60079-15; Ed 3
- CSA 60079-0:2011, CSA 60079-15:2012

Note For UL and other safety certifications, refer to the product label or the *Online Product Certification* section.

Electromagnetic Compatibility

This product meets the requirements of the following EMC standards for electrical equipment for measurement, control, and laboratory use:

- EN 61326 EMC requirements; Industrial Immunity
- EN 55011 (CISPR 11): Group 1, Class A emissions
- CE, C-Tick, ICES, and FCC Part 15 Emissions; Class A

Note In the United States (per FCC 47 CFR), Class A equipment is intended for use in commercial, light-industrial, and heavy-industrial locations. In Europe, Canada, Australia and New Zealand (per CISPR 11) Class A equipment is intended for use only in heavy-industrial locations.

Note Group 1 equipment (per CISPR 11) is any industrial, scientific, or medical equipment that does not intentionally generate radio frequency energy for the treatment of material or inspection/analysis purposes.

Note For EMC declarations and certifications, and additional information, refer to the *Online Product Certification* section.

CE Compliance CE

This product meets the essential requirements of applicable European Directives, as follows:

- 2014/35/EU; Low-Voltage Directive (safety)
- 2014/30/EU; Electromagnetic Compatibility Directive (EMC)
- 94/9/EC; Potentially Explosive Atmospheres (ATEX)

Online Product Certification

Refer to the product Declaration of Conformity (DoC) for additional regulatory compliance information. To obtain product certifications and the DoC for this product, visit *ni.com/certification*, search by model number or product line, and click the appropriate link in the Certification column.

Shock and Vibration

To meet these specifications, you must panel mount the system.

Operating vibration	
Random (IEC 60068-2-64)	5 g_{rms}, 10 Hz to 500 Hz
Sinusoidal (IEC 60068-2-6)	5 g, 10 Hz to 500 Hz
Operating shock (IEC 60068-2-27)	30 g, 11 ms half sine; 50 g, 3 ms half sine; 18 shocks at 6 orientations

Environmental

Refer to the manual for the chassis you are using for more information about meeting these specifications.

Operating temperature (IEC 60068-2-1, IEC 60068-2-2)	-40 °C to 70 °C
Storage temperature (IEC 60068-2-1, IEC 60068-2-2)	-40 °C to 85 °C
Ingress protection	IP40
Operating humidity (IEC 60068-2-78)	10% RH to 90% RH, noncondensing
Storage humidity (IEC 60068-2-78)	5% RH to 95% RH, noncondensing
Pollution Degree	2
Maximum altitude	2,000 m

Indoor use only.

Environmental Management

NI is committed to designing and manufacturing products in an environmentally responsible manner. NI recognizes that eliminating certain hazardous substances from our products is beneficial to the environment and to NI customers.

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Waste Electrical and Electronic Equipment (WEEE)

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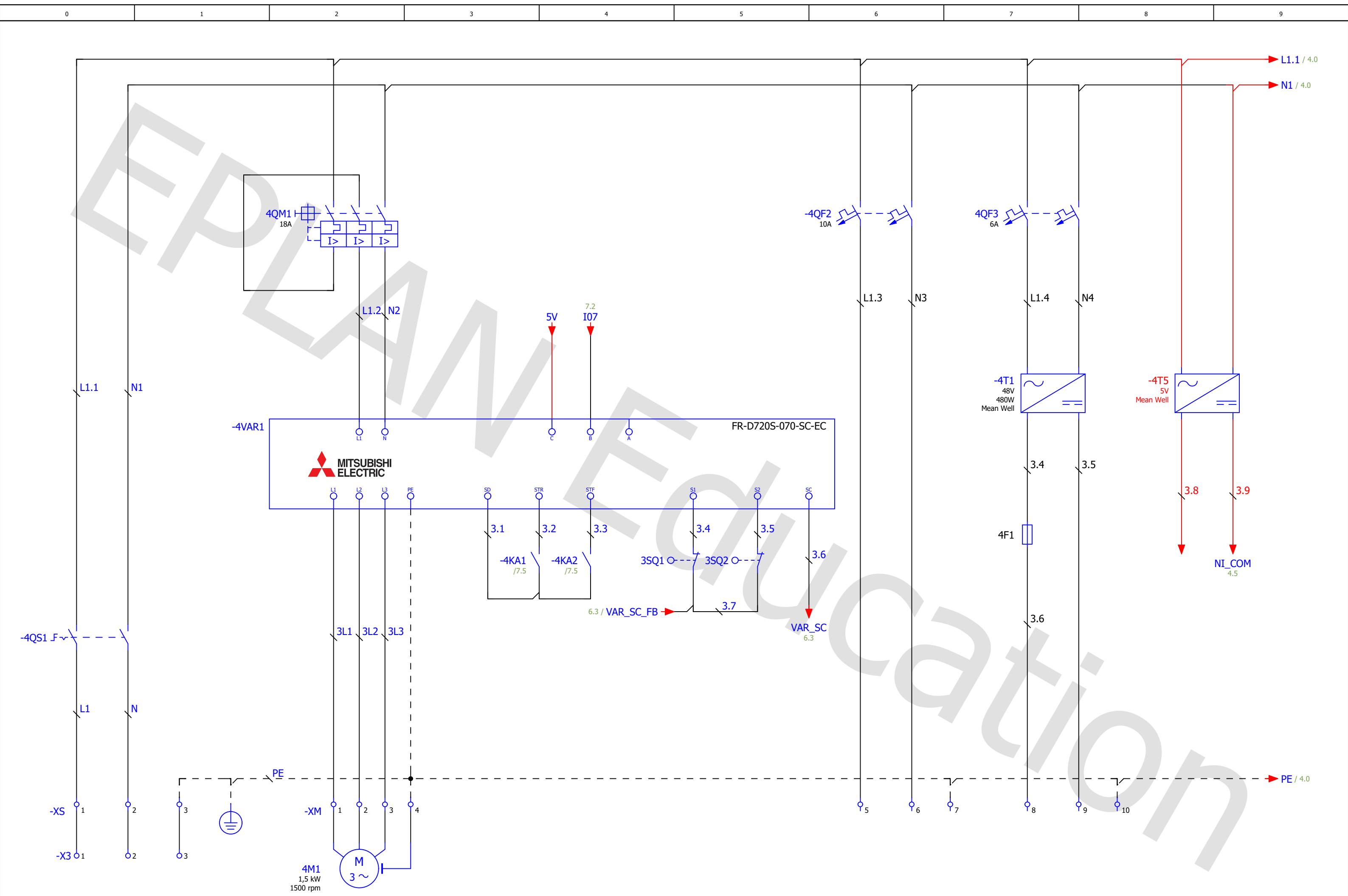
电子信息产品污染控制管理办法（中国 RoHS）

中国客户 National Instruments 符合中国电子信息产品中限制使用某些有害物质指令(RoHS)。关于 National Instruments 中国 RoHS 合规性信息，请登录 ni.com/environment/rohs_china。(For information about China RoHS compliance, go to ni.com/environment/rohs_china.)

374068A-02 Dec15

Apêndice K

Esquema elétrico da máquina atualizado



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N4
5V
7.2
I07
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-4T1
48V
480W
Mean Well
-4T5
5V
Mean Well
-4VAR1
FR-D720S-070-SC-EC
MITSUBISHI
ELECTRIC
3.4
3.5
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NI_COM
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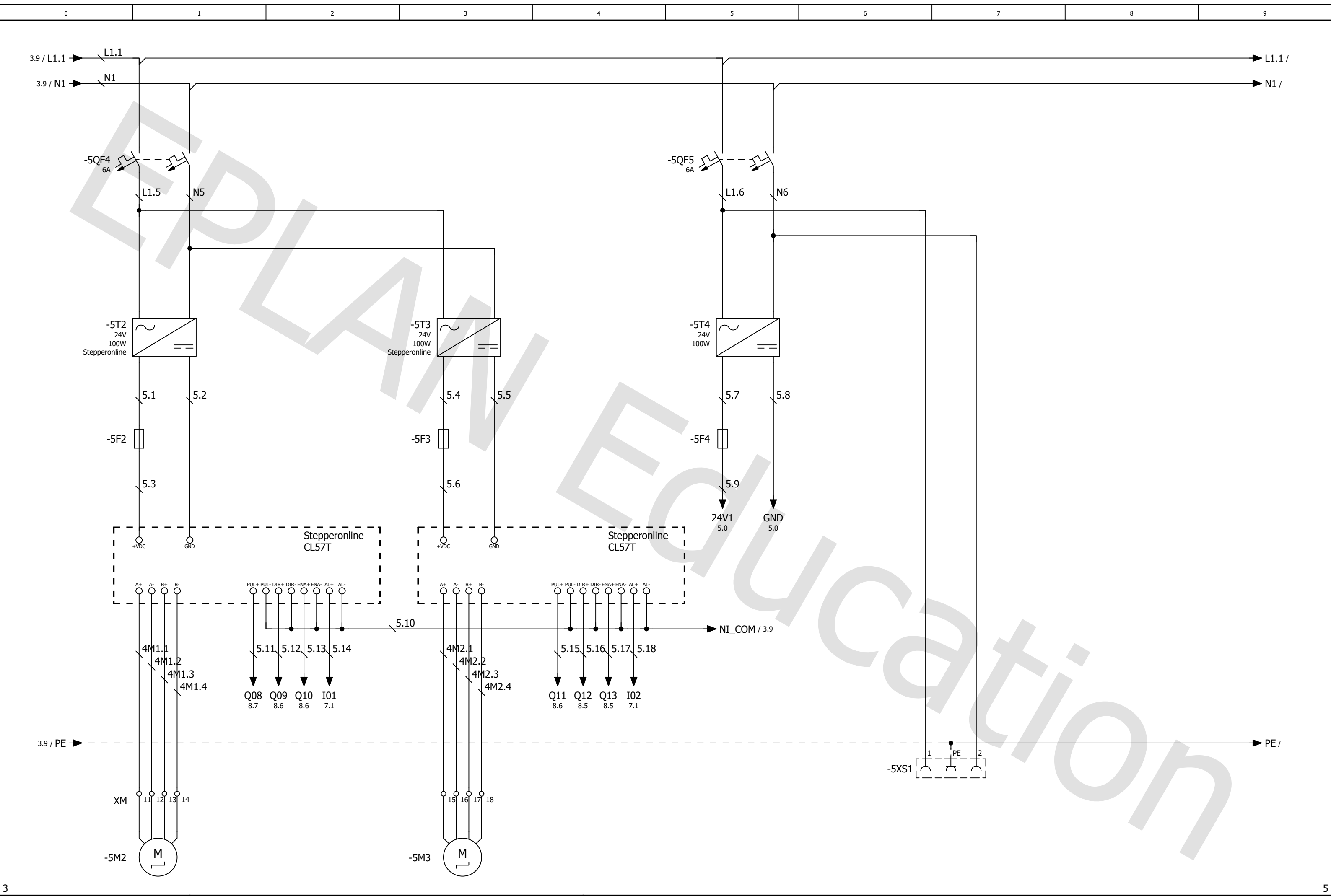

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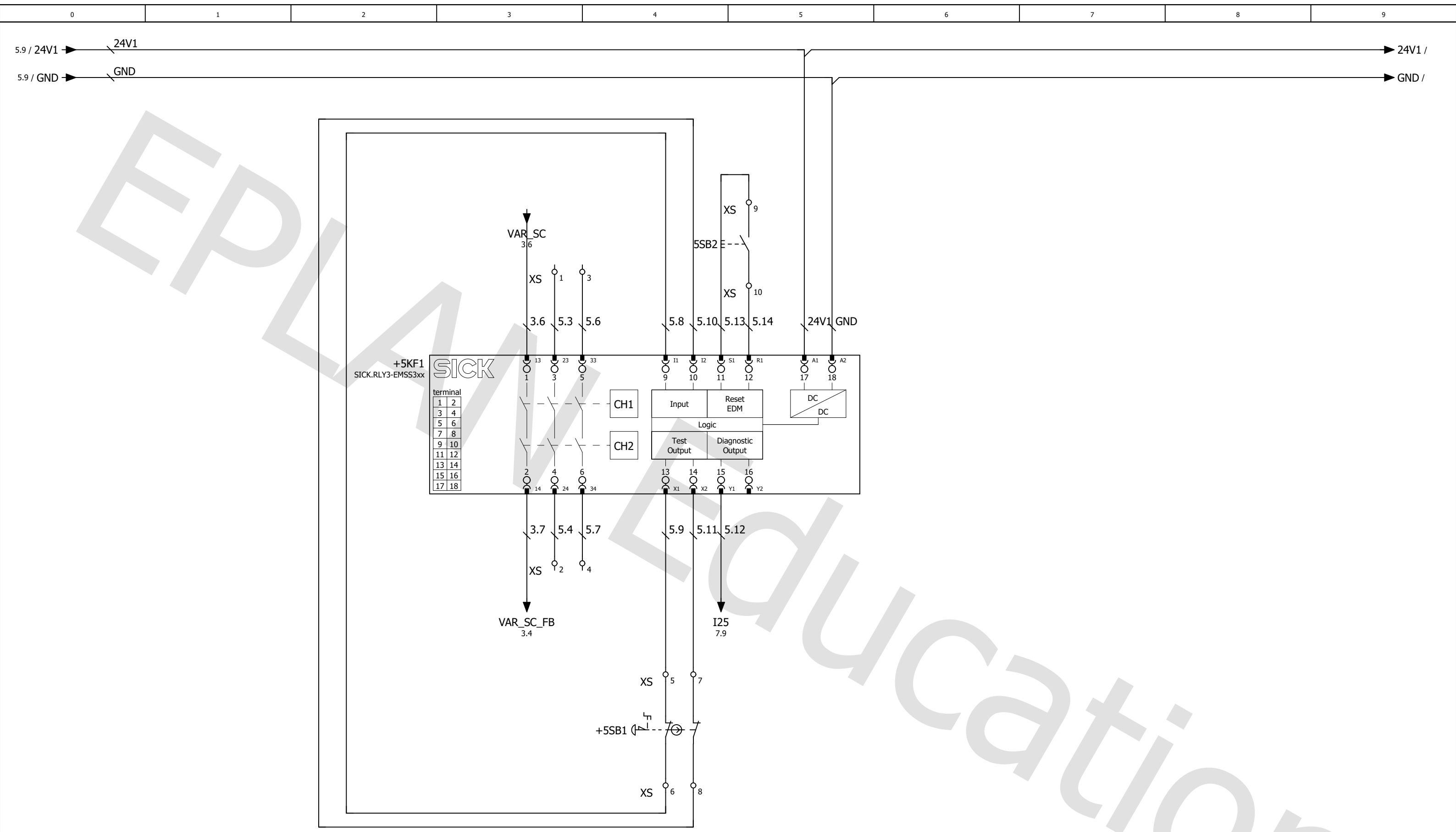
5.9 / 24V1
24V1
5.9 / GND
GND
24V1 /
GND /
VAR_SC
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XS
5SB2
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SICK.RLY3-EMSS3xx
SICK
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Diagnostic Output
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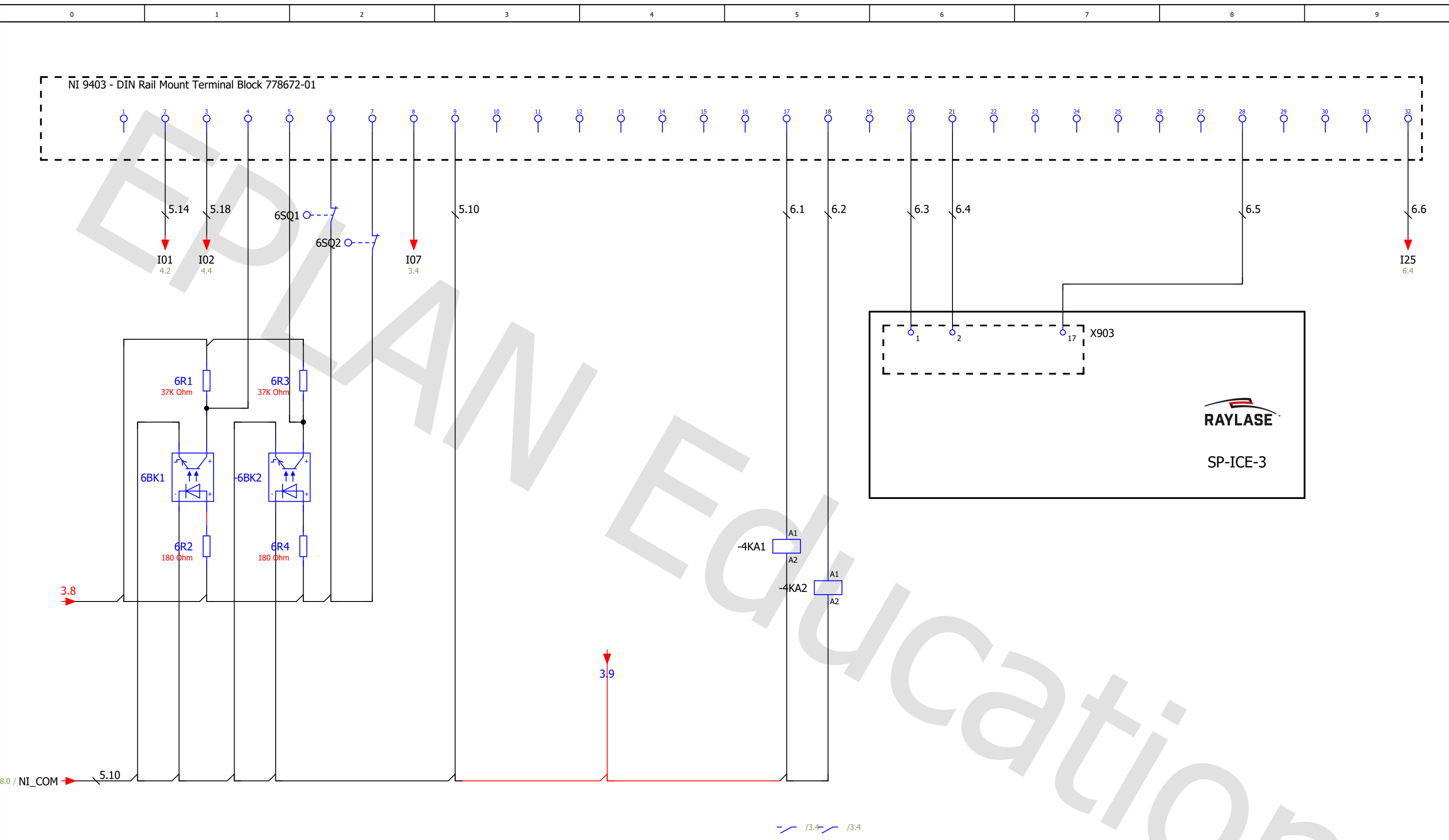

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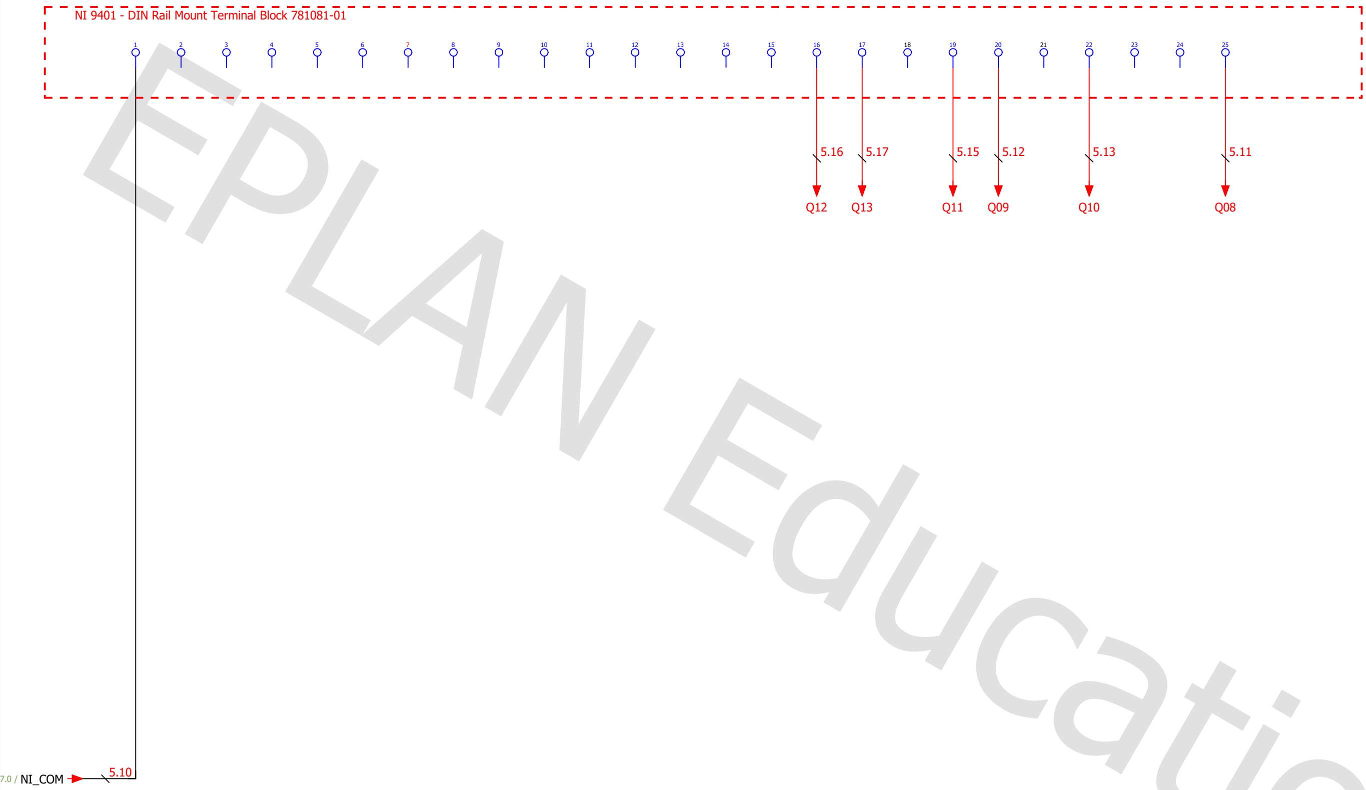

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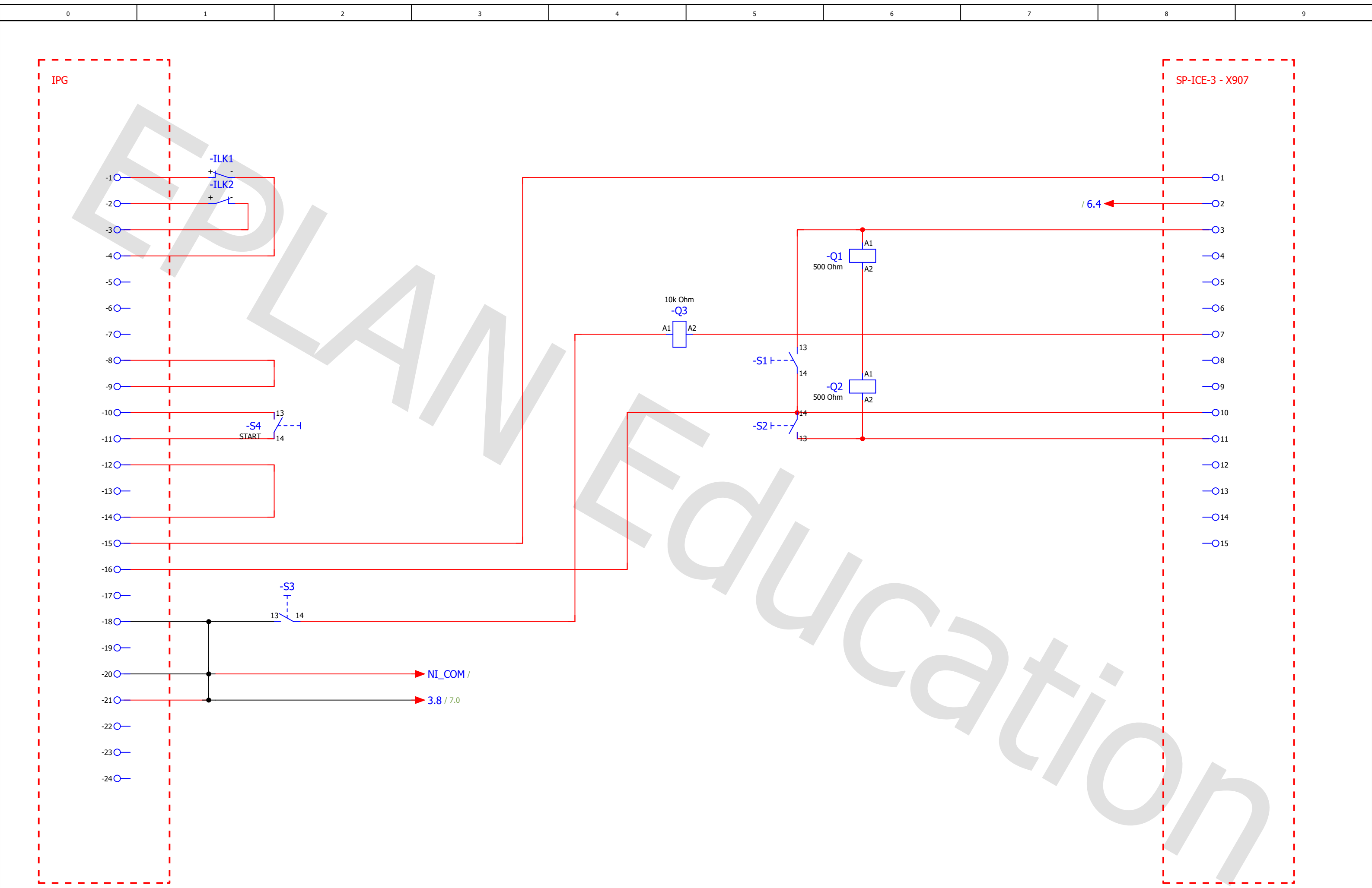

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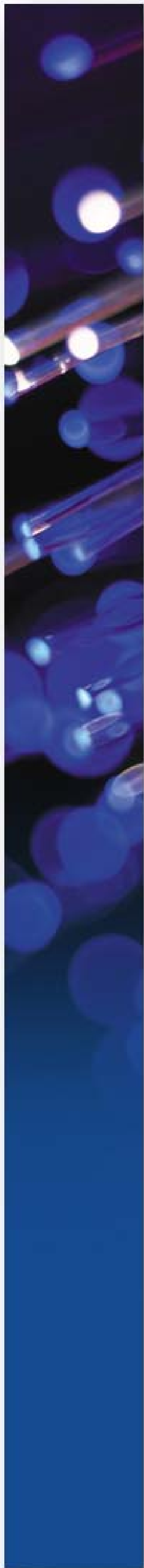
Apêndice L

Ficha técnica do laser *IPG YLR-200-AC*

http://www.uwlaser.com/uploadfiles/2020/04/20200423170358358.pdf



YLR-Series User Guide

Part Number: P21-010106, YLR-Series SLED 3.0
Published: April 2015
Revision: B
DCO: 956

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This product is patented. See the product for more information.

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Information relating to U.S. export rules and regulations can be found at the U.S. Bureau of Industry and Security Website. Information related to U.S. Customs and Border Protection can be found at the U.S. Customs Website.

Preface

Ensure you read and understand this guide in its entirety and familiarize yourself with the operating and maintenance instructions before you use the product. IPG strongly recommends that all operators of the product read and pay particular attention to all safety information contained herein prior to operating the product.

This guide should stay with the product to provide you and all future operators, users, and owners of the product with important operating, safety, and other information.

For technical assistance concerning the product, contact IPG Customer Service.

Audience

The audience for this guide are system integrators and technicians responsible for installing and operating the YLR-Series laser in industrial and non-industrial installations.

Contents

3 Computer Interface/Commands

4 Pulse Shaping

D Warranty

E Product Returns

F Glossary

1

Overview of the YLR-Series Fiber Lasers

Introduction

The IPG Photonics YLR-Series fiber lasers are developed to meet industrial market demands of efficient reliable maintenance-free high power lasers. These lasers are a diode-pumped Ytterbium fiber laser with output powers ranging from 1W up to 1.5 kW operating at the wavelength region of 1060 - 1100 nm.

The YLR-Series fiber lasers can be air or water-cooled. The wall plug efficiency for a fiber laser is typically exceeds 30 percent. All YLR-Series fiber lasers are Class 4 laser products and are designed and tested with important safety features. Follow this guide and apply laser safety practices for a safe and reliable device.

Laser light exhibits unique characteristics that pose safety hazards that are not normally associated with other light sources. Therefore, all operators and other people near the laser must be aware of these special hazards.

Audience

The audience for this guide are system integrators and technicians responsible for installing and operating the IPG YLR-Series fiber lasers in industrial and non-industrial installations.

Safety Information and Conventions

To ensure the safe operation and optimal performance of the product, follow all warnings in this guide. Safety precautions must be observed during all phases of operation, maintenance, and service.

Operators must adhere to these recommendations and to apply sound laser safety practices at all times. Never open the chassis. There are no user serviceable parts, equipment or assemblies associated with this product. All internal service and maintenance should only be performed by qualified IPG personnel.

Table 1-1 lists safety conventions and their meanings. These conventions are used throughout this guide.

Table 1-1. Safety Symbols

Symbol	Description
 Electrical  Laser	Text marked with an **Electrical Warning** symbol or **Laser Warning** symbol refers to a potential personal hazard. It requires a procedure that, if not correctly followed, can result in bodily harm to you or others. Do not proceed beyond the Electrical Warning or Laser Warning symbols until you completely understand and meet the required conditions.
	Text marked with a **Caution** symbol refers to a potential product hazard. It requires a procedure that, if not correctly followed, can result in damage or destruction to the product or components. Do not proceed beyond the Caution symbol until you completely understand and meet the required conditions.
No symbol	Text marked with **Important** refers to pertinent information regarding the operation of the product. Ensure you do not overlook this information.

Safety Features and Compliance to Government Requirements

Compliance to Regulatory Standards (on applicable units)

EMC Emissions:

EN 55011:2009 + A1:2010

CISPR 11:2009 + A1:2010

FCC Class A

EMC Immunity:

EN 61000-3-2:2006+A1:2009+A2:2009

EN 61000-3-3:2008

EN 61326-1:2006

EN 61000-4-2:2009

EN 61000-4-3:2006 + A1:2007 + A2:2010

EN 61000-4-4:2004+A1:2010

EN 61000-4-5:2006

EN 61000-4-6:2009

EN 61000-4-8:2010

EN 61000-4-11:2004

EMC Other:

This Class A digital apparatus complies with Canadian ICES-003.

Electrical Safety:

61010-1:2010

Laser Safety:

EN 60825-1:2007

CDRH 21 CFR 1040.10

Functional Safety:

The following safety functions are implemented to fulfill the requirements of EN ISO 13849-1:2008 + A1:2009 Cat.3 / PL d and Category 3 (Cat. 3). The safety functions are implemented exclusively in hardware:

- Stop initiated by a safeguard: The safety electronics of the laser monitors the feed fiber cable (optical fiber interlock). If the laser is emitting and the feed fiber is disconnected from a mating device or broken, the safety-related outputs become de-energized.
- Stop initiated by a safeguard: The safety electronics of the laser monitors E-Stop input. If the laser is emitting and the E-Stop is activated, the safety-related outputs become de-energized.
- Safe start/restart button: The safety electronics of the laser monitors safety-related outputs. A fault in the safety-related outputs is detected before the next demand upon the safety-related output.
- Discharge of stored energy: The safety electronics of the laser monitors safety-related inputs. If the laser is emitting and a stop is initiated by a safeguard, the stored energy for the laser is discharged.
- Prevention of unexpected startup: The safety electronics of the laser monitors safety-related inputs. Start of restart cannot occur after activation of a safeguard until safeguard is re-established and separate deliberate action occurs.

Class A Digital Device

This equipment is tested and complies with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment.

This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with this guide, can cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the users are required to correct the interference at their own expense.

Electromagnetic Compatibility

Compliance of the YLR-Series lasers with the EMC requirements is certified by the CE mark if identified by the CE label (Figure 1-1 on page 1-7).

The European requirements for Electromagnetic Compliance are specified in the "EMC Directive." Conformance to the "EMC Directive" is achieved through compliance with the harmonized standards EN55011 for emission and EN 61326-1:2006 for immunity. The laser meets the emission requirements for Class A, group 1 as specified in EN55011.

Laser Classification

The governmental standards and requirements specify that lasers must be classified according to their output power or energy and the laser wavelength. All YLR-Series lasers are classified as Class 4 laser products under 21 CFR, subchapter J, part II, 1040.10(d).

According to the European Community standards, this device is classified as Class 4 based on EN 60825-1, clause 9 This product emits invisible laser radiation at or around a wavelength of **1070 nm**, and the total light power radiated from the optical output is greater than **20 to 1500 W** (depending on model) per optical output port.

Direct or indirect exposure of this level of light intensity can cause damage to the eye or skin. Despite the radiation being invisible, the beam can cause irreversible damage to the retina and cornea. Appropriate and approved laser safety eyewear must be worn at all times while the laser is operational.

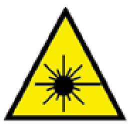
WARNING: You must use appropriate laser safety eyewear when operating the device. The selection of appropriate laser safety eyewear requires that the end user accurately identify the range of wavelengths emitted from this product. If the device is a tunable laser or Raman product, it emits light over a range of wavelengths.

You must ensure that the laser safety eyewear used protects against light emitted by the device over its entire range of wavelengths. Review the safety labeling on the product (see Figure 1-1 on page 1-7) and verify that the personal protective equipment (for example, enclosures, viewing windows or viewports, garments, and eyewear) being used is adequate for the output power and wavelength ranges listed on the product.

Suppliers include LaserVision USA, Kentek Corporation and Rockwell Laser Industries offer this laser safety material and equipment. There are other laser personal protective equipment providers. IPG provides the names of these providers solely as a convenience and does not endorse or recommend any of them, or their products or services. Furthermore, IPG assumes no liability for any of their recommendations, products, or services.

Whether the laser is used in a new installation or to retrofit an existing device, the end user is solely responsible for determining the suitability of all personal protective equipment.

CAUTION: Do not install or terminate fibers or collimators when laser is active.



WARNING: Use of controls or adjustments, or performance of procedures other than those specified herein, can result in hazardous radiation exposure.

CAUTION: Use of the device in a manner other than that described herein can impair the protection provided by the device.

Safety Label Locations

The YLR Series Laser has the required laser safety labels located on the outside of the chassis in various locations. These include warning labels indicating removable or displaceable of the protective housings, apertures through which laser radiation is emitted and labels of certification and identification.

Figure 1-1 shows the required laser safety labels and the locations for the Water-Cooled YLR-Series laser. Figure 1-2 on page 1-7 shows the required laser safety labels and the locations for the Air-Cooled YLR-Series laser.

These include warning labels indicating removable or displaceable protective housings, apertures through which laser radiation is emitted and labels of certification and identification.

Figure 1-1. Safety Label Locations - WC YLR-Series Laser

Figure 1-2. Safety Label Locations - AC YLR-Series Laser

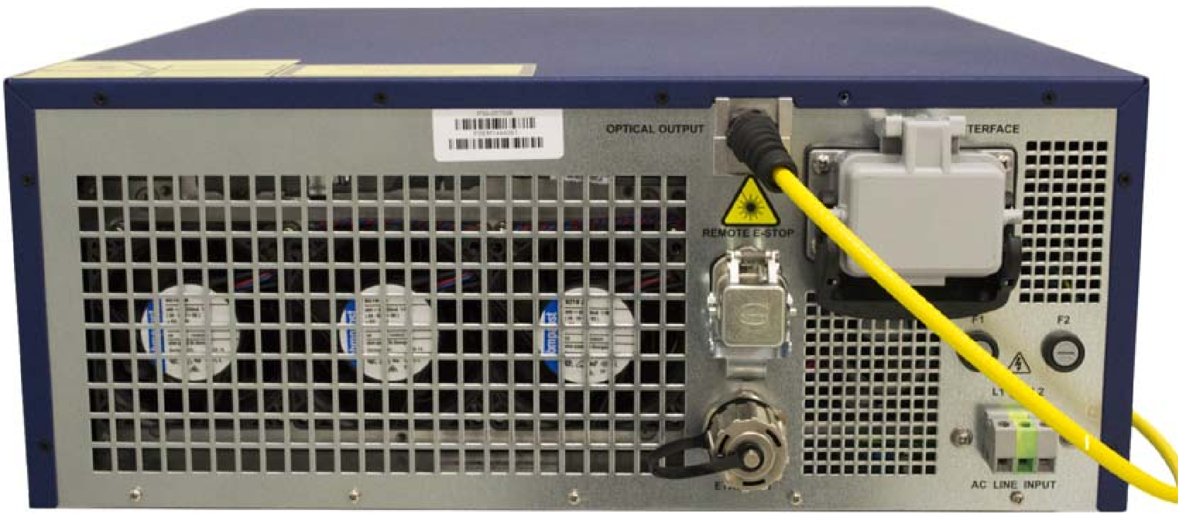
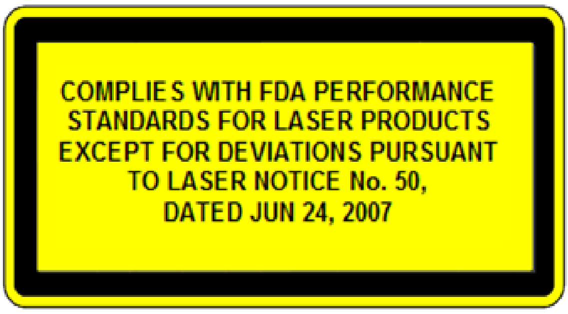
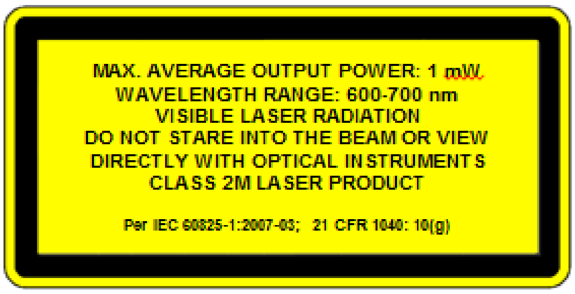
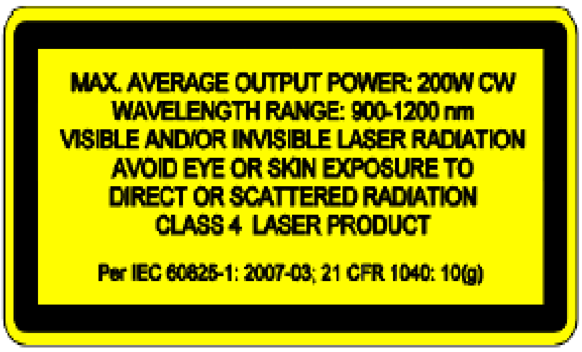
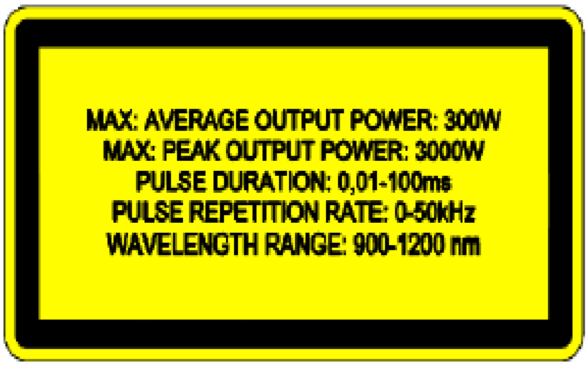
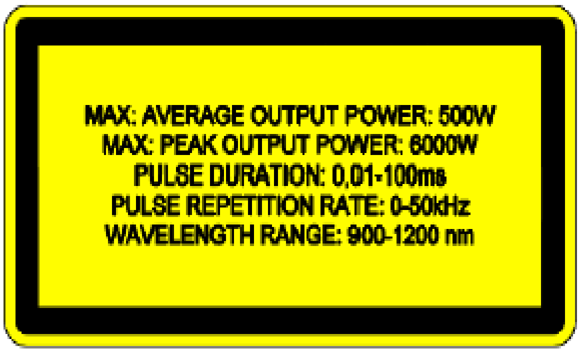
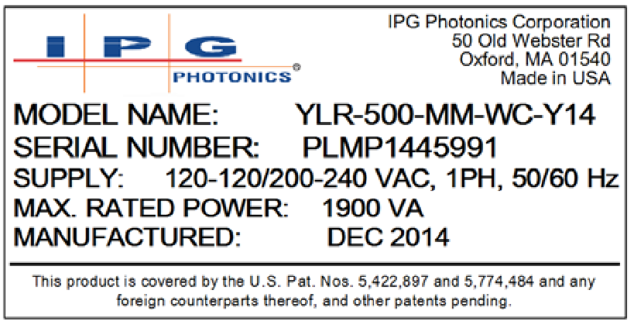


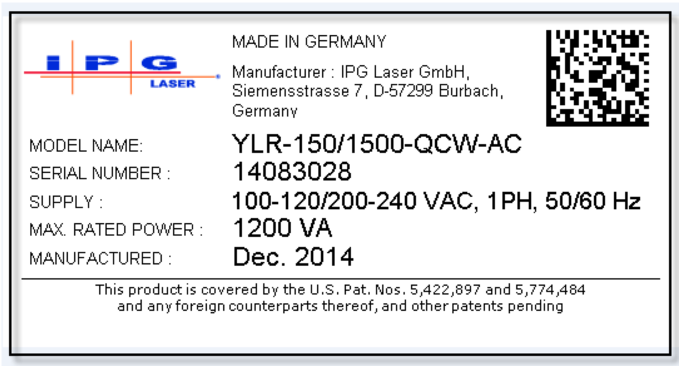
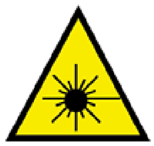
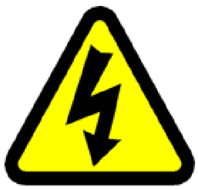
Table 1-2. Safety Label Descriptions

Item	Label Name	Description
1	Aperture Label	
2	FDA Compliance (for US Products)	
3	Class 2M Laser Product Label for Guide Laser	

4	Class 4 Laser Product (Models: YLR-10, YLR-15, YLR-20, YLR-25, YLR-30)	
4	Class 4 Laser Product (Models: YLR-40, YLR-50, YLR-60 to YLR-70)	
4	Class 4 Laser Product (Models: YLR-75, YLR-100, YLR-150)	

4	Class 4 Laser Product (Models: YLR-200, YLR-250, YLR-300, YLR-350)	
4	Class 4 Laser Product (Models: YLR-400, YLR-500, YLR-600, YLR-700)	
4	4. Class 4 Laser Product (Models: YLR-750, YLR-800, YLR-900, YLR-1000)	

4	Class 4 Laser Product (Models: QCW YLR-150/1500)	) 
4	4. Class 4 Laser Product (Models: QCW YLR-300/3000)	
5	Identification Plate (Products Made in the United States)[a]	

<table>
<tr><td>5</td><td>Identification Plate (Products Made in Germany)[b]</td><td>
</td></tr>
<tr><td>6</td><td>Laser Radiation Hazard Label</td><td></td></tr>
<tr><td>7</td><td>Protective Conductor Terminal[c]</td><td></td></tr>
<tr><td>8</td><td>Electrical Hazard Label</td><td></td></tr>
<tr><td>9</td><td>CE Compliance[d]</td><td></td></tr>
</table>

10	Fuse[e]	

a. Refer to Table 2-1 on page 2-2 for Model Designation Codes.

b. Refer to Table 2-1 on page 2-2 for Model Designation Codes.

c. This symbol is specifically reserved for the PROTECTIVE CONDUCTOR TERMINAL and no other. It is placed at the equipment earthing point and is mandatory for all grounded equipment.

d. This label indicates compliance with CE marking requirements.

e. This symbol is accompanied with type and rating (for example, T15A, 250VAC, ¼ x 1-1/4).

Emission-On Indicator

The laser is equipped with a an Emission-On Indicator light located on the front panel (see Figure 2-1 on page 2-3). The Emission-On Indicator is turned on when laser emission is ready to emit.

If the laser aperture or a remote laser control is located more than two meters from the indicator on the front panel, then an additional indicator must be located at the aperture or remote control.

Emission ON, Pin 24 on the remote connector is active high when the laser is ready to emit. It can used to provide a laser-ready warning at the aperture or remote control when these are located two or more meters from the front panel.

General Safety Instructions

WARNING: You must exercise caution to avoid and minimize specular reflections as these reflections occur at the laser's wavelength and are invisible.

Specular Reflections

Often there can be numerous secondary laser beams produced at various angles near the laser aperture. These beams are called “Specular Reflections” and are produced when the laser light reflects off a surface where the primary beam is incident.

Although these secondary beams might be less powerful than the total power emitted from the laser, the intensity might be great enough to cause damage to the eyes and skin as well as materials surrounding the laser.

Equipment and Solvents

Light-sensitive elements in equipment, such as video cameras, photomultipliers and photodiodes can also be damaged from exposure to the laser light.

WARNING: The laser light is strong enough to cut or weld metal, burn skin, clothing, and paint. In addition, this light can ignite volatile substances such as alcohol, gasoline, ether, and other solvents. Exposure to solvents or other flammable materials and gases must be avoided and must be relocated away from this device.

Safety Recommendations

IPG recommends that you follow these procedures to operate the IPG laser safely:

- Never look directly into the laser output port when power is supplied to the laser.
- Avoid positioning the laser and all optical components at eye level.
- Provide enclosures for laser beam.
- Ensure that all personal protective equipment (PPE) is suitable for the output power and wavelength range listed on the laser safety labels that are affixed to the product.

- Use the laser in a room with access controlled by door interlocks. Post warning signs. Limit access to the area to individuals who are trained in laser safety while operating the laser.
- Avoid using the laser in a darkened environment.
- Do not enable the laser without a coupling fiber or equivalent attached to the optical output connector.
- Always switch the laser off when working with the output such as mounting the fiber or collimator into a fixture. If necessary, align the output at low output power and then increase the output power gradually.
- Do not install or terminate fibers or collimators when laser is active.
- If this instrument is used in a manner not specified in this document, the protection provided by the instrument may be impaired and the warranty will be voided.

Optical Safety

CAUTION: If the output of the device is delivered through a lens with an anti-reflection coating, ensure that the lens is of good quality and clean. For cleaning instructions, refer to “Optical Fiber Connector Inspection and Cleaning” on page C-1.

Any dust on the end of the collimator assembly can burn the lens and damage the laser.

Hot or molten pieces of metal can be present when using this laser. Exercise caution if debris is being generated in your application.

Electrical Safety

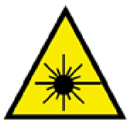
WARNING: The input voltage to the laser is potentially lethal. All electrical cables and connections should be treated as if it were a harmful level. All parts of the electrical cable, connector, or device housing should be considered dangerous.

To ensure electrical safety:

1. Make sure the device is properly grounded through the protective conductor of the AC power cable. Any interruption of the protective grounding conductor from the protective earth terminal can result in personal injury.
2. Always use your device in conjunction with properly grounded power source.

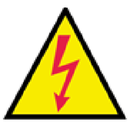
3. For continued protection against fire hazard, replace the line fuses (if applicable) with only the same types and ratings. The use of other fuses or material is prohibited.
4. Before supplying the power to the instrument, ensure that the correct voltage of the AC power source is used. Failure to use the correct voltage can cause damage to the instrument.
5. Before switching the power on, ensure that line voltage corresponds to the specified level.
6. There are no operator serviceable parts inside. Refer all servicing to qualified IPG personnel. To prevent electrical shock, do not remove covers. Any tampering with the product voids the warranty.

Environmental Safety



WARNING: Never look directly into a laser aperture (such as fiber, collimator, or scanning head) when the Start button or remote Start circuit is activated. Ensure that you wear appropriate laser safety eyewear at all times while operating the product.

Proper enclosures must be used to secure a laser safe work area. This includes but is not limited to laser safety signs, interlocks, appropriate warning devices and training/ safety procedures. In addition, it is important to install the output assembly away from eye level.



WARNING: Ensure that all personal protective equipment (PPE) is suitable for the output power and wavelength range listed on the laser safety labels that are affixed to the product.

The interaction between the laser and the material being processed can also generate high intensity UV and visible radiation. Ensure that all laser enclosures are in place to prevent to prevent eye and skin exposure to visible and invisible collateral radiation.

CAUTION: Damage to the laser is possible, unless caution is employed in operating the device.

IPG provides the following recommendations to promote the long life of the IPG laser:

- Do not expose the device to a high moisture environment (>95% humidity).

CAUTION: Water-cooled lasers must not operate at temperatures below the respective ambient dewpoint (see Table 1-3 on page 1-17).

- The device might have fans for active cooling. Ensure there is sufficient airflow to cool the device. Any objects or debris that cover the ventilation holes must be inspected. Filter media should be inspected at regular intervals to maintain sufficient airflow into the device.
- Operation at higher temperatures accelerate aging, increase threshold current, and lower slope efficiency. If the device is overheated, do not use it and call IPG for assistance.
- Ensure that the work area is properly vented. gases, sparks and debris that can be generated from interaction between the laser and the work surface can pose additional safety hazards.
- Inspect the filter media weekly and clean or replace as needed. See "Replacing the Filter Media" on page B-2 for details.

Table 1-3. Dewpoint Table

AMBIENT DEWPOINT[1]										
Room Temperature	Maximum Relative Humidity									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	95%
10 °C	-20	-11.9	-6.8	-3.0	0.6	2.6	4.8	7.6	8.4	9.2
15 °C	-16.4	-7.9	-2.4	1.5	4.7	7.3	9.6	11.6	13.4	14.2
20 °C	-12.5	-3.7	1.9	6.0	9.25	12.0	14.4	16.4	18.3	19.2
25 °C	-8.7	0.5	6.2	10.5	13.8	16.7	19.1	21.3	23.2	24.1
30 °C	-5.0	4.6	10.5	15.0	18.4	21.4	23.9	26.2	28.2	29.1
40 °C	2.6	12.7	19.1	23.8	27.6	30.7	33.5	35.9	38.0	39.0
50 °C	10.0	20.8	27.6	32.6	36.7	40.0	43.0	45.6	47.9	49.0
	Laser Operating Temperature Range									

[1] These values are calculated using the August-Roche-Magnus approximation.

Additional Safety Resources

For additional information regarding Laser Safety, refer to the following list:

Laser Institute of America (LIA)
13501 Ingenuity Drive, Suite 128
Orlando, Florida 32826
Phone: 407.380.1553, Fax: 407.380.5588
Toll Free: 1.800.34.LASER

American National Standards Institute
ANSI Z136.1, American National Standard for the Safe Use of Lasers
(Available through LIA)

International Electro-technical Commission
IEC 60825-1, Edition 2
Safety of laser products -
Part 1: Equipment classification, requirements and user's guide.
(Available through LIA)

Center for Devices and Radiological Health
21 CFR 1040.10 - Performance Standards for Light-Emitting Products
US Department of Labor - OSHA
Publication 8-1.7 - Guidelines for Laser Safety and Hazard Assessment

US Department of Labor - OSHA
Publication 8-1.7 - Guidelines for Laser Safety and Hazard Assessment

Laser Safety Equipment
Laurin Publishing
Laser safety equipment and Buyer's Guides

Note

IPG Photonics recommends that the user of this product investigate any local, state or country requirements as well as facility or building requirements that might apply to installing or using a laser or laser device.

Ensure that the standard you are using such as ANSI, IEC, and OSHA are current.

2

Using Your Device

Overview

The IPG Photonics YLR-Series fiber lasers are developed for use in industrial applications. The lasers are compact and efficient letting you replace bulky and less efficient lasers. Main application are welding, cutting, and brazing.

Main Features

- High quality fiber output
- High power
- Reliable, long lifetime
- Compact, rugged package
- Efficient
- External computer interface

Applications

- Industrial applications
- Scientific research

Model Configurations

IPG offers many YLR-Series configuration models. This guide is designed to provide complete instructions for all models. Therefore, specific difference in models is noted where applicable.

Laser Model Designation Codes

Figure 2-1 on page 2-2 shows the model designation methodology for all YLR-Series lasers. In addition, models are also categorized according to chassis type with their respective "U" or Rack Unit code.

The subsequent AC or WC code designates whether the model is air cooled or water cooled.

The U categories offered are 3U-AC, 3U-WC, 4U-AC, 4U-WC, and 6U-AC.

Figure 2-1. YLR-Series Laser Models

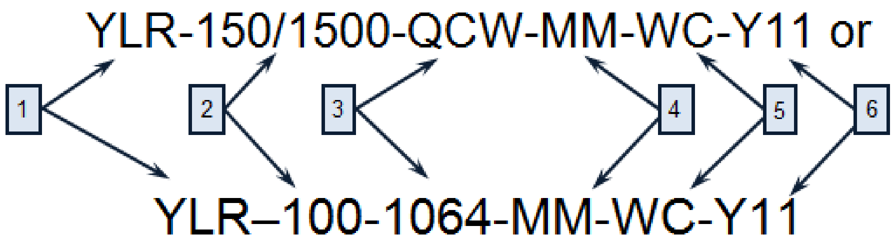


Table 2-1. Laser Model Designation Codes

Number	Item	Code
1	YLR	Ytterbium Laser 19-inch Rack Mount
2	Power in W	Range of 20 to 1500 Watts
3	Wavelength in nm	Item is listed if wavelength is not standard. 1070 nm (standard)
4	Polarization/Output Beam Characteristic	MM — for Multi-Mode LP — for Linearly Polarized If an item is not listed, then the beam is single-mode and randomly polarized.
5	Additional Information	WC — Water Cooled device AC — Air Cooled device
6	Additional Information	The last two digits of the model year,

Table 2-2. Available YLR Series Models

Category	Model
3U-AC	YLR-20, YLR-30, YLR-50, and YLR-100-AC
3U-WC	YLR-100-WC, YLR-200-WC, YLR-300-WC, YLR-400-WC, YLR-500-WC, YLR-600-WC, and YLR-700-WC
4U-AC	YLR-200-AC, YLR-300-AC, YLR-400-AC, and YLR-150/1500-QCW-AC
4U-WC	YLR-1000-WC
6U-AC	YLR-500-AC and YLR-600-AC

Certification

IPG Photonics certifies that your system is thoroughly tested and inspected and meets published specifications prior to shipping. Upon receiving your device, check the packaging and parts for any possible damage that might have occurred in transit. If there is damage, contact IPG Photonics immediately. It is the responsibility of the purchaser/end-user to bring the end system into compliance with all applicable regulations.

YLR Series — Front Panel View

The YRL Series front panel includes two options: panel with a display and panel without a display.

Figure 2-2 shows the front panel of the YLR-Series, which includes an option with a display. Table 2-3 lists details for each component.

Figure 2-2. Front Panel View with Display

Table 2-3. Front Panel Descriptions

Item	Feature	Description
1	Keyswitch (Local Interface option only)	The 3-position key switch controls the laser operation mode: Left position — Chassis Powered On, Remote Control Mode Central position — Chassis powered Off Right position — Chassis Powered On, Local Control Mode **Note:** The key cannot be removed in the Remote Control Mode or Local Control Mode positions.
2	Emergency Stop Button (E-Stop) (Local Interface option only)	Temporarily suspends power to the laser module. When active, the main DC power supply is disabled. You can reset it by turning clockwise.
3	Start Button with Indicator (Local interface option only)	When pressed, turns On the internal main power supply of the laser assuming that the Power key is in the Local Mode position. When the indicator is On, the internal power supply is active and the laser is capable of producing laser radiation.
4	Touch-Screen Display (Local interface option only)	Use to set device settings and to display measured parameters and alarm messages.
5	Emission On Indicator	Local Control Mode: The indicator blinks for a short period after emission is enabled and before laser radiation is emitted. once laser emission is ON, the indicator is in the steady state "ON." Remote Control Mode: The indicator is lit once emission is enabled.
6	Front Bezel Panel	Pull on each side to filter element for cleaning or replacement. Refer to Table B-1 on page B-2 for more information.

Figure 2-3 shows the front panel of the YLR-Series, which does not include a display. Table 2-4 lists details for each component.

Figure 2-3. Front Panel View without Display

Figure 2-4. Front Panel Descriptions

Item	Feature	Description
1	Power	When lit, indicates that internal main power supply of the laser is on. When the indicator is on, the internal power supply is active and the laser is capable of producing laser radiation.
2	PS Active	When lit, indicates that the main supply voltage is applied to the laser module inside the device.
3	Emission	When lit, indicates that the emission is activated.
4	Error	When lit, indicates an device error, such as a interlock door is open.
5	Front Bezel Panel	Pull on each side to filter element for cleaning or replacement. Refer to Table B-1 on page B-2 for more information.

YLR Series — Rear Panel View

The YLR-Series is available as a Water-Cooled (WC) or Air-Cooled (AC) laser.

Figure 2-5 shows details of the rear panel of the YLR-Series WC laser. Table 2-4 lists details for each component.

Figure 2-5. Rear Panel View - WC Laser

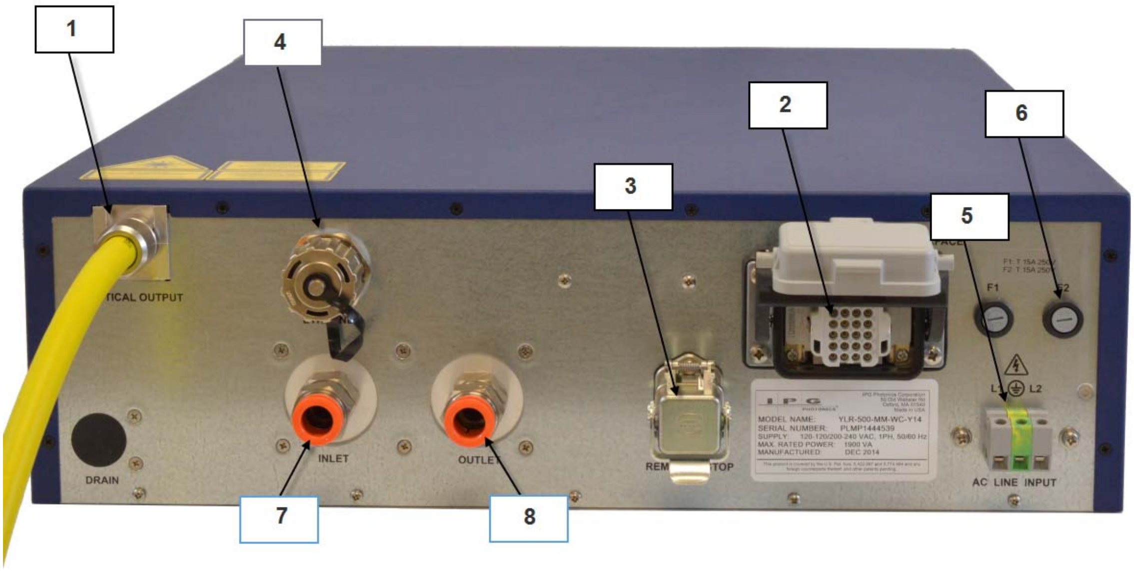


Table 2-4. Rear Panel Descriptions

Item	Feature	Description
1	Laser Output	The output of the laser (fiber cable) is delivered through this location.
2	Hardwiring Interface (24-pin)	The 24-pin connector provides an analog and digital interface for hardwiring control of the laser. See Table 2-5 on page 2-14 for detailed information.
3	Hardwiring Interface (7-pin)	The 7-pin connector provides status of the power supply and front panel Emergency Stop (if present). See Table 2-8 on page 2-23 for detailed information.
4	Ethernet	Ethernet port

Item	Feature	Description
5	AC line input	The 3-pin screw terminal connector for AC input wiring. Refer to the *SPECIFICATION YTTERBIUM FIBER LASER* document included with this product to determine your models power requirement.
6	AC line fuses	Replaceable fuses F1, F2 Refer to Table B-1 on page B-2 for more information.
7	Coolant Inlet	Liquid Coolant Input Refer to the *SPECIFICATION YTTERBIUM FIBER LASER* document included with this product for coolant details.
8	Coolant Outlet	Liquid Coolant Output Refer to the *SPECIFICATION YTTERBIUM FIBER LASER* document included with this product for coolant details.
9	Drain	Drain for the dehumidifier option.

Figure 2-6 shows details of the rear panel of the YLR-Series AC laser. Table 2-5 lists details for each component.

Figure 2-6. Rear Panel View - AC Laser

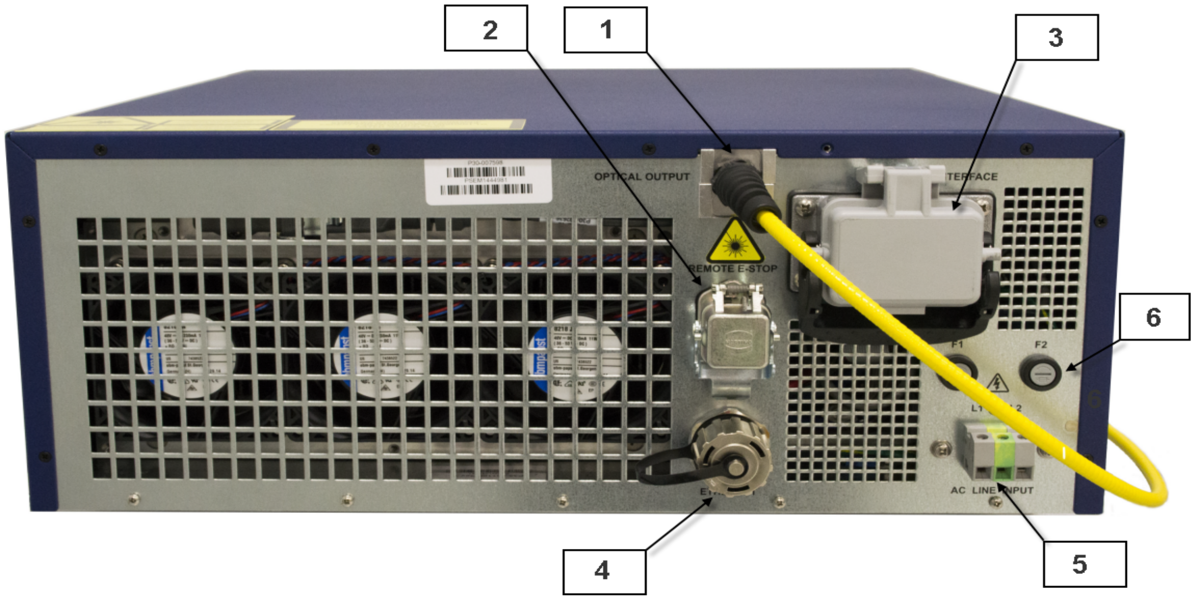


Table 2-5. Rear Panel Descriptions

Item	Feature	Description
1	Laser Output	The output of the laser (fiber cable) is delivered through this location.
2	Hardwiring Interface (7-pin)	The 7-pin connector provides status of the power supply and front panel Emergency Stop (if present). See Table 2-8 on page 2-23 for detailed information.
3	Hardwiring Interface (24-pin)	The 24-pin connector provides an analog and digital interface for hardwiring control of the laser. See Table 2-5 on page 2-14 for detailed information.
4	Ethernet	Ethernet port
5	AC line input	The 3-pin screw terminal connector for AC input wiring. Refer to the *SPECIFICATION YTTERBIUM FIBER LASER* document included with this product to determine your models power requirement.
6	AC line fuses	Replaceable fuses F1, F2 Refer to Table B-1 on page B-2 for more information.

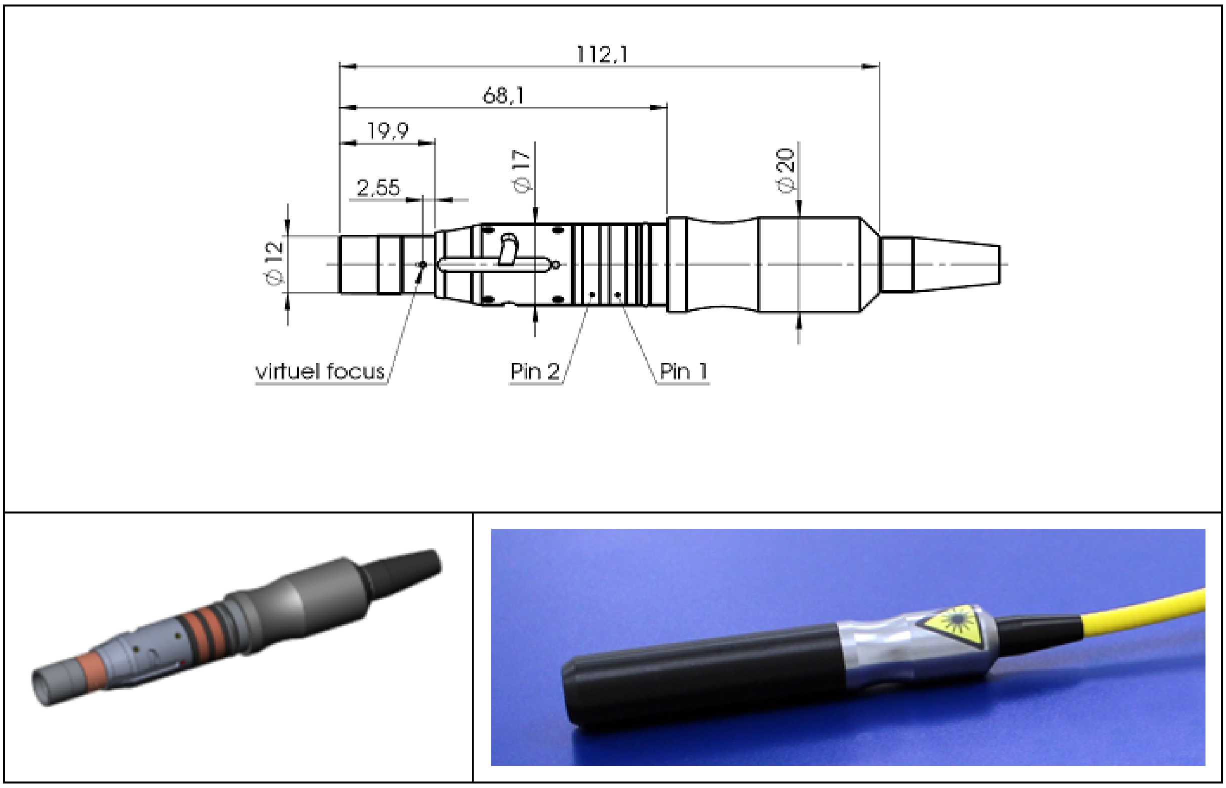
Optical Output Fiber Terminations

Products with a Connector

The end connector of the fiber (as shown in Figure 2-7) uses a protective cap that covers and protects the optical surface and electrical contacts when not in use.

These protective caps must be removed from the connectors when connecting the process fiber cable of the laser to an appropriate optical interface. You should remove the protective caps from the connectors immediately before optical cleaning and mounting in an adapter.

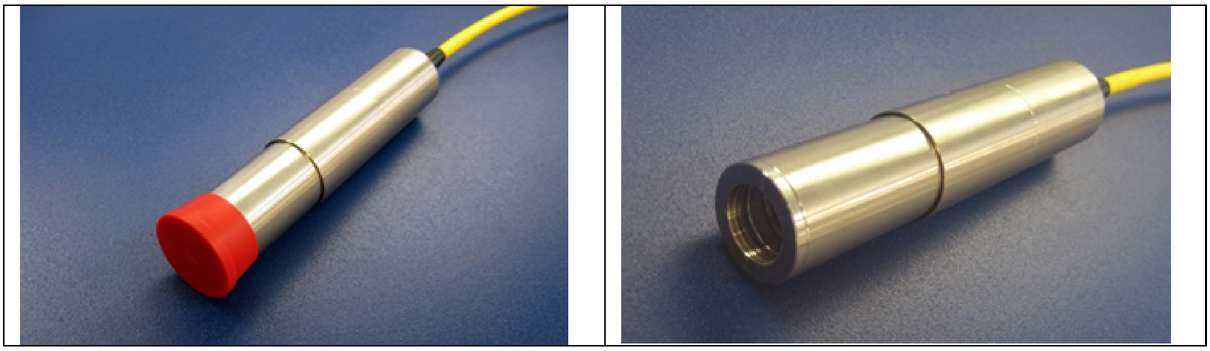
Figure 2-7. Optical Output Fiber Connector



Products with a Collimator

Collimators have a protective window that can be replaced if damaged (as shown in Figure 2-8). You must remove the collimator end cap prior to use. This cap can be re-used when storing the system. Cleaning of the protective window should be performed as needed using the same materials and techniques described in "Optical Fiber Connector Inspection and Cleaning" on page C-1.

Figure 2-8. Fiber End with Collimator



Model Specifications

Because the YLR-Series product line is extensive, all specifications for your specific model are listed in the supplemental document titled *SPECIFICATION YTTERBIUM FIBER LASER* included with the product. These specifications include:

- Optical
- Electrical
- Environmental
- External Layout and Dimensions

Unpacking Instructions

Note

If the packaging shows any signs of external damage, check unit for damages and notify the shipping agent immediately.

Particular care must be taken when you remove the unit from the packing case to ensure that the fiber optic cable is not broken or damaged. A comprehensive packing list is included with the system documentation.

Upon receipt of the laser, check all items against this list and contact IPG immediately if any of the items are missing or if any damage to the unit is evident. If any damage to the unit is evident or suspected, do not attempt to install or operate the laser in any case.

CAUTION: Lift and carry the device by supporting the device from the base. Use the handles (if available for your device) to help position the product while it is properly supported. Do not use the handles for lifting or carrying the device. Do not lift or position the device by any attached fibers or cables.

Laser models that are smaller and relatively lighter are packaged in foam insulated cardboard boxes. See “Unpacking a Unit from a Cardboard Box” on page 2-11.

Laser models that are larger and relatively heavy are packaged in foam insulated wooden crates. See “Unpacking a Unit from a Wooden Crates” on page 2-14.

To minimize the risk of damage to your system, IPG Photonics recommends that you unpack your laser using the following procedures.

Unpacking a Unit from a Cardboard Box

See Figure 2-9 on page 2-13 for an illustration of this procedure.

To unpack your unit from a cardboard box:

1. Place the package on a stable surface such as the floor or a large table.
2. For international shipments, remove the external box to access the primary box.
3. Open the primary box and remove the foam cover and store for later use.
4. Place the fiber on top of the unit and carefully lift it out of the box. IPG strongly recommends two people to lift the unit at all times.
5. Open the internal box and remove the top foam insert.

6. Check the inventory of following items:

Shipping Box Contents	Quantity
Cover, AC Power Inlet (P45-001394)	1
Strain Relief (P40-002294)	1
Strain Relief Nut (P40-002293)	1
Harting 24-pin Interface Connector Kit (P30-007268)	1
Connector (P40-001344)	1
Hood (P40-001343)	1
Cable Seal (P40-000891)	1
Contact Pins (P40-000888)	16
Contact Pins (P40-000887)	10
Keys	2
Harting 7-pin Interface Connector (P30-007305)	1

7. Retain all packaging for future transportation or storage needs.

Figure 2-9. Unpacking a Unit from a Cardboard Box

	
Primary Box	**Foam Cover**
	
Cover Removed	**Lifting the Unit**

Unpacking a Unit from a Wooden Crates

See Figure 2-10 on page 2-15 for an illustration of this procedure.

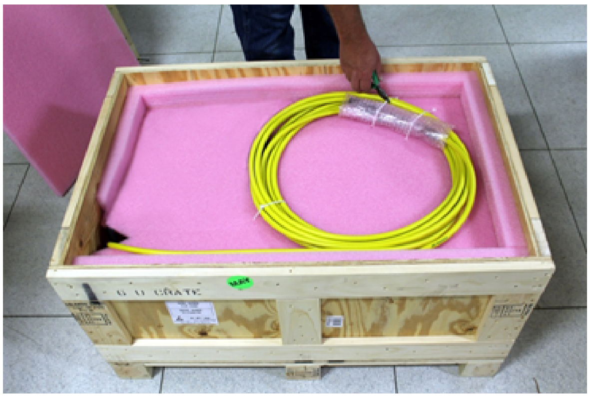
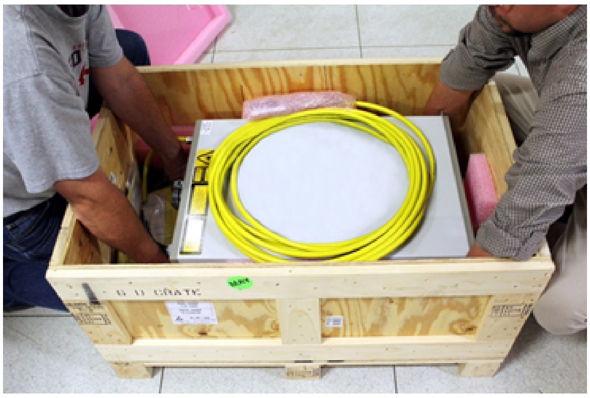
To unpack a unit from a wooden crate:

1. Place the package on a stable surface such as the floor or a large table. IPG recommends using a powered screwdriver to remove all of the top screws securing the top lid.
2. Remove the top lid and top foam insert.
3. Using a cutting tool remove the tie wraps securing the fiber to the second insert.
4. Place the fiber on top of the unit and carefully lift it out of the box. IPG strongly recommends two people to lift the unit at all times.
5. Check the inventory of following items:

Shipping Box Contents	Quantity
Cover, AC Power Inlet (P45-001394)	1
Strain Relief (P40-002294)	1
Strain Relief Nut (P40-002293)	1
Harting 24-pin Interface Connector Kit (P30-007268)	1
Connector (P40-001344)	1
Hood (P40-001343)	1
Cable Seal (P40-000891)	1
Contact Pins (P40-000888)	16
Contact Pins (P40-000887)	10
Keys	2
Harting 7-pin Interface Connector (P30-007305)	1

6. Retain all packaging for future transportation or storage needs.

Figure 2-10. Unpacking a Unit from a Wooden Crate

Primary Box	
Removing the Tie Wraps	
Lifting the Unit	

Using the YLR-Series

CAUTION: Refer to the *SPECIFICATION YTTERBIUM FIBER LASER* document included with this product for proper electrical power requirements.

Before switching the power on, ensure that the incoming AC voltage is equal to the level noted in the specification.

Operate only in an environment with sufficient airflow capacity that allows for the specified heat load developed during operation.

Connecting Electrical Power

Refer to the *SPECIFICATION YTTERBIUM FIBER LASER* document included with this product to determine your models power requirements.

Note

A power cord is not provided with the laser.

To connect the electrical power:

1. Wire the power input terminal block on the rear panel of the laser to the voltage, phase and frequency indicated on the *SPECIFICATION YTTERBIUM FIBER LASER* document for your particular model.

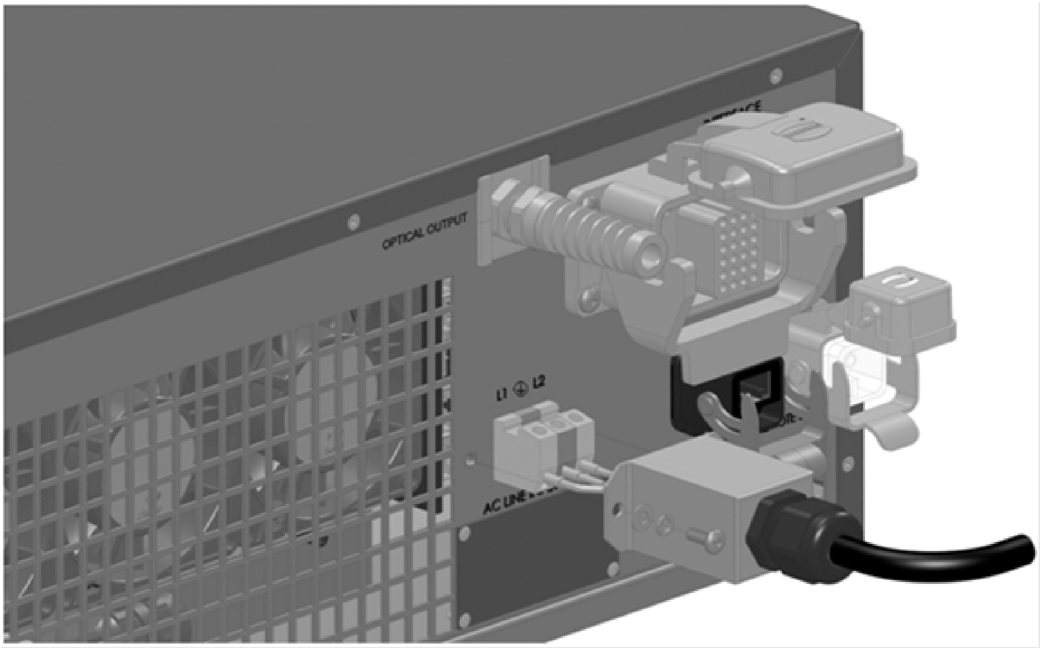
   L2 = Line Voltage, PE = Protective Earth, L1 = Line Voltage

2. Cover the input power terminal block with the supplied cover.
3. Secure the cable with the supplied strain relief.

   The electrical connection to the unit must be permanently connected to dedicated AC mains with a circuit breaker that does not exceed 20 Amps. This must be in close proximity to the unit and within easy reach of the operator and marked as the disconnecting device for the unit.

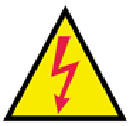
4. Follow all national and local requirements when wiring to the unit.

Figure 2-11. Power Cord Connection



Interface Wire Specification

The minimum wire gage is 18AWG at 15 meters (30 meters maximum regardless of gauge). The gage of the wire must increase as the distance increases. For connectivity, the wiring and/or cabling must have an overall shield to ensure proper functionality. The shield is to cover over all conductors and terminate at the unit where the conductors enter/exit the unit.



Connections to External Circuits

Except for Mains connection, the external connections between this product and other external devices are PELV (Protected Extra Low Voltage) as defined by IEC 61140. Non-Mains outputs of other devices connected to this product should also be PELV or SELV (Safety Extra Low Voltage).

Interlock Safety Circuit

YLR lasers include an Interlock Safety Circuit that uses a dual-channel system with monitored output and manual reset.

When you open the Interlock, the safety circuit opens and power to the laser diodes is removed.

Follow these steps:

1. Close the dual channel interlock (on 24-pin connector: pin1 is connected with pin4 and pin2 is connected with pin3). Otherwise, the internal main power supply is switched off and the emission cannot be turned on.

   Once any of the pairs of the mentioned above contacts is opened, you cannot switch the lasers power supply on until the second pair is opened and then both pairs are closed.

2. If you close the interlock (the Emergency Stop button is also released) and a fault is not detected, press the **Start** button to connect the remote start contacts, which enables the main power supply. The Power Supply (PS) Active signal enters a high state and power is supplied to the laser module. The laser diodes remain inactive until a separate Laser Enable signal transitions high and an output power level set to a non-zero value.

   The power to the laser diodes also turns on. However, under normal conditions the diodes only turn on after emission is enabled.

   When you open the interlock or a fault is detected, the laser diodes are disconnected from the main power supply. The Power Supply Active signal enters a low state.

   A detected fault is latched and circuits open the monitored manual reset loop, thus preventing the laser from being restarted until the fault is addressed. If a fault is detected, such as a shorted interlock channel, or a shorted **Start** button, the safety circuit does not reset until the fault is corrected.

   If the remote **Start** button is shorted (this is the equivalent of holding in the **Start** button), the circuit does not reset when the interlocks are closed until the safety circuit processes both channels open and then closed or the power to the safety circuit is cycled (with the Start button in the opened state in both cases).

Interface Connector Pin Assignments

Table 2-6 provides electrical pin assignments for these Interlock Channels.

Table 2-6. 24-Pin Connector Pinouts

Pin	Signal Name	Signal Type	Signal Level	Signal Drive	Typical Response Time	Description
1	Interlock Ch1A	Contact Closure[a] to pin 4	—	—	< 500 ms CW <1.2 s QCW	Emergency Shutdown according to ISO 13849-1 Cat.3 PL d.[b]
2	Interlock Ch2A	Contact Closure[a] to pin 3				
3	Interlock Ch2B	Contact Closure[a] to pin 2				
4	Interlock Ch1B	Contact Closure[a] to pin 1				
5	RS232 Tx	Serial Communication	—	—	120 ms	Transmit Data
6	RS232 Rx	Serial Communication	—	—		Receive Data
7	RS232 Com	Return	—	—		RS-232 Return
8	Remote Key Switch	Contact Closure[a]	—	—	5 s	Activates the laser control electronics in Remote mode.
9						
10	Remote Start Button	Momentary Contact Closure[a]	—	—	1 s	Activates the internal main power supply and connects it to the laser module in Remote mode.
11						
12	Analog Input to Control Current	Analog Input	1-10 VDC	1 mA (sink)	20 µs	Analog Input 1-10 VDC = 10 – 100% Setpoint
13	Analog Output Power Monitor	Analog Output	0-5 VDC	11 mA (source)	20 µs	Analog Output 0-4 VDC = 0 - $P_{nom.}$
14	Isolated Analog Com	Return	—	—	—	Return for signals on pins 12, 13.
15	Modulation +	Digital Input	5 to 24 VDC	6 mA (sink)	20 µs	5 -24 VDC Input.
16	Modulation -	Return	—	—		Return for signal on pin 15.
17[c]	Guide Control	Digital Input	5 to 24 VDC	6 mA (sink)	120ms	Positive edge turns On red guide laser in Remote Control Mode.
Pin	**Signal Name**	**Signal Type**	**Signal Level**	**Signal Drive**	**Typical Response Time**	**Description**

Table 2-6. 24-Pin Connector Pinouts

18[d]	Emission Enable	Digital Input	5 to 24 VDC	6 mA (sink)	120ms	Positive edge activates emission in Remote Control Mode.
19	Error/Ready	Digital Output	24 VDC	100 mA (source)	120 ms	Low indicates a laser error.
20	System Common	Return	—	—	—	Return for signals on pins 17-19, 21-24.
21	Error Reset	Digital Input	5 to 24 VDC	6 mA (sink)	120 ms	Positive edge resets all resettable errors.
22	Power On	Digital Output	24 VDC	100 mA (source)	120 ms	High indicates that key switch is turned on.
23	Power Supply Active	Digital Output	24 VDC	100 mA (source)	120 ms	High indicates that the internal main power supply is active.
24	Emission ON	Digital Output	24 VDC	100 mA (source)	120 ms	High at the emission is enabled.

a. Connection of potential free contacts only. External contact closure must be rated to > 1A /24 VDC.

b. To have a possibility of the internal main power supply activation, it is necessary to close the dual channel interlock (pin1 is connected with pin4 and pin2 is connected with pin3). Otherwise, the internal main power supply is switched off and the emission cannot be turned on. Once either of these connection pairs is opened, it is impossible to switch the lasers power supply on until the second pair is opened and then both pairs are closed.

c. To use this pin, external guide beam control must be enabled (EEABC command).

d. To use this pin, external emission control must be enabled (ELE command).

Note: Connector housing is EMC rated and is the intended connection point for the shielding of the customer's cabling.

Table 2-7. 24-Pin Connector — Additional Details

Pin	Signal Name	Description
1	Interlock Ch1A	These connections are intended to satisfy the Remote Interlock Connector requirement as defined by 21 CFR 1040.10 (f)(3) and IEC 60825-1 (4.4). If the connections between pins 1-4 or 2-3 are breeched by a door interlock or other means, laser emission is prevented.
2	Interlock Ch2A	
3	Interlock Ch2B	
4	Interlock Ch1B	
5	RS232 Tx	—
6	RS232 Rx	
7	RS232 Com	—
8	Remote Key Switch	Intended for use when the laser product is integrated into an end-user system. It is the responsibility of the purchaser/end-user to bring the end system into full compliance with all applicable regulations.
9		
10	Remote Start Button	Intended for use when the laser product is integrated into an end-user system. It is the responsibility of the purchaser/end-user to bring the end system into full compliance with all applicable regulations.
11		
12	Analog Input to Control Current	Intended to control the level of laser output power with either Local or Remote Control Mode enabled, power supply enabled, external emission control enabled (Remote Control Mode only), and analog control enabled. The output power is proportional to the analog voltage being supplied to the device. IPG recommends the integrator sets the voltage on this pin to zero volts when the emission, laser power supply, or the laser main power (VAC) is OFF. IPG also recommends the integrator use a analog voltage source capable of supplying a clean/stable signal. Suggested voltage sources might be in the form of a PLC, Arbitrary Waveform Generator, or other similar products.
13	Analog Output Power Monitor	—
14	Isolated Analog Com	—
15	Modulation +	Modulation mode must be enabled and can be used in either Local or Remote Control modes of operation. Review the product specification for allowable modulation settings specific to your product. Also, the modulation signal is not intended to be used for functional safety or as a safety device. IPG has incorporated a certified safety circuit for this purpose and it is the responsibility of the purchaser/end-user to bring the end system into full compliance with all applicable regulations.
16	Modulation -	—
17	Guide Control	—

Pin	Signal Name	Description
18	Emission Enable	Intended to control the level of laser output power with Remote Control Mode enabled, power supply enabled, and external emission control enabled. The emission enable signal is not intended to be used for functional safety or as a safety device. IPG has incorporated a certified safety circuit for this purpose and it is the responsibility of the purchaser/end-user to bring the end system into full compliance with all applicable regulations. Hardware Control must be set to enable in the laser web interface.
19	Error/Ready	—
20	System Common	—
21	Error Reset	—
22	Power On	Intended to be used by the integrator for indicating the laser control system is turned ON. The signal is active high when the local key is turned on or when the remote key is turned on for models without the display option. If Local Control Mode is ON or in the middle position and the remote key is ON, the control system is OFF. The integrator should use this signal to notify operators using the end product, that the key has been turned on. It is the responsibility of the purchaser/end-user to bring the end system into full compliance with all applicable regulations.
23	Power Supply Active	Intended to be used by the integrator for indicating the power supply is activated. The signal is available whether the laser is in Local Control or Remote Control Mode. The integrator should use this signal to warn operators using the end product that the power supply is active and the laser is capable of emitting laser radition. Since the laser emission is delivered through an optical cable which might be tens of meters in length. This signal is provided so proper warnings are made available at the laser aperture and the remote control system as defined by the integrator. It is the responsibility of the purchaser/end-user to bring the end system into full compliance with all applicable regulations.
24	Emission ON	Intended to be used by the integrator for indicating the laser emission is turned ON. The signal is available whether the laser is in local or remote mode. The integrator should use this signal to warn operators using the end product that emission is turned ON and the product can be or is emitting laser radiation. Since the laser emission is delivered through an optical cable which might be tens of meters in length, this signal is provided so proper warnings are made available at the laser aperture and remote control system as defined by the integration. **Note:** The signal is active when the emission is turned ON and remains active even if the laser output is set at “zero” and no actual laser emission is present. It is the responsibility of the purchaser/end-user to bring the end system into full compliance with all applicable regulations.

Table 2-8. 7-Pin Connector Pinouts

Pin	Signal Name	Signal Type	Signal Level	Signal Drive	Typical Response Time	Description/Comments
1	E-Stop Out Channel 3A	Contact Closure to pin 3[a]				Direct connection to E-Stop button on the front panel. If you press Emergency Stop on the front panel, channels 3 and 4 are open. Intended to be used by integrators to shut down parts of the system or entire system when the laser front panel E-stop is activated. Only applicable to laser option with display and controls on the front panel.
2	E-Stop Out Channel 4A	Contact Closure to pin 4[a]				
3	E-Stop Out Channel 3B	Contact Closure to pin 1[a]				
4	E-Stop Out Channel 4B	Contact Closure to pin 2[a]				
5	PS_Active1	Digital Output	24 VDC	<100mA (source)	120 ms[b]	A high condition indicates that the internal main power supply is active. Redundant signal for indicating the power supply has been activated. The signal is available whether the laser is in Local Control or Remote Control Mode. The integrator should use this signal to warn operators using the end product, that the power supply is active and capable of emitting laser radiation. It is the responsibility of the purchaser/ end-user to bring the end system into full compliance with all applicable regulations.
6	No Connection	—	—	—	—	
7	Common	Return	—	—	—	Return for signals on pins 5.

a. Contact closure components rated 24VDC, 1A.

b. Interlock response time (500 ms and 1.2s QCW models) must be additionally considered to ensure the safe state of the device.

Note: Connector housing is EMC rated and is the intended connection point for the shielding for the customer's cabling.

Initial Power-Up Sequence

CAUTION: All electrical connections (and water connections for Water-Cooled models) must be connected prior to applying power to the unit.

In addition and where applicable, all connections must be secured with screws to ensure proper functionality.

To initially power-up the system:

1. Ensure the **E-Stop** button on the front panel is pushed in.
2. Inspect the optical output end face to check for dust and debris (refer to “Optical Fiber Connector Inspection and Cleaning” on page C-1 for more information).
3. Properly align the output fiber into the delivery optics.
4. Properly secure optical output collimator.

WARNING: Never look directly into a live fiber and ensure that you wear appropriate laser safety eyewear at all times while operating the product. Ensure all power is removed from the laser when handling the delivery cable.

5. Ensure the Interlock (pins 1 to 4, 2 to 3) on the interface connector is closed.
6. Release (pull out) the **E-Stop** button on the front panel and ensure that the external **E-Stop** (from the 24-pin connector) is disengaged if used.
7. Ensure that the air-cooling vents are unobstructed to allow proper cooling of the device.
8. Verify that the external cooling unit is powered on (for Water-Cooled models only).

Key Control

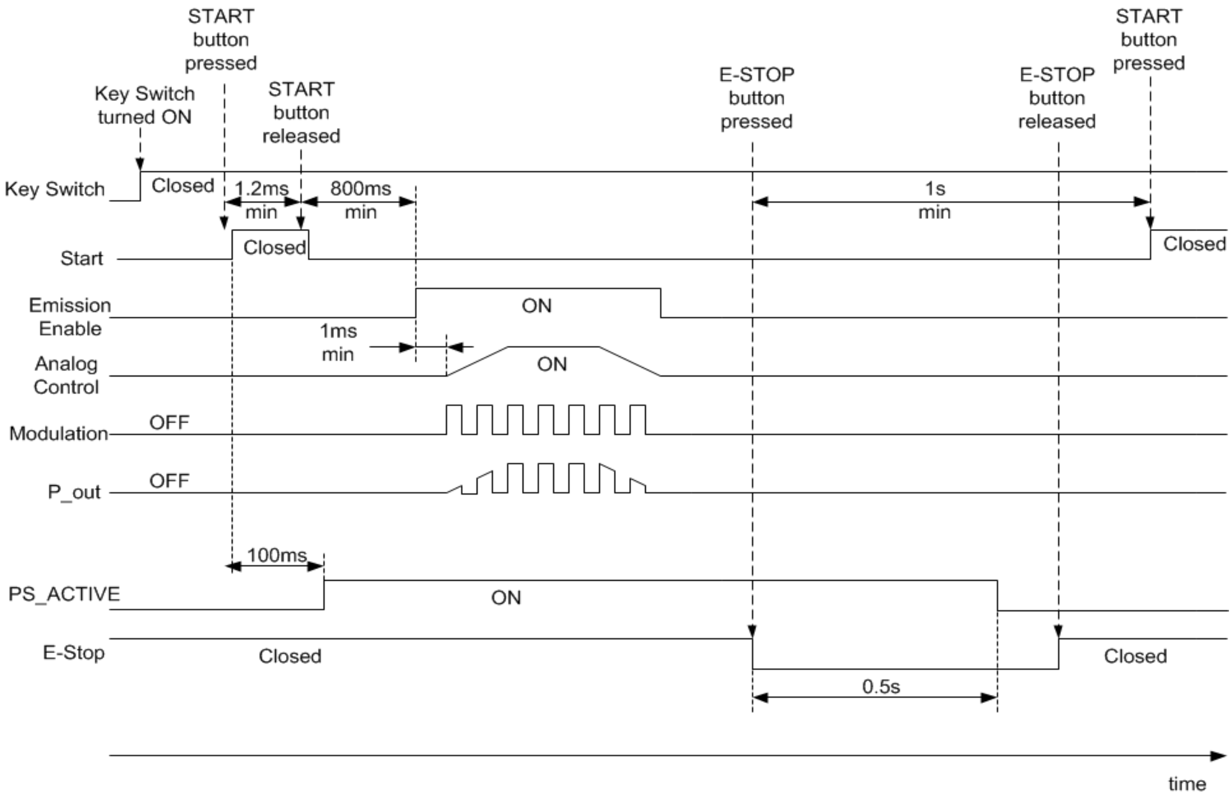
You cannot turn on or operate the device until the key switch is in the ON or REM position. ON or REM is only applicable to products with the Local Control option. Products that do not have this option need to close the remote key circuit, pins 8 and 9 on remote connector (refer to Table 2-6 on page 2-19).

You cannot switch between ON and REM without moving position into OFF and then waiting a few seconds.

YLR-Series System Operation

The YRL-Series system operation is illustrated in Figure 2-12.

Figure 2-12. YLR-Series Timing



Rear Panel: 7-pin and 24-pin Connectors

There are two connectors on the rear panel of chassis: 7-pin and 24-pin. Figure 2-13 on page 2-27 shows the connections to 24-pin connector. Figure 2-14 on page 2-28 shows the connections to the 8-pin connector.

The two Interlock contacts ILK1 and ILK2 are connected between pins 1-4 and 2-3.

The Keyswitch is connected between pins 8 and 9. This switch should be closed to power system up in Remote Control Mode. The Start button is connected between pins 10 and 11. When closed it starts system in Remote Control Mode.

There is an isolated RS-232 interface (signals on pins 5 and 6 are referenced to return on pin 7). Two isolated analog signals on pins 12 and 13 are referenced to analog return on pin 14. Two differential modulation signals on pins 15 and 16 are also isolated. The control and diagnostic signals on pins 17-19 and pins 21-24 are referenced to return on pin 20 and are isolated.

Figure 2-13. 24-Pin Connector Interfaces

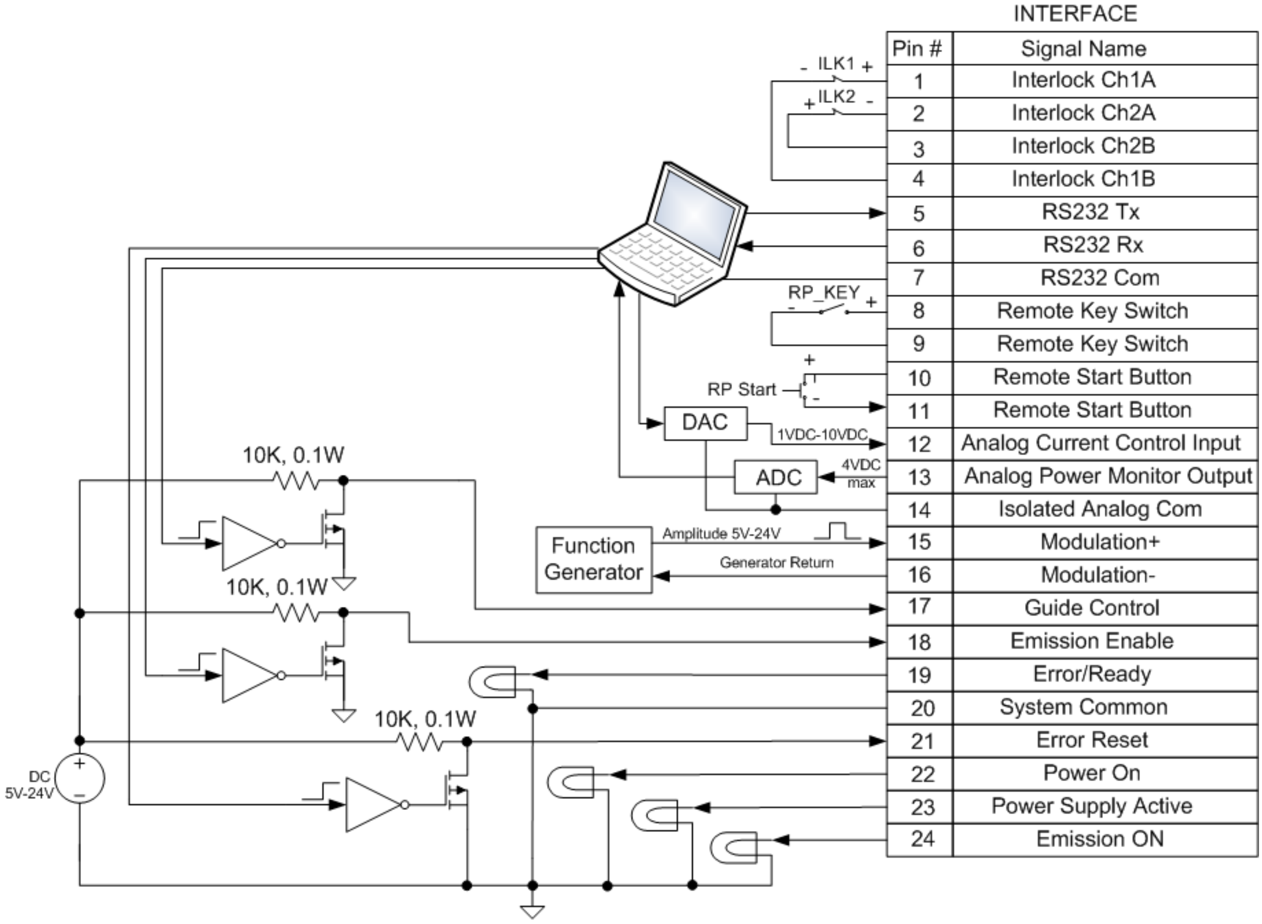
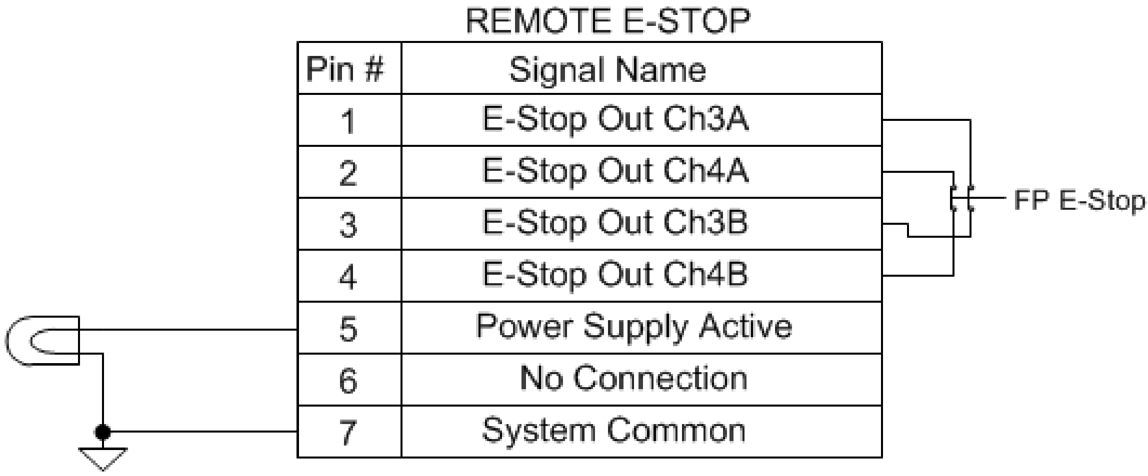


Figure 2-14. 7-Pin Connector



REMOTE E-STOP

Pin #	Signal Name
1	E-Stop Out Ch3A
2	E-Stop Out Ch4A
3	E-Stop Out Ch3B
4	E-Stop Out Ch4B
5	Power Supply Active
6	No Connection
7	System Common

Two contacts of the E-Stop button are connected between pins 1-4 and 2-3. When you push the E-Stop button, these contacts become open. They return to closed state when E-Stop button is released.

One isolated Power Supply Active signal on pins 5 is referenced to the return on pin 7.

Operation Control Modes

There are two control modes for the laser: Local and Remote. You select these modes using the Keyswitch on the front panel (see Figure 2-2 on page 2-3).

If the Keyswitch is in the ON position, the Local control mode is activated. If the Keyswitch is in REM position, the Remote control mode is activated.

Table 2-9 details the differences between these two modes:

Table 2-9. Local and Remote Control Modes

	Local (Keyswitch "ON" position	**Remote (Keyswitch "REM" position)**	
Control Electronics Enabling	Enabled	Remote Laser Power Keyswitch	
Main Power Supply Enabling	Start button	Remote Start Button	
Emission Control	RS-232, Ethernet, Touch-screen	Hardware Emission Control Enabled[a]	Hardware Emission Control Disabled[b]
		External Interface	RS-232, Ethernet
Guide Laser Control	RS-232, Ethernet, Touch-screen	External Aiming Beam Control Enabled[c]	External Aiming Beam Control Disabled[d]
		External Interface	RS-232, Ethernet
Operation Mode Selection	RS-232, Ethernet, Touch-screen	RS-232, Ethernet	

a. Default Setting: To set "Hardware Emission Control Enabled" send the command "ELE" via RS-232 interface or select it in setting menu using Touch Screen display.

b. To set "Hardware Emission Control Disabled" send the command "DLE" via the RS-232 interface or change it in settings menu using Touch Screen display.

c. To set "External Aiming Beam Control Disabled" send the command "DEABC" via the RS-232 interface or change it in settings menu using Touch Screen display.

d. To set "External Aiming Beam Control Disabled" send the command "DEABC" via the RS-232 interface or change it in settings menu using Touch Screen display.

Turning on the Device in Local Control Mode

To turn on the device in Local Control Mode:

1. Turn the front panel Keyswitch clockwise to the ON position.
2. Press the Start button to turn on the main power supply.
3. Wait until the laser becomes active.

   The laser is now ready for operation. You can now select a proper operation mode.

Turning on the Device in Remote Control Mode

To turn on the device in Remote Control Mode:

1. Turn the front panel Keyswitch counterclockwise to the REM position.
2. Close contact pins eight and nine to provide the remote keyswitch function.
3. Make momentary closure of pins 10 and 11 to activate the main power supply.
4. Turn the emission on. Refer to "Local and Remote Control Modes" on page 2-29.
5. Wait until the laser becomes active.

   The laser is now ready for operation. You can now select a proper operation mode.

Selecting Operation Modes

In both control modes (Local and Remote), there are two main modes of laser emission:

- Continuous (CW)
- Pulsed (QCW)

Pulse Mode (QCW)

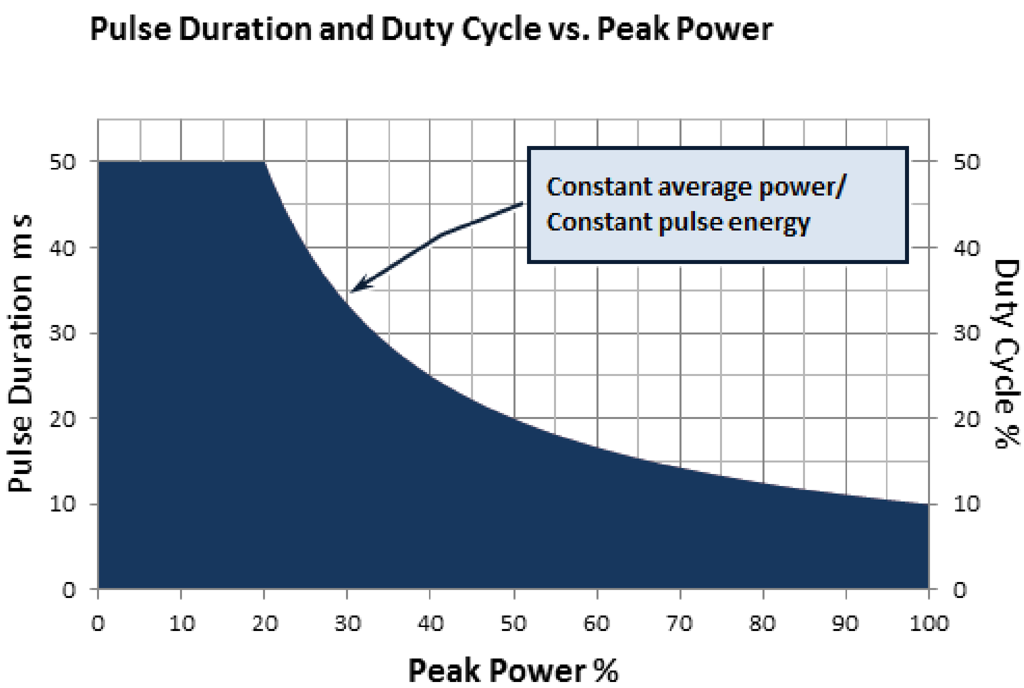
Pulse Mode (for QCW models only, Pulse-mode enabled) laser internally generates a sequence of pulses. Pulse duration and pulse repetition rate can be configured by:

- Sending corresponding commands via RS-232 interface, or
- Using the Pulse Settings sub-menu on the touch-screen display

The main difference between Pulse and CW modes is that in Pulse Mode the maximum peak power is considerably higher than in CW.

However, the maximum pulse duration and the maximum duty cycle are limited to certain values (refer to the *SPECIFICATION YTTERBIUM FIBER LASER* document and refer to Figure 2-15). When in CW mode, the maximum pulse duration and duty cycle are not applicable.

Figure 2-15. Pulse (QCW) Operational Range



Operational Sub-Modes

For each mode of laser emission (Continuous or Pulse), there are four operational sub-modes:

- Standalone
- Modulation
- Gate
- External (Analog) Power Control

The main difference between sub-modes of operation is how the laser power is set and the laser emission is switched on/off.

Continuous Mode (Pulse mode is disabled) laser generates CW emission (except for Gate mode).

Standalone Mode (Modulation and Gate control disabled)

The value of pump LD current (controls output power) is controlled by:

- Sending a RS-232 command, or
- Sending an Ethernet command, or
- Using control buttons on the touch-screen (in Local Mode).

Modulation Mode

- The value of pump LD current is controlled as in the Standalone Mode.
- Laser emission is turned on/off by the user-generated "Modulation" signal applied to pins 15-16 of External Interface Connector.

Gate Mode

- The value of pump LD current is controlled as in the Standalone Mode.
- Laser emission is controlled both, externally and internally . The user-generated "Gate" signal applied to pins 15-16 of External Interface Connector starts and stops internal generation of pulses.

External (Analog) Power Control

- The value of pump LD current value is controlled by the voltage applied between pins 12 and 14 of the External Interface Connector (see Table 2-5 on page 2-14 for more information).
- Pulse sequence generation, modulation and gating are performed as in corresponding modes above.

Pulse Shaper Program (Optional Feature)

- You can create and store arbitrary waveform pulses in the Pulse Profiles library.
- You can create and store Pulse sequences (combinations of pulse profiles, delays, and repeats) in the Pulse Sequences library.
- Pulses can be started by Emission On command/signal (when Gate Mode is disabled) or by the “Gate” signal applied to Pins 15-16 of External Interface Connector (when Gate Mode is enabled).
- You cannot select Waveform Mode if either External (Analog) Control or Modulation Mode is enabled.

  See “Pulse Shaping” on page 4-1 for details on using the Pulse Shaper program.

Using the Touch-Screen Display

You can use the touch-screen display on the front panel for manual control of the device. You can view information about the device’s state and settings. In addition, activating certain commands from the main window invokes additional submenu windows. In Remote Mode, the touch-screen display function is disabled and can only be used for display purposes.

Figure 2-16. Main Menu Screen

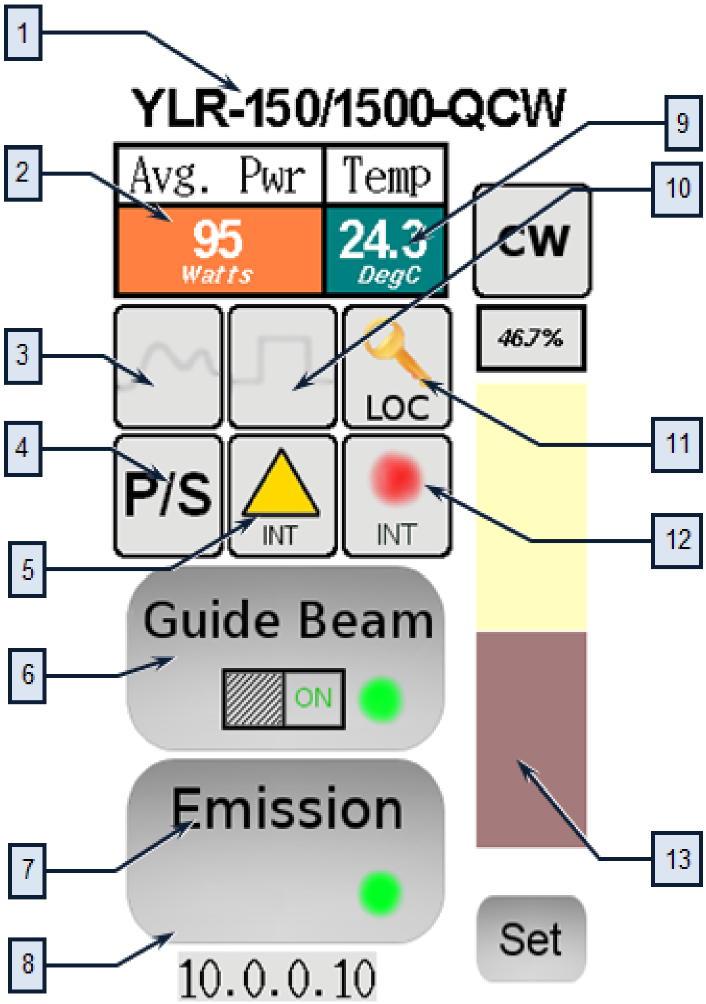


Table 2-10. Main Menu Descriptions for Touch-Screen Display

Item	Description
1	Model Name.
2	Power Indication/Setting: Touching this field displays the Setpoint window where you can enter the required setpoint value.
3	When active (inactive shown) indicates that the analog (external) power control is enabled or in Pulse Waveform Mode.
4	When active, shows that the main supply voltage is applied to the laser module inside the device.
5	Indicates the state of the emission control: “Internal” (hardware control disabled) or “External” (hardware control enabled).
6	Touching this button turns the guide laser ON or OFF.
7	Touch this button to activate or deactivate the emission.
8	IP address indication/setting. Touching this field opens the window where you assign an IP address to the system.
9	Internal Temperature display.
10	When active, indicates that the Modulation or Gate Mode is enabled.
11	Indicates the current operational state: Local or Remote.
12	Indicates the state of the guide laser control: Internal or External.
13	Setpoint Bar: Touch **Set** and drag your finger up or down to set the required value. Press **Lock** when finished.

Figure 2-17. Sub-Menus Screen

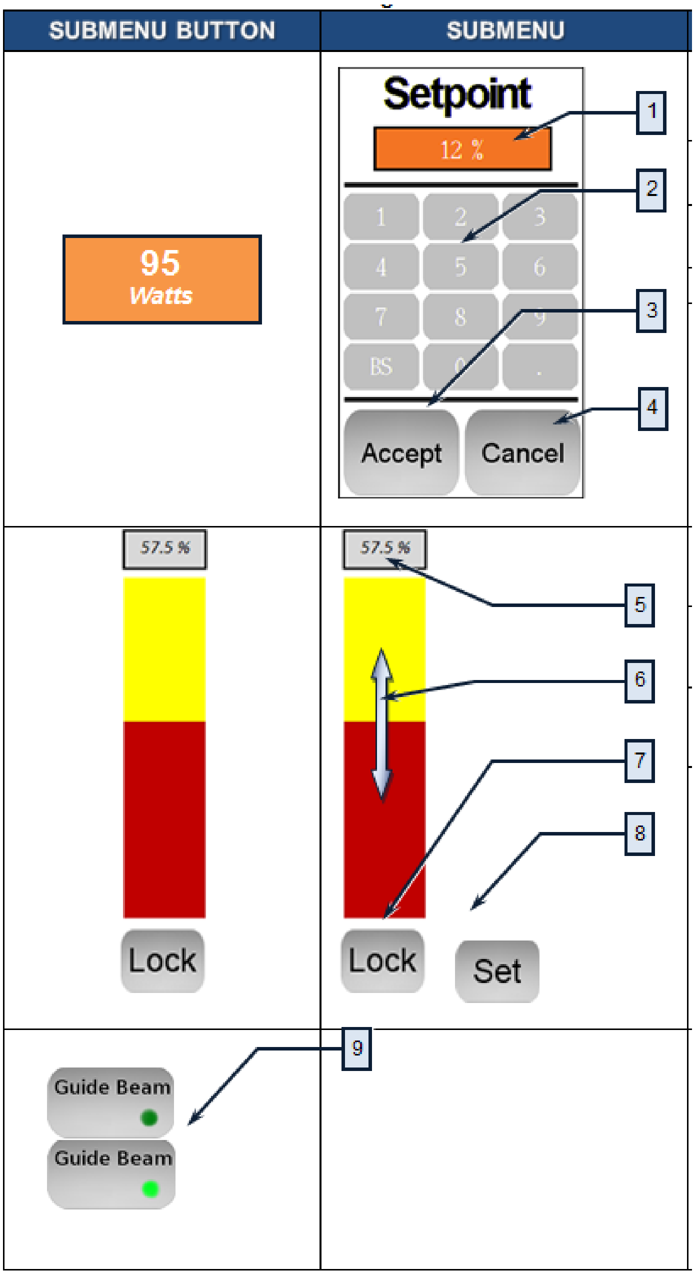


Table 2-11. Sub-Menus Descriptions

Item	Description
1	Current Power setpoint value (in percentage) of maximum power (for example, 12%).
2	Enter the Power setpoint in percentage of the maximum power.
3	Accept new Power setpoint.
4	Return to the previous screen.
5	Power setpoint value in percentage of maximum power (for example, 57.5%).
6	Power Control Bar (disabled when locked).
7	Press **Lock** to unlock the Power Control Bar function (“Set” is displayed).
8	Press **Set** to change the power to the new setpoint and lock the Power Control Bar.
9	Press to turn on the Guide Beam. A Green dot lights up

Figure 2-18. Sub-Menus Screen

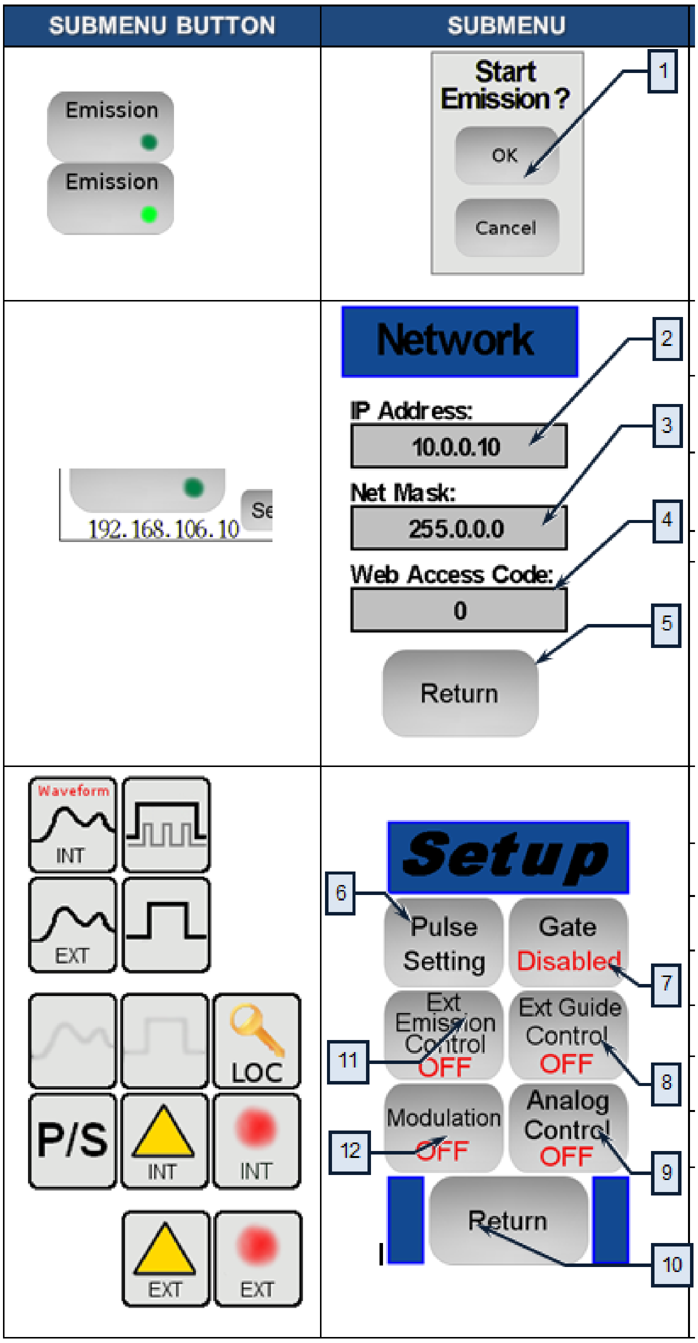


Table 2-12. Sub-Menus Descriptions

Item	Description
1	Press the Emission Button and you are asked to confirm the emission startup process by pressing **OK**. Press **Cancel** to exit.
2	Press the **IP address** box to enter a new IP address.
3	Press the **Net Mask** box to enter a new net mask address.
4	Press the **Web Access Code** box to enter a new web access address.
5	Press **Return** to go back to the previous screen.
6	Opens the Pulse Settings menu (function described lower in table).
7	Enable or Disable the Gate mode
8	Enable or Disable the External Guide Laser control.
9	Enable or Disable the External Analog Power control.
10	Return to the previous screen.
11	Enable or Disable the Emission Control mode.
12	Enable or Disable the Modulation mode.

Figure 2-19. Sub-Menus Screen

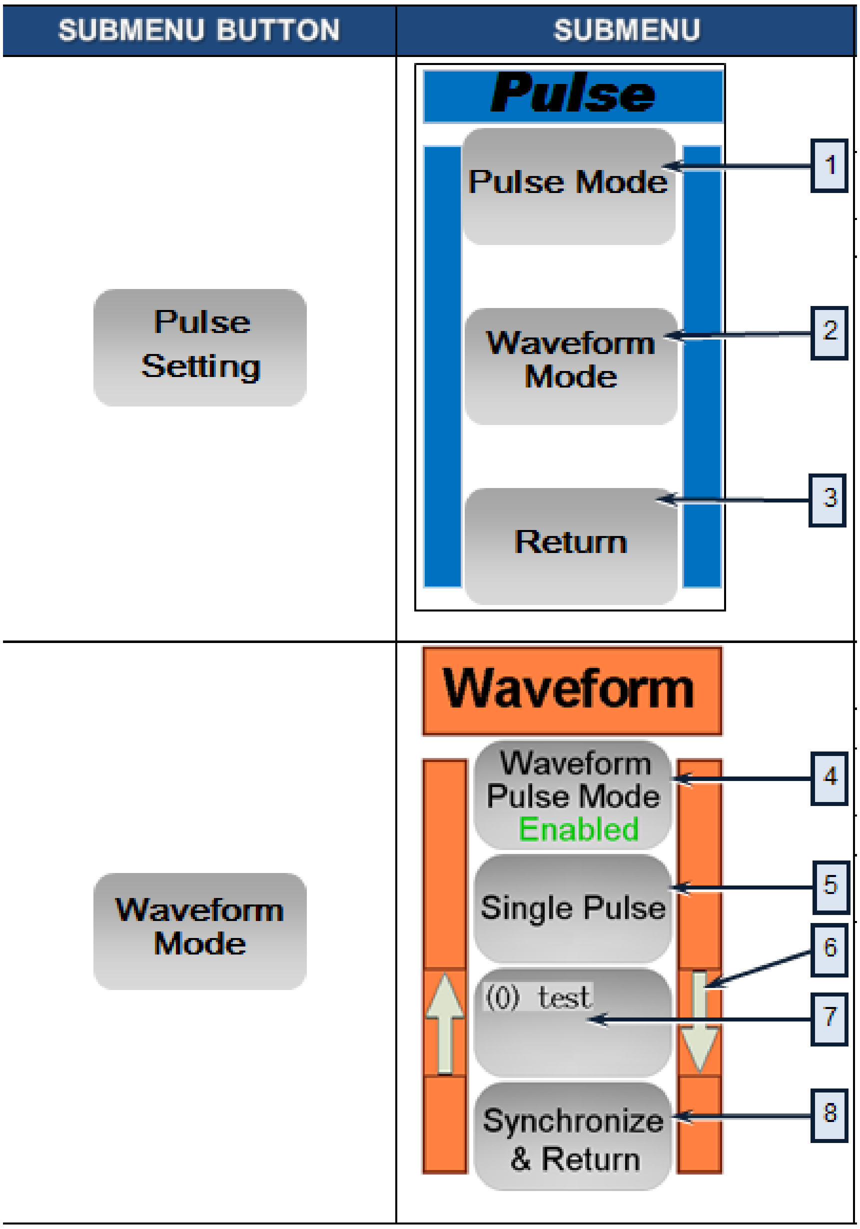


Table 2-13. Sub-Menus Descriptions

Item	Description
1	Opens Pulse Mode sub-menu.
2	Opens Waveform Mode sub-menu.
3	Return to the previous screen.
4	Enables or Disables the Waveform Pulse Mode.
5	Single Pulse/Pulse Sequence.
6	Use the Up/Down Arrows to scroll to select a program from memory.
7	Selected the program in memory.
8	Transfers the selected program to the laser.

Figure 2-20. Sub-Menus Screen

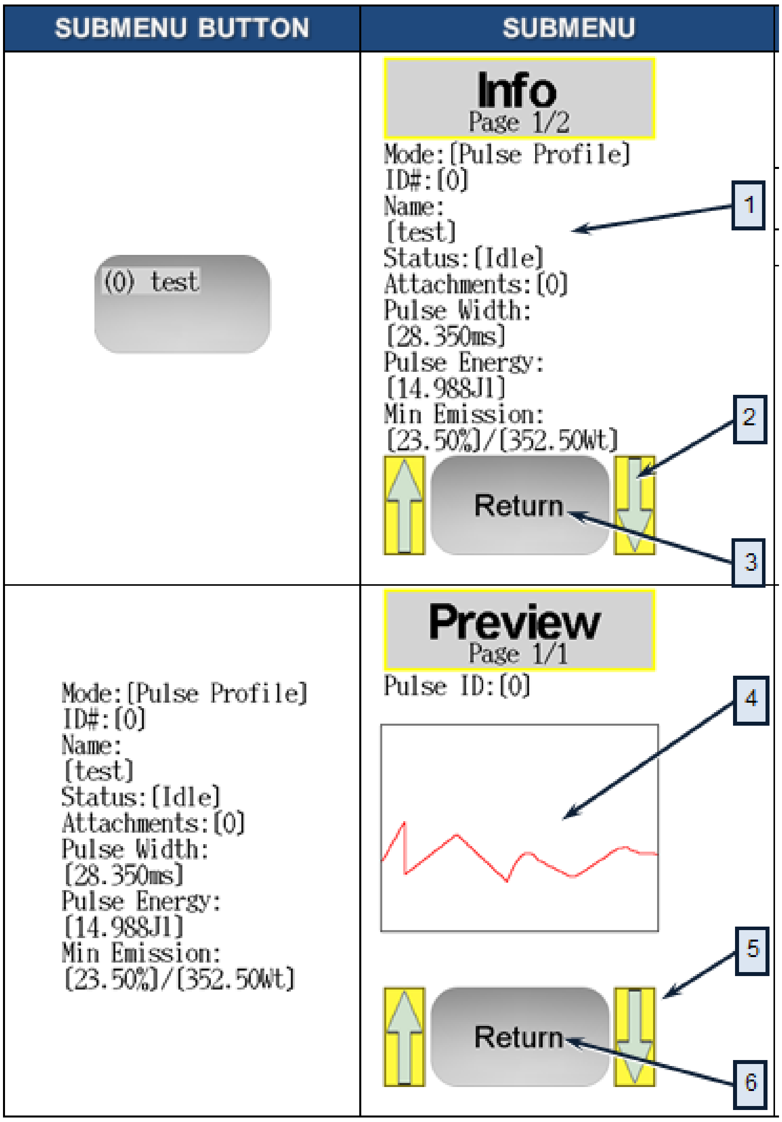


Table 2-14. Sub-Menus Descriptions

Item	Description
1	Pulse Program Information Screen. Clicking anywhere in this area displays the Preview Screen.
2	Use the Up and Down arrows to scroll to select a program from memory.
3	Return to the previous screen.
4	Pulse Program Preview screen.
5	Use the Up and Down arrows to scroll to select a program from memory.
6	Return to the previous screen.

Figure 2-21. Sub-Menus Screen

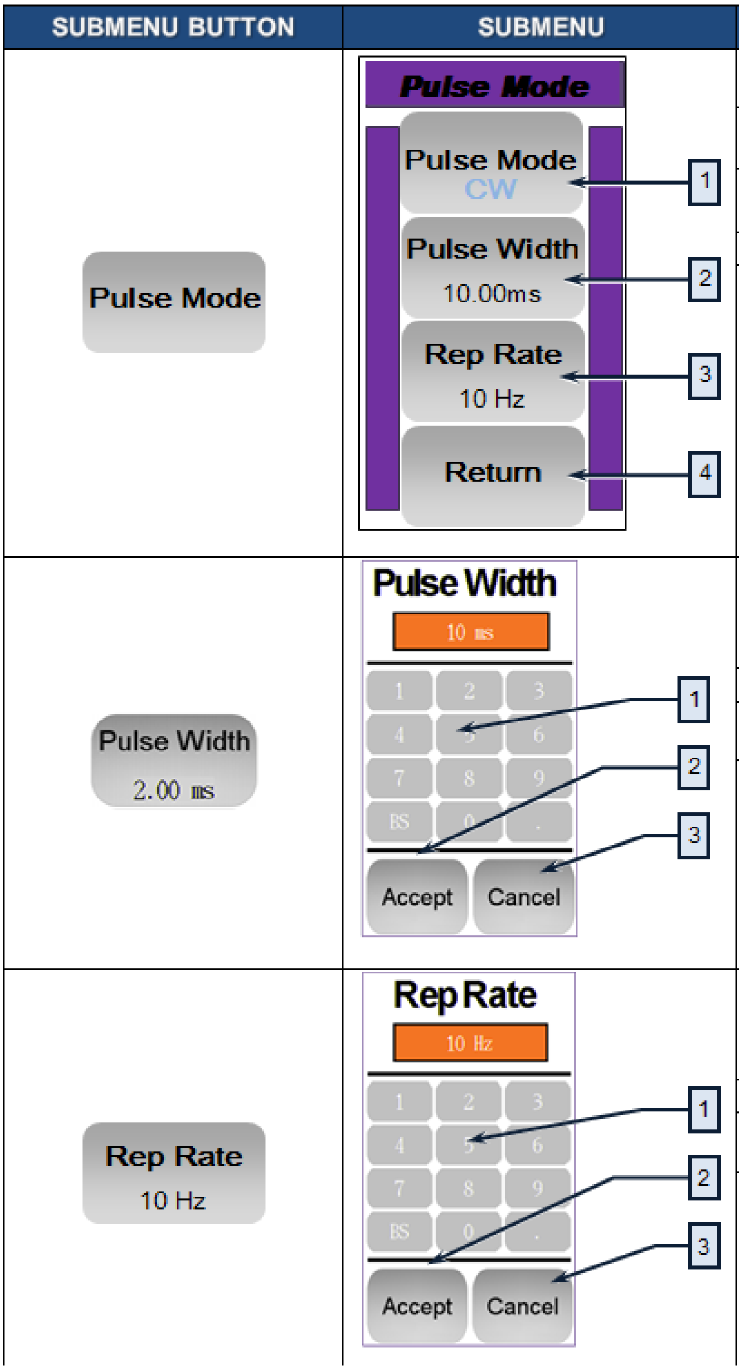


Table 2-15. Sub-Menus Descriptions

Item	Description
1	Toggles between the Continuous (CW) and Pulsed (QCW) modes.
2	Opens Pulse Width dialog.
3	Opens Pulse Width dialog.
4	Return to the previous screen.
5	Enter Pulse Width in milliseconds (ms) range is 0.2 to 20 ms in .05 ms increments.
6	Accept the Pulse Width.
7	Cancel and return to the previous screen.
8	Enter Repetition Rate in Hertz (Hz) range is 1 to 5000 Hz in 1 Hz increments.
9	Accept the Repetition Rate.
10	Cancel and return to the previous screen.

3

Computer Interface/Commands

RS-232 Configuration

A three-wire (RxD, TxD, GND) interface is used (null modem cable). The individual commands are described in “Interface Commands” on page 3-2. See “Interface Connector Pin Assignments” on page 2-19 for details on 24-pin interface connectivity.

The RS-232 interface is configured with the following parameters:

Table 3-1. RS-232 Parameters

Parameter	Value
Baud Rate	57,600
Data Bits	8
Stop Bits	1
Parity	None
Flow Control	None

Ethernet TCP/IP Interface

The IP address of the laser is shown on the front panel. Touching the screen where the address is shown displays the network setup menu where you can change the network settings.

The laser listens for connections on port 10001. The command must be sent as a single string in a single packet. The individual commands are described in “Interface Commands” on page 3-2.

Table 3-2. Ethernet Interface Pinouts

Pin	Description	Notes
1	TX+	Transmit Data +
2	TX-	Transmit Data -
3	RX+	Receive Data +
4	N/C	Not Connected

Pin	Description	Notes
5	N/C	Not Connected
6	RX-	Receive Data -
7	N/C	Not Connected
8	N/C	Not Connected

Interface Commands

All commands and responses consist of printable ASCII characters. Commands are typically three or four letter mnemonic codes followed by a parameter, if required.

All commands and responses are terminated with a <Carriage Return> (CR, 0x0D, \r) character If a CR terminated string is received, but a valid command is not found, a response of "BCMD" is sent.

The commands are shown in Table 3-3, "Interface Commands" as all uppercase for clarity; the actual commands are not case sensitive. A space character is also shown between the command and parameter for clarity. The space is not required.

Every command generates a response. The responses generally consist of the command echoed back. If there is a returned value, it is separated from the echoed command by a ':' character.

Table 3-3. Interface Commands

Code	Description	Example
ABN	Aiming Beam ON	Sent: "ANB" Response: "ABN" "ERR: Cannot enable guide beam because external guide control is enabled."
ABF	Aiming Beam OFF	Sent: "ABF" Response: "ABF" "ERR: Cannot disable guide beam because external guide control is enabled."
DEABC	Disable External Aiming Beam Control —Disables hardware aiming beam control.	Sent: "DEABC" Response: "DEABC"

Code	Description	Example
DEC	Disable External Control — Disables the analog current control input. Disables Dynamic Scaling in Waveform mode.[a]	Sent:"DEC"" Response: "DEC" or "ERR: Emission is ON!"
DGM	Disable Gate Mode — Disables internal pulse generator.	Sent: "DGM" Response: "DGM" or "ERR: Emission is ON!"
DLE	Disable Hardware Emission Control — Disables hardware emission control.	Sent: "DLE"" Response: "DLE" or "ERR: Emission is ON!"
DMOD	Disable Modulation — Disables the modulation mode.	Sent: "DMOD"" Response: "DMOD" or "ERR: Emission is ON!"
DPM[b]	Disable PULSE Mode — Disables PULSE mode.	Sent: "DPM" Response: "DPM" or "ERR: Emission is ON!"
EEABC	Enable External Aiming Beam Control - Enables hardware aiming beam control.	Sent: "EEABC" Response: "EEABC"
EEC	Enable External Control — Enables the analog current control input. Enables Dynamic Scaling in Waveform mode.[a]	Sent: "EEC" Response: "EEC" or "ERR: Emission is ON!"
EGM	Enable Gate Mode — Enables internal pulse generator gated by signal applied to modulation input.	Sent: "EGM" Response: "EGM" or "ERR: Emission is ON!"
ELE	Enable Hardware Emission Control — Enables hardware emission control.	Sent: "ELE" Response: "ELE" or "ERR: Emission is ON!"
EMOD	Enable Modulation – Enables the modulation mode.	Sent: "EMOD" Response: "EMOD" or "ERR: Emission is ON!"
EMOFF	Stop Emission – Stops emission.	Sent:: "EMOFF"" Response: "EMOFF" or "ERR: Emission is ON!"
EMON	Start Emission – Starts emission.	Sent: "EMON" Response: "EMON"
EPM[b]	Enable Pulse Mode — Enables Pulse mode.	Sent: "EPM" Response: "EPM"

Code	Description	Example
ESTA	Read Extended Device Status — The extended status is reported as a number of bit-encoded 32-bit words. The response contains the information required by IPG for remote troubleshooting.	Sent: “ESTA” Response: “ESTA: 256;0;0;0;0;0;0;0;46;3”
LFP[c]	Lock Front Panel – Locks touch-screen display on the front panel of the laser.	Sent:: “LFP” Response: “LFP” or “ERR: Emission is ON!”
HELP	In case of no parameters returns the list of applicable commands. In case of a specified command name as a parameter returns the command description.	Sent: “HELP” Response: “Commands: STA ROP RPP RCT EMON EMOFF RET … RIP SIP RMASK SMASK RBAUD SBAUD HELP Done HELP <Command> for more information on a specific command” Sent: “HELP RPP” Response: “HELP: RPP - Read Peak Power” Sent: “HELP RCD” Response: “HELP: RCD - Command Not Listed”

Code	Description	Example
RBAUD	Read Baud Rate — Reads the current RS-232 baud rate. The response is the command echoed back, followed by a delimiter of ": " and then the communication speed index (see below). Index Speed (bits/s) 0 - 110 1 - 300 2 - 1200 3 - 2400 4 - 4800 5 - 9600 6 - 19200 7 - 38400 8 - 57600 default 9 - 115200	Sent: "RBAUD" Response "RBAUD: 8"
RCE	Reset Critical Error — Followed by the code received from IPG clears critical errors.	Sent: "RCE 1123456123" Response: "RCE: Code Accepted" or "ERR: Code Incorrect"
RCS	Read Current Setpoint — Reads the setpoint for the LD current. The response is the command echoed back, followed by a delimiter of ": : and then the current setpoint in %.	Sent: "RCS" Response: "RCS: 56.7" (Indicates that the LD current setpoint is 56.7%)
RCT	Read Laser Temperature – Reads the internal temperature of the laser. The response is an echo of the command, a delimiter of ": ", and the temperature in degrees centigrade.	Sent: "RCT" Response: "RCT: 34.5"
REC	Read Error Counter — Reads critical error counter.	Sent: "REC" Response: "REC: 37"
RERR	Reset Errors — Resets any resettable errors.	Sent "RERR" Response: "RERR"
RET	Read Elapsed Time — Reads the elapsed time the laser has been ON. The time is returned in minutes.	Sent "RET" Response: "RET: 1105"
RFV	Read current software revision.	Sent: "RFV" Response: "RFV: 7.28;2.83;ND"
RMEC	Read Module Error Code. Returns error code stored in the laser or zero if normal operation.	Sent: "RMEC" Response: "RMEC: 0"
RNC	Read Minimum Current Setpoint — Reads the minimum current setpoint that can be set in the laser. The response is the command echoed back, followed by a delimiter of ": " and then the minimum current as a percentage of the maximum.	Sent: "RNC" Response: "RNC: 10.0" (Indicates that the minimum setpoint is 10.0 %)

Code	Description	Example
ROP	Read Output Power — Reads the output power in watts. The response is the command echoed back, a delimiter, and then either the power in watts "Off" if the emission is off, or "Low" if the power is below the reliable measurement threshold of the laser.	Sent: "ROP" Response: "ROP: 99.6" (Indicates that the output power is 99.6 watts) Sent: "ROP" Response: "ROP: Off" (Indicates that emission is off.)
RPP	Read Peak Power — Reads the output peak power in Watts. The response will be the command echoed back, a delimiter, and then either the power in watts "Off" if the emission is off, or "Low" if the power is below the reliable measurement threshold of the laser.	Sent: "RPP" Response: "RPP:730" (Indicates that the output peak power is 730 watts.) Sent: "RPP" Response: "RPP: Off" (Indicates that emission is off. Sent: "RPP" Response: "RPP: Low" (Indicates that the output power is below the accurate measurement range of the laser.)
RPRR	Read Pulse Repetition Rate — Reads the pulse repetition rate of the internal pulse generator. The response is the command echoed back, followed by a delimiter of ":" and then the pulse width in Hz.	Sent: "RPRR" Response: "RPRR: 10.00" (Indicates that the PRR is 10 Hz.)
RPW	Read Pulse Width — Reads the pulse width of the internal pulse generator. The response is the command echoed back, followed by a delimiter of ":"and then the pulse width in ms.	Sent: "RPW" Response: "RPW: 5.550" (Indicates that the pulse width is 5.55 ms.)
RSN	Read Serial Number — Reads the serial number of the device.	Sent: "RSN" Response: "RSN: 6103081"

Code	Description	Example
SBAUD	Set Baud Rate — Followed by an index (see below) sets RS-232 baud rate. The command sent via RS-232 has no response and the communication speed is changed just after receiving the command. The response to the command sent via Ethernet is the command echoed back, followed by a delimiter of ": "and then the communication speed index. Index Speed (bits/s) 0 - 110 1 - 300 2 - 1200 3 - 2400 4 - 4800 5 - 9600 6 - 19200 7 - 38400 8 - 57600 default 9 - 115200	Sent: "SBAUD 9" Response (Ethernet only): "BAUD: 9" or "ERR: Invalid Baud Setting. Valid Settings = [] [0:110] [1:300] [2:1200] [3:2400] [4:4800] [5:9600] [6:19200] [7:38400] [8:57600] [9:115200] [END]" or "ERR: Emission is ON!"
SDC	Set Diode Current — Sets the diode current. The units are in percent of maximum current. The setpoint must be below 100% and above the minimum current setpoint. The current can also be set to 0. The response from the laser is the command echoed back, a delimiter of ":" and then the current setpoint for the laser. A value that is outside the acceptable range will receive a response of "ERR: Out of Range."	Sent: "SDC 34.2" Response: "SDC: 34.2" (Current Setpoint is set to 34.2%.) Sent: "SDC 104.2" Response: "ERR: Argument out of range" (The setpoint is unchanged.) Sent: "SDC 34.2" Response: "ERR: External control enabled" (The setpoint is unchanged.)
SPRR	Set Pulse Repetition Rate — Sets the pulse repetition rate. The units are in Hz. The pulse width and the duty cycle (dependent on the pulse width and pulse repetition rate) must be within the specified range. The response from the laser is the command echoed back, a delimiter of ":" and then the pulse repetition rate. A value that is outside the acceptable range receives a response of "ERR: Duty cycle too high" or "ERR: Frequency out of range."	Sent: "SPRR 10" Response: "SPRR: 10" (PRR is set to 10 Hz.) Sent: "SPRR 100" Response: "ERR: Duty cycle too high" (PRR is unchanged.) Sent: "SPRR 100000" Response: "ERR: Argument out of range" (PRR is unchanged.)

Code	Description	Example
SPW	Set Pulse Width — Sets the pulse width. The units are in ms. The pulse width and the duty cycle (dependent on the pulse width and pulse repetition rate) must be within the specified range. The response from the laser is the command echoed back, a delimiter of ":" and then the pulse width. A value that is outside the acceptable range receives a response of "ERR: Out of range" or "ERR: Duty cycle too high."	Sent: "SPW 5.5" Response: "SPW: 5.5" (Pulse Width is set to 5.5 ms.) Sent: "SPW 11000" Response: "ERR: Argument out of range." (The pulse width is unchanged.) Sent: "SPW 8" Response: "ERR: Duty cycle too high." (The pulse width is unchanged.)
STA	Read device status — The status is reported as a bit-encoded 32-bit word. Undefined bits or bits defined as "Reserved" can be in any state and should be ignored. **Note:** Each of the bits have a meaning as listed in Table 3-4 on page 3-9.	Sent: "STA" Response: "STA: 4100" This translates to the following: 4100 = 0x1004, so bits 2 and 12 are set. This means that emission is on and modulation is enabled.
SIP	Set IP — Followed by a number in dot-decimal notation sets the IP address for the laser.	Sent: "SIP 10.0.0.2" Response: "SIP: 10.0.0.2"
SQSEL	Select Sequence — Selects Pulse Sequence Mode and Pulse Sequence ID. If the command is not followed by the ID number or the ID is invalid, then the existing (or last) selection is used. Note: It is not possible to switch to sequence mode if Waveform mode is enabled and no sequences exist. An error is returned if that is the case. If the Key Switch is in the Remote position, a waveform configuration is automatically executed before a response is returned.	Sent: "SQSEL 5" Response: "New setting applied. Waveform Mode: Pulse Sequence Selected Sequence: ID[5] – Name[Test1]"
UFP	Unlock Front Panel — Unlocks touch-screen display on the front panel of the laser.	Sent: "UFP" Response: "UFP" or "BCMD" in case of key is in REMOTE position" or "Emission is ON!"

a. Lasers with Pulse Shaping option only.

b. QCW Models only.

c. Laser with Touch-Screen Display only.

Table 3-4. Bit Meanings

Bit 0	-	0	=	Normal Operation
	-	1	=	Command Buffer Overload
Bit 1	-	0	=	Normal Operation
	-	1	=	Overheat
Bit 2	-	0	=	Emission Off
	-	1	=	Emission On
Bit 3	-	0	=	Back Reflection OK
	-	1	=	High Back Reflection Level
Bit 4	-	0	=	Analog Power Control Disabled
	-	1	=	Analog Power Control Enabled
Bit 5[a]	-	0	=	Normal Operation
	-	1	=	Pulse Too Long
Bit 6	-	Reserved		
Bit 7	-	Reserved		
Bit 8	-	0	=	Aiming Beam OFF
	-	1	=	Aiming Beam ON
Bit 9	-	0	=	Normal Operation
	-	1	=	Pulse too Short
Bit 10[a]	-	0	=	CW Mode
	-	1	=	Pulsed Mode
Bit 11	-	0	=	Power Supply ON
	-	1	=	Power Supply OFF
Bit 12	-	0	=	Modulation Disabled
	-	1	=	Modulation Enabled
Bit 13	-	Reserved		
Bit 14	-	Reserved		
Bit 15[b]	-	0	=	Emission is out of the 3 second start-up state.
	-	1	=	Emission is in the 3 second start-up state.

	(in ON position of the Keyswitch only)			
Bit 16	-	0	=	Gate Mode Disabled
	-	1	=	Gate Mode Enabled
Bit 17[a]	-	0	=	Normal Operation
	-	1	=	High Pulse Energy
Bit 18	-	0	=	Hardware Emission Control Disabled
	-	1	=	Hardware Emission Control Enabled
Bit 19	-	0	=	Normal Operation
	-	1	=	Power Supply Failure
Bit 20[b]	-	0	=	Front Panel Display is Unlocked
	-	1	=	Front Panel Display is Locked
Bit 21[b]	-	0	=	Keyswitch is in ON position
	-	1	=	Keyswitch is in REM position
Bit 22[c]	-	0	=	Waveform Pulse Mode OFF
	-	1	=	Waveform Pulse Mode ON
Bit 23[a]	-	0	=	Normal Operation
	-	1	=	Duty Cycle Too High
Bit 24	-	0	=	Normal Operation
	-	1	=	Low Temperature
Bit 25	-	0	=	Normal Operation
	-	1	=	Power Supply Alarm
Bit 26	-	Reserved		
Bit 27	-	0	=	Hardware Aiming Beam Control Disabled
	-	1	=	Hardware Aiming Beam Control Enabled
Bit 28	-	Reserved		
Bit 29	-	0	=	Normal Operation
	-	1	=	Critical Error
Bit 30	-	0	=	Fiber Interlock OK
	-	1	=	Fiber Interlock Active

Bit 31[a]	-	0	=	Normal Operation
	-	1	=	High Average Power

a. QCW Models only.
b. Lasers with Touch-Screen Display only.
c. Lasers with Pulse Shaping Option only.

Table 3-5. TCP-IP Configuration Commands

Code	Description	Example
DDHCP	Disable DHCP - Disables DHCP client	Sent: “DDHCP” Response: “DDHCP” or “ERR: Emission is ON!”
EDHCP	Enable DHCP - Enables DHCP client.	Sent: “EDHCP” Response: “EDHCP” or “ERR: Emission is ON!”
RDGW	Read Default Gateway — Reads the current default gateway of the device. The response is the command echoed back, followed by a delimiter of “: “ and then the default gateway in dot-decimal notation.	Sent: “RDGW” Response: “RDGW: 192.168.1.1”
RDHCP	Read DHCP — Reads the current status of DHCP client function. The response is the command echoed back, followed by a delimiter of “: “and then either “ON” or “OFF.”	Sent: “RDHCP” Response: “RDHCP: OFF”
RIP	Read IP —Reads the current IP address of the device. The response is the command echoed back, followed by a delimiter of “:” and then the IP address in dot-decimal notation.	Sent: "RIP" Response: "RIP: 192.168.1.230"
RLHN	Read Local Host Name — Reads the current local host name of the device. The response is the command echoed back, followed by a delimiter of “:” and then the name.	Sent: “RLHN” Response: “RLHN: IPG-12004020”
RMAC	Read MAC Address — Reads the current MAC address of the laser. The response is the command echoed back, followed by a delimiter of “:” and then the MAC address in a form of six groups of two hexadecimal digits, separated by hyphens (-).	Sent: “RMAC” Response: “RMAC: A1-B2-C3-D4-E5-F6”
RMASK	Read Subnet Mask — Reads the current subnet mask of the device. The response is the command echoed back, followed by a delimiter of “:” and then the subnet mask in dot-decimal notation.	Sent: “RMASK” Response: “RMASK: 255.255.240.0”

Code	Description	Example
RSTIP	Reset TCP/IP Settings - Resets the settings to the default ones: DHCP client OFF IP Address: 192.168.3.230 Default Gateway: 192.168.0.1 Subnet Mask: 255.255.240.0 Local Host Name: IPG-"serial number"	Sent: "RSTIP" Response: "RSTIP" or "ERR: Emission is ON!"
SDGW	Set Default Gateway — Followed by a number in dot-decimal notation sets the default gateway for the laser.	Sent: "SDGW 192.168.0.1" Response: "SDGW: 192.168.0.1" or "ERR: Emission is ON!"
SIP	Set IP — Followed by a number in dot-decimal notation sets the IP address for the laser.	Sent: "SIP 192.168.1.231" Response: "SIP: 192.168.1.231" or "ERR: Emission is ON!"
SMAC	Set MAC Address — Followed by six groups of two hexadecimal digits, separated by hyphens (-), sets the MAC address for the laser.	Sent: "SMAC 12-34-56-78-EF-EF" Response: "SMAC: 12-34-56-78-EF-EF" or "ERR: Emission is ON!"
SMASK	Set Subnet Mask - Followed by a number in dot-decimal notation sets the subnet mask for the laser.	Sent: "SMASK 255.255.0.0" Response: "SMASK: 255.255.0.0" or "ERR: Emission is ON!"
SLHN	Set Local Host Name — Specifies the name of the device within the network.	Sent: "SLHN IPG-12004020" Response: "SLHN: IPG-12004020" or "ERR: Emission is ON!"

The following commands in Table 3-6 are for lasers with the Pulse Shaping option only.

Table 3-6. Waveform Mode (Pulse Shaping) Specific Commands

Code	Description	Example
DWPM	Disable Waveform Pulse Mode — Disables internal arbitrary waveform generator (pulse shaping).	Sent: "DWPM" Response: "DWPM" or "ERR: Emission is ON!"
EWPM	Enable Waveform Pulse Mode -— Enables internal arbitrary waveform generator (Pulse Shaping).	Sent: "EWPM" Response: "EWPM" or "ERR: No pulses available, cannot enable waveform mode." or "ERR: No sequences available, cannot enable waveform mode." or "ERR: Emission is ON!" or "ERR: Laser is not in Pulse Mode!"
PCFG	Configure Waveform Mode — Returns the status of the Waveform Mode and the ID number of the selected Pulse Profile or Pulse Sequence.	Sent: "PCFG" Response: "PCFG: [] [Status:Disabled] [Mode:Profile] [ID:2] [END]"
PRLS	Profile List — Displays a list of available Pulse Profiles stored in the device library.	Sent: "PRLS" Response: "PRLS: [] [0:New Shape 0] [2:New Shape 2] [END]"
PRSEL	Select Profile — Selects Single Pulse Mode and Pulse Profile ID. If the command is not followed by the ID number or the ID is invalid, then the existing selection is used.	Sent: "PRSEL 2" Response: "PRSEL: [2:New Shape 2]" or "ERR: Entered pulse ID is not valid" or "ERR: No pulses are available"
SQLS	Sequence List — Displays a list of available Pulse Sequence programs stored in the device library.	Sent: "SQLS" Response: "SQLS: [] [0:New Program 0] [4:New Program 4] [END]"

Code	Description	Example
SQSEL	Select Sequence - Selects Pulse Sequence Mode and Pulse Sequence ID. If the command is not followed by the ID number or the ID is invalid, then the existing (or last) selection is used.	Sent: “SQSEL 4” Response: “SQSEL: [4:New Program 4]” or “ERR: Entered sequence ID is not valid” or “ERR: No sequences are available”

4

Pulse Shaping

Overview

The Pulse Shaper program lets you sketch pulse points. It automatically fills in pulse (power level) lines, and computes all the emission pulse characteristics simultaneously. It also performs auto-correction in case constraints are violated.

A laser emission pulse is a custom time-based emission power signal, constrained by an output sample time, maximum power, maximum energy and minimum current (power) threshold, all of which are pre-configured in the laser.

Pulses are not zeroed visually when they go under the power threshold, although that is not reflected in the pulse energy calculation.

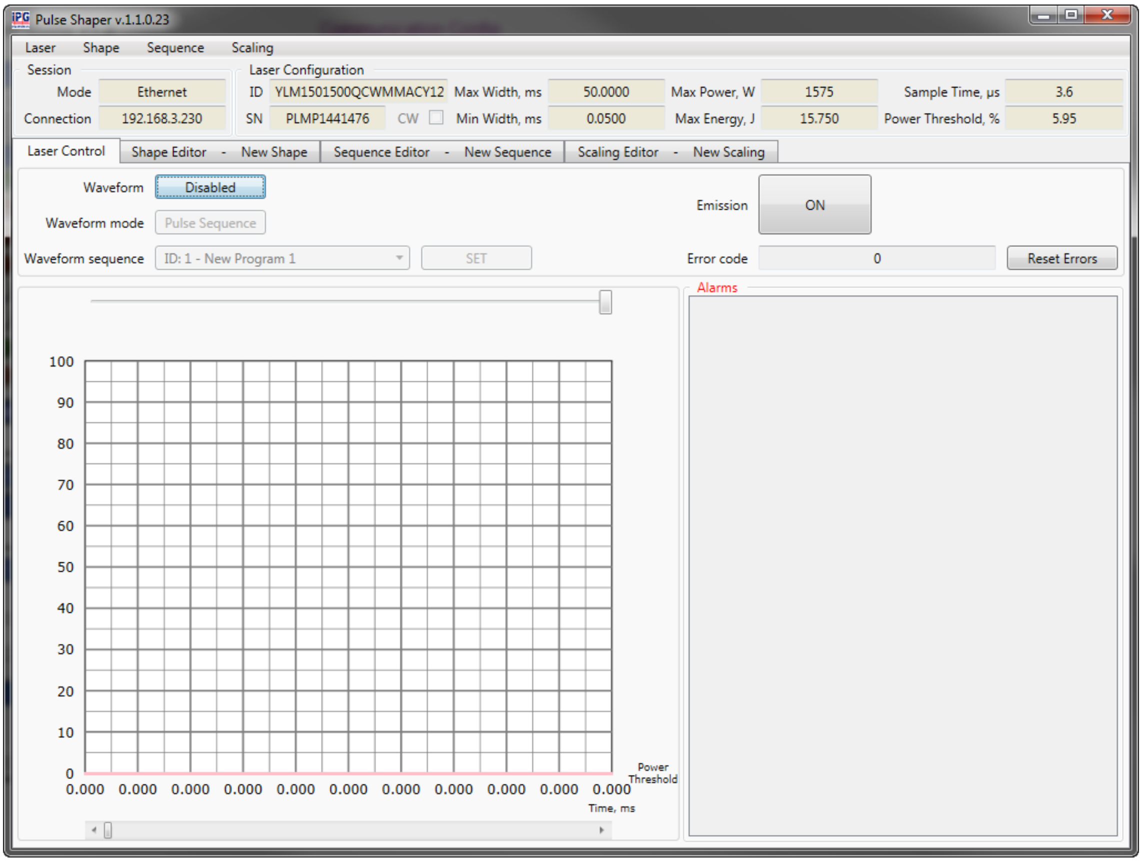
To avoid pulse energy limits, either shorten your pulse widths or reduce the value of the Time Scale.

Each time you change a Pulse Shape profile, the pulse widths are updated to reflect the current sketched pulse. You cannot exceed the limits established in the laser configuration.

You can create effective Pulse Shapes to meet the changing requirements of your applications. You can store Pulse Shapes in a Pulse Profiles library on the laser or locally to your computer. You can also create and store Pulse Sequences (combinations of pulse profiles, delays, and repeats) in a Pulse Sequences library or locally to your computer.

Figure 4-1 shows the Pulse Shaper interface.

Figure 4-1. Pulse Shaper Interface



PC Requirements

The following minimum requirements are necessary for installing and using the Pulse Shaping software:

- x86 machine with at least 512 MB RAM, 5 GB hard disk, mouse and keyboard, VGA monitor and a Ethernet or Serial (RS-232) communication port
- Operating System: Windows 7
- Software: MS .NET Framework, Version 4.5
- Pulse Shaping program: Designated release version executable

Ethernet TCP/IP Interface

See “Ethernet TCP/IP Interface” on page 3-1 for details on the Ethernet Interface.

See Table 3-2 on page 3-1 for a list of Ethernet Interface pinouts.

RS-232 Configuration

See “RS-232 Configuration” on page 3-1 for details on RS-232 configuration.

See Table 3-1 on page 3-1 for a list of RS-232 parameters.

Key Terms

- **Shape Editor** — Lets you create and edit various Pulse Shapes and save them in the Pulse library.
- **Sequence Editor** — Lets you create a sequence of pulses (pulse train) using Pulse Shapes from Pulse library.
- **Scaling Editor** — Lets you scale pulses within a sequence (ramp up and down).
- **Waveform** — A waveform is the shape and form of a signal.

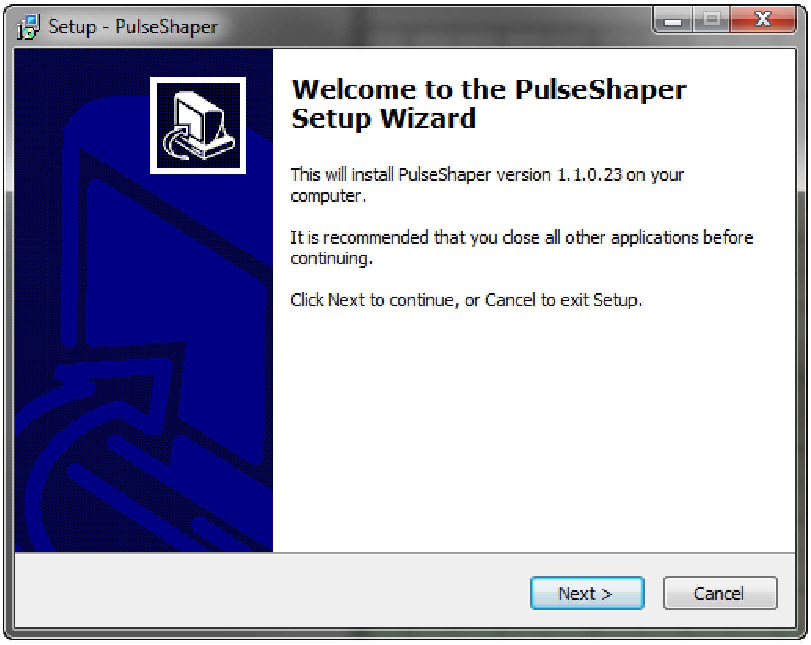
Installing the Pulse Shaper Software

To install the software package, run the Pulse Shaper Setup, which creates a folder with the Pulse Shaper program.

To install the Pulse Shaper software:

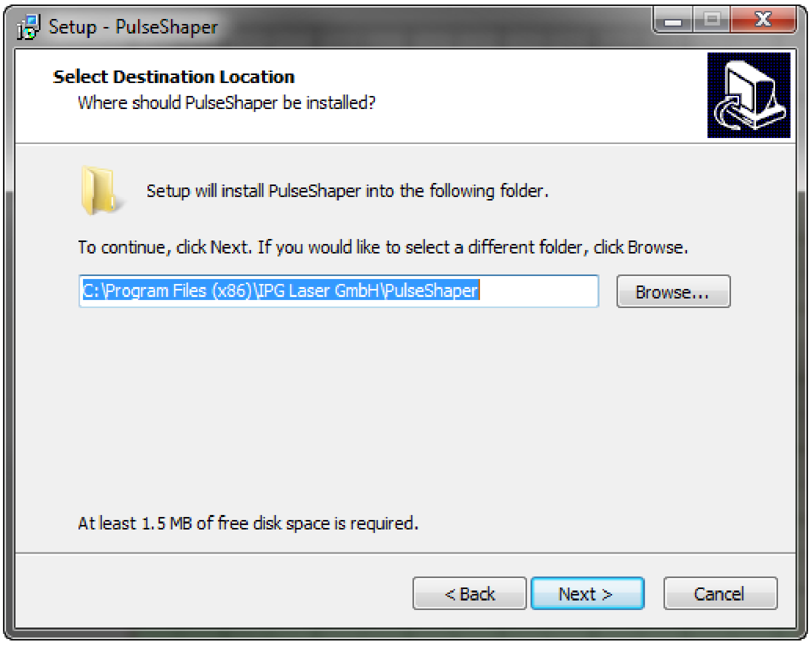
1. Run the **PulseShaper Setup.exe** and select a language. The PulseShaper Setup Wizard appears as shown in Figure 4-2.

Figure 4-2. PulseShaper Setup Wizard



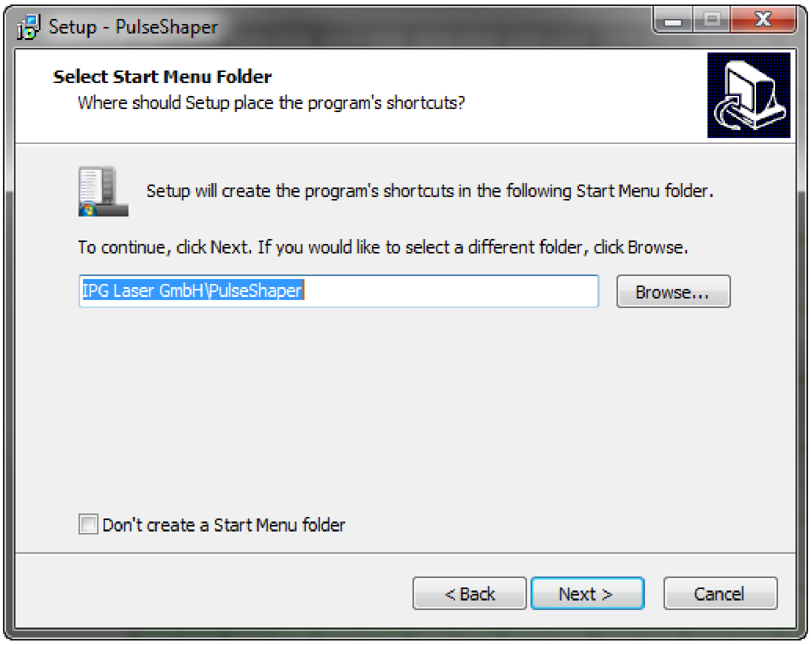
2. Click **Next** to continue.
3. Select a destination location or accept the default location for the installation as shown in Figure 4-3 and click **Next**.

Figure 4-3. PulseShaper Setup - Location Destination



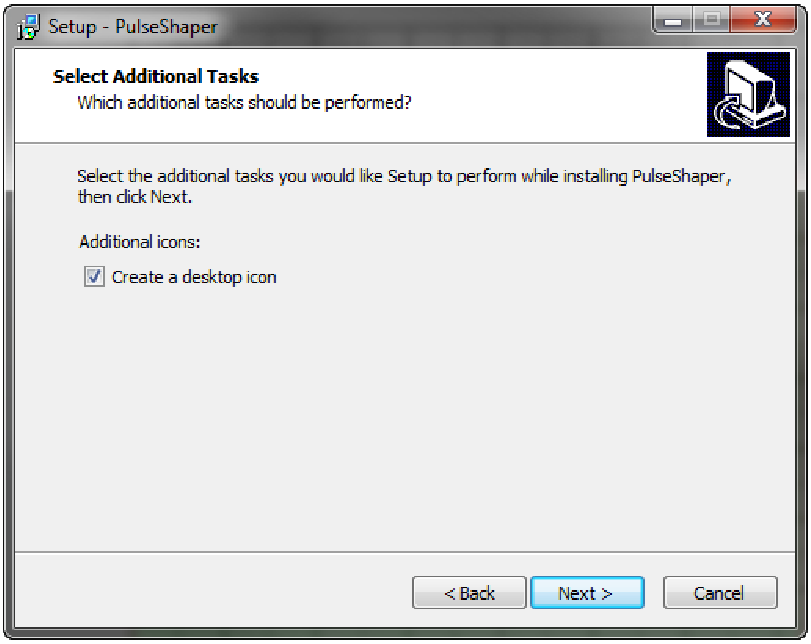
4. Click **Next** to accept the default Start Menu folder for the Pulse Shaper shortcut.
   a. Click **Browse** if you want to change the default Start menu to another location.
   b. Click the **Don't create a Start Menu folder** checkbox to skip this step.

Figure 4-4. PulseShaper Setup - Program Shortcut



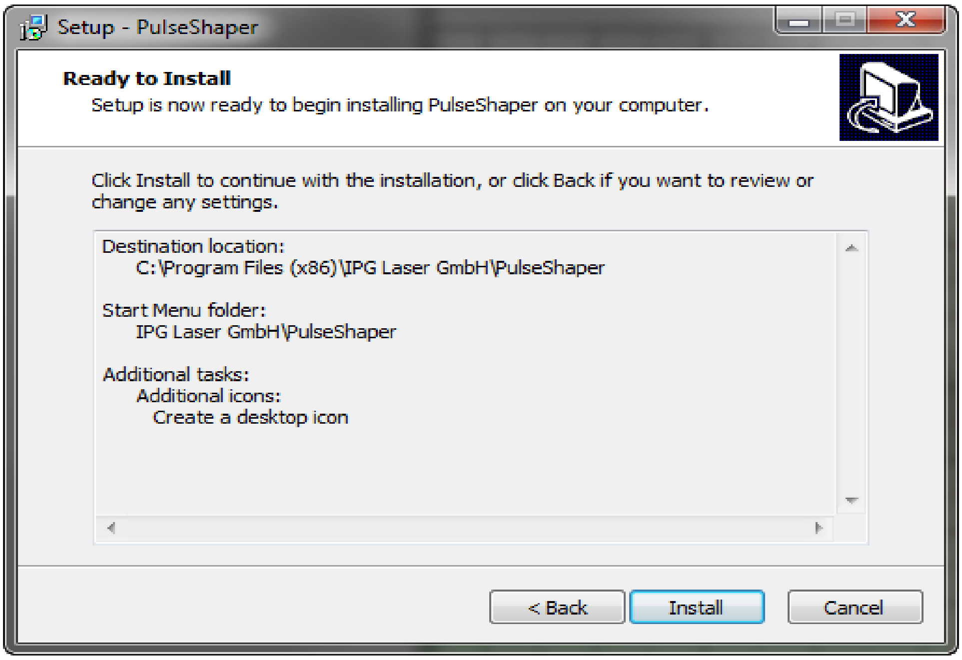
5. Click **Next** to create a PulseShaper icon on your desktop (default) as shown in Figure 4-5.
   a. Deselect the **Create a desktop icon** checkbox if you want to skip this step.

Figure 4-5. PulseShaper Setup - Desktop Icon



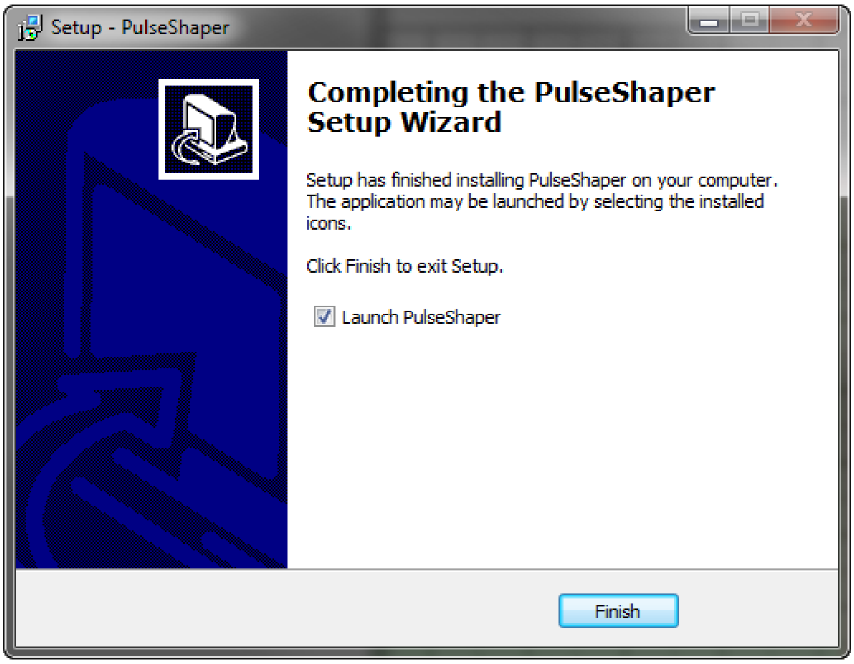
6. Click **Install** to continue with installation as shown in Figure 4-6.

Figure 4-6. PulseShaper Setup - Ready to Install



7. Click **Finish** to exit Setup as shown in Figure 4-7. By default, the Pulse Shaper program launches when you exit Setup.
   a. Deselect the **Launch PulseShaper** checkbox if you do not want Pulse Shaper to launch upon exiting Setup.

Figure 4-7. PulseShaper Setup - Finish

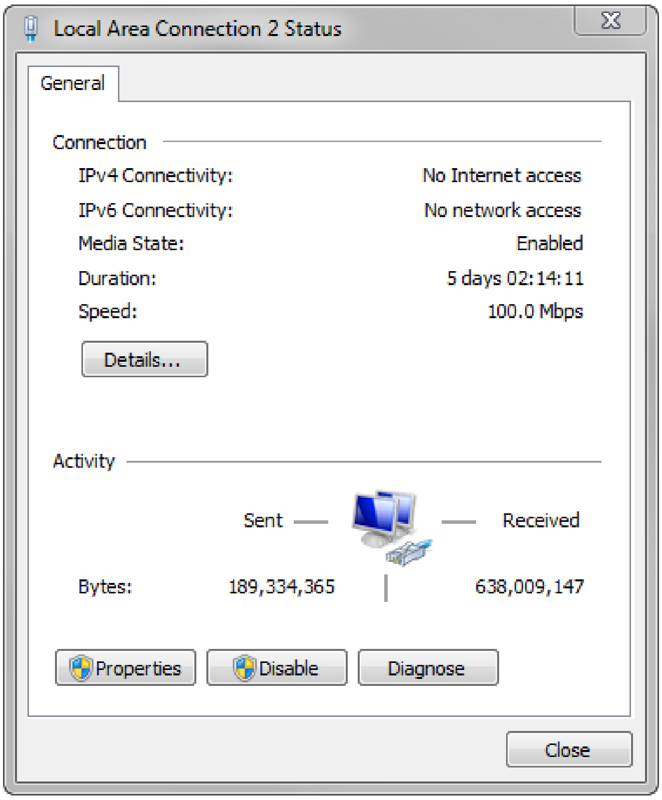


Configuring a Local Area Connection for Ethernet

To configure a local area connection for Ethernet:

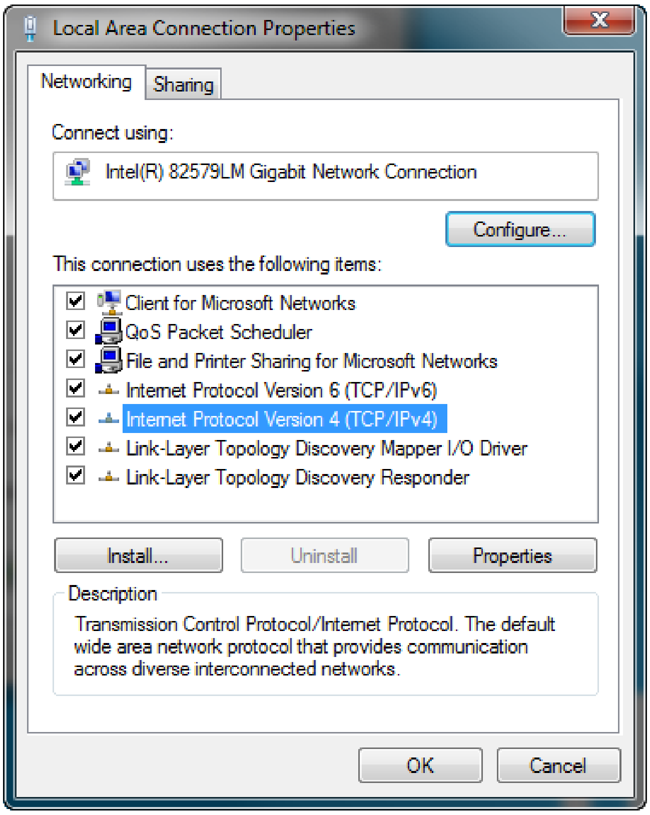
1. Go to **Control Panel -> Network and Internet -> Network and Sharing Center**.
2. Click **Change adapter settings**.
3. Select a Local Area Connection icon. The following window appears as shown in Figure 4-8.

Figure 4-8. Local Area Connection Status



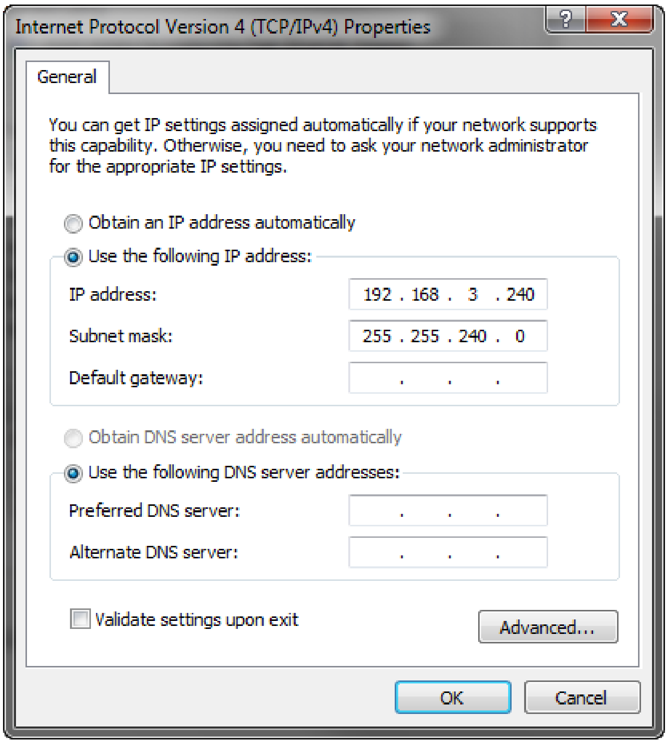
4. Click **Properties**. The following window appears as shown in Figure 4-9.

Figure 4-9. Local Area Connection Properties



5. Select **Internet Protocol Version 4 (TCP/IPv4)**.
6. Click the **Properties** button. The following window appears as shown in Figure 4-10.

Figure 4-10. Internet Protocol Version 4 Properties



7. Click the **Use the following IP address** radio button to manually assign the IP address.
8. Assign the IP address to 192.68.3.23x (x cannot be 0).
9. Assign the subnetmask setting to 255.255.240.0.
10. Click **OK** to accept these manual changes.

Pulse Shaper Configuration Procedures

You can connect to the Pulse Shaper program from either an Ethernet or RS-232 connection.

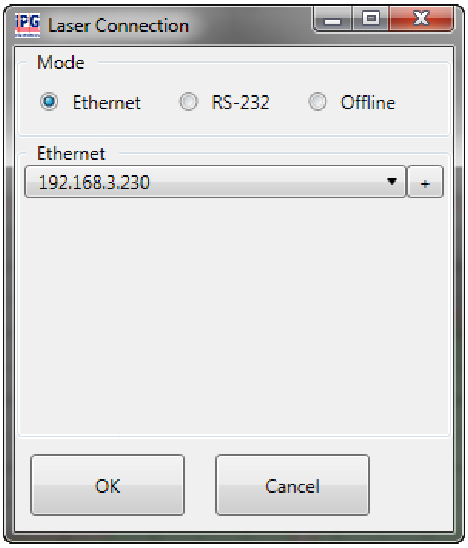
Connecting using Ethernet

You can connect to the Pulse Shaper using an Ethernet connection from your computer to the laser. This procedure starts a connection to the laser over a network via a specific IP Serial Port.

To connect using Ethernet:

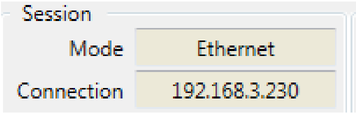
1. Connect your PC to the laser using network cable.
2. Configure the Local Area Connection settings for Ethernet as explained in “Configuring a Local Area Connection for Ethernet” on page 4-9.
3. Start the Pulse Shaper program.
4. Click **Laser->Connect**. The Laser Connection dialog box appears as shown in Figure 4-11.

Figure 4-11. Pulse Shaper - Ethernet Laser Connection



5. Click the **Ethernet** radio button.
6. Select the IP address of the laser from the drop-down listbox.
7. Click **OK**.

The status is displayed in the **Session** box indicating that the connection is successful.



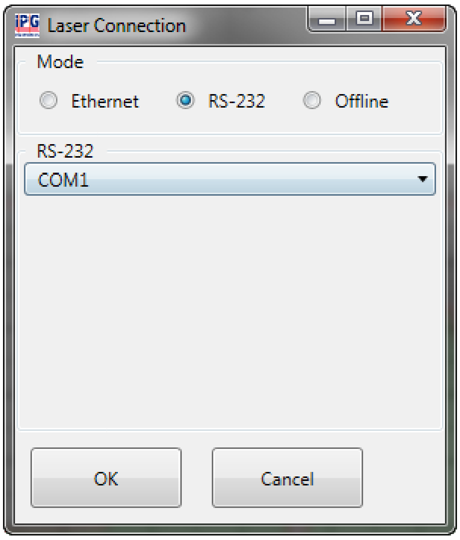
Connecting Using RS-232

You can connect to the Pulse Shaper program using an RS-232 Serial connection from your computer to the laser. This procedure starts a connection to the laser over RS-232 serial cable via a specific port on the host machine.

To configure an RS-232 serial connection:

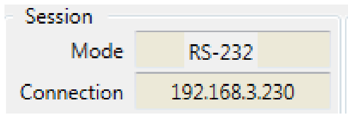
1. Connect a RS-232 serial cable from your computer to the laser.
2. Start the Pulse Shaper program.
3. Click **Laser->Connect**. The Laser Connection dialog box appears as shown in Figure 4-12.

Figure 4-12. Pulse Shaper - RS-232 Laser Connection



4. Click the **RS-232** radio button.
5. Select a valid COM port on the laser from the drop-down listbox.
6. Click **OK**.

The status is displayed in the **Session** box indicating that the connection is successful.



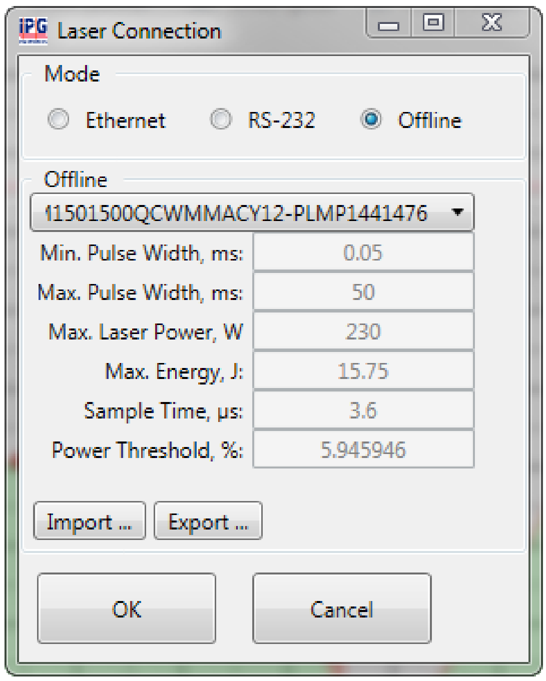
Using the Offline Option

You can export and import a configuration from a laser connection and store it for later use with the Offline option. When you export a configuration, the chart (including unused time segments) is preserved with the original time scale.

To use the Offline option:

1. Start the Pulse Shaper program.
2. Click **Laser->Connect**. The Laser Connection dialog box appears as shown in Figure 4-13.
3. Click **Offline**.

Figure 4-13. Pulse Shaper - Offline Option



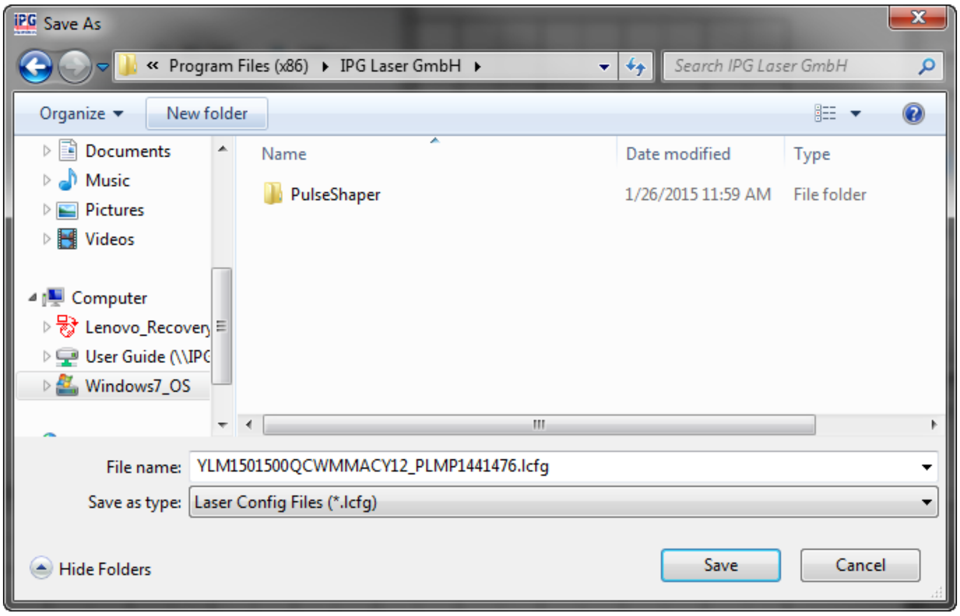
4. Export or import a pulse configuration as detailed in the next sections.

Exporting a Configuration

To export a saved configuration from a previous laser connection (lcfg file.):

1. Click **Export...** The following dialog box appears as shown in Figure 4-14 on page 4-15.

Figure 4-14. Export Configuration



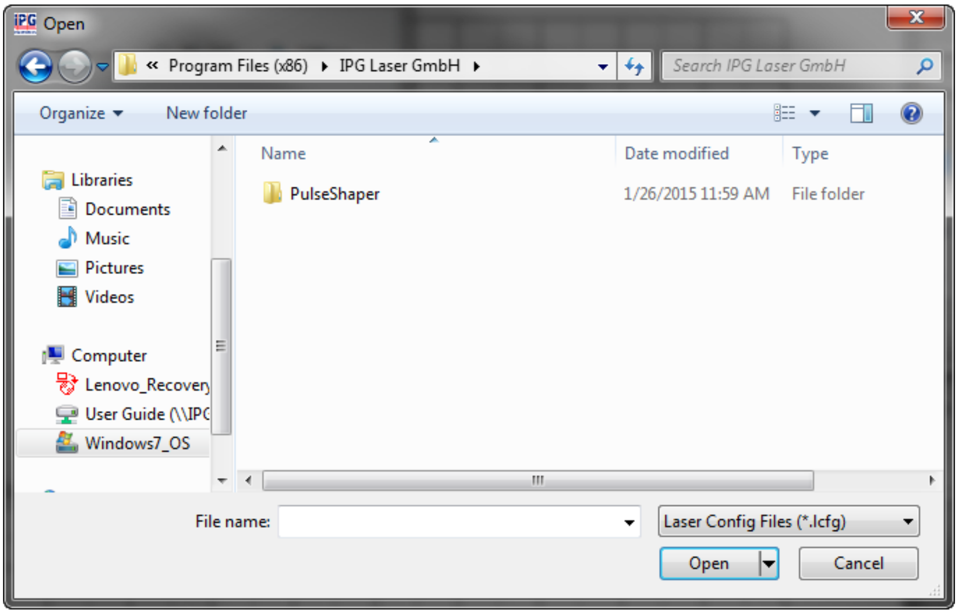
2. Accept the default filename or rename the file and click **Save**.

Importing a Configuration

To import a saved configuration from a previous laser connection (lcfg file.):

1. Click **Import...** The following dialog box appears as shown in Figure 4-15 on page 4-16.

Figure 4-15. Import Configuration



2. Select the configuration file (.lcfg) and click **Open**.

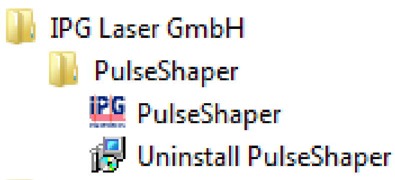
3. Click **Yes** to overwrite an existing configuration if applicable.

Using the Pulse Shaper Program

To start the Pulse Shaper program:

1. Go to **All Programs ->IPG Laser GmbH ->PulseShaper**.
2. Select **PulseShaper.**

Figure 4-16. Pulse Shaper Program



The Pulse Shaper interface appears as shown in Figure 4-17.

Figure 4-17. Pulse Shaper Interface

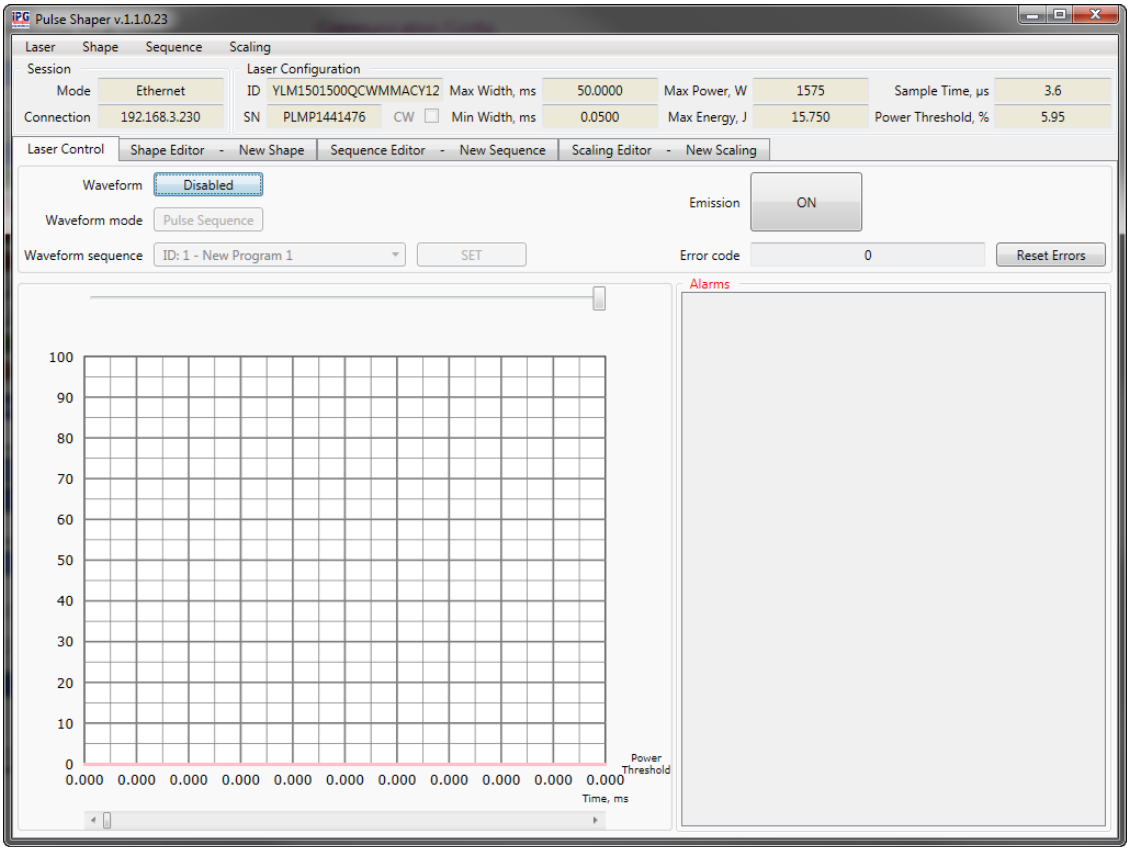


Table 4-1 provides the descriptions for the four menu items in the Pulse Shaper program.

Table 4-1. Pulse Shaper Menu Items

Menu Name	Description
Laser	• **Connect** — Connects to the laser via Ethernet or RS-232. You can also the Offline option and import a saved Pulse Profile configuration file. • **Disconnect** — Disconnects the Pulse Shaper program from the laser. • **Synchronization** — Synchronizes the Pulse Shapes with the laser using the Ethernet IP address or RS-232 connection. • **Backup** — Backs up the configuration profile to a .bkp file. • **Restore** — Restores the configuration profile from a backup file. All current data is replaced with data stored in the backup file. • **Pulse mode** — Indicates that Pulse mode is active. • **Exit** — Closes the Pulse Shaper program.
Shape	• **New** — Creates a new Pulse Shaping profile. • **Read from Laser** — Loads and displays a Pulse Shaping profile from the laser. • **Write to Laser** — Saves the current Pulse Shaping profile to the laser. This option only saves the effective pulse. • **Delete in Laser** — Deletes a Pulse Shaping profile that is stored in the laser. • **Read from File** — Loads and displays a Pulse Shaping profile from a saved file (.shp) on your computer. • **Write to File** — Saves the current Pulse Shaping profile to a file (.shp) to your computer.
Sequence	• **New** — Creates a new Pulse Sequence. • **Read from Laser** — Loads and display a Pulse Sequence from the laser. • **Write to Laser** — Saves a Pulse Sequence to the laser. • **Delete in Laser** — Deletes a Pulse Sequence from the laser. • **Read from File** — Loads and displays a Pulse Sequence from a saved file (.sec) on your computer. • **Write to File** — Saves a Pulse Sequence to a file (.sec) to your computer.
Scale	• **New** — Creates a new Pulse Scale. • **Read from Laser** — Loads and display a Pulse Scale from the laser. • **Write to Laser** — Saves current Pulse Scale to the laser. This option only saves the effective Pulse Scale. • **Delete in Laser** — Deletes a Pulse Scale that stored in the laser. • **Read from File** — Loads and display a Pulse Scale from a file (.scl) on your computer. • **Write to File** — Saves current Pulse Scale to a file (.scl) to your computer.

Table 4-2 provides descriptions for the Pulse Shaper main window options.

Table 4-2. Main Window Descriptions

Name	Description
Session Panel	
Mode	Displays the active session type.
Connection	Displays the connection status (Ethernet or RS-232).
Laser Configuration Panel	
ID	The configuration identification for the laser.
SN	The serial number of the laser.
CW	Indicates if the CW operating mode (Continuous Wave) is active. In CW mode, the maximum pulse duration and duty cycle are not applicable.
Max Width, ms	Maximum allowed pulse width.
Min Width, ms	Minimum allowed pulse width.
Max Power, W	Maximum allowed pulse power.
Max Energy, J	Maximum allowed pulse energy.
Sample Time, μs	Minimum interval for pulse points.
Power Threshold %	Emission (current) effective zero level.

Laser Control Tab

The Laser Control tab lets you activate a Pulse Sequence.

Figure 4-18 shows the Laser Control tab.

Figure 4-18. Laser Control Tab

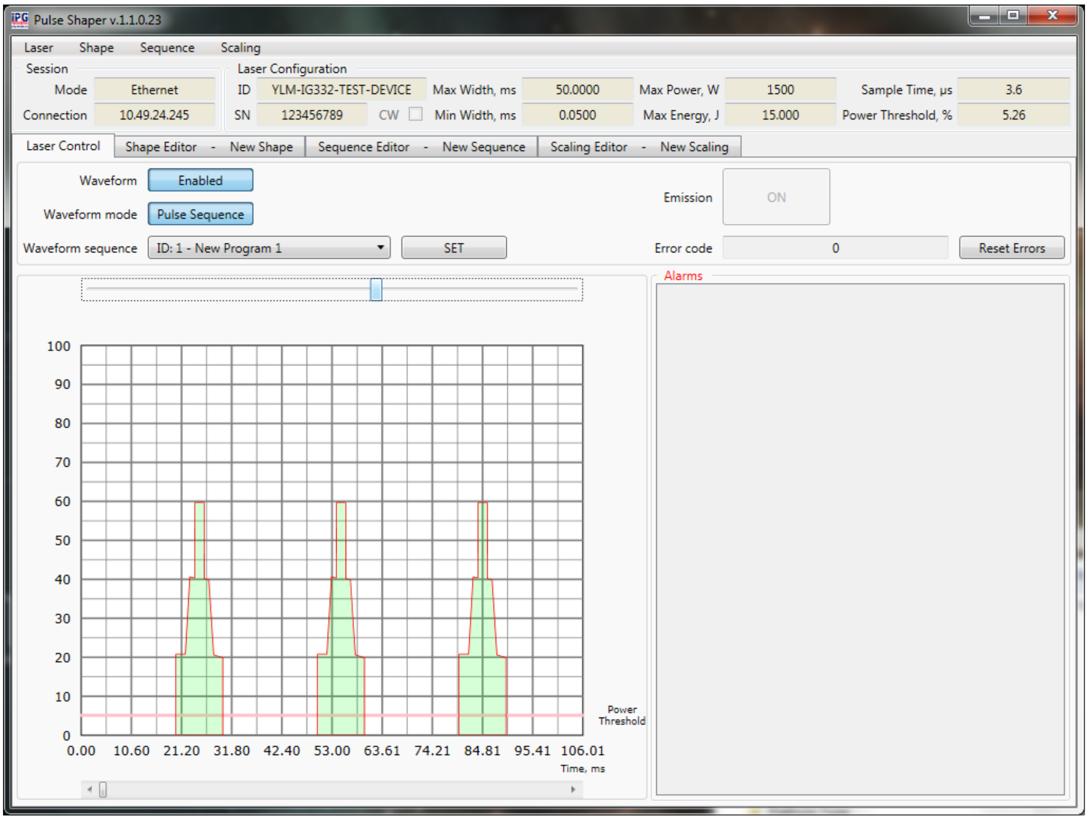


Table 4-3 provides descriptions for the options in the Laser Control tab.

Table 4-3. Laser Control Tab Descriptions

Name	Description
Waveform	Toggles the waveform status.
Waveform mode	Toggles between a Single Pulse and Pulse Sequence.
Waveform sequence	Select a Pulse Sequence from the listbox. Click **SET** to apply the Pulse Sequence for viewing in the chart.
Emission	Click **ON** to show the emission power in the chart.
Error Code	Click **Reset Errors** to clear error codes after they are addressed.

Shape Editor Tab

The Shape Editor lets you create and edit various Pulse Shape profiles and save them in the Pulse Shapes library on the laser or locally to your computer.

Figure 4-19 shows the Shape Editor tab.

Figure 4-19. Shape Editor Tab

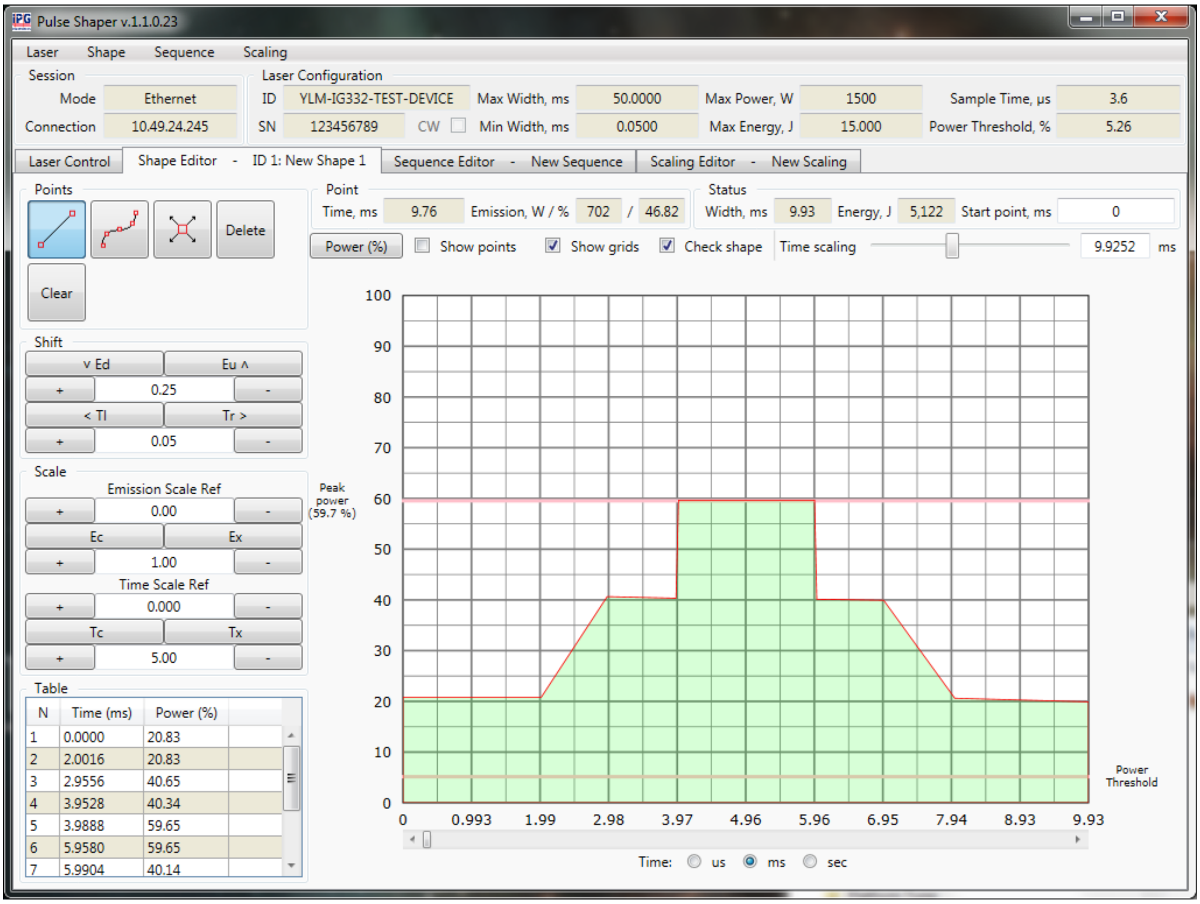


Figure 4-20 shows the Points Panel in the Shape Editor tab.

Figure 4-20. Shape Editor Tab - Points Panel

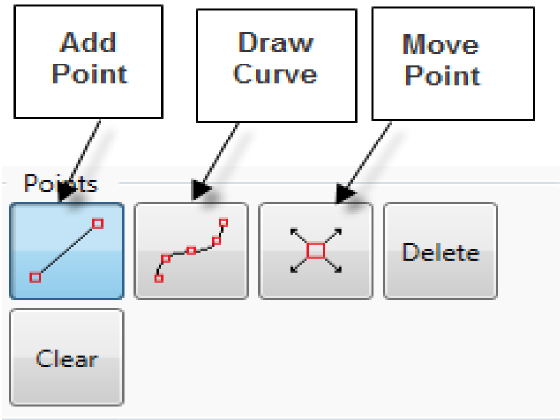


Figure 4-21 shows the Shift Panel in the Shape Editor tab.

Figure 4-21. Shape Editor Tab - Shift Panel

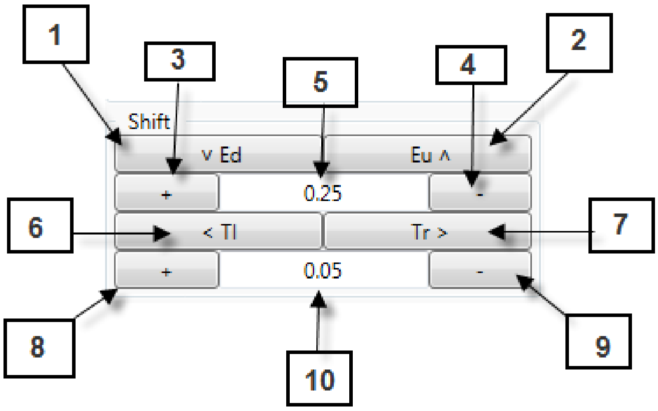


Table 4-4 provides descriptions for the Point and Shift Panel controls in the Shape Editor tab.

Table 4-4. Shape Editor Tab - Points and Shift Panel Controls

Item	Name	Description
Points		
	Add Point Tool	Plots pulse points in the chart and automatically forms lines.
	Draw Curve Tool	Plots an arbitrary pulse in the chart and automatically forms points and lines along the graph (using your mouse).
	Move Point Tool	Relocates a pulse point on the chart.
	Delete Point	Deletes a pulse point from the Table box.
	Clear	Clears the entire pulse chart.
Shift Panel[a]		
1	Emission Shift Down	Shifts all pulse points down in emission.
2	Emission Shift Up	Shifts all pulse points up in emission.
3	Increase Emission Shift Step	Increases the emission shifting step size.
4	Decrease Emission Shift Step	Decreases the emission shifting step size.
5	Emission Step	Sets the emission shifting step size (.25 - 100%).
6	Time Shift Left	Shift all pulse points back in time.
7	Time Shift Right	Shifts all pulse points forward in time.
8	Increase Time Shift Step	Increases the time shifting step size.
9	Decrease Time Shift Step	Decreases the time shifting step size.
10	Emission Scale Ref	Sets the reference point for emission scaling (0 - 100%).

a. Due to the digitized nature of the pulses, approximations are used to compute modulations. Modulation step values (especially very small ones) might not have an effect. IPG recommends you save the original pulse while manipulating the pulse for easy comparison between the modulated pulse and the original.

Figure 4-22 shows the Scale Panel in the Shape Editor tab.

Figure 4-22. Shape Editor Tab - Scale Panel

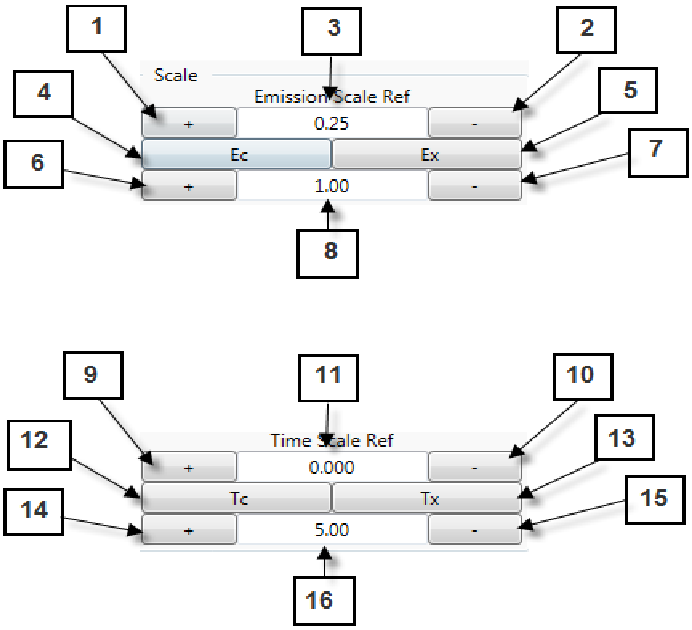


Table 4-5 provides descriptions for the Scale Panel controls in the Shape Editor tab.

Table 4-5. Shape Editor Tab - Scale Panel Controls

	Name	Description
Emission Scale Ref[a]		
1	Increase Emission Scale Ref	Increases the reference point for emission scaling.
2	Decrease Emission Scale Ref	Decreases the reference point for emission scaling.
3	Time Step	Sets the time shifting step size (ms).
4	Compress Emission	Compresses all pulse points in emission with regards to the reference point.
5	Expand Emission	Expands all pulse points in emission with regards to the reference point.
6	Decrease Emission Scale Step	Decreases the step size for emission scaling.
7	Increase Emission Scale Step	Increases the step size for emission scaling.
8	Emission Scale Step	Sets the step size for emission scaling (.25 - 100%).
Time Scale Ref		
9	Increase Time Scale Ref	Increases the reference point for time scaling.
10	Decrease Time Scale Step	Decreases the step size for time scaling.
11	Time Scale Ref	Sets the reference point for time scaling (0 - 50ms).
12	Compress Time	Compresses all pulse points in time with regards to the reference point.
13	Expand Time	Expands all pulse points in time with regards to the reference point.
14	Increase Time Scale Step	Increases the step size for time scaling.
15	Decrease Time Scale Ref:	Decreases the reference point for time scaling.
16	Mod Time Scale	Sets the step size for time scaling (.25 - 100%).

a. Due to the digitized nature of the pulses, approximations are used to compute modulations, so modulation step values, especially the very small ones might not have an effect. It is recommended to save original pulse while manipulating the pulse so it's easy to compare the modulated pulse against the original.

Figure 4-23 shows the chart in the Shape Editor tab.

Figure 4-23. Shape Editor Tab - Chart

Table 4-5 provides descriptions for the options in the Chart in the Shape Editor tab.

Table 4-6. Shape Editor Tab - Chart

	Name	Description
Chart Panel[a]		
1	Time (X-axis)	Time domain in µs, ms, or sec.
2	Emission (Y-axis)	Emission level in percent power.
3	Power Threshold	Visual representation of the current threshold level in the laser configuration. Appears in pink box in the chart. Any pulse data within does not have any power.
4	Profile Memory	Current pulse memory utilization/maximum allowable.

a. Due to the digitized nature of the pulses, approximations are used to compute modulations, so modulation step values, especially the very small ones might not have an effect. It is recommended to save original pulse while manipulating the pulse so it is easy to compare the modulated pulse against the original.

Creating a New Pulse Shape Profile

To create a new Pulse Shape profile:

1. Select **Shape -> New**.
2. Select a time scale unit (µs, ms, or sec) from one of the **Time:** buttons at the bottom of the window.
3. Draw the shape by adding points.
4. To change points, modify values in the Table box in the left pane.
5. Once the Pulse Shape is complete, you can save it to the Pulse Shapes library or locally on your computer.
    a. To save to the Pulse Shapes library, on the laser select **Shape -> Write to Laser**.
    b. To save to your computer, select **Shape -> Write to File**.

Creating a Single Pulse Shape

For simple applications, you might require only a Single Pulse shape.

To create a single Pulse Shape:

1. Select **New** from the **Shape** menu. A new shape appears in the Shape Editor tab.
2. Select the **Add Point** tool and use your mouse to plot points along the pulse chart. Lines are automatically generated to connect the plotted dots.
3. Click the **Show points** checkbox to display the graphical points along the grid lines in the chart.
4. Select the **Move** tool and drag and move any pulse point. You should be able to move the pulse point in any direction.
5. Select **Delete** and click on any existing point. The point is removed and the pulse line is regenerated to connect the neighboring points.
6. Select the **Add Point** tool and click between any two existing pulse points. The pulse lines are updated to connect the new point to the neighboring ones.
7. Click **Clear** to remove the entire pulse chart.

Shifting a Pulse Shape

You can manipulate an existing Pulse Shape to create new variations. This method can save you time and achieve better symmetry. See Figure 4-21 for an illustration of Shift Panel controls.

To shift a pulse:

1. Select **New** from the **Shape** menu.
2. Create a preliminary pulse (preferably an alternating one) such as a square or sine wave.
3. Set an emission step percentage value in the Shift Panel.
4. In the Shift Panel, click Emission Shift Down (**Eu** ∧) or Emission Shift Up (∨ **Ed**) to introduce an emission offset to the pulse.
5. Set a certain Time Step value in the Shift Panel.
6. Click Time Shift Left (**Tr>**) Time Shift Right (**<Tl**) to introduce a time offset to the pulse.
7. Set an Emission Scale Ref percentage value. It should be the effective zero point of your pulse to get the best result.

   For example, if you are modulating a sine wave, set to be in the center point. Also, set an Emission Scale percentage value then click Expand Emission or Compress Emission to scale effective emission with respect to the reference point.
8. Use the **Time scaling** slider to set a Time scale value. It should be the effective zero point of your pulse to get the best result.

Note

Because of the sample time constraint, scaling can be unsymmetrical, and there could be a small range of ineffective scaling factors, all that is due to the sample approximation during the calculations. IPG recommends you save the original pulse prior to modulating a pulse.

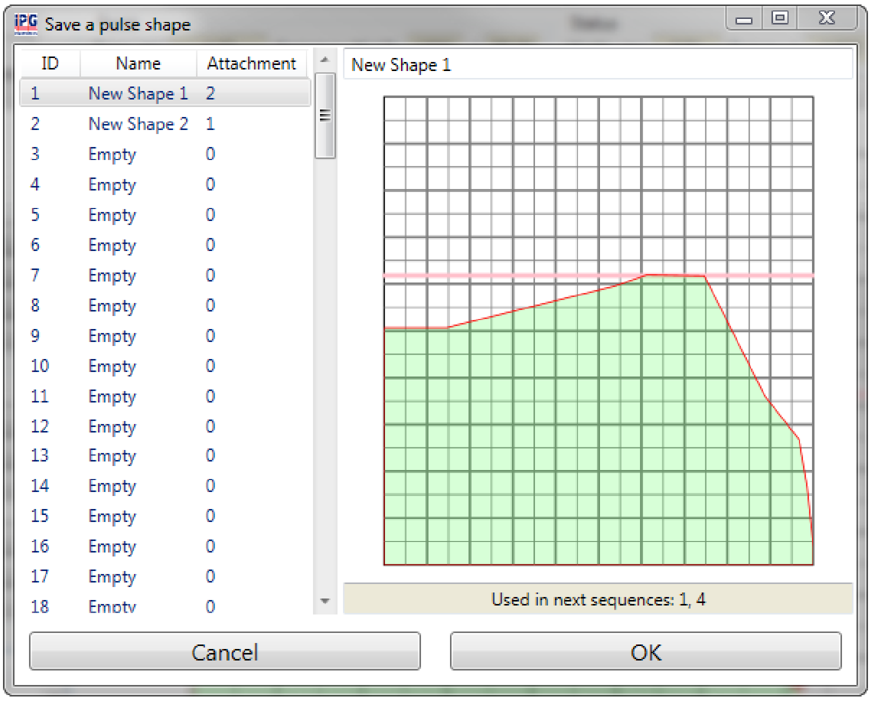
Pulse Shape Storage and Recall

On a Laser

This section requires connection to the laser. It is important to write pulses to the laser to use and activate them.

1. Sketch a Pulse shape as explained in "Creating a Single Pulse Shape" on page 4-28.
2. Select **Shape->Write to Laser.**

Figure 4-24. Write a Pulse Profile to the Laser



3. Select a pulse ID or enter a new name for the pulse profile and click **OK**.

   The message "Shape was saved" appears.

   The pulse data is encoded and transmitted to the laser for storage.

To recall:

1. Select **Shape->Read from Laser**.
2. Select a pulse profile ID and click **OK**.

The Pulse Shape is fetched, decoded, and displayed on the chart. The displayed pulse might appear differently as any unused time in the chart is removed as only the effective pulse width is saved.

On a Host PC

You can write Pulse Sequences to your computer to use and activate them in the Sequence Editor.

To save a Pulse Sequence your computer:

1. Select **Shape -> Write to File**.
2. Enter a name for the file and click **Save**.

To recall a Pulse Shape:

1. Select **Shape->Read from File**.
2. Select a pulse ID and click **OK**.

   The Pulse Shape is fetched and loaded into the chart.

Deleting a Pulse Profile

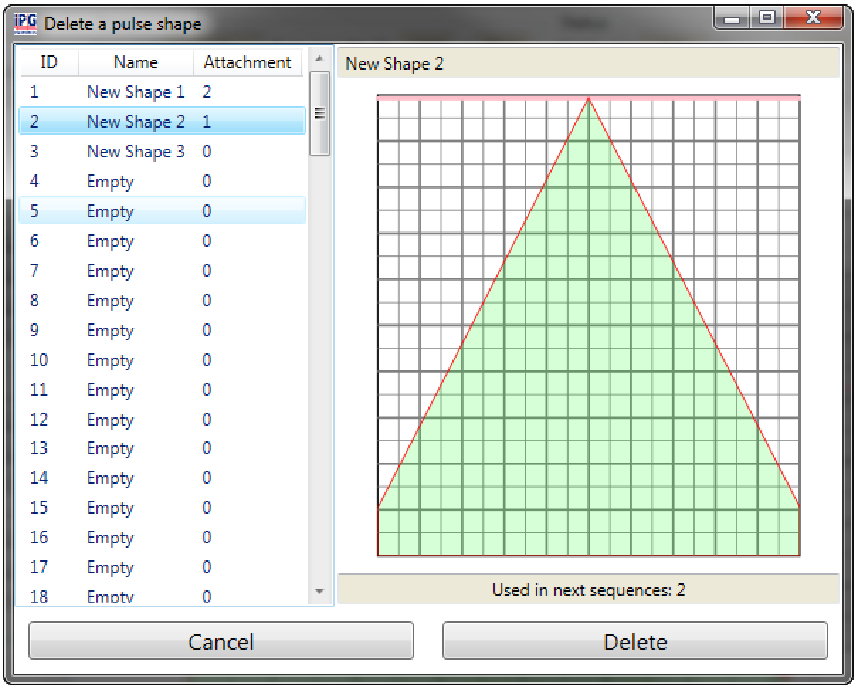
You can only delete or make changes to a pulse if the pulse profile status is “Idle”. The “In Use” status identifies that the laser is configured with that pulse.

You cannot delete a pulse profile that has an attachment status greater than zero, which means that the pulse is used by one or more existing sequences. However, you can overwrite a pulse if you accept to bypass the warning.

To delete a Pulse Shape profile:

1. Select **Shape->Delete in Laser**. The Delete a Pulse Shape dialog box appears.

Figure 4-25. Delete a Pulse Profile in the Laser



2. Select a profile ID to delete.
3. Click **Delete.**
4. Click **Yes** in the confirmation box.

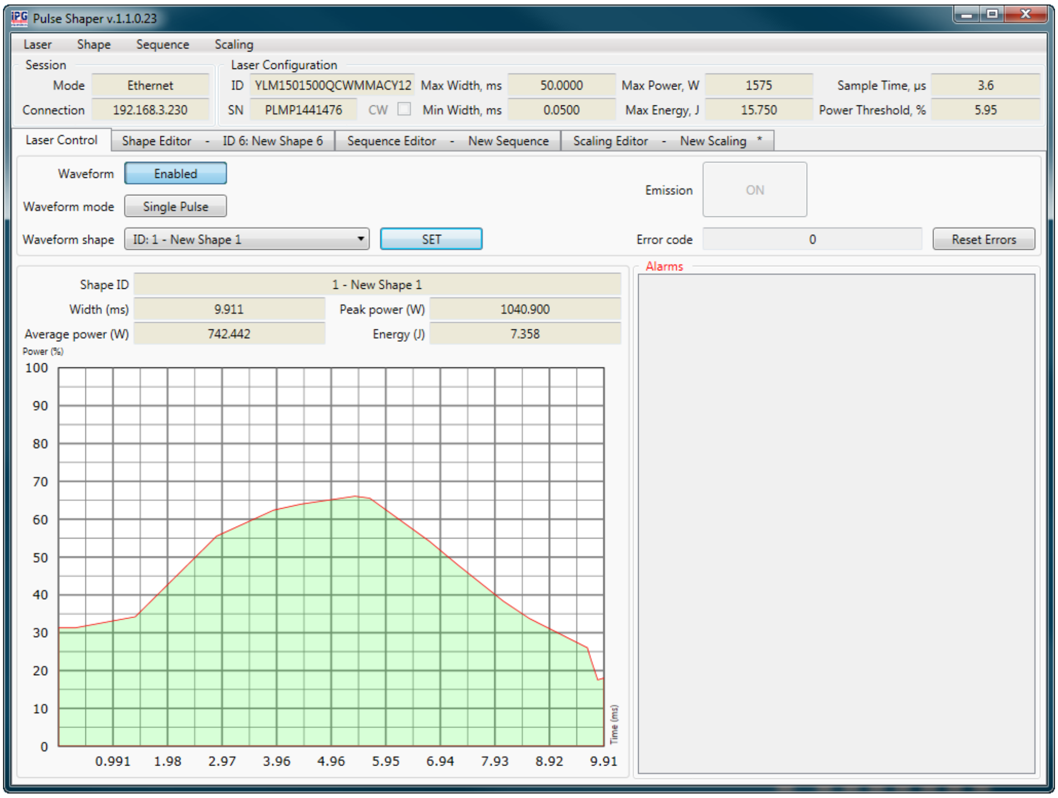
Single Pulse Activation

To activate a Single Pulse:

1. Select **Laser -> Connect**. See "Pulse Shaper Configuration Procedures" on page 4-12 for the steps for connecting via Ethernet or RS-232.
2. Click the Laser Control tab.
3. Toggle the **Waveform** button to **Enabled**.
4. Toggle the **Waveform mode** to **Single Pulse**.
5. Select a Waveform shape from the listbox.
6. Click **SET**.
7. Click **Emission** to confirm and start countdown.

   The selected pulse is emitted after the countdown.
8. Click **Emission** again to clear the status. This also stops a pulse sequence if it is set to infinite repeats.

Figure 4-26. Single Pulse Activation



Single Pulse Activation using the Touch-Display Screen

This section requires connection to the laser.

1. After storing a pulse to the laser, ensure the Emergency Stop button is released on the laser and then press the green button to turn on the power supply.

Note

Both Analog and Modulation modes must be set to “Off” to configure the pulse mode. You can access these modes from the Setup submenu in the Touch-Screen Display.

2. On the laser touch-screen, select **Setup->Pulse Setting-> Waveform Mode**.
3. Toggle **Waveform Pulse Mode** to Enabled.
4. Select **Single Pulse**.
5. Use the Up/Down arrows to select a specific pulse.

Note

If no pulse profile is saved the laser's pulse profile list, then “!! No Profiles Available!!” is displayed.

6. Pulse Information/Preview (optional) —To view information about the pulse, click on the Pulse Browser button. This is the button with the name of the pulse. Once the information page appears, you can use the arrows to scroll through all available pages.
7. Click anywhere in the text space to go to the Preview page. You can see the shape of the pulse.
8. Click **Return** twice to go back to the Waveform page.
9. Click **Configure & Return**.

   It is important to configure the laser with the selected pulse (once) before usage.
10. After the configuration is complete, click **Return** twice to go back to the main page.
11. Click **Emission** and then click **OK** to confirm and start countdown. The selected pulse is emitted after the countdown.
12. Click **Emission** again to clear the status.

Scaling Editor

The Scaling Editor lets you scale pulses within a sequence (ramp up and down).

If Analog Power Control is enabled, it allows on-the-fly scaling of the Pulse Sequence by varying analog input signal. You do not need to use Scaling Editor. See “Accessing the Web User Utility” on page A-5 to enable Analog Power Control.

Figure 4-27 shows the Scaling Editor tab.

Figure 4-27. Scaling Editor

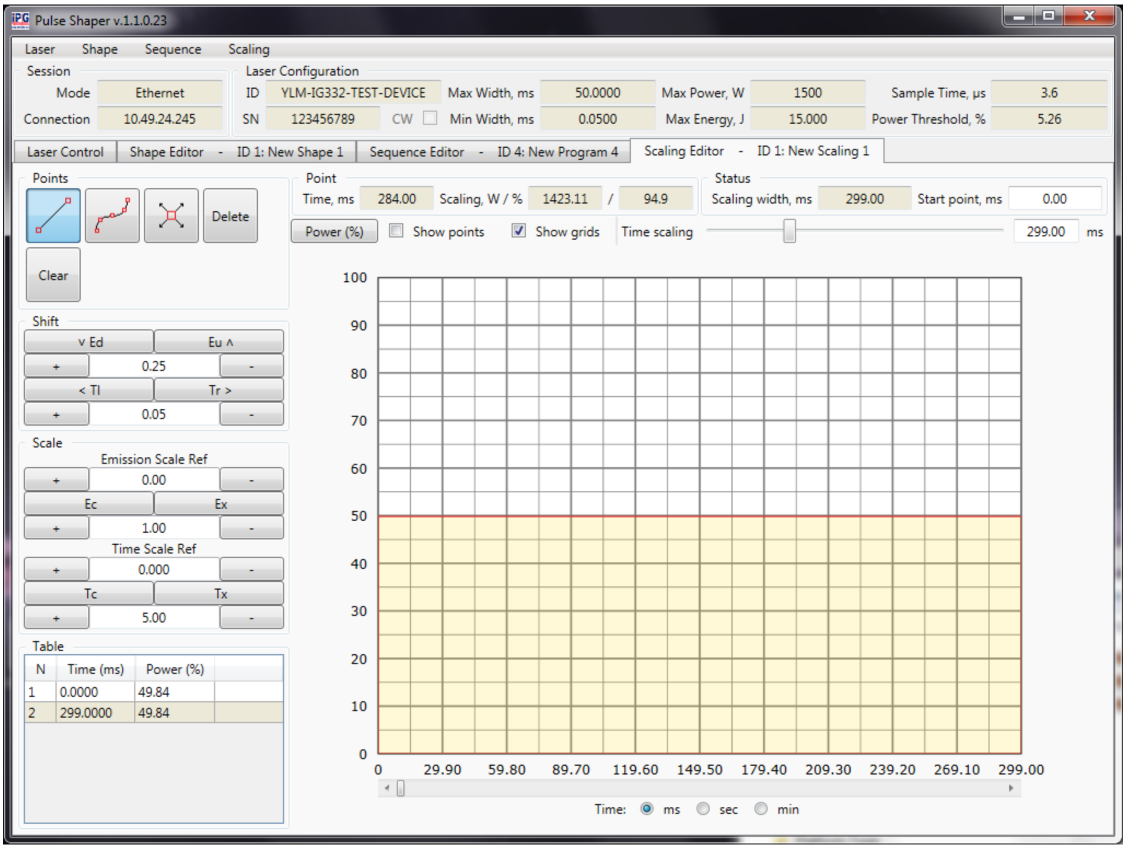


Table 4-5 provides descriptions for in Scaling Editor controls.

Table 4-7. Scale Editor Controls

	Name	Description
Point Panel		
1	Time, ms, sec, or min	Time scale unit in ms, sec, or min.
2	Scaling, W %	Enter a start point value for viewing the Pulse Scale in the chart.
3	Power (%)	Click the **Power** button to toggle between percentage and watts.
4	Show points	Click the **Show points** checkbox to display graphical points along the grid lines in the Scale chart. This option is disabled by default.
5	Show grid	Click **Show grids** to display a grid of horizontal and vertical lines for aligning pulse points in the Scale chart.This option is enabled by default.
6	Time scaling	Use the **Time scaling** slider to adjust the zoom in and out. Use the time shift controls and alignment cursors for more accurate editing. Use the Time and Emission indicators in the Status panel for guidance.
Status Panel		
3	Scaling width, ms, sec, or min	Total time between start and finish.
4	Start point, ms, sec, or min.	Start value from a certain point.

Creating a New Pulse Scale

.To create a Pulse Scale:

1. Select **Scale -> New**.
2. Select a scaling width.
3. Draw the scale by adding points.
   a. To save to the Pulse Sequence library, on the laser select **Scale -> Write to Laser**.
   b. To save to your computer, select **Scale -> Write to File.**

Sequence Editor

A Pulse Sequence is an arrangement of pulses, designed for finite or infinite repeats, and organized into steps. Each step has an assigned an existing pulse, pre-delay, and repeat amount.

The Pulse Shaping program checks each created sequence for average power and other laser limitation violation, and prompts you to make adjustments.

The Sequence Editor lets you create a sequence of pulses (pulse train) using Pulse Shapes from Pulse Sequence library.

Figure 4-28 shows the Sequence Editor tab.

Figure 4-28. Sequence Editor Tab

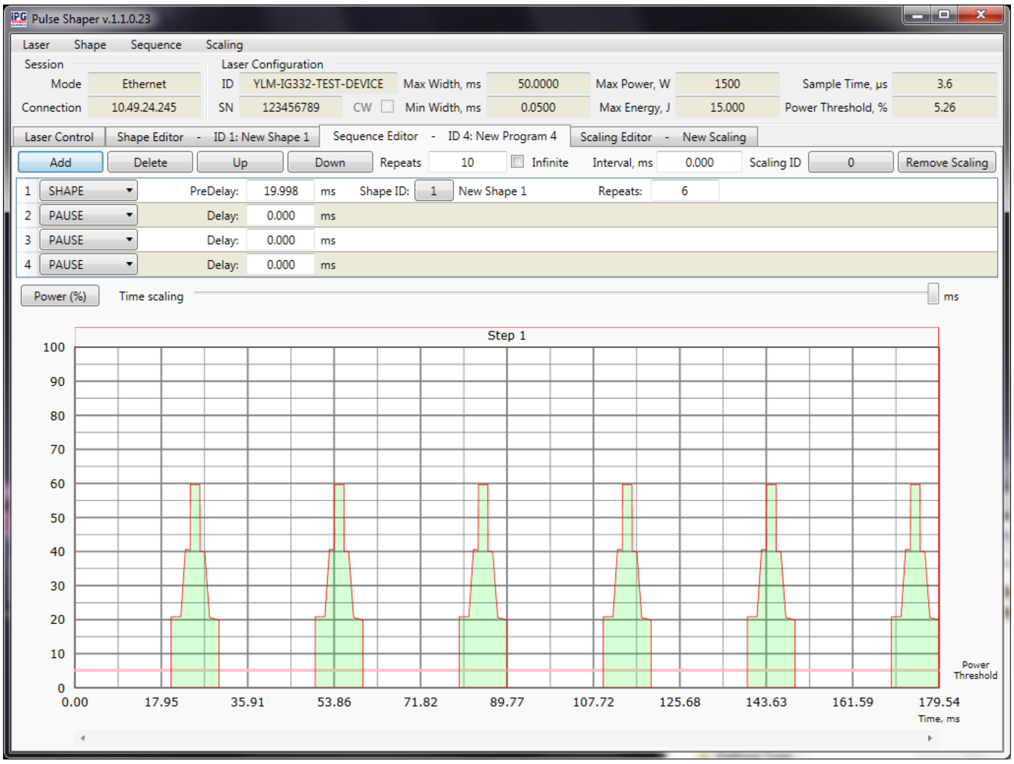


Table 4-8 provides descriptions for in Sequence Editor controls.

Table 4-8. Sequence Editor Controls

Name	Description
Add	Click **Add** to insert a sequence step prior to the one currently selected.
Delete	Click **Delete** to remove the selected sequence step.
Up	Click **Up** to move the selected sequence up in the order of sequence steps.
Down	Click **Down** to move the selected sequence step down in the order of sequence steps.
Repeats	The number of repeats for the current sequence.
Infinite	Check the **Infinite** checkbox for continuous repeats of the current sequence.
Interval. ms	Enter a interval value.
Scaling ID	Click to open the Pulse Scaling dialog box where you can select a scaling ID.
Remove Scaling	Click **Remove Scaling** to remove the select scaling ID from the **Scaling ID** box.
Name	Names of the current sequence.
Pre-Delay	A delay that precedes every repetition of the corresponding sequence step.
Repeats	The number of times to repeat the corresponding.

Creating a New Pulse Sequence

You can make a pulse train with variable Pulse Shapes and pulse repetition rates.

To create a Pulse Sequence:

1. Select **Laser -> Connect**. See "Pulse Shaper Configuration Procedures" on page 4-12 for the steps for connecting via Ethernet or RS-232.
2. Select **Sequence -> New**.
3. Select the required Pulse Shape from Pulse Shapes library.
4. Define the delays between pulses in the **Delay** box.
5. Enter the number of repeats in the **Repeats** box.
6. Select scaling of pulses (ramp up/ramp down) from the Pulse library and add them on top of the sequence.

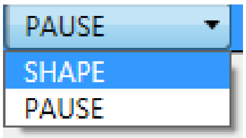
   If Analog Power Control is enabled, it allows on-the-fly scaling of the Pulse Sequence by varying analog input signal. You do not need to use Scaling Editor. See "Accessing the Web User Utility" on page A-5 to enable Analog Power Control.

   a. To save to the Pulse Sequence library, on the laser select **Sequence -> Write to Laser**.
   b. To save to your computer, select **Sequence -> Write to File**.

Building a Sequence

To build a sequence:

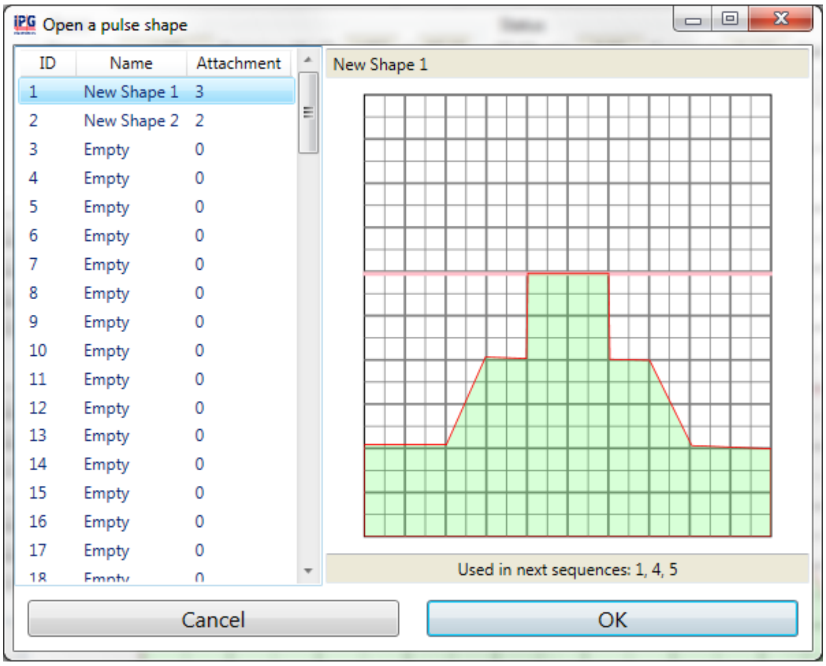
1. Select **New** from the **Sequence** menu. A new Pulse Sequence appears in the Sequence Editor tab.
2. Click **Add** to add a sequence step.
3. Enter a value (in ms) in the **Delay** box.
4. Select a Pulse Profile from the listbox.



5. Enter a number of repeats (number of times the selected Pulse Profile with delay must be repeated) in the **Repeats** box.
6. Click **Add** again to add more sequence steps.

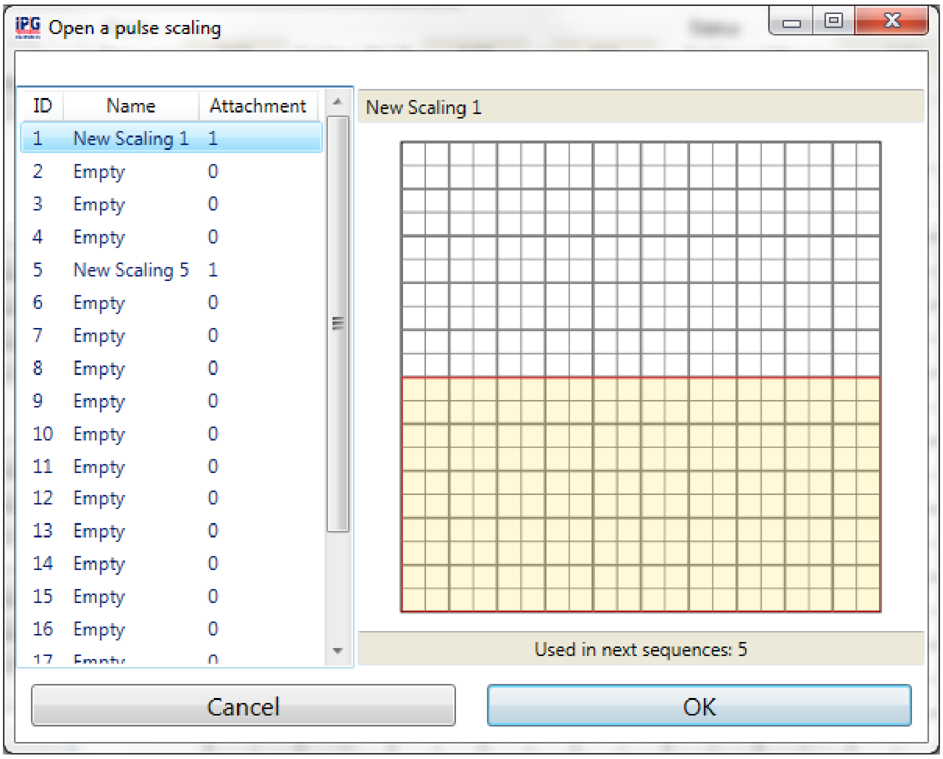
   You can set the number of sequence repeats by setting values in the **Repeats** box and **Interval, ms** box.
7. Click the Shape ID button to display a list of Pulse Shapes as shown in Figure 4-29.

Figure 4-29. Pulse Shapes Dialog Box



8. Select a shape ID for the sequence and click **OK**.
9. Click the Scaling ID button to display a list of Pulse Scaling IDs as shown in Figure 4-30.

Figure 4-30. Pulse Scaling Dialog Box



10. Select a scaling ID for the sequence and click **OK**.

    The preview of the sequence is refreshed when changes are made to the pulse. Additionally, laser limitation violations are re-checked.

Modifying a Pulse Sequence

To modify a sequence:

1. Highlight an existing step.
2. Click **Up** to shift up the selected sequence step in the sequence order.
3. Click **Down** to shift down the selected sequence step in the sequence order.
4. Click **Delete** to remove the selected sequence step.

Pulse Sequence Storage and Recall

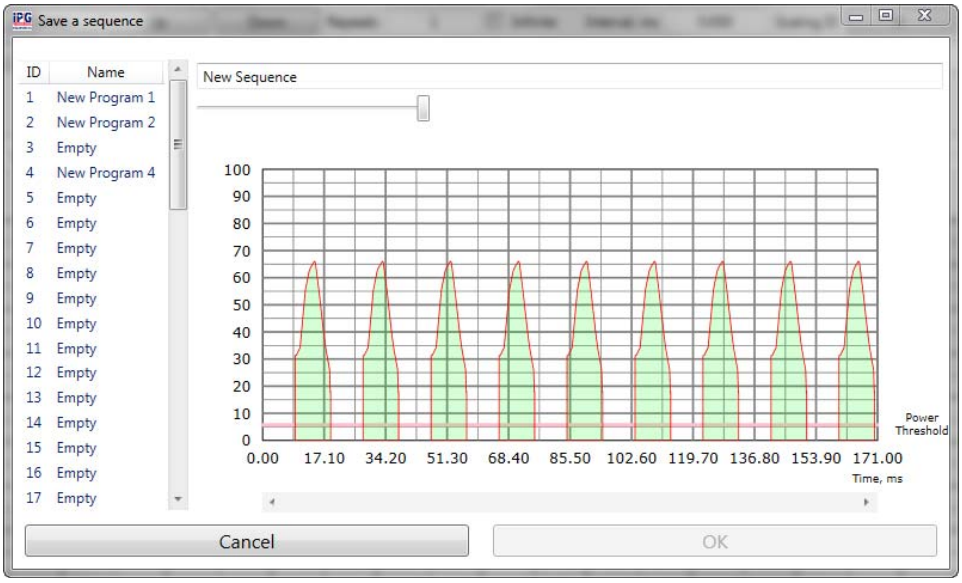
This section requires connection to the laser.

On a Laser

You can write Pulse Sequences to the laser to use and activate them in the Sequence Editor.

1. Select **Sequence->Write to Laser.** The Save Sequence dialog box appears.

Figure 4-31. Save Sequence



2. Select a sequence ID or enter a new name for the sequence and click **OK**.

   The message “Sequence was saved” appears.

To recall a Pulse Sequence:

3. Select **Sequence->Read from Laser**.
4. Select a sequence ID and click **OK**.

   The sequence is fetched and loaded into the chart.

On a Host PC

You can write Pulse Sequences to your computer to use and activate them in the Sequence Editor.

To save a Pulse Sequence your computer:

1. Select **Sequence -> Write to File**.
2. Enter a name for the file and click **Save**.

To recall a Pulse Sequence:

1. Select **Sequence->Read from File**.
2. Select a sequence ID and click **OK**.

   The sequence is fetched and loaded into the chart.

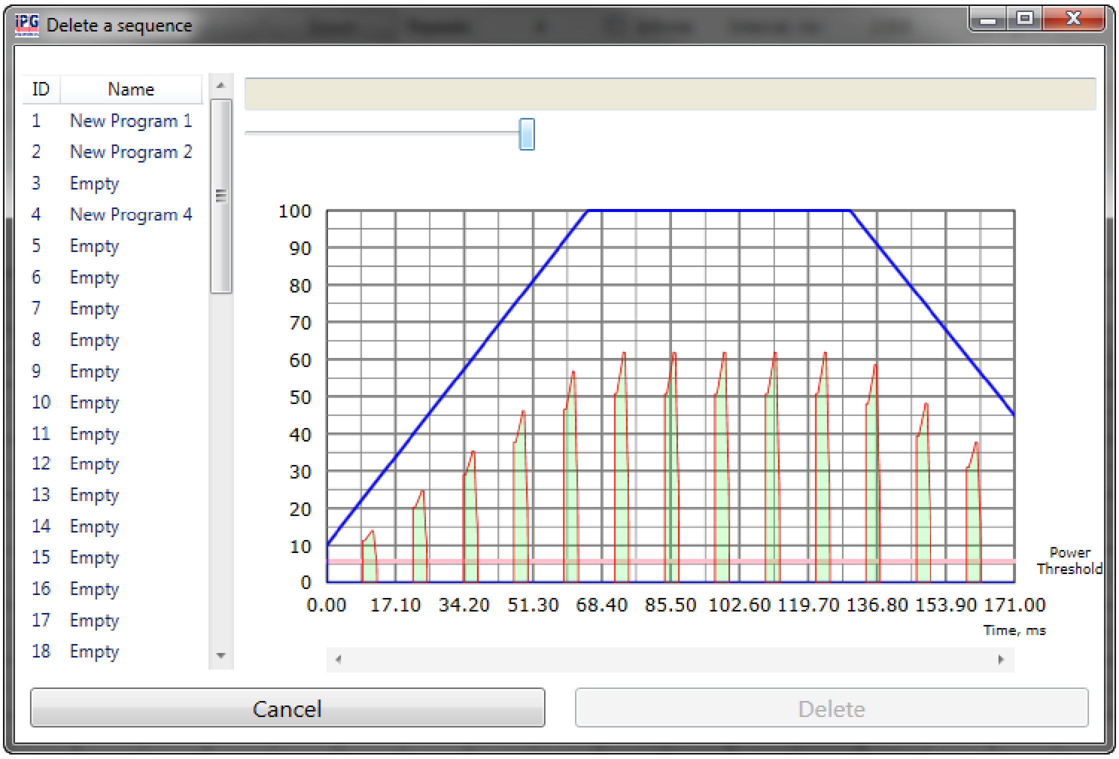
Deleting a Pulse Sequence

You cannot delete a Pulse Sequence if the status is not "Idle." When the status is "In Use" it means that the laser is configured with that Pulse Sequence.

To delete a Pulse Sequence:

1. Select **Sequence->Delete in Laser**.

Figure 4-32. Delete a Sequence in the Laser



2. Select a sequence ID to delete.
3. Click **Delete**.
4. Click **Yes** in the confirmation box.

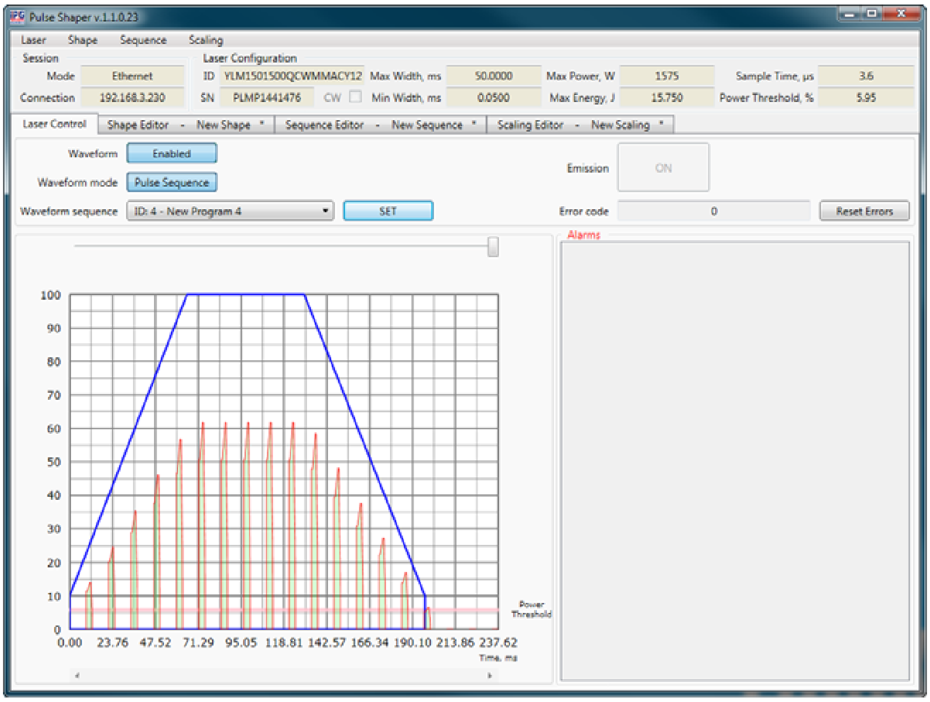
Pulse Sequence Activation

To activate a Pulse Sequence:

1. Click the Laser Control tab.
2. Toggle the **Waveform** button to **Enabled**.
3. Toggle the **Waveform mode** to **Pulse Sequence**.
4. Select a Waveform sequence from the listbox.
5. Click **SET**.
6. Click **Emission** to confirm and start countdown.

   The selected pulse is emitted after the countdown.
7. Click **Emission** again to clear the status. This also stops a pulse sequence if it is set to infinite repeats.

Figure 4-33. Pulse Sequence Activation



Pulse Sequence Activation using the Touch-Screen Display

You can use the Touch-Screen Display on the laser's front panel for manual control. You can view information about the laser's state and settings.

After storing a Pulse Sequence to the laser, ensure the E-stop button is released on the laser. Then press the green button to turn on the power supply.

Note

Both Analog and Modulation modes must be set to "Off" to correctly configure the Pulse Sequence mode. To change them, select **Pulse Menu->Pulse Setting**.

To activate a Pulse Sequence from the Touch-Screen Display on the laser:

1. Select **Pulse Menu->Pulse Setting->Waveform Mode.**
2. Toggle **Waveform Pulse Mode** to **Enabled**.
3. Select **Pulse Sequence**.
4. Use the Up and Down arrows to select a specific Pulse Sequence.
5. Pulse Sequence Information/Preview (Optional) - To view information about the Pulse Sequence, click on the Pulse Browser button. The information page appears. You can use the arrows to scroll through all available pages.
6. Click anywhere in the text space to go to the Preview page. You can see the shape of the pulses in the sequence. Use the arrows to see the entire page.
7. Click **Return** twice to go back to the Waveform page.

   It is important to configure the laser with the selected pulse sequence (once) before usage.
8. Click **Configure & Return**. After the configuration is complete, click Return twice to go back to the main page.
9. Click **Emission**, and then click **OK** to confirm and start countdown.

   The selected pulse is emitted after the countdown. Click **Emission** again to clear the status. This also stops a pulse sequence if it is set to infinite repeats.

Remote Control Interface

This interface is designed to provide remote control. It covers the pulse-shaping feature and it not meant to be a comprehensive control utility.

Note This interface works simultaneously with the Touch-Screen display.

To start the interface:

1. Select **Remote Control** from the top menu.
2. Use the Setup panel to enable the Waveform (pulse) mode.
3. Select the pulse or sequence mode.
4. Select a pulse or sequence then configure the laser.

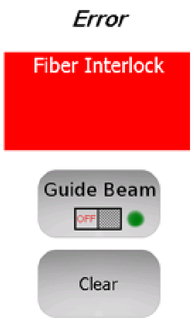
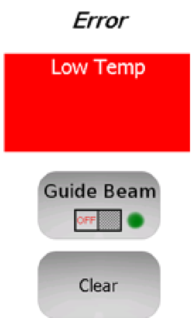
5

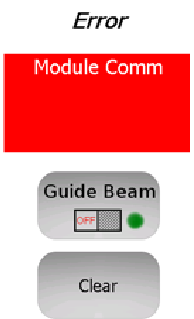
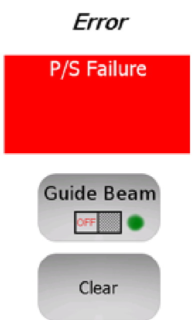
Troubleshooting

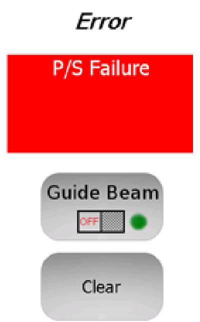
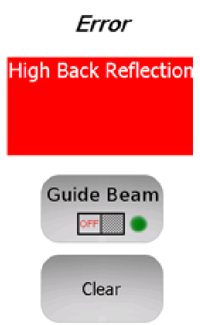
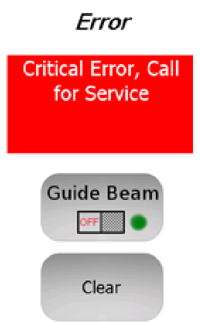
Error Messages on the Display and Status Bits

The following table lists errors and possible solutions, which are associated with the displayed errors on the touch-screen display or returned status bits via the RS-232 connection.

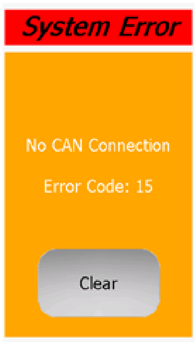
Table 5-1. Error Messages with Possible Solutions

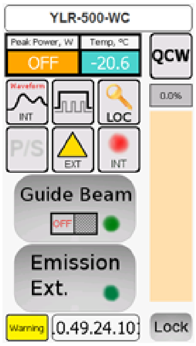
Issue	Comments
Optical Interlock (Bit 30)	
	Result: The internal main power supply is automatically switched off. Cause: Either the delivery fiber cable is mechanically damaged or the output connector is not plugged into an appropriate optical head. Possible Solution: Send reset error command (“RERR”). If the message does not disappear, contact a representative from IPG Photonics for assistance.
Low Temperature (Bit 24)	
	Result: The power supply and laser emission is switched off. Cause: The case temperature of the laser is too low. Check if outside conditions are within the specified range. Possible Solution: This message and error bit disappear as soon as case temperature of the laser module drops in the operating range.

Issue	Comments
Overheat (Bit 1)	
	Result: The power supply and laser emission is switched off. Cause: This means that case temperature of the laser is too high. Possible Solution: Check if outside conditions are within the specified range and if the conditions for sufficient airflow are provided. This message and error bit disappear as soon as case temperature of the laser modules drops in the operating range.
Module Disconnected (Bit 6)	
	Result: The power supply and laser emission is switched off. Cause: This means that digital data communication with the laser module inside the device is broken. Possible Solution: Try to reset the error. If it appears again, contact IPG Photonics for assistance.
Power Supply Failure (Bit 19)	
	Result: The power supply and laser emission is switched off. Cause: This means that even though the internal main power supply is switched on there is no voltage applied to the laser module. Possible Solution: Try to reset the error. If it appears again, contact IPG Photonics for assistance.

Issue	Comments
Power Supply Failure 2 (Bit 25)	
	Result: The internal main power supply is automatically deactivated. Cause: This means that though the internal main power supply is switched on and the voltage is applied to the laser module, the value of this voltage is not within the preinstalled range. Possible Solution: Reset the error and switch on the internal main power supply. If the error reappears, contact IPG Photonics for assistance.
High Back Reflection (Bit 3)	
	Result: Laser emission is switched off. Cause: The back reflected power exceeded the pre-installed maximal applicable level. Possible Solution: Check if the focus position is correctly adjusted and that there are no surfaces, which can lead to the high level of back reflection. Reset the error using RS-232 ("RERR" command) or touch-screen display on the front panel.
Critical Error (Bit 29)	
	Result: The power supply and laser emission is switched off. Cause: The system has detected an error that is considered critical. Possible Solution: Neither reset command ("RERR") nor restart of the device clears this error. Contact IPG Photonics for assistance. Be ready to read the Module Error Code (RMEC command) from the laser and submit it to an IPG Technical Support Specialist.

Issue	Comments
Duty Cycle Too High	
	Result: The duty cycle is too high. Cause: The duty cycle is the percentage of how long the laser is in the “on” state in the given modulated period. Possible Solution: Check the modulation signal. Try to reset the error. If it appears again, contact IPG Photonics for assistance.
High Pulse Energy	
	Result: The pulse energy of the laser is too high. Cause: A pulsed laser periodically emits pulses of energy in an ultra-short time duration. Possible Solution: Check the modulation signal. Try to reset the error. If it appears again, contact IPG Photonics for assistance.

Issue	Comments
Average Power Too High	
	Result: The laser power is too high. Cause: The system has detected an error that is considered critical. Possible Solution: Check the modulation signal. Try to reset the error. If it appears again, contact IPG Photonics for assistance.
Pulse Too Long	
	Result: The laser pulse is too long. Cause: The system has detected an error that is considered critical. Possible Solution: Check the modulation signal. Try to reset the error. If it appears again, contact IPG Photonics for assistance.
Internal Communication Error	
	Result: There is no CAN connection. Cause: Occurs when there is no connection to the Controller Area Network (CAN). Possible Solution: Try to reset the error. If it appears again, contact IPG Photonics for assistance.

Issue	Comments
Pulse Too Short	
	Result: Pulse Too Short warning appears in touch-screen display. Cause: The system has detected an error that is considered critical. Possible Solution: Click Warning in the touch-screen display. The warning message appears. Try to reset the error. If it appears again, contact IPG Photonics for assistance.

A

Web User Utility

Overview

You can troubleshoot your laser using the IG337 Web User Utility, which provides status information and digital control functionality.

This appendix explains how to configure your computer's communication protocols to connect to the laser via a PC.

Configuration Procedures

You can connect to the Web User Utility from either an Ethernet or RS-232 connection.

Configuring an Ethernet Connection

The following procedure assumes you are familiar with operating the YLM-QCW laser. IPG recommends that you review all safety and operational procedures before proceeding.

1. Connect PC to the laser using a standard Ethernet cable.
2. Manually configure the Local Area Connection settings for Ethernet (see “Configuring a LAN Connection for Ethernet” on page A-2).
3. Open your web browser and enter the IP address of the Internet Protocol. If the connection is successful, the IG337 Web User Utility page appears (as shown in Figure A-6).

Configuring an RS-232 Serial Connection

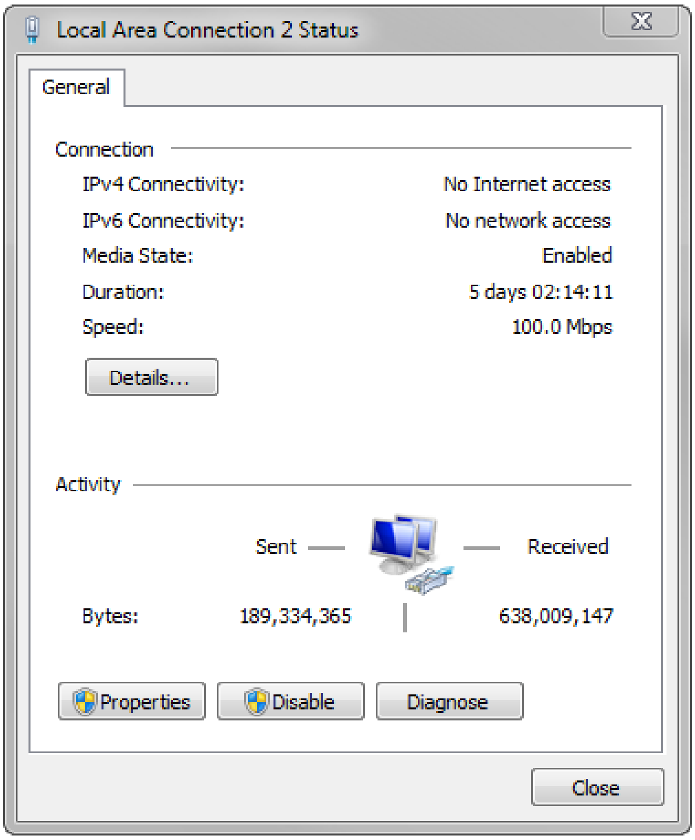
See “Connecting Using RS-232” on page 4-13 for step-by-step instructions.

Configuring a LAN Connection for Ethernet

To configure a LAN connection for Ethernet:

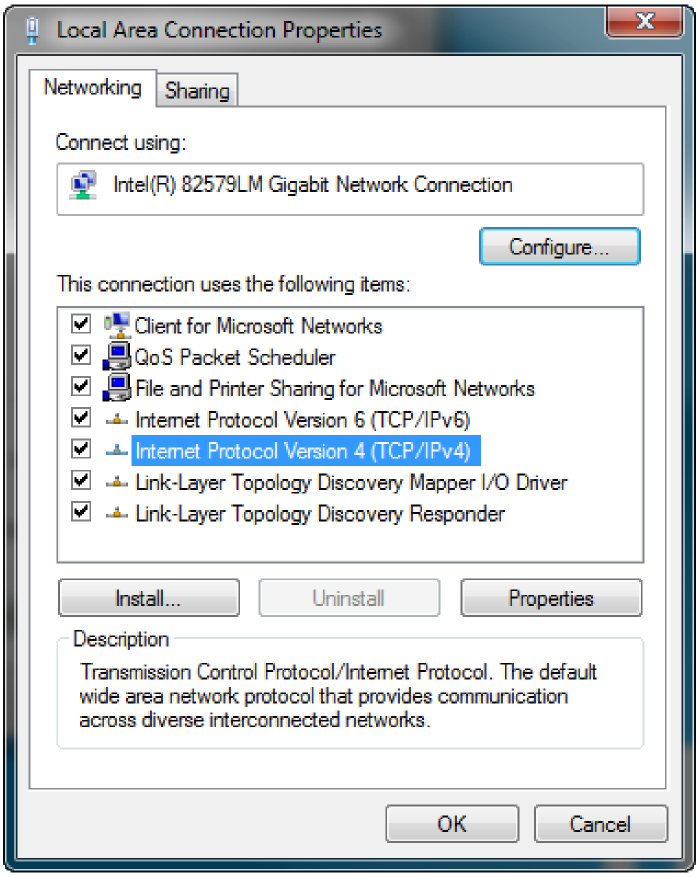
1. Go to **Control Panel -> Network and Internet -> Network and Sharing Center**.
2. Click **Change adapter settings**.
3. Select a Local Area Connection icon. The following window appears as shown in Figure A-1.

Figure A-1. Local Area Connection Status



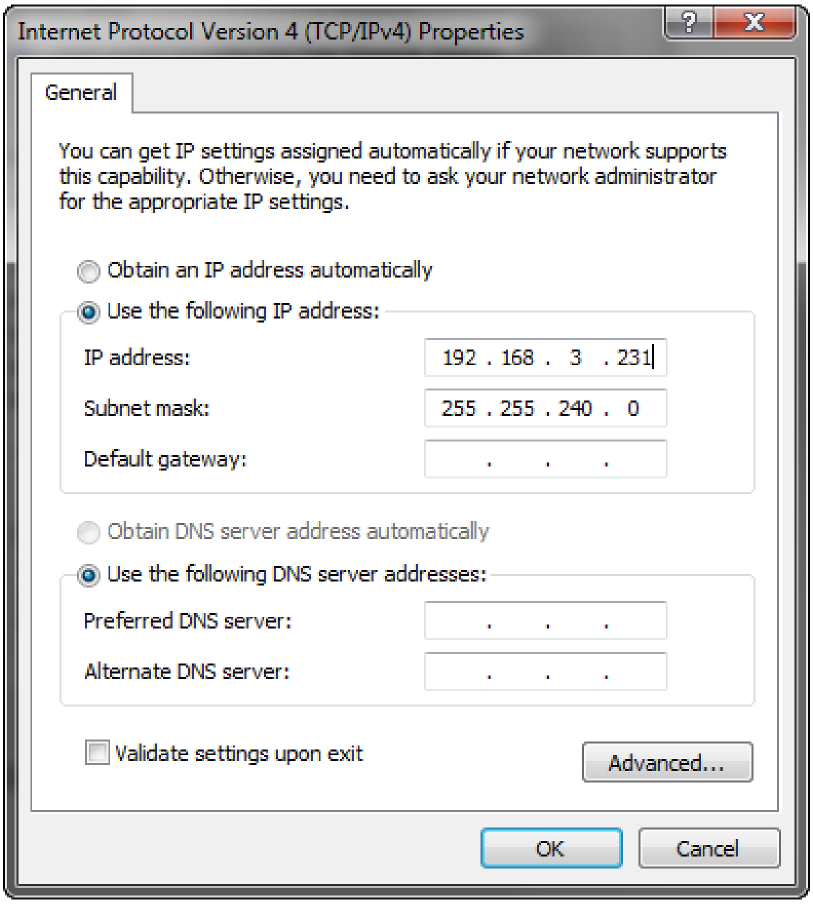
4. Click **Properties**. The following window appears as shown in Figure A-2.

Figure A-2. Local Area Connection Properties



5. Select **Internet Protocol Version 4 (TCP/IPv4).**
6. Click **Properties**. The following window appears as shown in Figure A-3.

Figure A-3. Internet Protocol Version 4 Properties



7. Click the **Use the following IP address** radio button to manually assign the IP address.
8. Assign the IP address to 192.168.3.23x (x cannot be 0 as it is the default IP address of the Laser).
9. Assign the Subnetmask to 255.255.240.0.
10. Click **OK** to accept your changes.

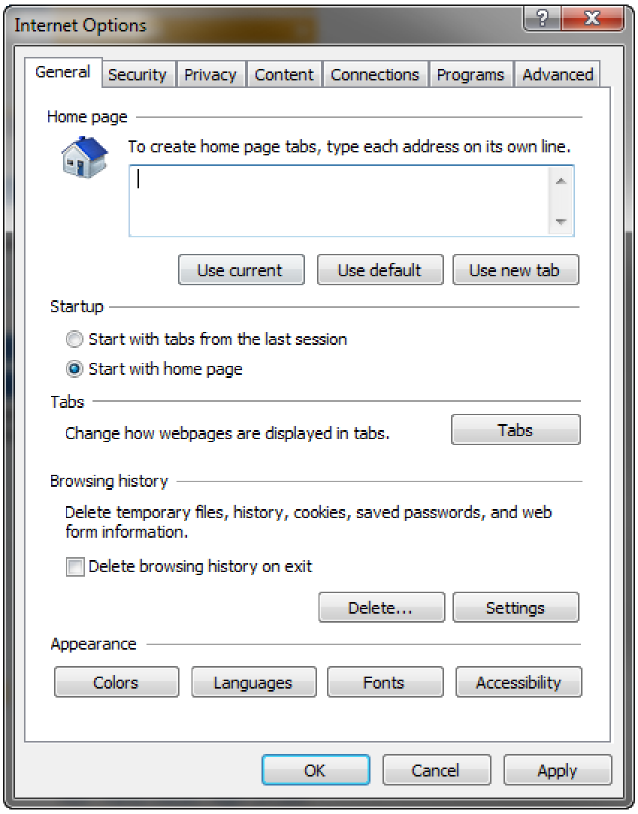
Website Data Settings

To ensure the most current Web User Utility interface is downloaded to your web browser, you need to modify the Website data settings in Internet Explorer.

To modify the Website data settings:

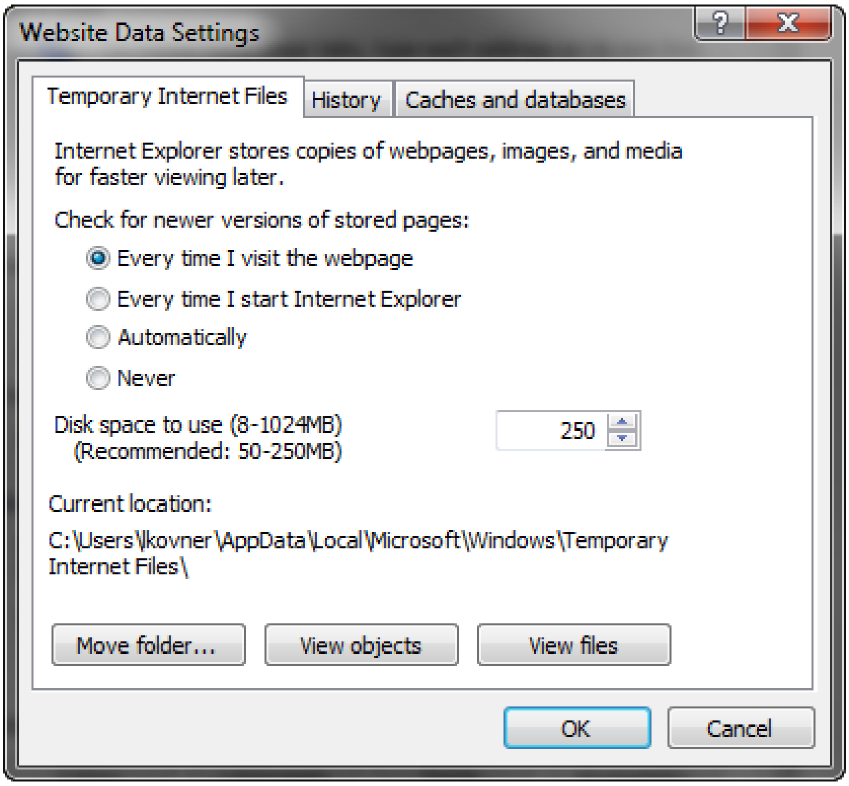
1. Open Internet Explorer.
2. Select **Tools -> Internet Options**.

Figure A-4. Internet Explorer Options



3. Click **Settings**.

Figure A-5. Website Data Settings



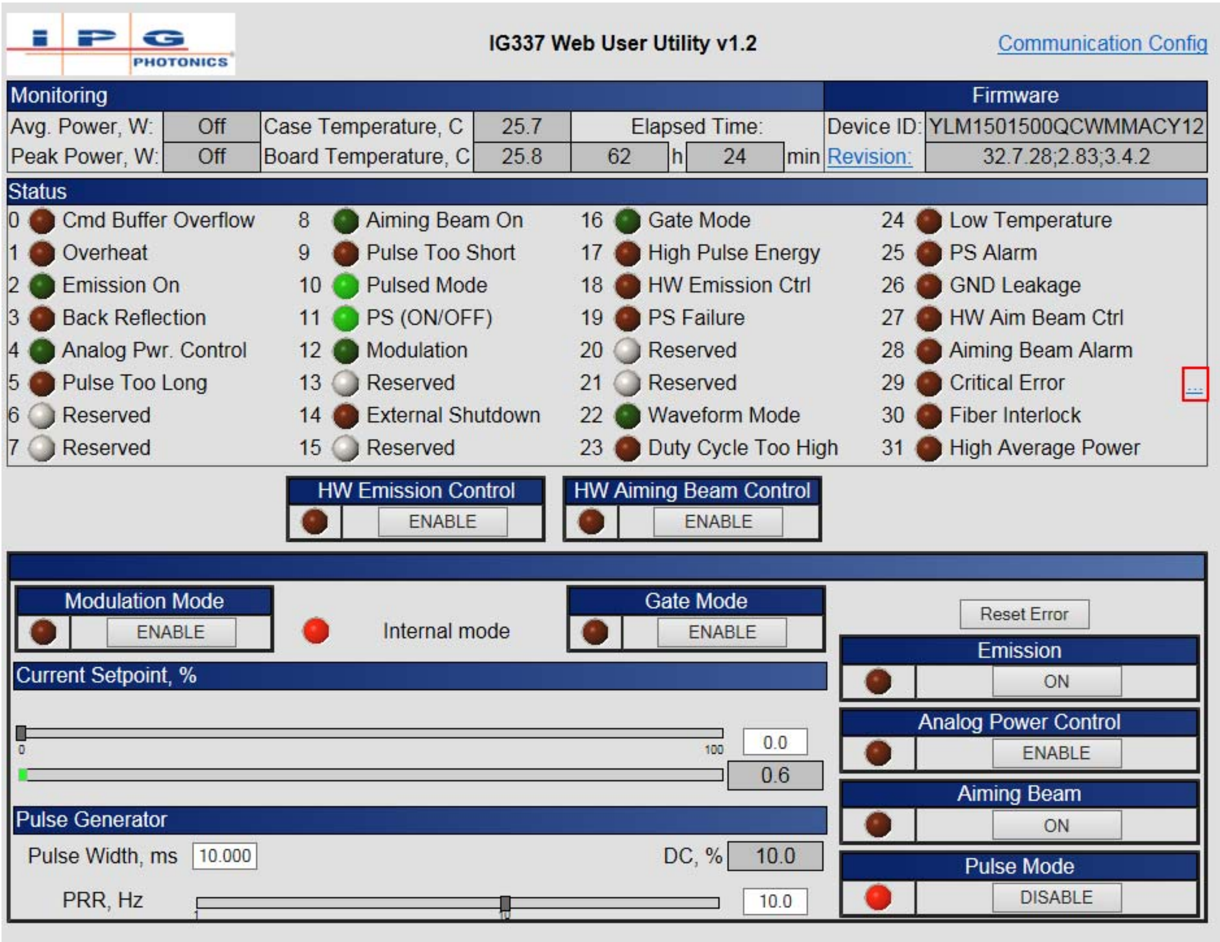
4. Click **Everytime I visit the webpage**.
5. Click **OK** to save this setting.

Accessing the Web User Utility

To access Web Utility:

1. Enter the IP address of the laser in a web browser. The Web User utility appears.

Figure A-6. IG337 Web User Utility

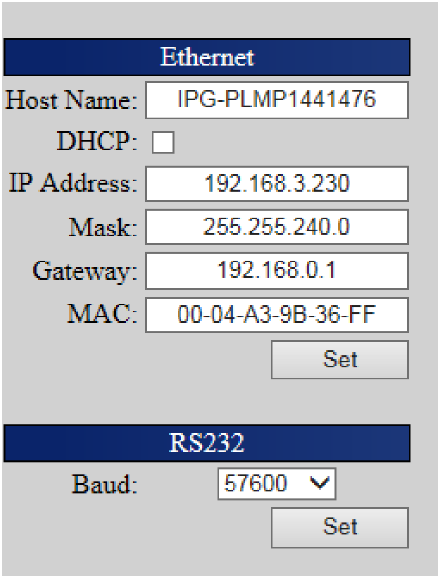


The items (0 to 31) in the Status group are listed in Table 3-5 on page 3-8 (Bit Meanings).

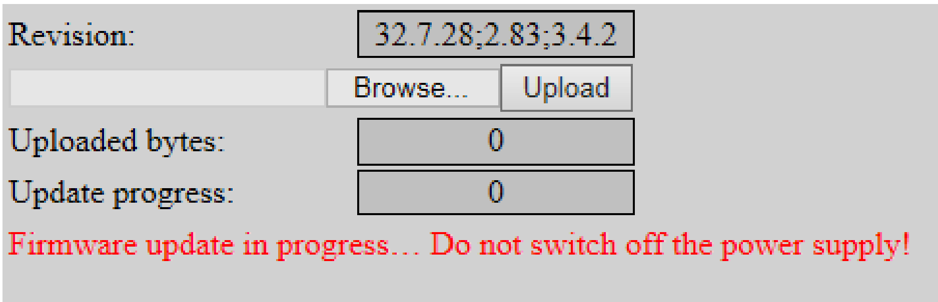
See Table 2-6 on page 2-19 for details on main control functions.

See Figure 2-13 on page 2-17 guidelines on setting the Pulse Generator.

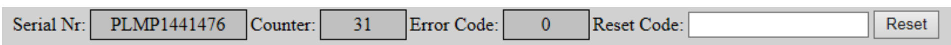
2. Click the **Communication Configuration** link at the top of the screen to change the IP address or baud rate. The following page appears.



3. Click the **Revision** link to upload the latest laser module software version. The following page appears:



4. Click the **Ellipsis** button (...) to reset critical errors. The following page appears:



5. Provide the Serial Number, Counter, and Error Code to receive a reset code from IPG Customer Service.

6. Turn on the Aiming Beam and verify that it is visible at the optical output.

B

Service

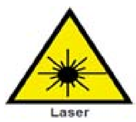
Service and Repairs

There are no operator serviceable parts inside. Only the fuses and filter media are replaceable. Refer all internal servicing to qualified IPG personnel.

Many issues and questions regarding the safety, set-up, operation and maintenance of the IPG products can be resolved by reading this guide carefully. However, if you have questions regarding the safety, set-up, operation or maintenance of your IPG product, call the Customer Service department.

If you cannot resolve the issues by using this guide or over the telephone with a technical support representative, you might need to return the product to IPG. See “Product Returns” on page E-1 for more details.

Serviceable Items

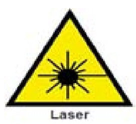


The unit should never be operated with any of the covers removed, including the front panel fan covers.

The input voltage to the laser is potentially lethal. All electrical cables and connections should be treated as if it were a harmful level. All parts of the electrical cable, connector or device housing should be considered dangerous.

This device is classified as a high power Class 4 laser instrument under 21 CFR 1040.10. This product emits invisible laser radiation at or around a wavelength of 1070 nm, and the total light power radiated from the optical output is greater than 20 to 1500 W (depending on model) per optical output port.

This level of light can cause damage to the eye and skin. Despite the radiation being invisible, the beam may cause irreversible damage to the cornea. Laser safety eyewear is not provided with this instrument, but must be worn at all times while the laser is operational.



Service personnel should always follow correct Lockout/Tagout procedures per your company's policy to ensure all potential energy is removed from the system before servicing.

Replacing Fuses

Fuse Ratings: Refer to Table 18: Replacement Parts

To replace the main power fuses:

1. Disconnect the power source and remove the keys from laser.
2. Turn the laser so the rear panel is easily accessible.
3. Locate the fuses and unscrew the covers.

Important

Replace blown or damaged fuses with only the same amperage fuses. Replace the fuse(s) and covers and tighten securely.

Replacing the Filter Media

Inspect the filter media weekly and clean or replace as needed. Only use IPG parts when replace filter media.

To access the filters, use the following procedure:

1. Unplug the line cord and remove keys from laser.
2. Remove the front bezel on the front panel of the laser (refer to Figure 5: Front Panel). Upon removal, the filter element will be exposed.
3. Remove the used filter and clean or replace with a new filter (Refer to Table B-1).
4. Snap the cover back on and dispose of the dirty filter element.

Table B-1. Replacement Parts

Description	Laser Category[a]	Part Number
Filter Media	3U	P45-004679
Filter Media	4U	P45-004676
Filter Media	6U	P45-004679 and P45-004704
Fuse T 10A 250VAC	3U AC	P40-001743
Fuse T 15A 250VAC	3U WC, 4U AC (CW and QCW), 6U AC	P40-001564

a. Refer to Laser Model Designation Codes

C

Optical Fiber Connector Inspection and Cleaning

Overview

You should regularly check the fiber connector for dust, dirt, or damage before you connect to any external optic. The use of a dirty, or improperly cleaned, fiber connector can lead to serious damage to the laser (Figure C-6 on page C-7 illustrates possible fiber failures).

IPG Photonics is not responsible for any damages due to contaminated connectors. Tampering with the fiber connectors without training by IPG voids the warranty.

For cleaning a fiber connector, you need the following materials:

- Powder free rubber gloves or finger cots
- Lint free optical cleaning wipes and/or swabs
- Acetone (optical grade, water free)
- Compressed air (oil free, water free)
- Microscope (IPG model or equivalent)
- Light Source

Figure C-1. Materials for Cleaning a Fiber Connector

Important

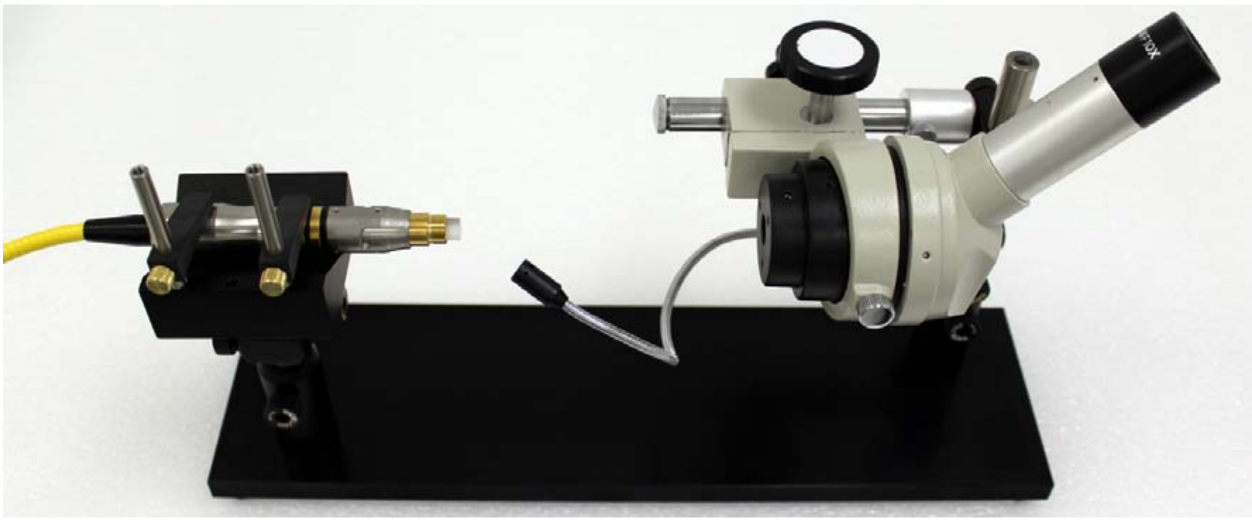
You need to wear powder free rubber gloves during this cleaning procedure. Damage to the fiber connector can occur due to mishandling. The use of incorrect cleaning procedures or chemicals for cleaning is not covered by the warranty.

Acetone should be handled and stored in accordance to any local regulations (e.g. OSHA Regulation 29 CFR 1910.1200). Refer to each solvent's MSDS (Material Safety Data Sheet) for additional information.

To clean the fiber connector:

1. Switch off the laser main power by pressing the Emergency Stop button on the front of the unit and turning the Keyswitch to the center position.
2. Leave protective cap on and clean the fiber connector exterior with optical cleaner, wipe it with a clean optical wipe and dry with compressed air.
3. Place fiber connector in the holder of the microscope.
4. Place pressure on the center of the securing arm before tightening the locking screw as shown in Figure C-2.

Figure C-2. Fiber Connector Mounted on IPG Microscope



5. Remove cap and sleeve from connector as shown in Figure C-3.

Important

Place the cap face down on a clean surface. Placing the cap face down on a lint free wipe is the best choice if the surfaces are questionable.

Figure C-3. Fiber Cap and Sleeve Removed

6. Focus the microscope onto the connector surface.
7. Use light source to illuminate the face of the connector so that the light is reflected from the surface of the microscope. This is achieved if you see a bright golden shine from the IPG (yellow cable) connector end-face or a blue surface for the connector (see Figure C-6 on page C-7).

Important Always look at the surface at a slight angle to improve visibility.

8. Inspect the surface carefully. Any contamination might lead to dark spots on the surface and eventual fiber failure (see Figure C-6 on page C-7 for examples). If contamination is visible on the quartz block, continue to the next step. Proceed to Step 14 if there is no contamination visible.
9. Try to blow away the dust with compressed air from the side.

Important Never blow air directly at the surface because you could embed contaminants into the surface. Always blow across the surface.

10. While wearing powder free gloves, fold the lint free optical wipe into halves until it is roughly 1 X 1 ½" rectangle (see Figure C-4 on page C-5). Put a few drops of optical cleaner onto the lint free optical cleaning wipe on the folded edge of the wipe as indicated.

Important Do not ever reuse a lint free optical wipe or swab to clean the end face.

11. Re-inspect the lens.
12. Repeat step 10 with Acetone if lens is still contaminated.
13. If necessary, put a drop of Acetone onto a cleaning swab and gently wipe away contamination in a circular motion being careful not to scratch the lens. Then repeat from step 10.

Do not touch the tip of the cleaning swab with your fingers and use each swab only once to prevent contamination.

14. Repeat above cleaning steps until all contamination is removed. This cleaning procedure can be stopped at any time if a good result has already been achieved.

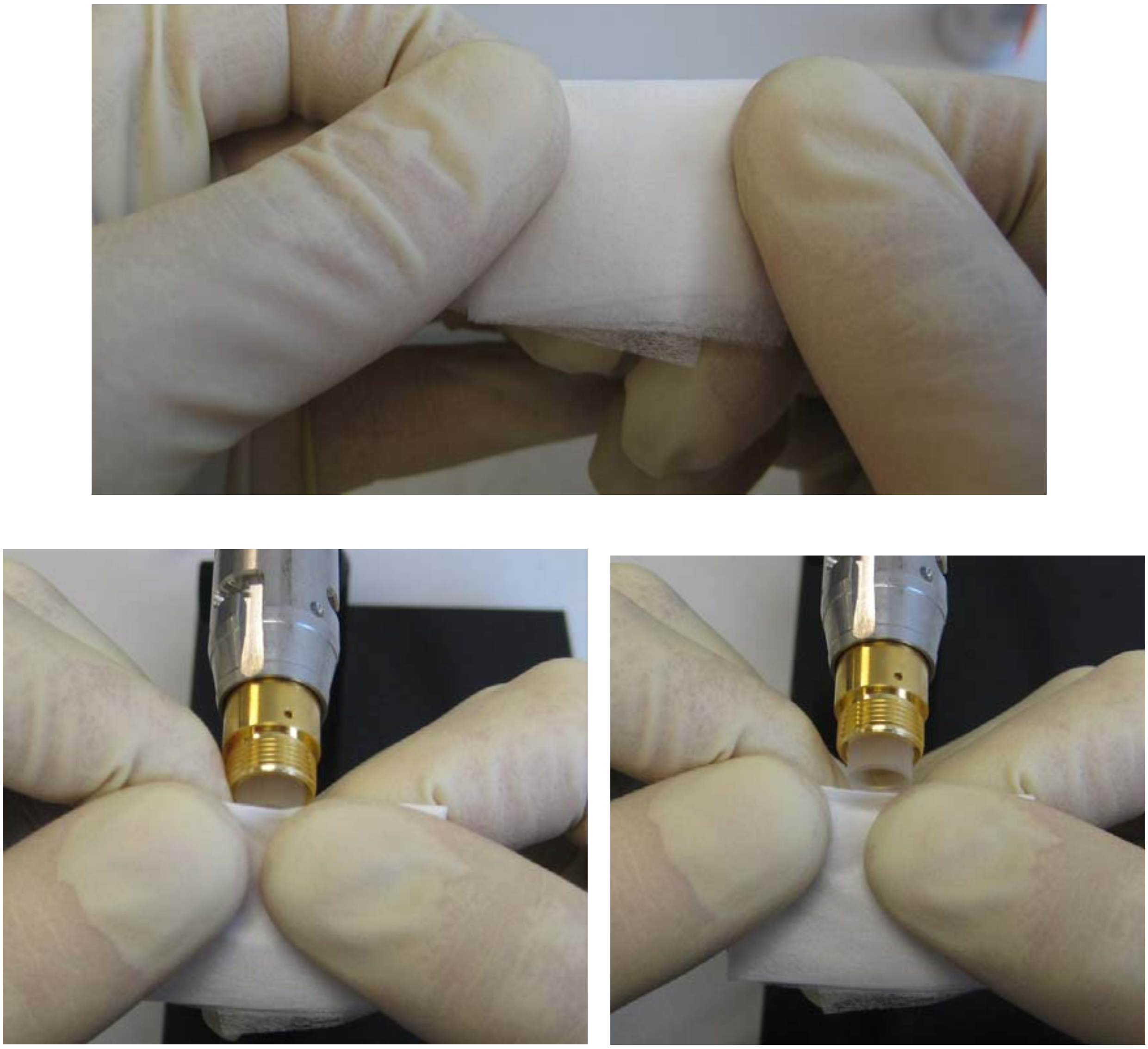
    After fiber connector is clean use compressed air to clean the protective sleeve and install onto the connector.

Damage to the fiber connector can occur due to mishandling, the use of incorrect cleaning procedures, or chemicals for cleaning. This is not covered by the warranty.

15. If the fiber is not to be connected immediately with a suitable optical component, use compressed air to clean the protection cap and install over the fiber end.

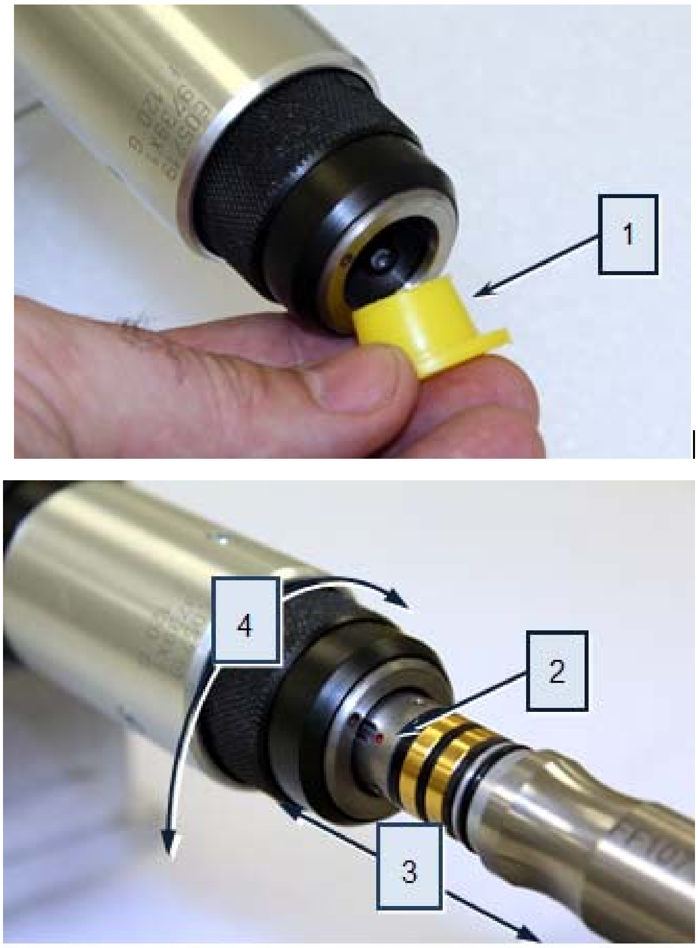
Important Make sure you clean the cap and sleeve before installing them back onto connector.

Figure C-4. Fiber End-Face Cleaning



Start to clean with even pressure. **Drag in only one direction.**

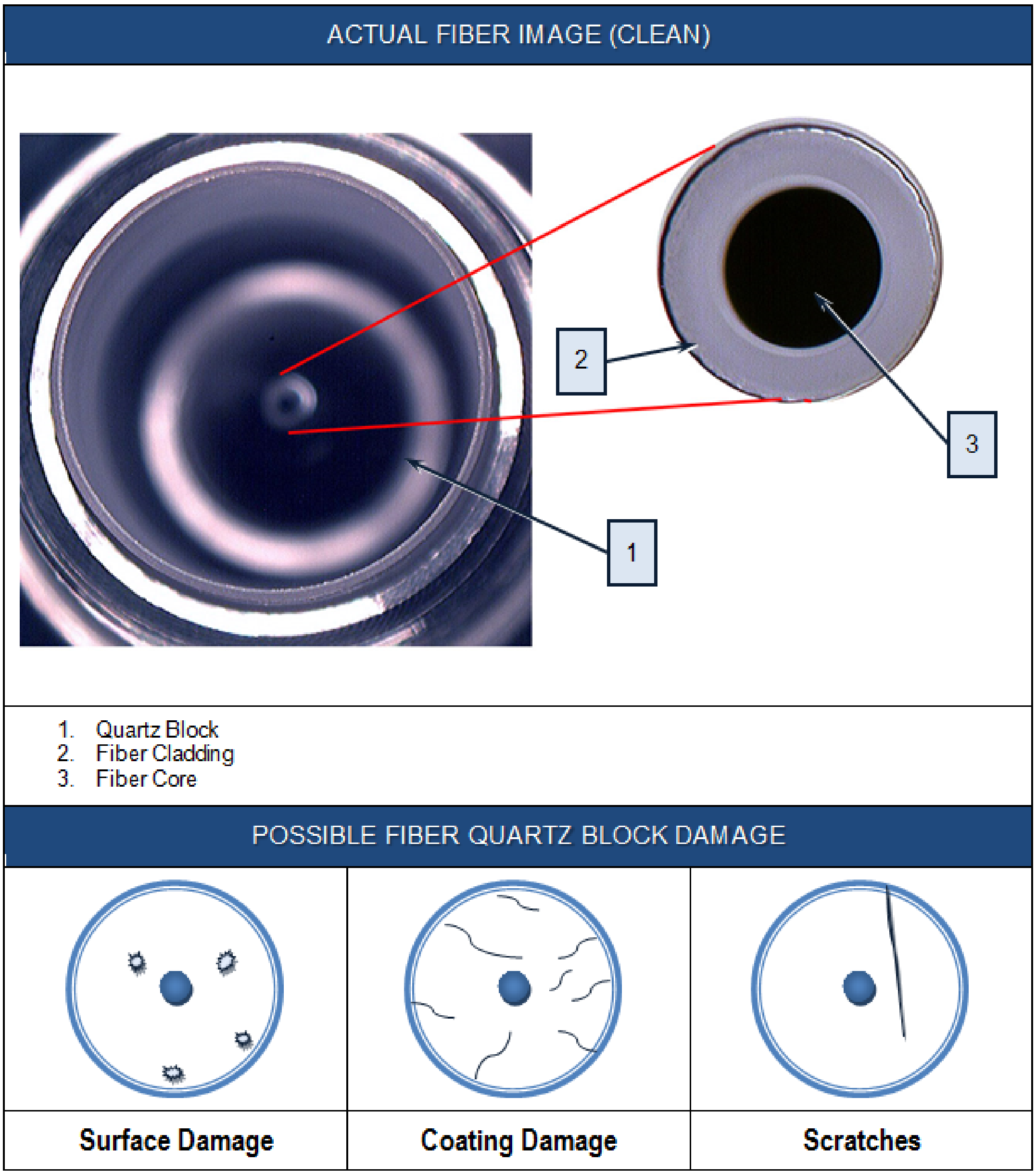
Figure C-5. Installing the Fiber



1. Remove the plastic protection cap at the bayonet enclosure.
2. For connecting the fiber to the bayonet, the red dot at the fiber has to be in line with the red dot at the bayonet enclosure.
3. Gently slide the fiber all the way into the fiber port.
4. Lock the fiber into place by rotating the bayonet knurled ring.

Important Hand tighten only as the use of tools can lead to damage to the bayonet enclosure.

Figure C-6.   Fiber Quartz Block Inspection



D

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Product Returns

Returns to the United States

All product returns require a Return Merchandise Authorization (RMA) from IPG.

To obtain an RMA, call the Customer Service department of IPG Photonics Corporation at 508-373-1100 (US) or +49 2736 44 20 451 (Germany).

If you return a product with a RMA, please perform the following procedure:

1. Products must be carefully packed in a suitable shipping container(s). Buyer assumes all responsibility for products damaged in shipment to IPG.
2. Buyer must issue a purchase order for the value of the replaced parts/service items and IPG will issue credit or invoice when the parts/service is received. Speak to IPG Service Manager for the amount authorized under the required purchase order.
3. All requests for repair or replacement under this warranty must be made to IPG within 30 days after discovery of the defect (but not later than 7 days after warranty expiration).
4. All products returned to IPG but which meet applicable specifications, not defectively manufactured or used not in accordance with this User's Guide, will result in the Buyer being charged IPG's standard examination charge.
5. Complete packing list with product model and serial number will ensure prompt repair.
6. Be sure to include with the returned product your 'ship to' address for the return of the serviced product.

Shipping Instructions:

Warranty Returns

Domestic & International Buyers* pay for one-way freight costs and insurance to IPG. IPG will pay for freight return cost and insurance back to the Buyer.

Non-Warranty Returns

Domestic & International Buyers* pay for two-way freight costs and insurance to IPG. If shipment consists of returns that are both warranty and non-warranty, the shipment will be considered as non-warranty.

Shipping address for returns to US:

IPG Photonics Corporation

50 Old Webster Road

Oxford, MA 01540

Attn: Product Returns

Tel: 508-373-1100

Returns to Germany

Shipping address for returns to Germany:

IPG Laser GmbH

Siemensstrasse 7

D-57299 Burbach, Germany

Attn: Product Returns

Tel: +49-(0)2736-44-20-451

1. IPG Laser GmbH will only accept returns for which an approved Return Material Authorization (RMA) has been issued by IPG Laser GmbH. You should address to the customer support team at +49-(0)2736-44-20-451 or support.europe@ipg-photonics.com to discuss the return and request an RMA number. You must return defective products freight prepaid and insured to IPG Laser at the address shown herein. All products which have returned to IPG Laser but which are found to meet all previously applicable specifications for such products or which indicate damage to the fiber connectors not resulting from defect manufacturing, shall be subject to IPG Laser' standard examination charge in effect at the time and these costs shall be charged to the Buyer. All products returned to IPG Laser which are not accompanied by an itemized statement of defects, shall be returned to the Buyer at the Buyer's expense and IPG Laser shall not carry out any evaluation of such products. IPG Laser warrants to Buyer that its services, labor and replacement parts, assemblies and modules will be free of defects in material and workmanship for ninety (90) days from the date of shipment or performance of services.
2. Warranty Returns - Domestic & *International Buyers should pay for one-way freight costs to IPG Laser. IPG Laser will reimburse Buyers for applicable reasonable third-party freight costs and IPG Laser will pay for freight return cost back to the Buyer.
3. Non-Warranty Returns - Domestic & *International Buyers are responsible for two-way freight costs. If shipment consists of returns that are both warranty and non-warranty, the shipment will be considered as non-warranty. Any UNAUTHORIZED shipments billed to IPG Laser without authorization will be re-invoiced to the Buyer. Confirming purchase orders are required for non-warranty returns.

4. *International Returns must include applicable DUTIES AND TAXES, and you must mark air bills with "RETURNED FOR REPAIR." In any event, where IPG Laser accepts a shipment, IPG Laser will invoice to the Buyer for any charges as stated above.
5. Returns for credit will not be accepted unless authorized in advance, in writing by IPG Laser, in accordance with IPG Laser' Terms and Condition, including the warranty provisions. In most cases, restocking fees will apply.
6. All returns must be packaged adequately to avoid damage during shipment.
7. Complete packing list with product model and serial number will insure prompt repair, if the other terms of this form are followed.
8. See the IPG Terms and Conditions for the applicable warranty for the products before you request the return of the products.
9. RMA number will expire 31 days after the date of issue. Thereafter, units received in under the expired RMA number will result in a longer turnaround time. Include a copy of the completed RMA form with the return of your unit(s).

F

Glossary

°C	Degrees centigrade or Celsius
°F	Degrees Fahrenheit
λ	Lambda (wavelength symbol)
µs	Microsecond = 10-6 second
Amp	Amperes
AC	Alternating current
ADC	Analog-to-digital converter
ASCII	American Standard Code for Information Interchange (U.S. Government)
BTU	British thermal unit
CAN	Controller Area Network
CDRH	Center for Devices and Radiological Health (U.S. Government)
CFR	Code of Federal Regulation (U.S. Government)
cm	Centimeters = 10-2 meters
CPU	Central processing unit
CW	Continuous wave (operating mode)
DC	Direct current
EN	European Norm
Hz	Hertz or cycles per second (frequency)
kg	Kilograms
kV	Kilovolts = 103 volts
kW	Kilowatts = 103 watts

l	Liters (volume)
lbs	Pounds
IP	Internet protocol
LD	Laser diode
LCD	Liquid crystal display
LED	Light emitting diode
nm	Nanometer = 10-9 meters
mA	Milliamps = 10-3 amperes
mm	Millimeter = 10-6 meters
MHz	Megahertz = 106 Hertz
mrad	Milliradian = 10-3 radians (geometry)
rms	Root mean square or quadratic mean
QCW	Quasi-Continuous wave (operating mode)
TCP	Transmission control protocol
VAC	Voltage alternating current
VDC	Volts Direct Current
W	Watts (power)

Index

To learn more, visit www.ipgphotonics.com

March 2015

Part Number
P21-010106

Apêndice M

Resultados do teste do laser *IPG YLR-200-AC*

	TEST RESULTS YTTERBIUM FIBER LASER Model YLR-200-AC S/N 18070428	Form: Revision: Spec: Page:	G69-00557 1 G22-15652 rev.6 1 of 5
IPG LASER			

This product is covered by the U.S. Pat. Nos. 5,422,897 and 5,774,484 and any foreign counterparts thereof, and other patents pending.

The information and the following charts provided below is the result of tests performed in controlled environments by IPG Laser. These provided useful, but not warranted, information about the functions and performance of the product.

N	Characteristic	Symbol	Test Conditions	Min	Typ.	Max	Test Results	Unit
	Optical characteristics							
1.1	Operation Mode				CW / modulated		CW / modulated	
1.2	Nominal Output Power	P_{nom}	I = 95.9 % after collimator	200			200	W
1.3	Maximal Output Power	P_{max}	I = 100 % after collimator				209	W
1.4	Emission Wavelength	λ			1070		1070.0	nm
1.5	Emission Linewidth	$\Delta\lambda$			2.5	4	3.0	nm
1.6	Short-term Power Instability		$P_{out} = P_{nom}$ frequency range: 10kHz - 20MHz		1	2	0.6	rms %
1.7	Long-term Power Instability		$P_{out} = P_{nom}$ T = constant		± 1	± 3	± 0.1	%
1.8	Switching ON Time		$P_{out} = P_{nom}$		30	50	22.5	µs
1.9	Switching OFF Time		$P_{out} = P_{nom}$		30	50	7.6	µs
1.10	Power Modulation Rate		$P_{out} = P_{nom}$			50	Tested	kHz
1.11	Red Guide Laser Power		after collimator	0.1		1	0.2	mW
	Optical output							
2.1	Output Fiber Termination				QBH-compatible connector		Tested	
2.2	Beam Divergence (calculated)	θ	Full angle, 86% level	130	140	150	139	mrad
2.3	Output Termination				Collimator		F85 D25 AC SN: 26848	
2.4	Beam Quality	M^2			1.05	1.1	1.07	
2.5	Beam Diameter	W	86% level				11.8	mm
2.6	Beam Divergence	θ	Full angle, 86% level				0.31	mrad
	General characteristics							
3.1	Cooling Method				Forced Air		Forced Air	
	Electrical characteristics							
4.1	Operating Voltage, single-phase				100-120/200-240 VAC, 50/60 Hz		230	VAC
4.2	Maximum Power Consumption				700	800	650	W
4.3	Control				Display with touch-screen [1)]		Tested	
					Analog		Tested	
					RS-232		Tested	
					Ethernet		Tested	

[1)] Optional configuration

IPG LASER	**TEST RESULTS** **YTTERBIUM FIBER LASER** **Model YLR-200-AC** **S/N 18070428**	Form: Revision: Spec: Page:	G69-00557 1 G22-15652 rev.6 2 of 5

N	Charecteristic	Test Conditions	Test Results
	Lasers interfaces		
5.1	Harting Han 7-pin interface connector		Tested
5.2	Ethernet interface connector		Tested
	Harting Han 24-pin interface connector		
5.3	RS-232 interface		Tested
	Safety functions		
5.4	Interlock channel 1	Emergency shutdown	Tested
	Interlock channel 2		Tested
	Control interface		
5.5	Analog current control input	Analog input: 1 - 10 VDC = 10 - 100 % setpoint	Tested
5.6	Analog output power monitor	Analog output: 0 - 4 VDC = 0 - Pnom	Tested
5.7	Modulation	5 - 24 VDC Input	Tested

Date: 10.08.2018

Tested by: S. Winkel

Approved by: Dr. G. Sargsyan

This document has been created automatically and is valid without a signature

	TEST RESULTS YTTERBIUM FIBER LASER Model YLR-200-AC S/N 18070428	Form: Revision: Spec: Page:	G69-00557 1 G22-15652 rev.6 3 of 5

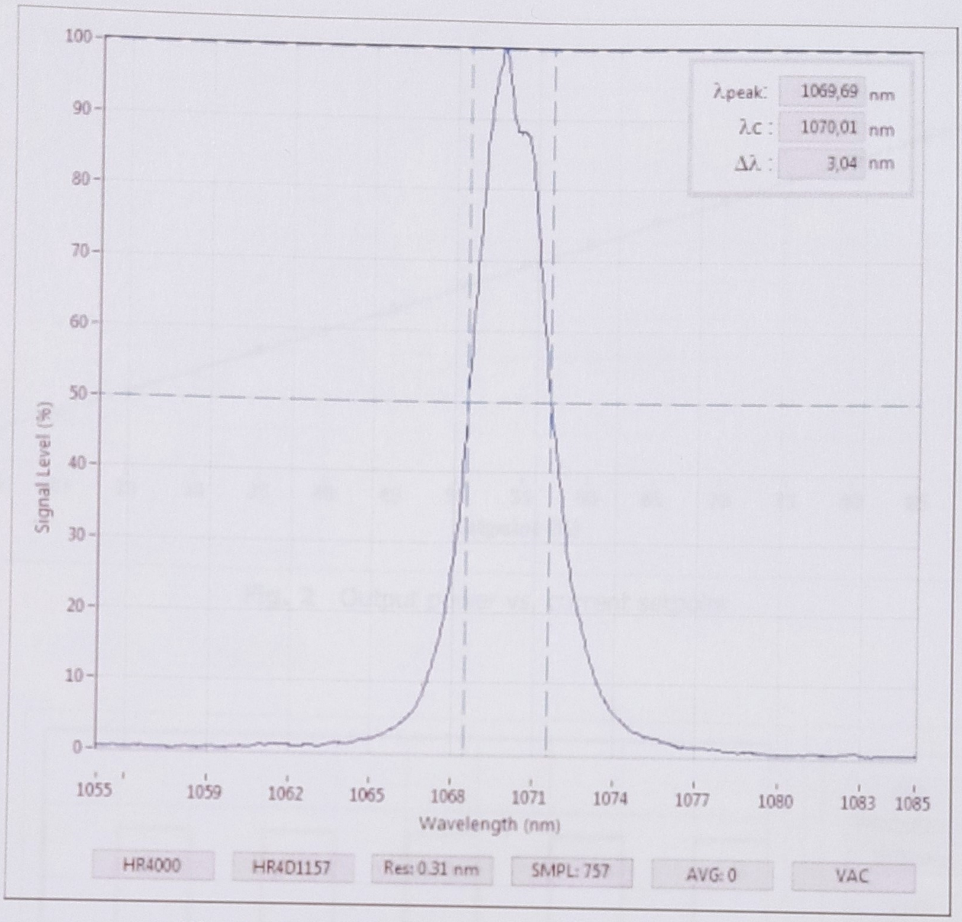


Fig. 1 Output spectrum at nominal output power

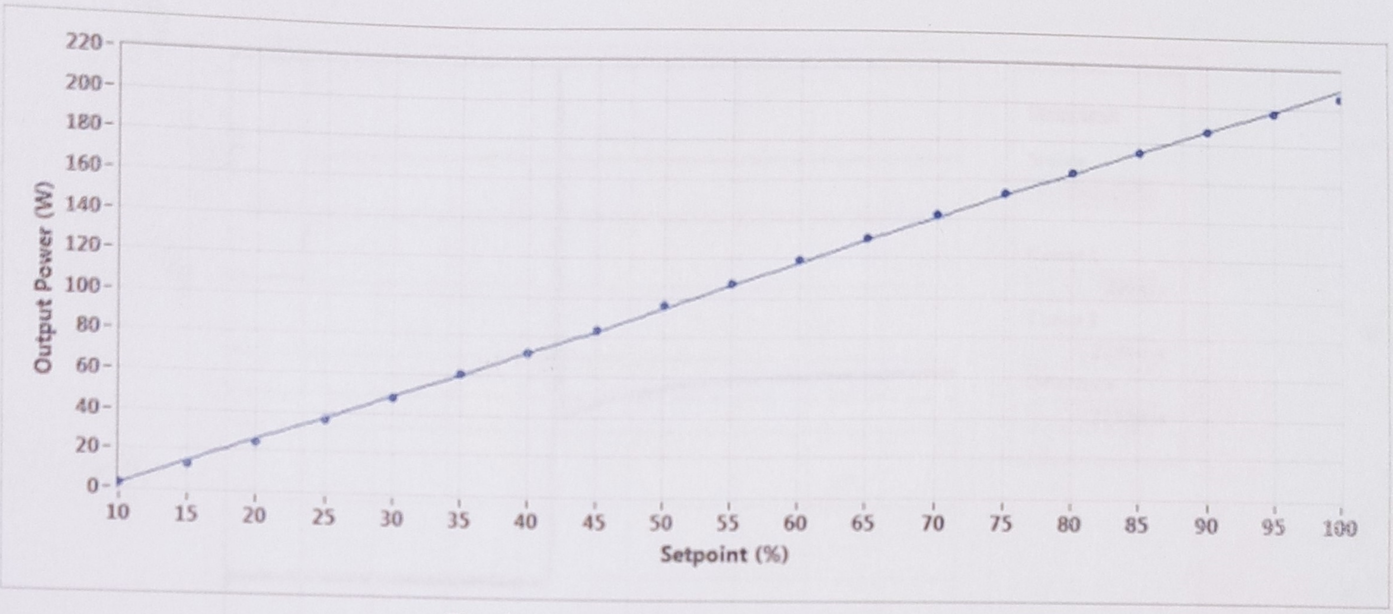


Fig. 2 Output power vs. current setpoint

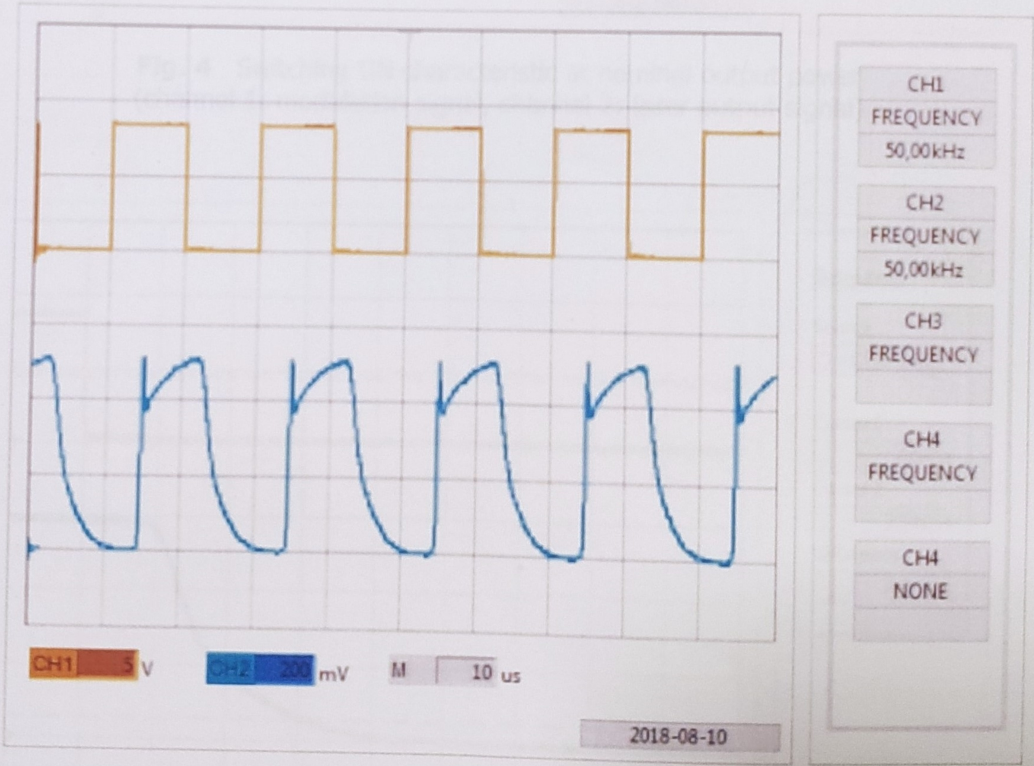


Fig. 3 Laser output digital modulation at frequency of 50 kHz at nominal output power (channel 1: modulation signal, channel 2: laser output signal)

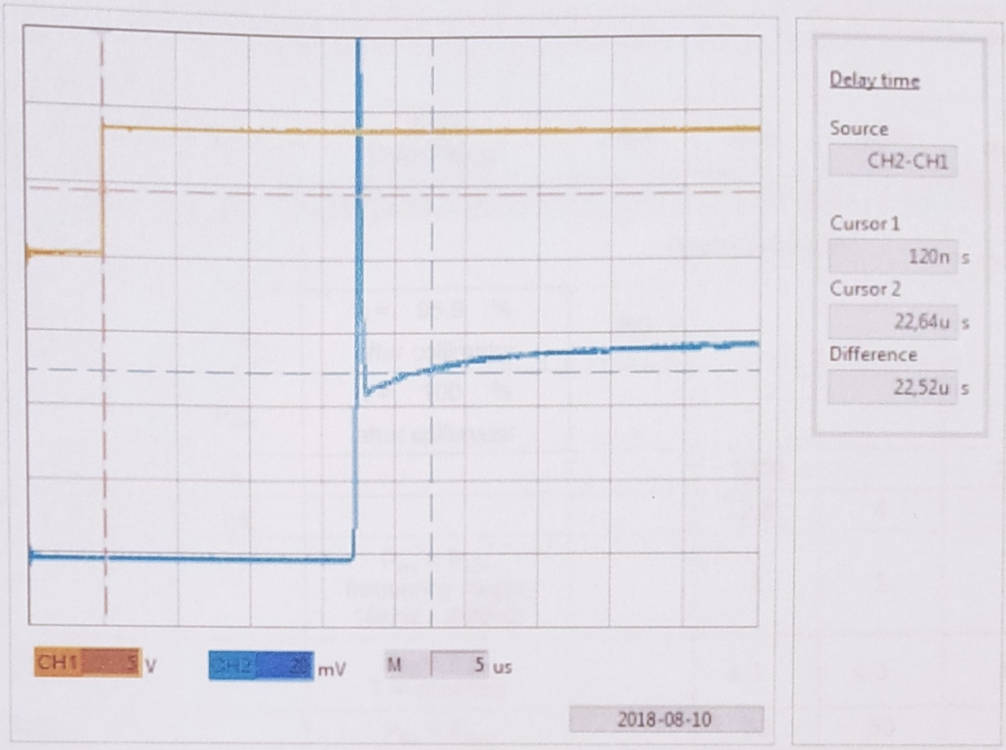


Fig. 4 Switching ON characteristic at nominal output power (channel 1: modulation signal, channel 2: laser output signal)

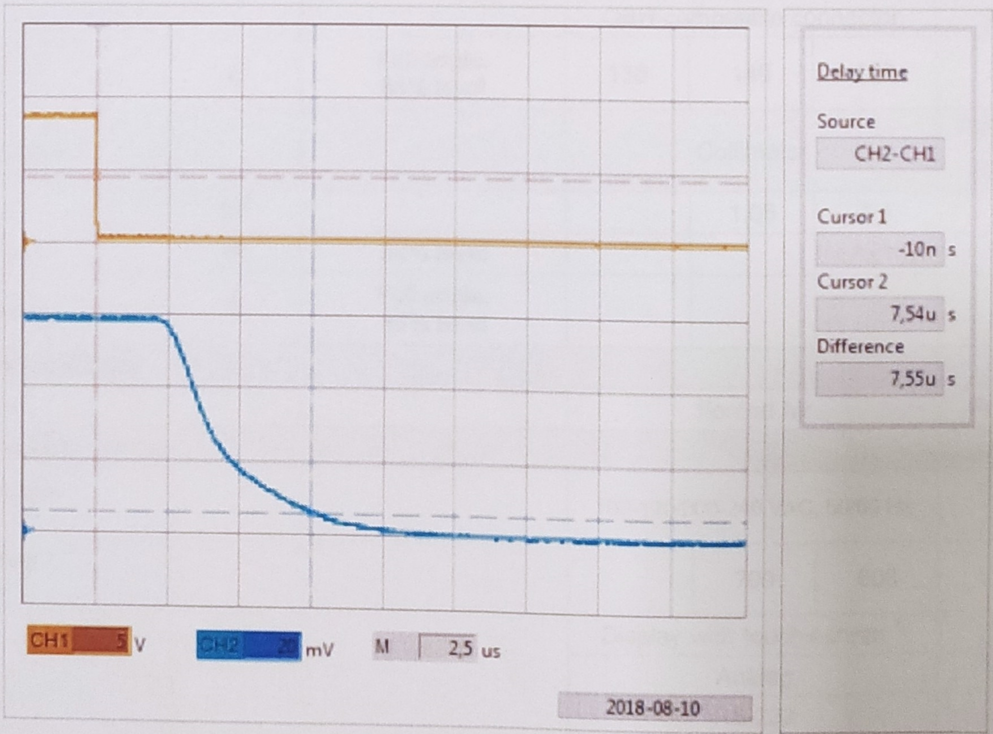
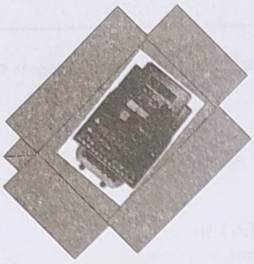


Fig. 5 Switching OFF characteristic at nominal output power (channel 1: modulation signal, channel 2: laser output signal)

Apêndice N

Quick start guide do variador *RS510*

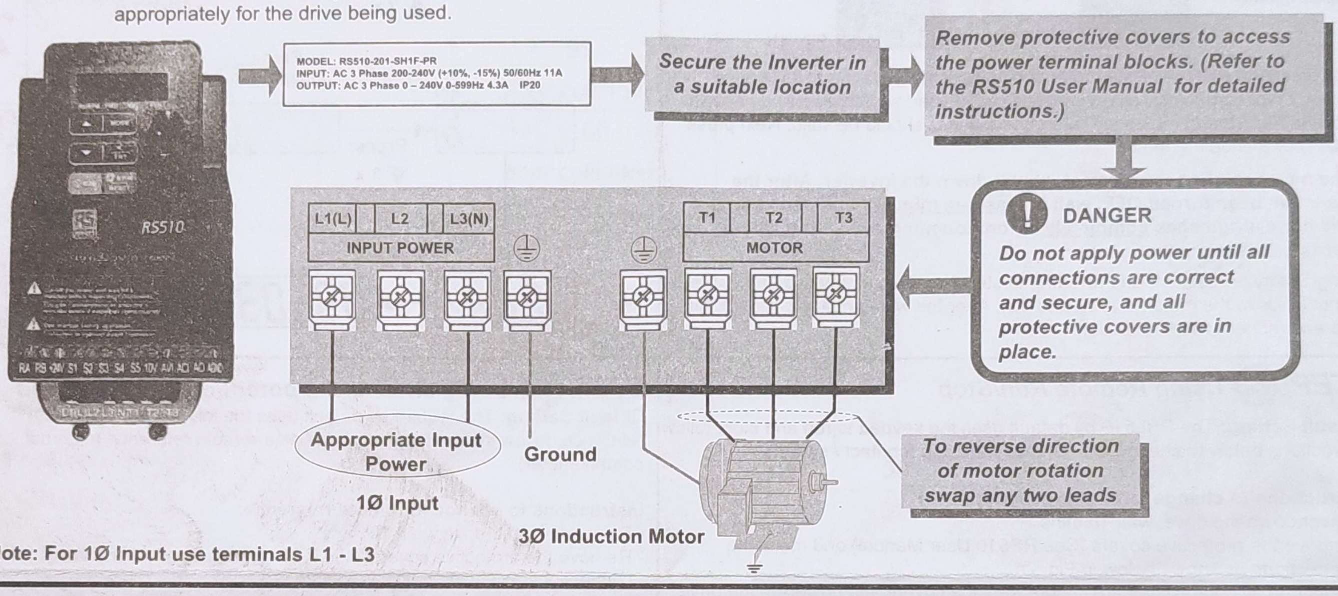


OUT of the Box Startup – Overview

This document is intended as a quick start guide to get familiarity with keypad navigation, changing parameters, and setting the RS510 drive up for external start/stop and external potentiometer signal. Please note this document is not a substitute for the RS510 User Manual and it is important that you reference the RS510 user manual before proceeding.

STEP ① Check Nameplate and Connect Input / Output Wiring -

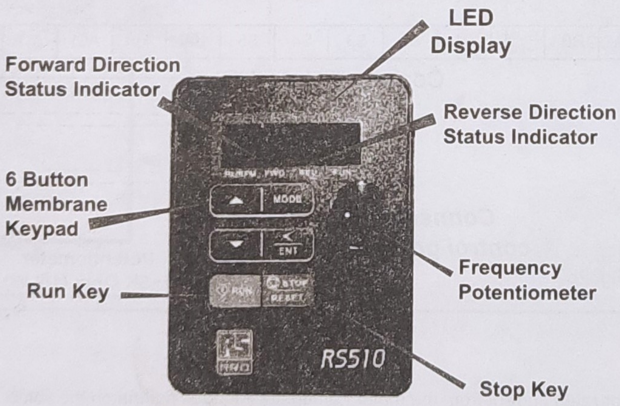
Check the inverter nameplate to insure that the information agrees with your order. Also insure that the power available is rated appropriately for the drive being used.



Note: For 1Ø Input use terminals L1 - L3

STEP ② Power-up the Inverter, check the Digital Operator

In this step, after the initial power-up you will become familiar with the indications and functions of the Digital Operator.



KEYS (8) Description

RUN: RUN Inverter in Local Mode

STOP / RESET: STOP Inverter, RESET alarms and faults

▲:Parameters navigation Up, Increase parameters or reference value
▼:Parameters navigation Down, decrease parameters or reference value

MODE: Switches between available displays

</ENTER: "<" Left Shift: Used to change parameters or values, ENTER: used to display the preset value of parameters and to save changes

RS510 Control Settings (Factory Default)

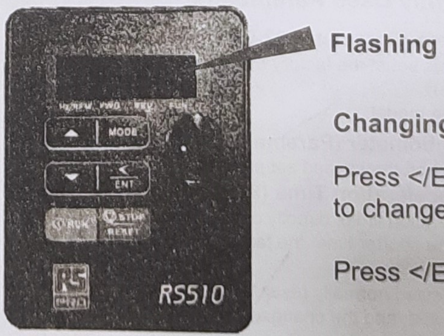
RUN/STOP Control: Keypad (RUN / STOP key)

Press RUN to start the drive or STOP to stop the drive.

See **step 5.** to change to RUN/STOP to external switch/contact.

SPEED Control: Keypad (Default 5.00 Hz)

See **step 6**. to change to external potentiometer control.



Changing Speed Reference

Press </ENT button and use ▲▼ to change reference.

Press </ENT button to save

STEP 3 Check Motor Rotation

This test is to be performed solely from the inverter keypad. Apply power to the inverter after all the electrical connections have been made and protective covers have been re-attached. At this point, **DO NOT RUN THE MOTOR**, the keypad should display as shown below in Fig. 1a and the speed reference **5.00 Hz** should be blinking.

Important: Motor rotation and direction only applies to standard AC motors with a base frequency of 60Hz. For 50Hz or other frequency AC motors please set V/F pattern in group 01 before running the motor.

DANGER

Fig. 1a

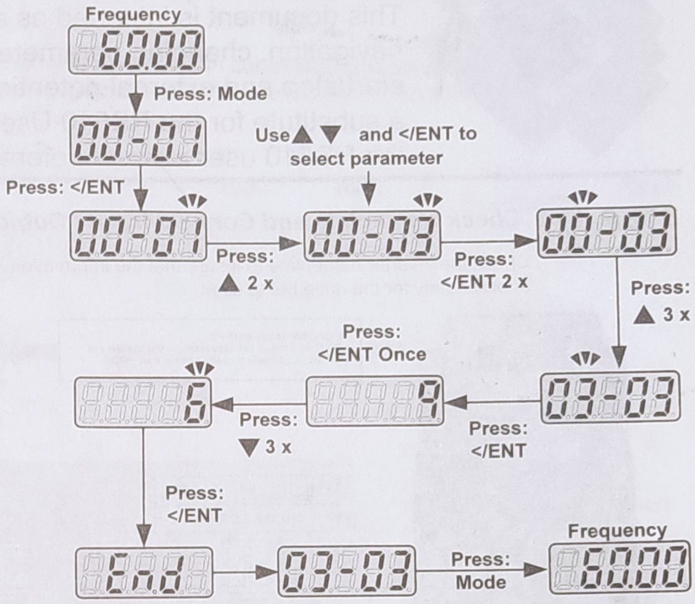
Fig. 1b

Next press the **RUN** key. The motor should now be operating at low speed running in forward (clockwise) direction. The keypad should display as shown above in Fig. 1b and the speed reference 5.00 Hz should be solid. Next press **STOP** key to stop the motor.

If the motor rotation is incorrect, power down the inverter. After the power has been turned OFF, wait at least ten minutes until the charge indicator extinguishes completely before touching any wiring, circuit boards or components.

Using Safety precaution, and referring to step 1 exchange any two of the three output leads to the motor (T1, T2 and T3). After the wiring change, repeat this step and recheck motor direction.

STEP 4 How to Change Parameters (Example 03-03 change to 6)



STEP 5 Using Remote Run/Stop

Default Setting: The RSL510 by default uses the keypad to run and stop, follow instructions below to change to a remote start/stop (contact / switch).

Instructions to change to remote run/stop:

- Power down the drive, wait 10 mins.
- Remove the protective covers (See RS510 User Manual) and make the connections as shown below in Fig. 2a.
- Verify that all connections are secure, replace covers and power-up the drive.

Do not apply power until all connections are correct and secure, and all protective covers are in place.

After power-up set parameters **00-02=1** (Run Source from Control Terminals).

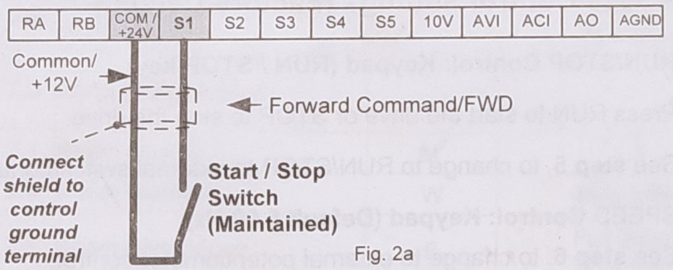


Fig. 2a

STEP 6 Using an external potentiometer for speed control

Default Setting: The RS510 by default uses the keypad for frequency reference, follow instructions below to use a remote reference (external potentiometer).

Instructions to change to remote reference:

- Power down the drive, wait 10 mins.
- Remove the protective covers (See RS510 User Manual) and make the connections as shown below in Fig. 2b.
- Verify that all connections are secure, replace covers and power-up the drive.

Do not apply power until all connections are correct and secure, and all protective covers are in place.

After power-up set parameter **00-05=2** (Speed Reference from Control Terminals).

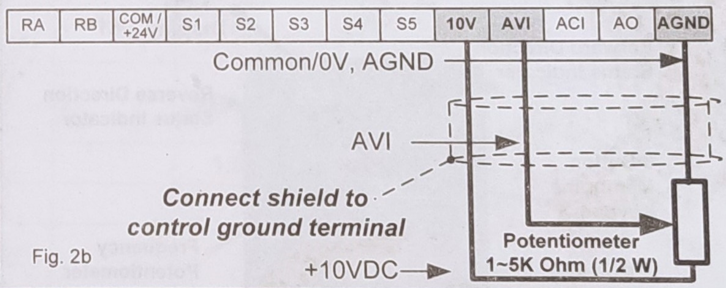


Fig. 2b

STEP 7 Frequently Used Parameters

Motor Nameplate Data (Parameter 02-01)

The motor rated current is set at the factory based on the inverter model. Enter the motor rated current from the motor nameplate if it does not match the value shown in parameter 02-01.

Setting range: Varies by model.

Using Keypad Potentiometer (Parameter 00-05)

To use the potentiometer on the keypad set parameter 00-05 to 1.

Acceleration and Deceleration Time (Parameter 00-14, 00-15)

Acceleration and Deceleration times directly control the system dynamic response. In general, the longer the acceleration and deceleration time, the slower the system response, and the shorter time, the faster the response. An excessive amount of time can result in sluggish system performance while too short of a time may result in system instability.

The default values suggested normally result in good system performance for the majority of general purpose applications. If the values need to be adjusted, caution should be exercised, and the changes should be in small increments to avoid system instability.

00-14 Acceleration time 1

00-15 Deceleration time 1

These parameters set the acceleration and deceleration times of the output frequency from 0 to maximum frequency and from maximum frequency to 0.

Factory Reset (Parameter 13-08)

To reset all parameters back to factory default set parameter 13-08 to 1160.

For the complete RS510 parameter listing and descriptions, refer to the Instruction manual.

Apêndice O

Manual do variador *RS510*

https://docs.rs-online.com/4c73/A700000006570788.pdf

Microprocessor Controlled
IGBT Drive
Inverter Motor Speed Regulator
Operating Manual

RS510 Series

200V	**0.4~2.2kW (0.5~3HP)**
400V	**0.75~11kW (1~15HP)**

Table of Contents

Chapter 0 Preface

0.1 Preface

To extend the performance of the product and ensure personnel safety, please read this manual thoroughly before using the inverter. Should there be any problem in using the product that cannot be solved with the information provided in the manual, contact our technical or sales representative who will be willing to help you.

※Precautions

The inverter is an electrical product. For your safety, there are symbols such as "Danger", "Caution" in this manual as a reminder to pay attention to safety instructions on handling, installing, operating, and checking the inverter. Be sure to follow the instructions for highest safety.

Danger	Indicates a potential hazard that could cause death or serious personal injury if misused.
⚠ Caution	Indicates that the inverter or the mechanical system might be damaged if misused.

Danger

- Risk of electric shock. The DC link capacitors remain charged for five minutes after power has been removed. It is not permissible to open the equipment until 5 minutes after the power has been removed.
- Do not make any connections when the inverter is powered on. Do not check parts and signals on circuit boards during the inverter operation.
- Do not disassemble the inverter or modify any internal wires, circuits, or parts.
- Ensure that the Inverter Ground terminal is connected correctly.

⚠ Caution

- Do not perform a voltage test on parts inside the inverter. High voltage can destroy the semiconductor components.
- Do not connect T1, T2, and T3 terminals of the inverter to any AC input power supply.
- CMOS ICs on the inverter's main board are susceptible to static electricity. Do not touch the main circuit board.

Chapter 1 Safety Precautions

1.1 Before Power Up

Danger
➢ Make sure the main circuit connections are correct. Single phase L1(L),L3(N), are power-input terminals and must not be mistaken for T1,T2 and T3. Otherwise, inverter damage can result.

Caution
➢ The line voltage applied must comply with the inverter's specified input voltage.(See the nameplate) ➢ To avoid the front cover from disengaging, or other damage do not carry the inverter by its covers. Support the drive by the heat sink when transporting. Improper handling can damage the inverter or injure personnel and should be avoided. ➢ To avoid the risk of fire, do not install the inverter on a flammable object. Install on nonflammable objects such as metal. ➢ If several inverters are placed in the same control panel, provide heat removal means to maintain the temperature below 50 degree C to avoid overheat or fire. ➢ When disconnecting the remote keypad, turn the power off first to avoid any damage to the keypad or the inverter.

Warning
➢ This product is sold subject to EN 61800-3 and EN 61800-5-1. In a domestic environment this product may cause radio interference in which case the user may be required to apply corrective measures.

Caution
➢ Work on the device/system by unqualified personnel or failure to comply with warnings can result in severe personal injury or serious damage to material. Only suitably qualified personnel trained in the setup, installation, commissioning and operation of the product should carry out work on the device/system. ➢ Only permanently-wired input power connections are allowed.

1.2 During Power Up

Danger

- When the momentary power loss is longer than 2 seconds, the inverter will not have sufficient stored power for its control circuit. Therefore, when the power is re-applied, the run operation of the inverter will be based on the setup of following parameters:
  - Run parameters. 00-02 or 00-03.
  - Direct run on power up. Parameter. 07-04 and the status of external run switch,

  Note-: the start operation will be regardless of the settings for parameters 07-00/07-01/07-02.

  Danger. Direct run on power up.

  If direct run on power up is enabled and inverter is set to external run with the run FWD/REV switch closed then the inverter will restart.

  Danger

  Prior to use, ensure that all risks and safety implications are considered.

- When the momentary power loss ride through is selected and the power loss is short, the inverter will have sufficient stored power for its control circuits to function, therefore, when the power is resumed the inverter will automatically restart depending on the setup of parameters 07-00 & 07-01.

1.3 Before Operation

Caution

- Make sure the model and inverter capacity are the same as that set in parameter 13-00.

Note : On power up the supply voltage set in parameter 01-01 will flash on display for 2 seconds.

1.4 During Operation

Danger
➢ Do not connect or disconnect the motor during operation. Otherwise, It may cause the inverter to trip or damage the unit.

Danger
➢ To avoid electric shock, do not take the front cover off while power is on. ➢ The motor will restart automatically after stop when auto-restart function is enabled. In this case, care must be taken while working around the drive and associated equipment . ➢ The operation of the stop switch is different than that of the emergency stop switch. The stop switch has to be activated to be effective. Emergency stop has to be de-activated to become effective.

Caution
➢ Do not touch heat radiating components such as heat sinks and brake resistors. ➢ The inverter can drive the motor from low speed to high speed. Verify the allowable speed ranges of the motor and the associated machinery. ➢ Note the settings related to the braking unit. ➢ Risk of electric shock. The DC link capacitors remain charged for five minutes after power has been removed. It is not permissible to open the equipment until 5 minutes after the power has been removed.

Caution
➢ The Inverter should be used in environments with temperature range from (14-104℉) or (-10 to 40℃) and relative humidity of 95%.

Note: models with fan : -10~50℃ , models without fan : -10~40℃

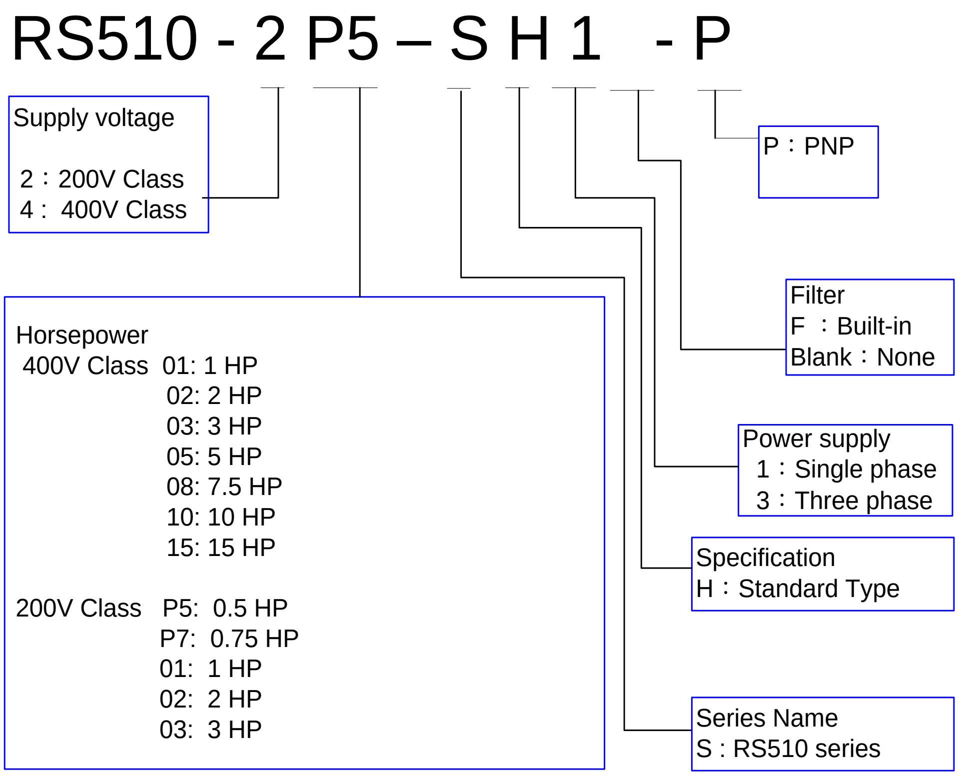
Danger
➢ Make sure that the power is switched off before disassembling or checking any components.

1.5 Inverter Disposal

Caution
Please dispose of this unit with care as an industrial waste and according to your required local regulations. ➢ The capacitors of inverter main circuit and printed circuit board are considered as hazardous waste and must not be burnt. ➢ The Plastic enclosure and parts of the inverter such as the cover board will release harmful gases if burnt.

Chapter 2 Part Number Definition

2.1 Model part number

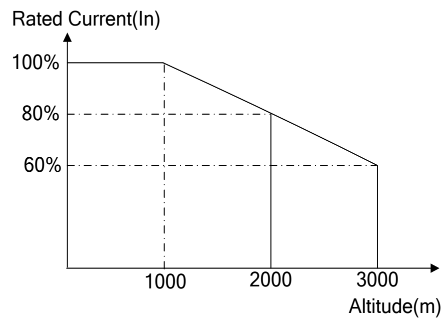


Chapter 3 Environment & Installation

3.1 Environment

Installation environment has a direct effect on the correct operation and the life expectancy of the inverter, Install the inverter in an environment complying with the following conditions:

<table>
<tr><th colspan="3">Protection</th></tr>
<tr><td>Protection class</td><td colspan="2">IP20 Open Type</td></tr>
<tr><th colspan="3">Suitable environment</th></tr>
<tr><td>Operating temperature</td><td colspan="2">-10~40°C (-10~50°C with fan) (non-freezing)
If several inverters are installed in the same control panel, ensure adequate spacing and provide the necessary cooling and ventilation for successful operation.</td></tr>
<tr><td>Storage temperature</td><td colspan="2">-20~60°C</td></tr>
<tr><td>Relative Humidity</td><td colspan="2">Max 95% (without condensation)</td></tr>
<tr><td>Altitude</td><td>Altitude：Below 1000m (3281ft)

It is required to reduce 2% of inverter rated current at each additional 100m. The maximum altitude is 3000m</td><td>
</td></tr>
<tr><td>Vibration</td><td colspan="2">Frequency: 10Hz - 150Hz - 10Hz
Amplitude(0.3mm): 10Hz ≦f ≦57Hz
Acceleration(2G): 57Hz ≦f ≦150Hz
(According to IEC60068-2-6 standard)</td></tr>
</table>

Installation site

Install in an environment that will not have an adverse effect on the operation of the unit and ensure that there is no exposure to areas such as that listed below:-

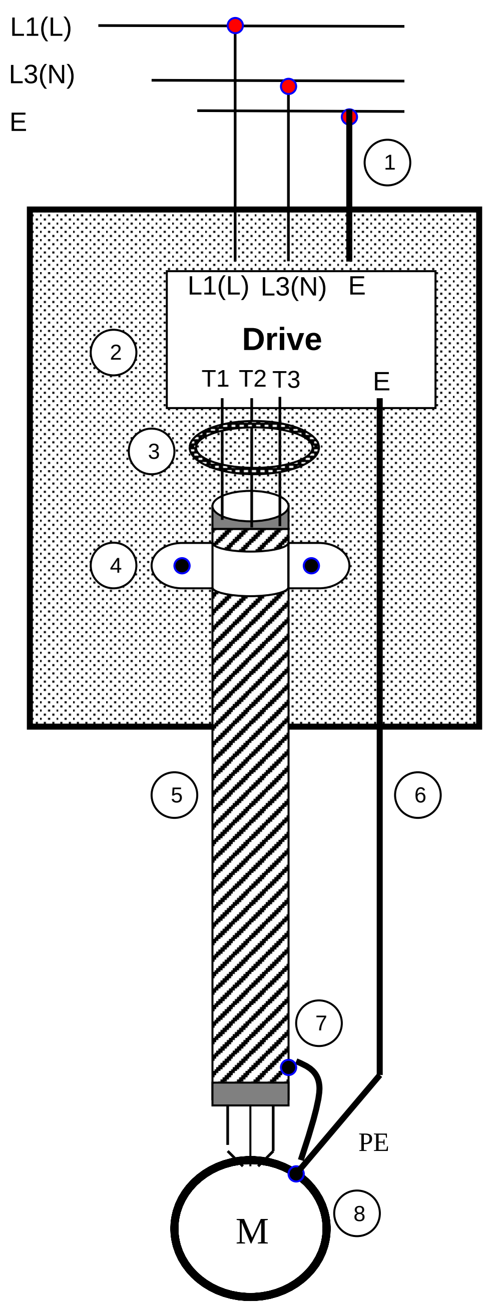
- Direct sunlight, Rain or moisture
- Oil mist and salt
- Dust, lint fibers, small metal filings and corrosive liquid and gas
- Electromagnetic interference from sources such as welding equipment
- Radioactive and flammable materials
- Excessive vibration from machines such as stamping, punching machines
- Add vibration-proof pads if necessary

3.1.1 Wiring and EMC guidelines

For effective interference suppression, do not route power and control cables in the same conduit or trunking.
To prevent radiated noise, motor cable should be put in a metal conduit. Alternatively an armored or shielded type motor cable should be used.
For effective suppression of noise emissions the cable armor or shield must be grounded at both ends to the motor and the inverter ground. These connections should be as short as possible.
Motor cable and signal lines of other control equipment should be at the least 30 cm apart.

RS510 has a built in Class “A” EMC filter to first Environment Restricted. (Category C2).
For some installations such as residential,(Category C1) an optional external Class “B” type filter will be necessary. Please consult your local supplier.

Typical Wiring.



1.Protective Earth Conductor.
Conductor size for enclosure & Backplate must comply with the local electrical standards. Min 10mm².

2.Backplate. Galvanised steel (Unpainted).

3.Ferrite core / Output reactor
ferrite cores can be used to reduce radiated noise due to long motor cables.
If ferrite core is used loop motor wires, 3 times round the core. Install core as close to the inverter as possible

Output reactors provide additional benefit of reducing dv/dt for protection of motor windings.

4.Metal Cable clamp. no more than 150mm from the inverter.
Note: If no enclosure & backplate is used then connect the cable shield by a good 360 º termination to the Inverter output terminal E.

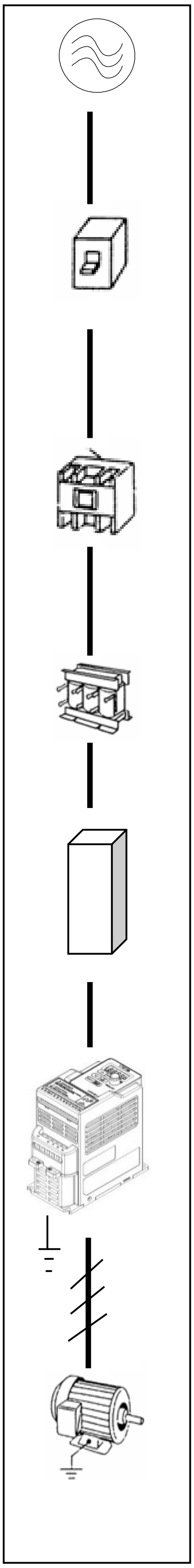
5.Screened (Shielded four core cable).

6.Separate Protective Earth wire, routed outside motor cable separated be at least 100mm.
Note:- this is the preferred method specially for large output cables and long length. Multi-core screened (3 core & protective earth) can be used for small power and short length.

7.Connect the cable shield by a good 360º termination and connect to the motor protective earth terminal.
This link must be as short as possible.

8.Motor Earth terminal(Protective Earth).

3.1.2 Considerations for peripheral equipment



Power	Ensure that the supply voltage is correct. A molded-case circuit breaker or fused disconnect must be installed between the AC source and the inverter
Circuit Breaker & RCD	Use a molded-case circuit breaker that conforms to the rated voltage and current of the inverter. Do not use the circuit breaker as the run/stop switch for the inverter. Residual Current Circuit Breaker(RCD) Current setting should be 200mA or above and the operating time at 0.1 second or longer to prevent malfunctions.
Magnetic contactor	Normally a magnetic contactor is not needed. A contactor can be used to perform functions such as external control and auto restart after power failure. Do not use the magnetic contactor as the run/stop switch for the inverter.
AC reactor for power quality improvement	When a 200V/400V inverter with rating below 15KW is connected to a high capacity power source (600kVA or above) then an AC reactor can be connected for power factor improvement and reducing harmonics.
Input noise filter	RS510 inverter has a built-in filter to Class “A” first Environment. (CategoryC2) To satisfy the required EMC regulations for your specific application you may require an additional EMC filter.
Inverter	Connect the single phase power to Terminals, L1(L) & L3(N) and three phase power to Terminals : Warning! Connecting the input terminals T1, T2, and T3 to AC input power will damage the inverter. Output terminals T1, T2, and T3 are connected to U, V, and W terminals of the motor. To reverse the motor rotation direction just swap any two wires at terminals T1, T2, and T3. Ground the Inverter and motor correctly. Ground Resistance for 200V power<100 Ohms.
Motor	Three-phase induction motor. Voltage drop on motor due to long cable can be calculated. Volts drop should be < 10%. Phase-to-phase voltage drop (V) = $\sqrt{3}$ ×resistance of wire (Ω/km)×length of line (m)×current×10^{-3}

(For detailed information for the above peripheral equipment refer to Chapter 6)

3.2 Specifications
3.2.1 Product Specifications

200V Class : Single phase. **F : Standards for built-in filter**

Model :RS510-□□□-SH1F-P	2P5	2P7	201	202	203
Horse power (HP)	0.5	0.75	1	2	3
Suitable motor capacity (kW)	0.4	0.55	0.75	1.5	2.2
Rated output current (A)	2.6	3.4	4.3	7.5	10.5
Rated capacity (kVA)	1.00	1.30	1.65	2.90	4.00
Input voltage range(V)	Single Phase : 200~240V (+10%-15%),50/60HZ				
Output voltage range(V)	Three phase 0~240V				
Input current (A)	7.2	9	11	15.5	21
Weight(kG)	0.9	0.9	0.9	1.4	1.4
Weight with filter(kG)	1.0	1.0	1.0	1.5	1.5
Momentary power loss time (s)	1.0	1.0	1.0	2.0	2.0
Enclosure	IP20				

400V Class : Three phase. **F : Standards for built-in filter**

Model : RS510-□□□-SH3F-P	401	402	403
Horse power (HP)	1	2	3
Suitable motor capacity (kW)	0.75	1.5	2.2
Rated output current (A)	2.3	3.8	5.2
Rated capacity (kVA)	1.7	2.9	4.0
Input voltage range(V)	Three Phase : 380~480V (+10%-15%),50/60HZ		
Output voltage range(V)	Three phase 0~480V		
Input current (A)	4.2	5.6	7.3
Weight(kG)	1.4	1.4	1.4
Weight with filter(kG)	1.5	1.5	1.5
Momentary power loss time (s)	2.0	2.0	2.0
Enclosure	IP20		

Model : RS510-□□□-SH3F	405	408	410	415
Horse power (HP)	5	7.5	10	15
Suitable motor capacity (kW)	3.7	5.5	7.5	11
Rated output current (A)	9.2	13.0	17.5	24
Rated capacity (kVA)	7.01	9.91	13.34	18.29
Input voltage range(V)	Three Phase :380~480V (+10%-15%),50/60HZ			
Output voltage range(V)	Three Phase 0~480V			
Input current (A)	10.1	14.3	19.3	26.4
Weight(kG)	2.2	2.2	6.3	6.3
Weight with filter(kG)	2.4	2.4	6.3	6.3
Momentary power loss time (s)	2	2	2	2
Enclosure	IP20			

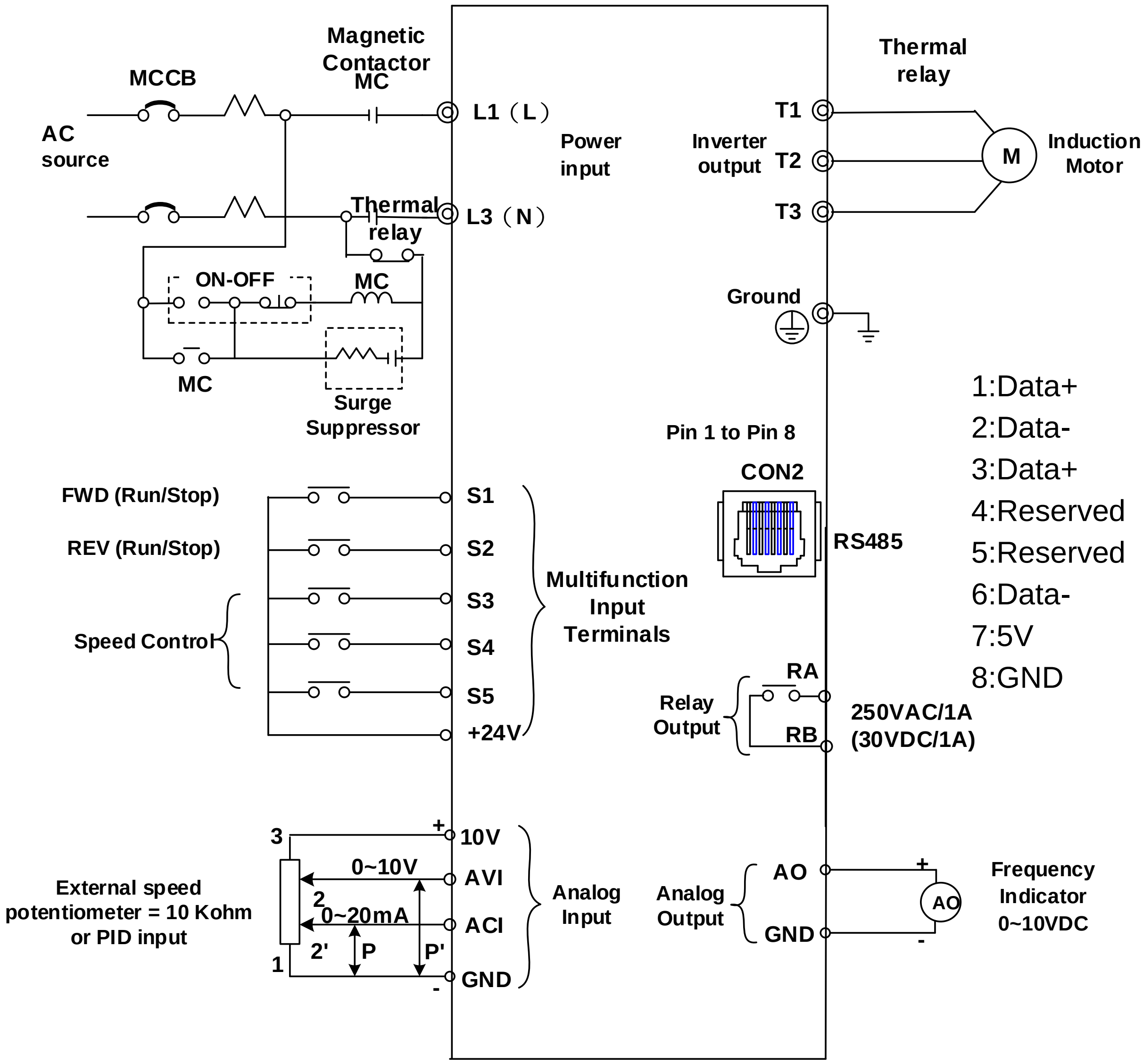
*The input current is calculated value at full rated output current.

3.2.2 General Specifications

Item		RS510
Control Mode		V/F Control + SLV control
Frequency	Range	0.01~599.00Hz
	Speed accuracy (100% torque)	V/F: 3% SLV: 1%
	Starting Torque	V/F: 3Hz / 100% SLV: 3Hz / 150%
	Setting resolution	Digital input : 0.01Hz
		Analog input : 0.015Hz/60Hz
	Setting	Keypad : Set directly with▲▼ keys or the VR (Potentiometer) on the keypad
		External Input Terminals: AVI(0/2~10V), ACI(0/4~20mA)input Multifunction input up/down function(Group3)
		Setting frequency by Communication method.
	Frequency limit	Lower and upper frequency limits 3 -skip frequency settings.
Run	Operation set	Keypad run, stop button
		External terminals: Multi- operation-mode 2 / 3 wire selection Jog operation
		Run signal by communication method.
Main Controls	V / F curve setting	6 fixed curve and one customized curve
	Carrier frequency	1~16kHz(default 5kHz)
	Acceleration and deceleration control	2 off Acc / dec time parameters. 4 off S curve parameters.
	Multifunction input	19 functions (refer to description on group3) 5 points, Frame1/2 : NPN&PNP by separate models Frame 3/4 : NPN&PNP switchable
	Multifunction output	16 functions (refer to description on group3)
	Multifunction analog output	5 functions (refer to description on group4) 1 point (0~10V)
	Main features	Overload Detection, 8 preset speeds, Auto-run, Acc/Dec Switch (2 Stages), Main/Alt run Command select, Main/Alt Frequency Command select, PID control, torque boost, V/F start Frequency ,Fault reset.
Display	LED	Display: parameter/parameter value/frequency/line speed/DC voltage/output voltage/output current/PID feedback/input and output terminal status/Heat sink temperature/Program Version/Fault Log.
	LED Status Indicator	For run/stop/forward and reverse.
Protective Functions	Overload Protection	Integrated motor and Inverter overload protection. (150% rated current for 60sec)
	Over voltage	Over 410V
	Under voltage	Under 190V
	Momentary Power Loss Restart	Inverter auto-restart after a momentary power loss.
	Stall Prevention	Stall prevention for Acceleration/ Deceleration/ and continuous Run.
	Short-circuit output terminal	Electronic Circuit Protection
	Grounding Fault	Electronic Circuit Protection

	Additional protective functions	heatsink over temperature protection, Auto carrier frequency reduction with temperature rise, fault output, reverse prohibit, Number of auto restart attempts, Parameter lock, over voltage protection(OVP), motor PTC over-temperature protection
International Certification		CE/UL/cUL/RCM
Communication		RS485 (Modbus) built in, with one to one or one to many control. Built-in BacNet communication. Profibus, DeviceNet, CANopen, TCP/IP by gateways.
Environment	Operating temperature	-10~50°C(with fan), -10~40°C(without fan)
	Storage temperature	-20~60°C
	Humidity	Under 95%RH (no condensation)
	Shock	2G ($19.6m/s^2$) for 57~150Hz and below. 0.3mm for 10~57Hz
	EMC Compliance	EN61800-3, First Environment Portion models can pass C1 level with grounding kit.
	LVD Compliance	EN 61800-5-1
	Electrical Safety	UL508C
	Protection level	IP20

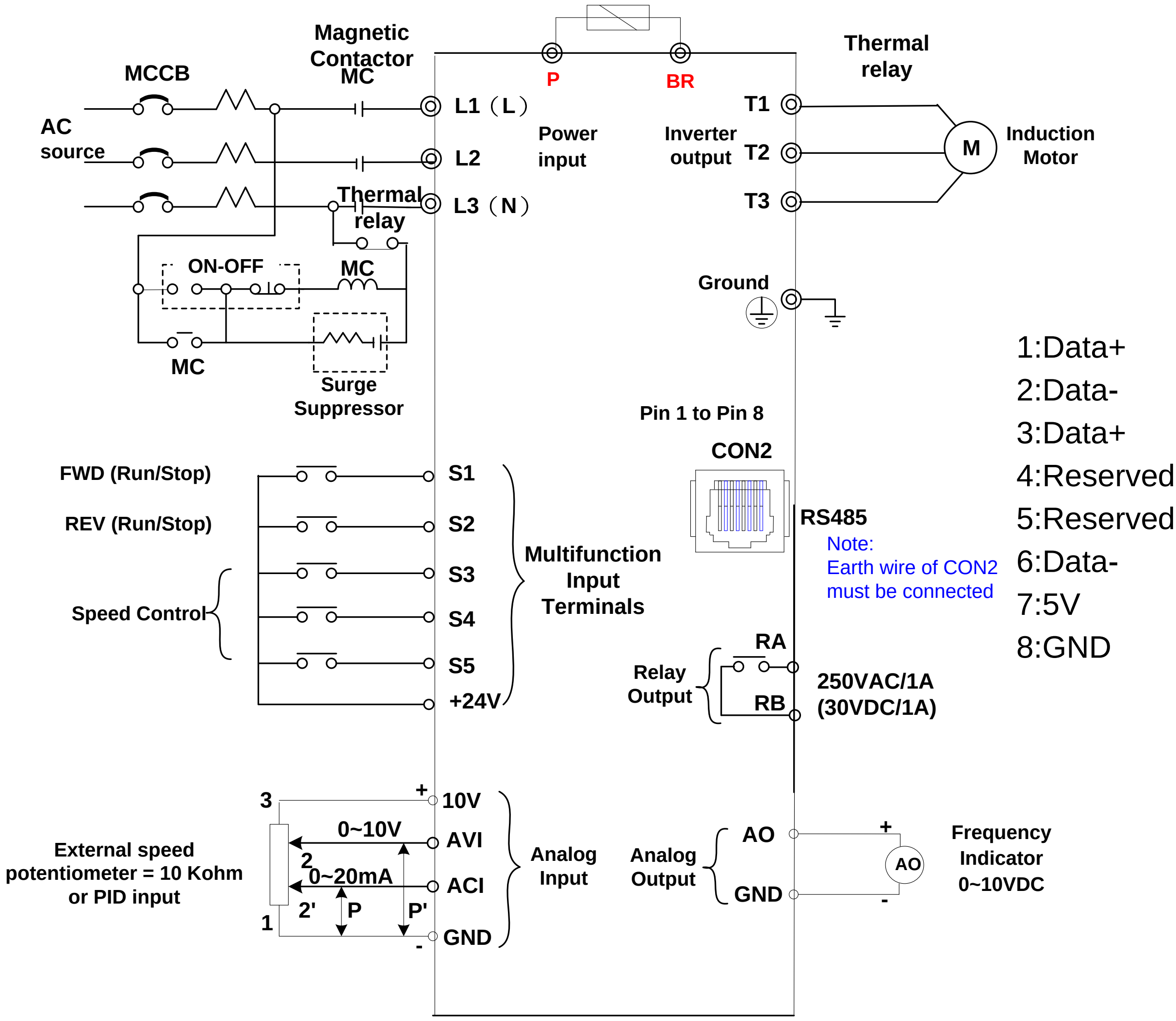
3.3 Standard wiring
3.3.1 Single phase (PNP) input



Model:

: RS510-2P5-SH1F-P / RS510-201-SH1F-P
RS510-202-SH1F-P / RS510-203-SH1F-P

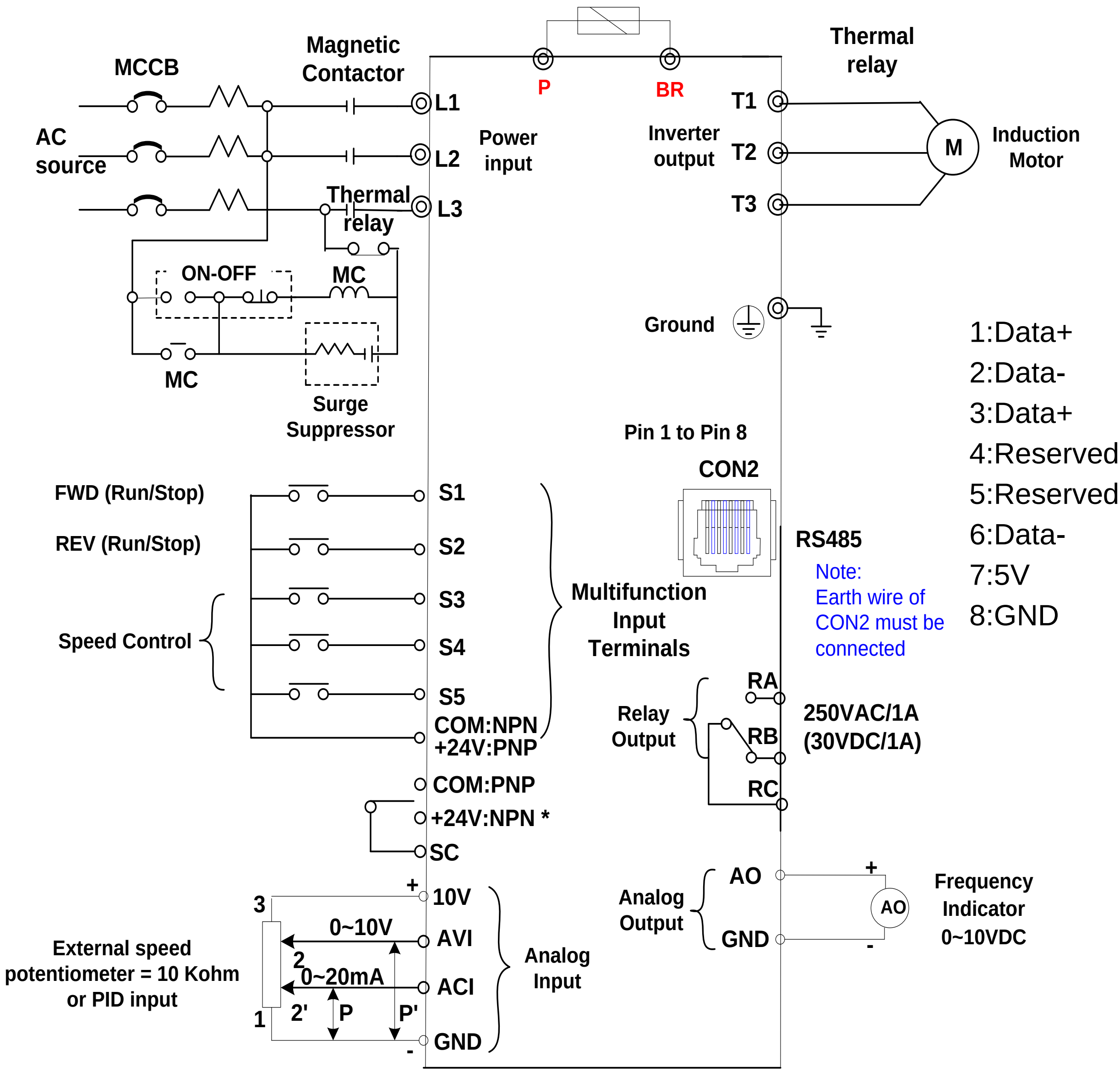
3.3.2 Three phase (PNP) input



Model:

400V : RS510-401-SH3(F)-P, RS510-402-SH3(F)-P, RS510-403-SH3(F)-P

3.3.3 NPN/PNP selectable models



Model:

400V : RS510-405-SH3(F), RS510-408-SH3(F), RS510-410-SH3(F), RS510-415-SH3(F)

NPN/PNP input type selection

PNP: 1.Link SC and COM terminal
2.Use +24v terminal for S1~S5 common point

NPN: 1.Link SC and +24V terminal
2.Use COM terminal for S1~S5 common point

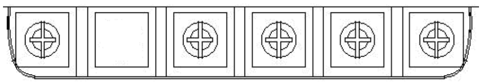
Please ensure correct connection before setting parameter group3 digital inputs.

3.4 Terminal Description

3.4.1 Description of main circuit terminals

Terminal symbols	TM1 Function Description
L1(L)	Main power input, single phase: L1(L) / L3(N) Three phase(400V): L1 / L2 / L3
L2	
L3(N)	
P*	Externally connected braking resistor. **P,BR for 401/402/403/405/408/410/415 series**
BR*	
T1,T2,T3	Inverter output, connect to U, V, W terminals of motor
⏚	Ground terminal

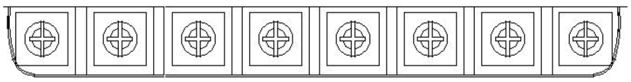
Single phase 230V



L1(L) L2 L3(N) T1 T2 T3

Note: the screw on L2 terminal is removed for the single phase input supply models.

Three phase 400V series



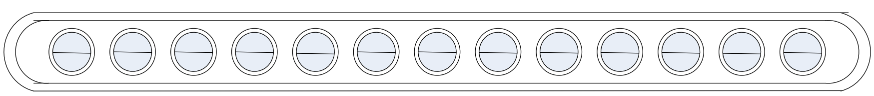
L1 L2 L3 P BR

3.4.2 Description of control circuit terminals

Frame1&Frame2

Terminal symbols	TM2 Function Description	Signal Level
RA	Relay output terminal, Specification: 250VAC/1A(30VDC/1A)	250VAC/1A(30VDC/1A)
RB		
24V	S1~S5 (COMMON) 【PNP】	±15%,Max output current 30mA
S1~S5	Multi-function input terminals(refer to group3)	24 VDC, 4.5 mA, optical coupling isolation (Max,voltage30 VDC, Input impedance 6kΩ)
10V	Built in power for an external speed potentiometer	10V,(Max current:20mA)
AVI	Analog voltage input, Specification : 0/2~10VDC (choose by parameter 04-00)	0~10V(Input impedance 200kΩ)
ACI	Analog current input, Specification : 0/4~20mA (choose by parameter 04-00)	0~20mA(Input impedance 249Ω)
AO	Multi-function analog output terminal. Maximum output 10VDC/1mA	0~10V(Max current 2mA)
AGND	Analog ground terminal	

PNP :



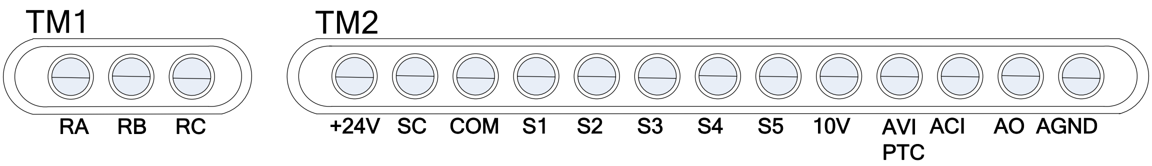
RA RB +24V S1 S2 S3 S4 S5 10V AVI ACI AO AGND

Frame3&Frame4

Terminal symbols	TM1 Function Description
RA	Relay output terminal, Specification: 250VAC/5A(30VDC/5A) RA: Normally open RB: Normally close RC: common point
RB	
RC	

Terminal symbols	TM2 Function Description	Signal Level
+24V	Common point of PNP input	±15%,Max output current 30mA
SC	NPN/PNP selectable terminal. NPN input: +24V&SC need to be shorted. PNP input: COM&SC need to be shorted.	
COM	voltage reference point for S1~S5	
S1~S5	Multi-function input terminals(refer to group3)	24 VDC, 4.5 mA, Optical coupling isolation (Max,voltage30 Vdc, Input impedance 6kΩ)
10V	Built in Power for an external speed potentiometer (Max output : 20mA)	10V,(Max current:20mA)
AVI/PTC	Analog voltage input/motor over temperature protection signal input, Specification : 0/2~10VDC	0~10V(Input impedance 200kΩ)
ACI	Analog current input, Specification : 0 /4~20mA(choose by parameter 04-00)	0~20mA(Input impedance 249Ω)
AO	Multi function analog output terminal. Maximum output 10VDC/1mA	0~10V(Max current 2mA)
AGND	Analog ground terminal	

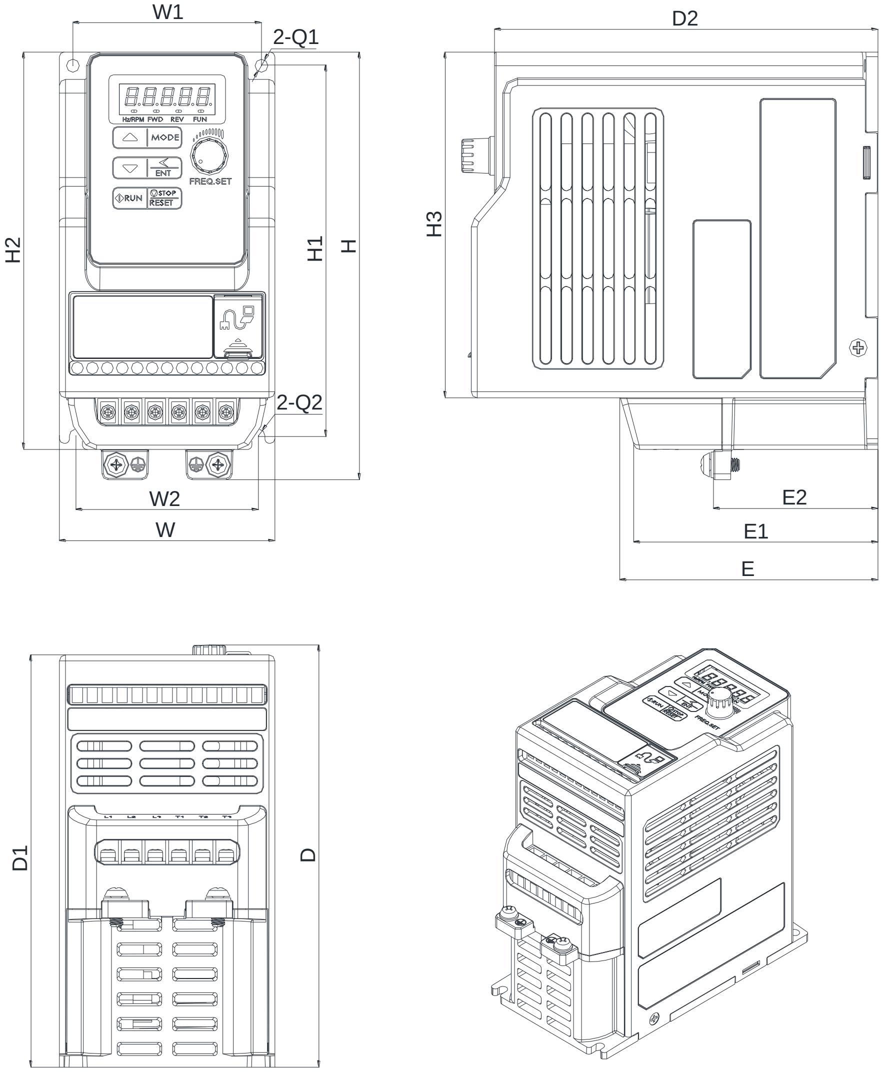
NPN/PNP control terminals:



3.5 Outline Dimensions(unit: mm)

Tolerance Table				
0～6±0.8	6～30±1.5	30～120±2.5	120～315±4.0	315～1000±6.0

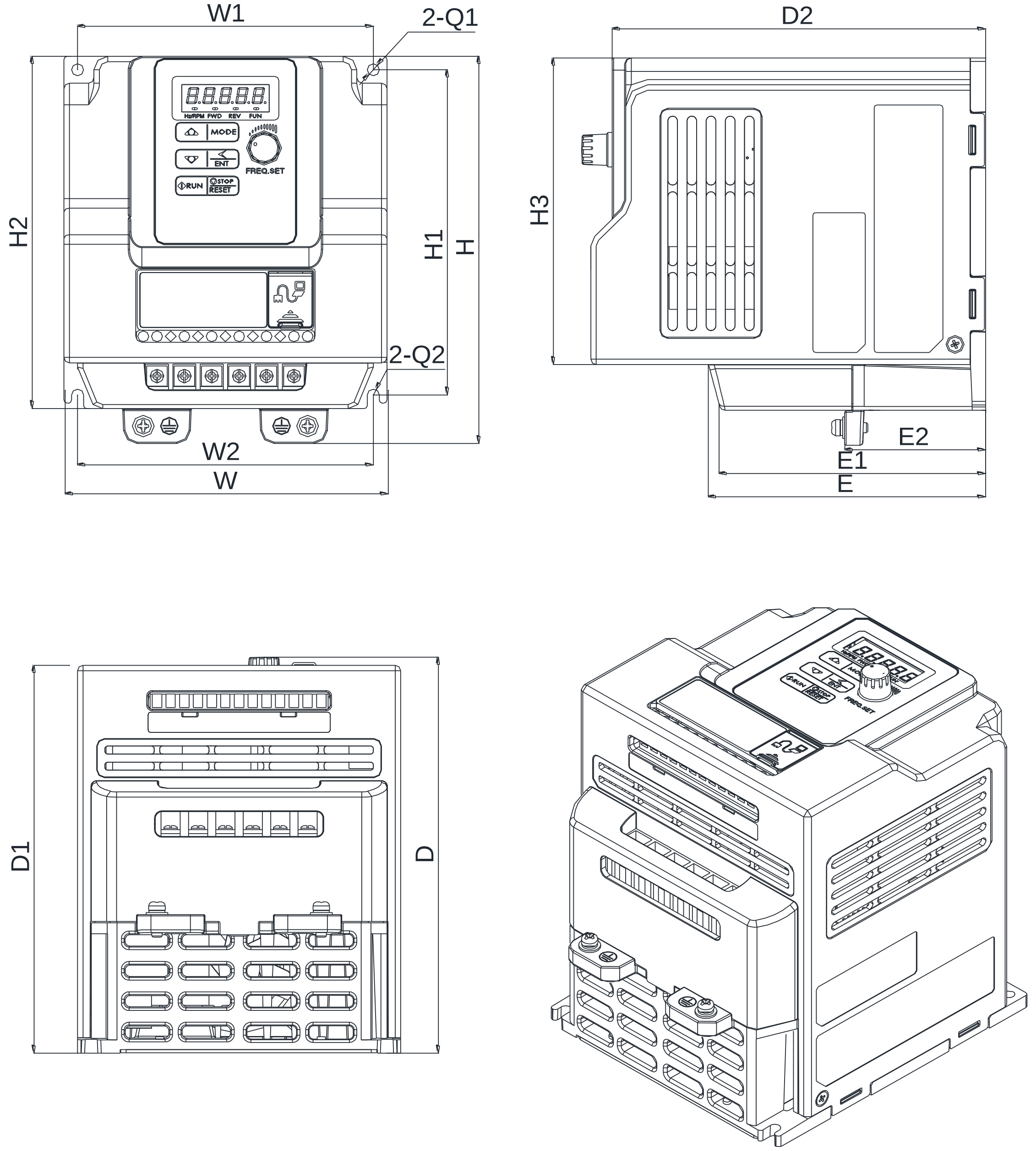
Frame1 200V



Model	dimension													
	W	W1	W2	H	H1	H2	H3	D	D1	D2	E	E1	E2	Q1	Q2
RS510-2P5-SH1F-P RS510-201-SH1F-P	72	63	61	141	131	122	114	141	136	128.2	86.3	81.1	55	4.4	2.2

F : Built-in EMC filter

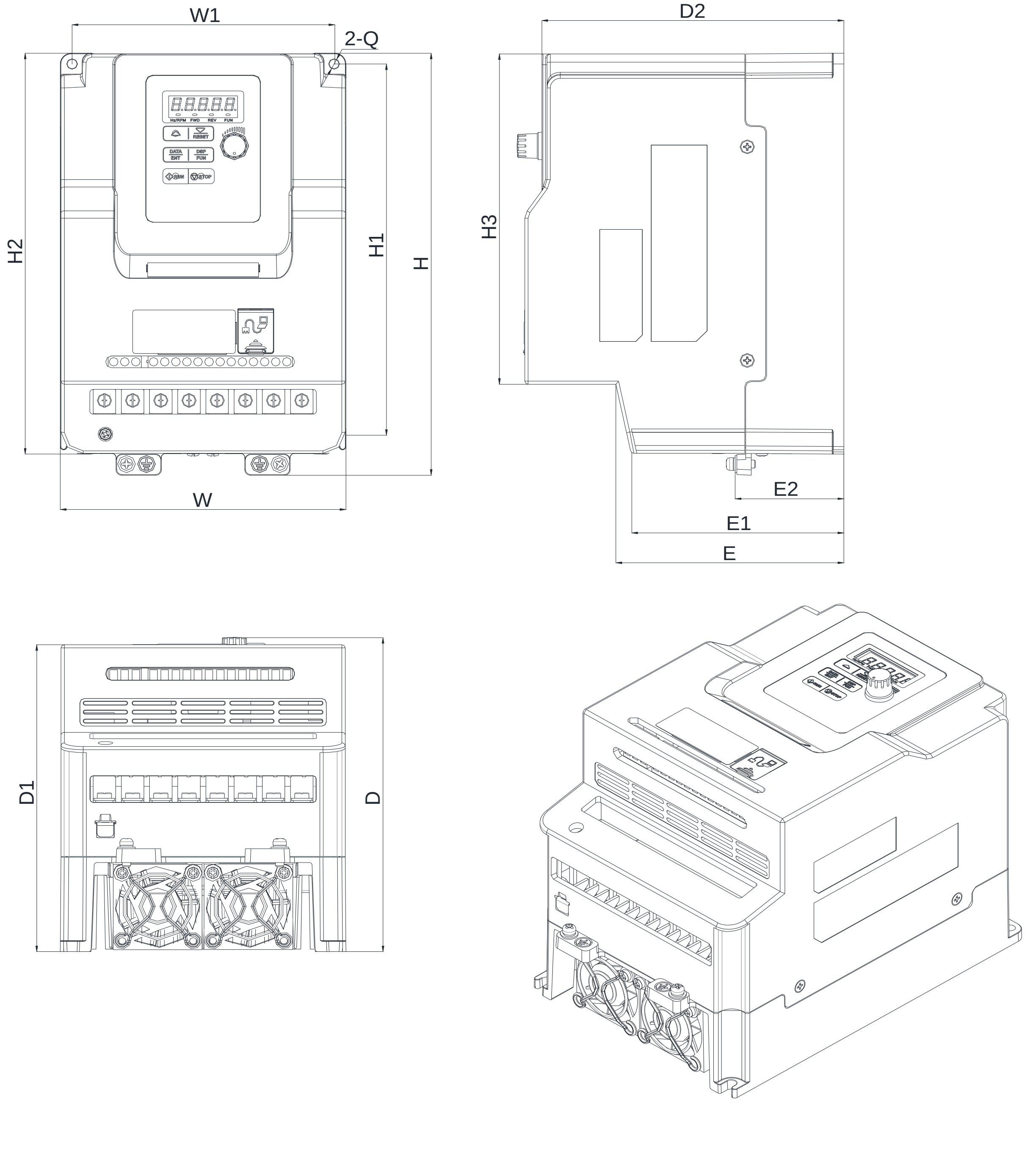
Frame 2 . 200V & 400V



Model	dimension														
	W	W1	W2	H	H1	H2	H3	D	D1	D2	E	E1	E2	Q1	Q2
RS510-202-SH1F-P	118	108	108	144	131	121	114	150	144.2	136.4	101.32	96.73	51.5	4.4	2.2
RS510-203-SH1F-P															
RS510-401-SH3F-P															
RS510-402-SH3F-P															
RS510-403-SH3F-P															

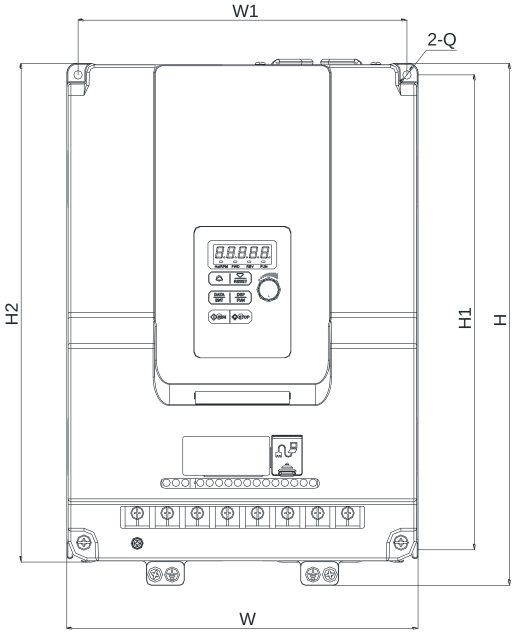
F : Built-in EMC filter

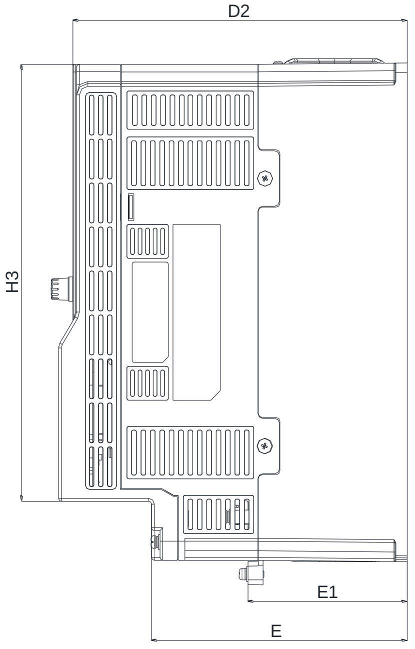
Frame 3. 400V

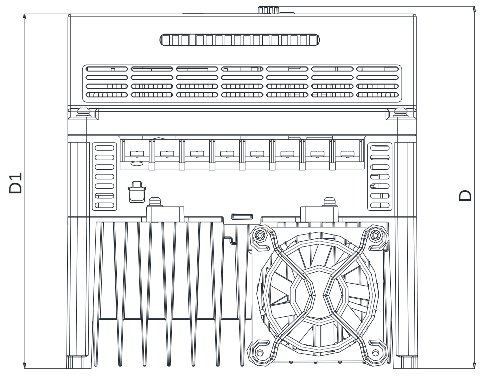


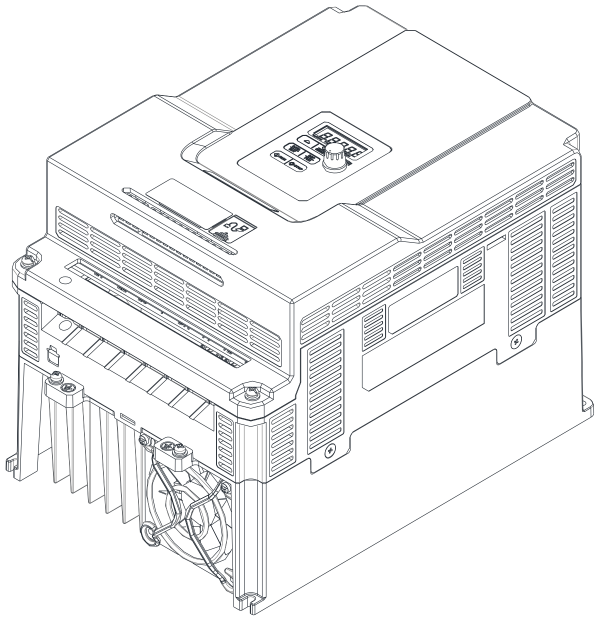
Model	dimension												
	W	W1	H	H1	H2	H3	D	D1	D2	E	E1	E2	Q
RS510-405-SH3F RS510-408-SH3F	129	118	197	177	188	154	148	143	136	102	96	48	4.5

Frame 4. 400V







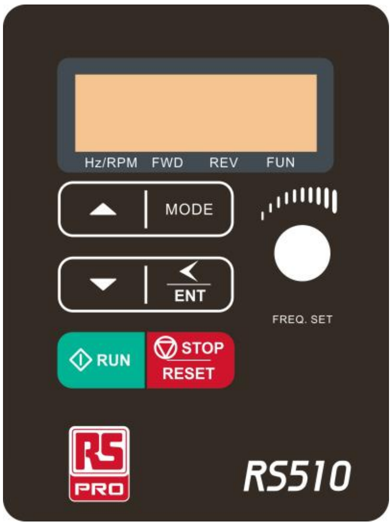


Model	dimension											
	W	W1	H	H1	H2	H3	D	D1	D2	E	E1	Q
RS510-410-SH3F	187	176	273	249	261	228	190	185	177	136	84	4.5
RS510-415-SH3F												

Chapter4 Software Index

4.1 Keypad Description

4.1.1 Operator Panel Functions



Type	Item	Function
Digital display & LEDs	Main digital displays	Frequency Display, Parameter, voltage, Current, Temperature, Fault messages.
	LED Status	Hz/RPM: ON when the frequency or line speed is displayed. OFF when the parameters are displayed. FWD: ON while the inverter is running forward. Flashes while stopped. REV: ON while the inverter is running reverse. Flashes while stopped. FUN: ON when the parameters are displayed. OFF when the frequency is displayed.
Variable Resistor	FREQ SET	Used to set the frequency
Keys On Keypad	RUN	RUN: Run at the set frequency.
	STOP/RESET (Dual function keys)	STOP: Decelerate or Coast to Stop. RESET: Use to Reset alarms or resettable faults.
	▲	Increment parameter number and preset values.
	▼	Decrement parameter number and preset values.
	MODE	Switch between available displays
	</ENTER (Dual function keys, a short press for left shift function, a long press for ENTER function)	“<” Left Shift: Used while changing the parameters or parameter values ENTER: Used to display the preset value of parameters and for saving the changed parameter values.

4.2 Programmable Parameter Groups

Parameter Group No.	Description
Group 00	Basic parameters
Group 01	V/F Pattern selections & setup
Group 02	Motor parameters
Group 03	Multi function digital Inputs/Outputs
Group 04	Analog signal inputs/ Analog output
Group 05	Preset Frequency Selections.
Group 06	Auto Run(Auto Sequencer) function
Group 07	Start/Stop command setup
Group 08	Drive and motor Protection
Group 09	Communication function setup
Group 10	PID function setup
Group 11	Performance control functions
Group 12	Digital Display & Monitor functions
Group 13	Inspection & Maintenance function

Parameter notes for Parameter Groups	
***1**	Parameter can be adjusted during running mode
***2**	Cannot be modified in communication mode
***3**	Does not change with factory reset
***4**	Read only

Group 00- The basic parameters group					
No.	**Description**	**Range**	**Factory Setting**	**Unit**	**Note**
00-00	control mode	0: V/F mode 1: SLV mode	0	-	
00-01	Motor rotation	0: Forward 1: Reverse	0	-	*1
00-02	Main Run Source Selection	0: Keypad 1: External Run/Stop Control 2: Communication	0	-	
00-03	Alternative Run Source Selection	0: Keypad 1: External Run/Stop Control 2: Communication	0	-	
00-04	Operation modes for external terminals	0: Forward/Stop-Reverse/Stop 1: Run/Stop-Reverse/Forward 2: 3-Wire Control Mode-Run/Stop	0	-	
00-05	Main Frequency Source Selection	0: Keypad 1: Potentiometer on Keypad 2: External AVI Analog Signal Input 3: External ACI Analog Signal Input 4: External Up/Down Frequency Control 5: Communication setting Frequency 6: PID output frequency	0	-	
00-06	Alternative Frequency Source Selection	0: Keypad 1: Potentiometer on Keypad 2: External AVI Analog Signal Input 3: External ACI Analog Signal Input 4: External Up/Down Frequency Control 5: Communication setting Frequency 6: PID output frequency.	4	-	
00-07	Main and Alternative Frequency Command modes	0: Main Or Alternative Frequency 1: Main frequency+Alternative Frequency	0	-	
00-08	Communication Frequency Command	0.00~599.00		Hz	*4
00-09	Frequency command Save mode (Communication mode)	0: Save the frequency before power down 1: Save the communication frequency	0	-	
00-10	Initial Frequency Selection (keypad mode)	0: by Current Frequency Command 1: by 0 Frequency Command 2: by 00-11	0	-	
00-11	Initial Frequency Keypad mode	0.00~599.00	50.00/60.00	Hz	
00-12	Frequency Upper Limit	0.01~599.00	50.00/60.00	Hz	
00-13	Frequency Lower Limit	0.00~598.99	0.00	Hz	
00-14	Acceleration Time 1	0.1~3600.0	10.0	s	*1
00-15	Deceleration Time 1	0.1~3600.0	10.0	s	*1
00-16	Acceleration Time 2	0.1~3600.0	10.0	s	*1
00-17	Deceleration Time 2	0.1~3600.0	10.0	s	*1
00-18	Jog Frequency	1.00~25.00	2.00	Hz	*1
00-19	Jog Acceleration Time	0.1~25.5	0.5	s	*1
00-20	Jog Deceleration Time	0.1~25.5	0.5	s	*1

Group 01- V/F Pattern selection & Setup					
No.	**Description**	**Range**	**Factory Setting**	**Unit**	**Note**
01-00	Volts/Hz Patterns	1~7	1/4	-	
01-01	V/F Max voltage	170.0～264.0	Based on 13-08	Vac	
01-02	Max Frequency	1.40 ~ 599.00	50.00/60.00	Hz	
01-03	Max Frequency Voltage Ratio	0.0 ~ 100.0	100.0	%	
01-04	Mid Frequency 2	1.30 ~ 599.00	2.50/3.00	Hz	
01-05	Mid Frequency Voltage Ratio 2	0.0 ~ 100.0	10.0/6.8	%	
01-06	Mid Frequency 1	1.30 ~ 599.00	2.50/3.00	Hz	
01-07	Mid Frequency Voltage Ratio 1	0.0 ~ 100.0	10.0/6.8	%	
01-08	Min Frequency	1.30 ~ 599.00	1.30/1.50	Hz	
01-09	Min Frequency Voltage Ratio	0.0 ~ 100.0	8.0/3.4	%	
01-10	Volts/Hz Curve Modification (Torque Boost)	0 ~ 10.0	0.0	%	***1**
01-11	V/F start Frequency	0.00~10.00	0.00	Hz	
01-12	No-load oscillation suppression gain	0.0~200.0	0	%	
01-13	Motor Hunting Prevention Coefficient	1~8192	800		
01-14	Motor Hunting Prevention Gain	0~100	0	%	
01-15	Motor Hunting Prevention Limit	0~100.0	5.0	%	
01-16	Auto-Torque Compensation Filter Coefficient	0.1~1000.0	0.1	ms	
01-17	Auto-torque Compensation Gain	0~100	0	%	
01-18	Auto-torque Compensation Frequency	1.30~5.00	2	Hz	

Group 02- Motor parameters					
No.	**Description**	**Range**	**Factory Setting**	**Unit**	**Note**
02-00	Motor No Load Current	----	by motor nameplate	A	
02-01	Motor Rated Current (OL1)	----	by motor nameplate	A	
02-02	V/F Slip Compensation	0.0 ~ 100.0	0.0	%	*1
02-03	Motor Rated Speed	----	by motor nameplate	Rpm	
02-04	Motor Rated Voltage	----	by motor nameplate	Vac	
02-05	Motor Rated Power	0~22.0	by motor nameplate	kW	
02-06	Motor Rated Frequency	0~599.0	by motor nameplate		
02-07	Motor Auto Tuning	0: Disable 1: Static auto tuning	0		
02-08	Stator Resistor Gain	0~600	by series		
02-09	Rotor Resistor Gain	0~600	by series		
02-10	Reserved				
02-11	Reserved				
02-12	Reserved				
02-13	SLV Slip Compensation Gain	0~200	by series	%	
02-14	SLV Torque Compensation Gain	0~200	100	%	
02-15	Low Frequency Torque Gain	0~100	50	%	

Group 02- Motor parameters					
No.	**Description**	**Range**	**Factory Setting**	**Unit**	**Note**
02-16	SLV Without Load Slip Compensation Gain	0~200	by series	%	
02-17	SLV With Load Slip Compensation Gain	0~200	150	%	
02-18	SLV With Load Torque Compensation Gain	0~200	100	**%**	
02-19	SLV Slip Compensation Select	0: Slip Compensation 1 2: Slip Compensation 2	0		

Group 03- Multi function Digital Inputs/Outputs					
No.	**Description**	**Range**	**Factory Setting**	**Unit**	**Note**
03-00	Multifunction Input Term. S1	0: Forward/Stop Command or Run /Stop	0	-	
03-01	Multifunction Input Term. S2	1: Reverse/Stop Command Or REV/FWD	1	-	
03-02	Multifunction Input Term. S3	2: Preset Speed 1 (5-02)	2	-	
03-03	Multifunction Input Term. S4	3: Preset Speed 2 (5-03)	3	-	
03-04	Multifunction Input Term. S5	4: Preset Speed 4 (5-05) 6: Jog Forward Command 7: Jog Reverse Command 8: Up Command 9: Down Command 10: Acc/Dec 2 11: Acc/Dec Disabled 12: Main/Alternative Run Command select 13: Main/Alternative Frequency Command select 14: Rapid Stop (Decel to stop) 15: Base Block 16: Disable PID Function 17: Reset 18: Auto Run Mode enable	17	-	
03-05	Reserved				
03-06	Up/Down frequency band	0.00~5.00	0.00	Hz	
03-07	Up/Down Frequency modes	0: Preset frequency is held as the inverter stops, and the UP/Down function is disabled. 1: Preset frequency is reset to 0 Hz as the inverter stops. 2: Preset frequency is held as the inverter stops, and the UP/Down is available.	0	-	
03-08	S1~S5 scan confirmation	1~200. Number of Scan cycles	10	2ms	
03-09	S1~ S5 switch type select	xxxx0:S1 NO xxxx1:S1 NC xxx0x:S2 NO xxx1x:S2 NC xx0xx:S3 NO xx1xx:S3 NC x0xxx:S4 NO x1xxx:S4 NC 0xxxx:S5 NO 1xxxx:S5 NC	00000	-	
03-10	Reserved				
03-11	Output Relay(RY1)	0: Run 1: Fault 2: Setting Frequency Reached	0	-	

Group 03- Multi function Digital Inputs/Outputs					
No.	**Description**	**Range**	**Factory Setting**	**Unit**	**Note**
		3: Frequency Reached (3-13±3-14)			
		4: Output Frequency Detection1(> 3-13)			
		5: Output Frequency Detection2(< 3-13)			
		6: Auto-Restart			
		7: Momentary AC Power Loss			
		8: Rapid Stop			
		9: Base Block			
		10: Motor Overload Protection(OL1)			
		11: Drive Overload Protection(OL2)			
		12: Reserved			
		13: Output Current Reached			
		14: Brake Control			
		15: PID feedback disconnection detection			
03-12	Reserved				
03-13	Output frequency detection level (Hz)	0.00~599.00	0.00	Hz	*1
03-14	Frequency Detection band	0.00~30.00	2.00	Hz	*1
03-15	Output Current Detection Level	0.1~15.0	0.1	A	
03-16	Output Current Detection Period	0.1~10.0	0.1	s	
03-17	External Brake Release level	0.00~20.00	0.00	Hz	
03-18	External Brake Engage Level	0.00~20.00	0.00	Hz	
03-19	Relay Output function type	0: A (Normally open) 1: B (Normally close)	0	-	
03-20	Braking Transistor On Level	240.0~400.0V 220/230V:	380	VDC	
03-21	Brake Transistor Off Level	240.0~400.0V 220/230V:	360	VDC	

※ "NO" indicates normally open, "NC" indicates normally closed.

Group 04- Analog signal inputs/ Analogue output functions							
No.	**Description**	**Range**			**Factory Setting**	**Unit**	**Note**
04-00	AVI/ACI analog Input signal type select		AVI	ACI	0	-	
		0 :	0~10V	0~20mA			
		1 :	0~10V	4~20mA			
		2 :	2~10V	0~20mA			
		3 :	2~10V	4~20mA			
04-01	AVI Signal Verification Scan rate	1~200			50	2ms	
04-02	AVI Gain	0 ~ 1000			100	%	*1
04-03	AVI Bias	0 ~ 100			0	%	*1
04-04	AVI Bias Selection	0: Positive 1: Negative			0	-	*1
04-05	AVI Slope	0: Positive 1: Negative			0	-	*1
04-06	ACI Signal Verification Scan rate	1~200			50	2ms	
04-07	ACI Gain	0 ~ 1000			100	%	*1
04-08	ACIBias	0 ~ 100			0	%	*1

Group 04- Analog signal inputs/ Analogue output functions					
No.	**Description**	**Range**	**Factory Setting**	**Unit**	**Note**
04-09	ACI Bias Selection	0: Positive 1: Negative	0	-	*1
04-10	ACI Slope	0: Positive 1: Negative	0	-	*1
04-11	Analog Output mode(AO)	0: Output Frequency 1: Frequency Command 2: Output Voltage 3: DC Bus Voltage 4: Motor Current	0	-	*1
04-12	Analog Output AO Gain (%)	0 ~ 1000	100	%	*1
04-13	Analog Output AO Bias (%)	0 ~ 1000	0	%	*1
04-14	AO Bias Selection	0: Positive 1: Negative	0	-	*1
04-15	AO Slope	0: Positive 1: Negative	0	-	*1
04-16	Potentiometer Gain on Keypad	0~1000	100	%	*1
04-17	Potentiometer Bias on Keypad	0~100	0	%	*1
04-18	Potentiometer Bias Selection on Keypad	0: Positive 1: Negative	0	-	*1
04-19	Potentiometer Slop on Keypad	0: Positive 1: Negative	0	-	*1

Group 05- Preset Frequency Selections.					
No.	**Description**	**Range**	**Factory Setting**	**Unit**	**Note**
05-00	Preset Speed Control mode Selection	0: Common Accel/Decel Accel/Decel 1 or 2 apply to all speeds 1: Individual Accel/Decel Accel/ Decel 0-7 apply to the selected preset speeds (Acc0/Dec0~ Acc7/Dec7)	0	-	
05-01	Preset Speed 0 (Keypad Freq)	0.00 ~ 599.00	5.00	Hz	*1
05-02	Preset Speed1 (Hz)		5.00	Hz	*1
05-03	Preset Speed2 (Hz)		10.00	Hz	*1
05-04	Preset Speed3 (Hz)		20.00	Hz	*1
05-05	Preset Speed4 (Hz)		30.00	Hz	*1
05-06	Preset Speed5 (Hz)		40.00	Hz	*1
05-07	Preset Speed6 (Hz)		50.00	Hz	*1
05-08	Preset Speed7 (Hz)		50.00	Hz	*1
05-09 ~ 05-16	Reserved				
05-17	Preset Speed0-Acctime	0.1 ~ 3600.0	10.0	s	*1
05-18	Preset Speed0-Dectime		10.0	s	*1
05-19	Preset Speed1-Acctime		10.0	s	*1
05-20	Preset Speed1-Dectime		10.0	s	*1
05-21	Preset Speed2-Acctime		10.0	s	*1
05-22	Preset Speed2-Dectime		10.0	s	*1

05-23	Preset Speed3-Acctime		10.0	s	*1
05-24	Preset Speed3-Dectime		10.0	s	*1
05-25	Preset Speed4-Acctime		10.0	s	*1
05-26	Preset Speed4-Dectime		10.0	s	*1
05-27	Preset Speed5-Acctime		10.0	s	*1
05-28	Preset Speed5-Dectime		10.0	s	*1
05-29	Preset Speed6-Acctime		10.0	s	*1
05-30	Preset Speed6-Dectime		10.0	s	*1
05-31	Preset Speed7-Acctime		10.0	s	*1
05-32	Preset Speed7-Dectime		10.0	s	*1

Group 06- Auto Run(Auto Sequencer) function					
No.	**Description**	**Range**	**Factory Setting**	**Unit**	**Note**
06-00	Auto Run (sequencer) mode selection	0: Disabled. 1: Single cycle. (Continues to run from the Unfinished step if restarted). 2: Periodic cycle. (Continues to run from the unfinished step if restarted). 3: Single cycle, then holds the speed Of final step to run. (Continues to run from the unfinished step if restarted). 4: Single cycle. (Starts a new cycle if restarted). 5: Periodic cycle. (Starts a new cycle if restarted). 6: Single cycle, then hold the speed of final step to run (Starts a new cycle if restarted).	0	-	
06-01	Auto _ Run Mode frequency command 1	0.00~599.00	0.00	Hz	*1
06-02	Auto _ Run Mode frequency command 2		0.00	Hz	*1
06-03	Auto _ Run Mode frequency command 3		0.00	Hz	*1
06-04	Auto _ Run Mode frequency command 4		0.00	Hz	*1
06-05	Auto _ Run Mode frequency command 5		0.00	Hz	*1
06-06	Auto _ Run Mode frequency command 6		0.00	Hz	*1
06-07	Auto _ Run Mode frequency command 7		0.00	Hz	*1
06-08 ~ 06-15	Reserved				

Group 06- Auto Run(Auto Sequencer) function					
No.	**Description**	**Range**	**Factory Setting**	**Unit**	**Note**
06-16	Auto_ Run Mode running time setting 0	0.0 ~ 3600.0	0.0	s	*1
06-17	Auto_ Run Mode running time setting 1		0.0	s	*1
06-18	Auto_ Run Mode running time setting 2		0.0	s	*1
06-19	Auto_ Run Mode running time setting 3		0.0	s	*1
06-20	Auto_ Run Mode running time setting 4		0.0	s	*1
06-21	Auto_ Run Mode running time setting 5		0.0	s	*1
06-22	Auto_ Run Mode running time setting 6		0.0	s	*1
06-23	Auto_ Run Mode running time setting 7		0.0	s	*1
06-24 ~ 06-31	Reserved				
06-32	Auto_ Run Mode running direction 0	0: Stop 1: Forward 2: Reverse	0	-	
06-33	Auto_ Run Mode running direction 1		0	-	
06-34	Auto_ Run Mode running direction 2		0	-	
06-35	Auto_ Run Mode running direction 3		0	-	
06-36	Auto_ Run Mode running direction 4		0	-	
06-37	Auto_ Run Mode running direction 5		0	-	
06-38	Auto_ Run Mode running direction 6		0	-	
06-39	Auto_ Run Mode running direction 7		0	-	

Group 07- Start/Stop command setup					
No.	**Description**	**Range**	**Factory Setting**	**Unit**	**Note**
07-00	Momentary Power Loss and Restart	0: Momentary Power Loss and Restart disable 1: Momentary power loss and restart enable	0	s	
07-01	Auto Restart Delay Time	0.0~800.0	0.0	s	
07-02	Number of Auto Restart Attempts	0~10	0	-	
07-03	Reset Mode Setting	0: Enable Reset Only when Run Command is Off 1: Enable Reset when Run Command is On or Off	0	-	
07-04	Direct Running After Power Up	0: Enable Direct run on power up 1: Disable Direct run on power up	1	-	
07-05	Delay-ON Timer	1.0~300.0	1.0	s	

07-06	DC Injection Brake Start Frequency (Hz) In Stop mode	0.10 ~ 10.00	1.5	Hz	
07-07	DC Injection Brake Level (%) In stop mode	0 ~ 20 (Frame1/2). Based on the 20% of maximum output voltage	5	%	
		0 ~ 100 (Frame3/4) based on the rated current	50		
07-08	DC Injection Brake Time (Seconds) In stop mode	0.0 ~ 25.5	0.5	s	
07-09	Stopping Method	0: Deceleration to stop 1: Coast to stop	0		
07-10	DC Braking Level at Start	0~100	0	%	
07-11	DC Braking Time at Start	0.0~25.5	0.0	s	

Group 08- Drive & Motor Protection functions

No.	Description	Range	Factory Setting	Unit	Note
08-00	Trip Prevention Selection	xxxx0: Enable Trip Prevention During Acceleration xxxx1: Disable Trip Prevention During Acceleration xxx0x: Enable Trip Prevention During Deceleration xxx1x: Disable Trip Prevention During Deceleration xx0xx: Enable Trip Prevention in Run Mode xx1xx: Disable Trip Prevention in Run Mode x0xxx: Enable over voltage Prevention in Run Mode x1xxx: Disable over voltage Prevention in Run Mode	00000	-	
08-01	Trip Prevention Level During Acceleration (%)	50 ~ 200	by series	Inverter Rated Current 100%	
08-02	Trip Prevention Level During Deceleration (%)	50 ~ 200	by series		
08-03	Trip Prevention Level In Run Mode (%)	50 ~ 200	by series		
08-04	over voltage Prevention Level in Run Mode	350.0~390.0	380.0	VDC	*1
08-05	Electronic Motor Overload Protection Operation Mode	xxxx0: Disable Electronic Motor Overload Protection	00001	-	
		xxxx1: Enable Electronic Motor Overload Protection			
		xxx0x: Motor Overload Cold Start			
		xxx1x: Motor Overload Hot Start			
		xx0xx: Standard Motor			

Group 08- Drive & Motor Protection functions					
No.	**Description**	**Range**	**Factory Setting**	**Unit**	**Note**
		xx1xx: Invertor Duty Motor (Force Vent)			
08-06	Operation After Overload Protection is Activated	0: Coast-to-Stop After Overload Protection is Activated 1: Drive Will Not Trip when Overload Protection is Activated (OL1)	0	-	
08-07	Over heat Protection (cooling fan control)	0: Auto (Depends on temp.) 1: Operate while in RUN mode 2: Always Run 3: Disabled	1	-	
08-08	AVR Function (Auto Voltage Regulation)	0: AVR function enable 1: AVR function Disable 2: AVR function disable for stop 3: AVR function disable for deceleration 4: AVR function disable for stop and deceleration. 5: When VDC>(360V/740V), AVR function disable for stop and deceleration.	4	-	
08-09	Input phase lost protection	0: Disabled 1: Enabled	0	-	
08-10	PTC Overheat Function	0: Disable	0		
		1: Decelerate to stop			
		2: Coast to stop			
		3: Continue running, when **warning level** is reached. Coast to stop, when **protection level** is reached.			
08-11	PTC Signal Smoothing Time	0.01~10.00	0.2	Sec	
08-12	PTC Detection Time Delay	1~300	60	Sec	
08-13	PTC Protection Level	0.1~10.0	0.7	V	
08-14	PTC Detection Level Reset	0.1~10.0	0.3	V	
08-15	PTC Warning Level	0.1~10.0	0.5	V	
08-16	Fan Control Temperature Level	10.0~50.0	50.0	°C	
08-17	Over current protection level	0.0 ~ 60.0	0.0	A	
08-18	Over current protection time	0.0 ~ 1500.0	1.0	s	
08-19	Motor Overload Protection Level	0: Motor Overload Protection Level 0 1: Motor Overload Protection Level 1 2: Motor Overload Protection Level 2	0		

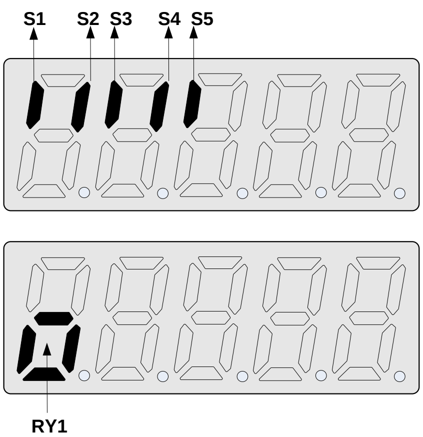
Group 09- Communication function setup					
No.	**Description**	**Range**	**Factory Setting**	**Unit**	**Note**
09-00	Assigned Communication Station Number	1 ~ 32	1	-	*2*3
09-01	Communication Mode Select	0: Modbus RTU code 1: Modbus ASCII code 2: BACnet	0	-	*2*3
09-02	Baud Rate Setting (bps)	0 :4800 1: 9600 2: 19200 3: 38400	2	bps	*2*3
09-03	Stop Bit Selection	0: 1 Stop Bit 1: 2 Stop Bits	0	-	*2*3
09-04	Parity Selection	0: Without Parity 1: With Even Parity 2: With Odd Parity	0	-	*2*3
09-05	Data Format Selection	0: 8-Bits Data 1: 7-Bits Data	0	-	*2*3
09-06	Communication time-out detection time	0.0 ~ 25.5	0.0	s	
09-07	Communication time-out operation selection	0: Deceleration to stop (00-15: Deceleration time 1) 1: Coast to stop 2: Deceleration to stop (00-17: Deceleration time 2) 3: continue operating	0	-	
09-08	Error 6 verification time.	1 ~ 20	3		
09-09	Drive Transmit delay Time（ms)	5 ~ 65	5	2ms	
09-10	BACnet stations	1~254	1		*2*3

Group10- PID function Setup					
No.	**Description**	**Range**	**Factory Setting**	**Unit**	**Note**
10-00	PID target value selection (when 00-05\00-06=6 ,this function is enabled)	0: Potentiometer on Keypad 1: Analog Signal Input. (AVI) 2: Analog Signal Input. (ACI) 3: Frequency set by communication 4: KeyPad Frequency parameter 10-02	1	-	*1
10-01	PID feedback value selection	0: Potentiometer on Keypad 1: Analog Signal Input. (AVI) 2: Analog Signal Input. (ACI) 3: Communication Setting Frequency	2	-	*1
10-02	PID Target （keypad input)	0.0~100.0	50.0	%	*1
10-03	PID Mode Selection	0: Disabled 1: Deviation D Control. FWD Characteristic. 2: Feedback D Control FWD Characteristic.	0	-	

Group10- PID function Setup					
No.	**Description**	**Range**	**Factory Setting**	**Unit**	**Note**
		3: Deviation D Control Reverse Characteristic. 4: Feedback D Control Reverse Characteristic. 5: Frequency Command + Deviation D Control. FWD Characteristic. 6: Frequency Command + Feedback D Control FWD Characteristic. 7: Frequency Command + Deviation D Control Reverse Characteristic. 8: Frequency Command + Feedback D Control Reverse Characteristic.			
10-04	Feedback Gain Coefficient	0.00 ~ 10.00	1.00	%	*1
10-05	Proportional Gain	0.0 ~ 10.0	1.0	%	*1
10-06	Integral Time	0.0 ~ 100.0	10.0	s	*1
10-07	Derivative Time	0.00 ~ 10.00	0.00	s	*1
10-08	PID Offset	0: Positive 1: Negative	0	-	*1
10-09	PID Offset Adjust	0 ~ 109	0	%	*1
10-10	PID Output Lag Filter Time	0.0 ~ 2.5	0.0	s	*1
10-11	Feedback Loss Detection Mode	0: Disabled 1: Drive keeps running after feedback loss 2: Drive stops after feedback loss	0	-	
10-12	Feedback Loss Detection Level	0 ~ 100	0	%	
10-13	Feedback Loss Detection Delay Time	0.0 ~25.5	1.0	s	
10-14	Integration Limit Value	0 ~ 109	100	%	*1
10-15	Integral Value Resets to Zero when Feedback Signal Equals the Target Value	0: Disabled 1: 1 Second 30: 30 Seconds (0 ~ 30)	0	-	
10-16	Allowable Integration Error Margin (units)(1unit = 1/8192)	0 ~ 100	0	-	
10-17	PID Sleep Frequency Level	0.00~599.00	0.00	Hz	
10-18	PID Sleep Function Delay Time	0.0 ~25.5	0.0	s	
10-19	PID Wake up frequency Level	0.00 ~ 599.00	0.00	Hz	
10-20	PID Wake up function Delay Time	0.0 ~ 25.5	0.0	s	
10-21	Max PID Feedback Setting	0 ~999	100	-	*1
10-22	Min PID Feedback Setting	0 ~999	0	-	*1

Group11- Performance Control functions					
No.	**Description**	**Range**	**Factory Setting**	**unit**	**Note**
11-00	Reverse operation control	0: Reverse command is enabled 1: Reverse command is disabled	0	-	
11-01	Carrier Frequency (kHz)	1~16	5	KHz	
11-02	Carrier mode Selection	0: Mode0, 3phase PWM modulation 1: Mode1, 2phase PWM modulation 2: Mode2, 2phase soft PWM modulation	1	-	
11-03	Carrier Frequency Reduction by temperature rise	0: disabled 1: enabled	0	-	
11-04	S-Curve Acc 1	0.0 ~ 4.0	0.00	s	
11-05	S-Curve Acc 2	0.0 ~ 4.0	0.00	s	
11-06	S-Curve Dec 3	0.0 ~ 4.0	0.00	s	
11-07	S-Curve Dec 4	0.0 ~ 4.0	0.00	s	
11-08	Skip Frequency 1	0.00 ~ 599.00	0.00	Hz	*1
11-09	Skip Frequency 2	0.00 ~ 599.00	0.00	Hz	*1
11-10	Skip Frequency 3	0.00 ~ 599.00	0.00	Hz	*1
11-11	Skip Frequency Bandwidth (±)	0.00 ~ 30.00	0.00	Hz	*1
11-12	Reserved				
11-13	Regeneration Prevention Function	0: Disable 1: Enable 2: Enable (during constant speed only)	0	-	
11-14	Regeneration Prevention Voltage Level	200v: 300.0~400.0 400v: 600.0~800.0	380/760	V	
11-15	Regeneration Prevention Frequency Limit	0.00 ~ 15.00	3.00	Hz	
11-16	Regeneration Prevention Voltage Gain	0~200	100	%	
11-17	Regeneration Prevention Frequency Gain	0~200	100	%	
11-18	Speed loop proportion gain	0~65535	10000		
11-19	Speed loop integration gain	0 ~65535	800		
11-20	Speed loop differential gain	0 ~65535	0		
11-21	Stop Key Selection	0: Enable Stop Key when Run Command not from Keypad 1: Disable Stop Key when Run Command not from Keypad	0		

Group12 Digital Display & Monitor functions

No.	Description	Range	Factory Setting	Unit	Note
12-00	Extended Display Mode	00000 ~77777. Each digit can be set to 0 to 7 0: Default display (frequency&parameters) 1: Output Current 2: Output Voltage 3: DC voltage 4: Temperature of Heat sink 5: PID feedback 6: Analog Signal Input. (AVI) 7: Analog Signal Input. (ACI)	00000	-	*1
12-01	PID Feedback Display format	0: Integer (xxx) 1: One decimal Place (xx.x) 2: Two Decimal Places (x.xx)	0	-	*1
12-02	PID Feedback Display Unit Setting	0: xxx-- 1: xxxpb (pressure) 2: xxxfl (flow)	0	-	*1
12-03	Custom Units (Line Speed) Value	0~65535	1500/1800	RPM	*1
12-04	Custom Units (Line Speed) Display Mode	0: Drive Output Frequency is Displayed 1: Line Speed. Integer.(xxxxx) 2: Line Speed..One Decimal Place (xxxx.x) 3: Line Speed.Two Decimal Places (xxx.xx) 4: Line Speed.Three Decimal Places (xx.xxx)	0	-	*1
12-05	Inputs and output Logic status display (S1 to S5) & RY1		-----	-	*4
12-06	Output Power	----	0.0	kW	
12-07	Motor Current Percentage	----	0	%	

Group 13 Inspection & Maintenance functions					
No.	**Description**	**Range**	**Factory Setting**	**unit**	**Note**
13-00	Drive Horsepower Code	----	-	-	*3
13-01	Software Version	----	-	-	*3*4
13-02	Fault Log (Last 3 Faults)	----	-	-	*3*4
13-03	Accumulated Operation Time1 1	0~23	-	hour	*3
13-04	Accumulated Operation Time1 2	0~65535	----	day	*3
13-05	Accumulated Operation Time Mode	0: Time Under Power 1: Run Mode Time Only	0	-	*3
13-06	Parameter Lock	0: Enable all Functions 1: Preset speeds 05-01~05-08 cannot be changed 2: All Functions cannot be changed Except for Preset speeds 05-01~05-08 3: Disable All Function	0	-	
13-07	Parameter Lock Code	00000~65535	00000	-	
13-08	Reset Drive to Factory Settings	1150: Initialization (50Hz,220V/380V) 1160: Initialization (60Hz,220V/380V) 1250: Initialization (50Hz,230V/400V) 1260: Initialization (60Hz,230V/460V) 1350: Initialization (50Hz,220V/415V) 1360: Initialization (60Hz,230V/400V)	1250	-	

Chapter 5 Troubleshooting and maintenance

5.1 Error display and corrective action

5.1.1 Manual Reset and Auto-Reset

Faults which cannot be recovered manually			
Display	**content**	**Cause**	**Corrective action**
-OV-	Voltage too high when stopped	Detection circuit malfunction	Consult with the supplier
-LV-	Voltage too low when stopped	1. Power voltage too low 2. Pre-charge resistor or fuse burnt out. 3. Detection circuit malfunction	1.Check if the power voltage is correct 2. failed resistor or fuse 3. Consult with the supplier
-OH-	The inverter is overheated when stopped	1. Detection circuit malfunction 2. Ambient temperature too high or bad ventilation	Improve the ventilation conditions, if no result then replace the inverter
OH-C	The inverter is overheated during running	1. IGBT temperature is too high or poor ventilation 2. temperature sensor error or circuit malfunctions	1. Reduce carrier frequency 2. Improve the ventilation conditions, if no result then replace the inverter
CtEr	Current Sensor detection error	Current sensor error or circuit malfunction	Consult with the supplier
HPErr	Inverter capacity setting error: Inverter capacity setting 13-00 does not match the rated voltage.	The inverter capacity setting (13-00) does not match the hardware voltage levels	Check the inverter capacity setting (13-00) to meet the hardware voltage levels.
Err4	CPU Unusual interruption	External noise interference	1.Remove the interference source then restart by switching power OFF/ON 2 If not resolved then Consult with the supplier
EPr	EEPROM problem	Faulty EEPROM	Consult with the supplier
COt	Communication error	Communications disruption	Check the wiring

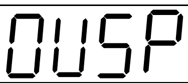
Faults which can be recovered manually and automatically

Display	content	Cause	Corrective action
OC-A	Over-current at acceleration	1.Acceleration time too short 2.The capacity of the motor exceeds the capacity of the inverter 3.Short circuit between the motor coil and the case 4.Short circuit between motor wiring and ground 5.IGBT module damaged	1.Set a longer acceleration time 2.Replace inverter with one that has the same rating as that of the motor 3.Check the motor 4.Check the wiring 5.Consult with the supplier
OC-C	Over-current at fixed speed	1. Transient load change 2. Transient power change	1.Increase the capacity of the inverter 2.Install inductor on the power supply input side
OC-d	Over-current at deceleration	The preset deceleration time is too short.	Set a longer deceleration time
OC-S	Over current at start	1.Short circuit between the motor coil and the case 2.Short circuit between motor coil and ground 3.IGBT module damaged	1.Inspect the motor 2.Inspect the wiring 3.Consult with the supplier
OV-C	Excessive Voltage during operation/ deceleration	1.Deceleration time setting too short or excessive load inertia 2.Power voltage varies widely (fluctuates)	1.Set a longer deceleration time 2.Consider use of a brake resistor and/or brake module 3.Consider use of a reactor at the power input side
PF	Input phase Loss	Abnormal fluctuations in the main circuit voltage	1.Check the main circuit power supply wiring. 2.Check the power supply voltage

Faults which can be recovered manually but not automatically

Display	content	Cause	Corrective action
OC	Over-current during stop	Detection circuit malfunction	Consult with the supplier
OL1	Motor overload	loading too large	Consider increasing the Motor capacity
OL2	Inverter overload	Excessive Load	Consider increasing the inverter capacity

Faults which can be recovered manually but not automatically

Display	content	Cause	Corrective action
CL 	Inverter over current: Wait 1 minute to reset .If it occurs CL or OL2 up to 4 successive times then wait 5 minutes to reset	inverter over current warning： inverter current reach the level of over current protection	Check load condition and running period time.
LV-C 	Voltage too low during operation	1.Power voltage too low 2.Power voltage varies widely (fluctuates)	1.Improve power quality 2.Consider adding a reactor at the power input side
OVSP 	motor rotation over speed	The actual rotation speed is different to the set speed.	1.Check for excessive load 2.Check weather frequency setting signal is right or not
OH4 	motor over heat error	1.If temperature detected increases above the set limit in parameter 08-13 and for the delay time set in parameter 08-12 then the display will show “OH4” (motor over heat detection), and the motor will coast to stop. 2.Motor over heat detection “OH4” can be reset when the temperature detection level is lower than the set level in parameter【08-14 PTC reset level】.	1.To improve the ventilation condition 2.Adjust parameter 08-15

5.1.2 Keypad Operation Error Instruction

Display	content	Cause	Corrective action
LOC	1.Parameter already locked 2.Motor direction locked 3.Parameter password (13-07) enabled	1.Attempt to modify frequency parameter while 13-06>0. 2.Attempt to reverse direction when 11- 00=1. 3.Parameter (13 - 07) enabled, set the correct password will show LOC.	1.Adjust 13-06 2.Adjust 11-00
Err1	Keypad operation error	1.Press ▲ or ▼while 00-05/00-06>0 or running at preset speed. 2.Attempt to modify the Parameter. Can not be modified during operation (refer to the parameter list)	1.The ▲ or▼ is available for modifying the parameter only when 00-05/00-06=0 2.Modify the parameter in STOP mode.
Err2	Parameter setting error	1. 00-13 is within the range of (11-08 ±11-11) or (11-09 ±11-11) or (11-10 ±11-11) 2. 00- 12≦00-13 3. 00-05 and 00-06 have been set the same. 4. Modifying parameters 01-01~01-09 when 01-00≠7. 5. When 00-05/00-06=2, and 08-10=1~3; When PID function be used with 10-00/10-01 =1 and 08-10=1~3 6. Parameter password function(13-07) set incorrect	1.modify11-08~11-10 or 11-11 2.00- 12>00-13 3.set 00-05 and 00-06 to be different 4.set 03-21 <03-20 5.PTC function source can not be set the same source(AVI) with frequency command and PID command. 6.Please set correct password
Err5	Modification of parameter is not available in communication	1.Control command sent during communication. 2.Attempt to modify the function 09-02~ 09-05 during communication	1.Issue enable command before communication 2.Set parameters 09-02~ 09-05 function before communication
Err6	Communication failed	1.Wiring error 2.Communication Parameter setting error. 3.Incorrect communication protocol	1.Check hardware and wiring 2.Check Functions(09-00~ 09- 05).
Err7	Parameter conflict	1.Attempt to modify the function 13-00/13-08. 2.Voltage and current detection circuit is abnormal.	If reset is not possible, please consult with the supplier.

5.1.3 Special conditions

Display	Fault	Description
StP0	Zero speed at stop	In V/f mode, STP0 comes out at less than 1.3Hz (50Hz set) or at less than 1.5Hz (60Hz set) In SLV mode, STP0 comes out at less than 1Hz
StP1	Fail to start directly On power up.	1. If the inverter is set for external terminal control mode (00-02/00-03=1) and direct start is disabled (07-04=1) 2. The inverter cannot be started and will flash STP1. 3. The run input is active at power-up, refer to descriptions of (07-04).
StP2	Keypad Stop Operated when inverter in external Control mode.	1. If the Stop key is pressed while the inverter is set to external control mode (00-02/00-03=1) then'STP2'flashes after stop. 2. Release and re-activate the run contact to restart the inverter.
E.S.	External Rapid stop	When external rapid stop input is activated the inverter will decelerate to stop and the display will flash with E.S. message.
b.b.	External base block	When external base block input is activated the inverter stops immediately and then the display will flash with b.b. message.
PdEr	PID feedback loss	PID feedback loss is detected.
Alter	auto tuning error	other errors show up in the process of auto tuning.
OH3	motor over heat warning	If 08-10 = 3, When over temperature is detected by signal at terminal AVI increasing above the warning detection limit set in parameter 08-15, then the display will show "OH3"(motor over heat warning level) and the motor will continue to run.

5.2 General troubleshooting

Status	Checking point	Remedy
Motor runs in wrong direction	Is the wiring for the output terminals correct?	Wiring must match U, V, and W terminals of the motor.
	Is the wiring for forward and reverse signals correct?	Check for correct wiring.
The motor speed can not be regulated.	Is the wiring for the analog frequency inputs correct?	Check for correct wiring.
	Is the setting of operation mode correct?	Check the Frequency Source set in parameters 00-05/00-06.
	Is the load too excessive?	Reduce the load.
Motor running speed too high or too low	Check the motor specifications (poles, voltage…) correct?	Confirm the motor specifications.
	Is the gear ratio correct?	Confirm the gear ratio.
	Is the setting of the highest output frequency correct?	Confirm the highest output frequency
Motor speed varies unusually	Is the load too excessive?	Reduce the load.
	Does the load vary excessively?	1.Minimize the variation of the load. 2.Consider increasing the capacities of the inverter and the motor.
	Is the input power unstable or is there a phase loss ?	1.Consider adding an AC reactor at the power input side if using single-phase power.
		2. Check wiring if using three-phase power
Motor can not run	Is the power connected to the correct L1, L2, and L3 terminals? is the charging indicator lit ?	1.Is the power applied? 2.Turn the power OFF and then ON again. 3.Make sure the power voltage is correct. 4.Make sure screws are secured firmly.
	Is there voltage across the output terminals T1, T2, and T3?	Turn the power OFF and then ON again.
	Is overload causing the motor to stall?	Reduce the load so the motor will run.
	Are there any abnormalities in the inverter?	See error descriptions to check wiring and correct if necessary.
	Is there a forward or reverse run command ?	
	Has the analog frequency signal been input?	1.Is analog frequency input signal wiring correct? 2.Is voltage of frequency input correct?
	Is the operation mode setting correct?	Operate through the digital keypad

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