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Table of contents

1	Introduction	3
2	Objective	3
3	Industrially led workshop	3
4	Summary	8

Annex - Screenshots of presentations given at the ModuLase workshop

1 Introduction

This document fulfils the requirement of the European Commission H2020 framework (FoF-13-2016: Photonics Laser-Based production) Project 'Development and Pilot Line validation of a Modular re-configurable Laser Process Head' ('ModuLase'). Work package 7 (WP7): Deliverable 7.3 'Conduct live demonstration to industrially led audience on up to five laser processes involved'.

This deliverable results from the activities in Task 7.3 'Demonstration of the ModuLase system to an industrial audience'. It was led by GEL and supported by all the other ModuLase partners. It focused on delivering a demonstration of the ModuLase system to an industrial audience outside the ModuLase consortium. The demonstration covered the following topics:

- Overview of the ModuLase concept and achievements of the project.
- Overview of the key developed ModuLase technologies, integrated together to deliver the ModuLase system.
- Demo videos recorded in an industrial environment at GEL pilot laser cell, demonstrating the integrated ModuLase technologies on three end-users case studies, across three laser processes: welding, cutting and cladding.

This is a 'Demonstration type' deliverable in the ModuLase project. A report document is being provided for review and documentation purposes.

2 Objective

To demonstrate the ModuLase system on three industrial case study components, proving the concept of flexible manufacturing.

3 Industrially led workshop

A final ModuLase workshop was held toward the end of the project, on the 21st May 2021, gathering several industrial stakeholders from industry to present the main results and developments of the project.

This event was initially planned to be hosted physically at GEL facilities, to allow a real time live demonstration of the ModuLase system. However, due to the COVID pandemic, the event had to be readapted and was ultimately hosted on-line. The ModuLase partners worked together to showcase achievements of the ModuLase project and agenda of the event can be found in Table 1 below.

Table 1 ModuLase Event Agenda

9h00	Welcome <i>by Rita Bola, EWF</i>
09h15	ModuLase Overview: Main Objectives vs. Achievements <i>by Paola De Bono, TWI</i>
09h45	Beam Forming Unit implementation and advantages <i>by Nick Ellis, ULO</i>
10h00	The modularity of the end-effectors <i>By Ricardo Garcia, SODECIA</i>
10h15	Why to include a monitoring tool in the system? <i>By Eva Vaamonde, AIMEN</i>
10h30	System User Interface <i>By Philip Wallington, Q-sys and Stefano Tedeschi, TWI</i>
10h40	Virtual Networking Coffee Break
10h55	Demonstration of ModuLase System Capabilities <i>by Stuart Dutton and Patrick O'Malley, Graham Engineering</i>
11h25	Q&A Session Livestreamed form Graham Shop-floor <i>Moderated by Rita Bola, EWF</i>
12h00	Session closure <i>by Rita Bola, EWF</i>

The workshop started with a welcome by EWF, Dissemination and Exploitation Manager in ModuLase, on behalf of the ModuLase Consortium. An overview of the project's main objectives and achievements was presented by TWI, ModuLase project coordinator; followed by an introduction of the individual developed technologies:

- Beam Forming Unit implementation and advantages - by Nick Ellis, ULO.
- The modularity of the end-effectors - by Ricardo Garcia, SODECIA.
- Monitoring unit - by Eva Vaamonde, AIMEN.
- System User Interface - By Philip Wallington, Q-sys, and Stefano Tedeschi, TWI.

The above presentations were subsequently followed by an on-line demonstration of the ModuLase system, focusing on the three end-users case studies summarised in Table 2. The capability of the ModuLase system was demonstrated across three laser processes: welding, cutting and cladding.

Table 2 Summary of case studies

Application	Partner	Material	Images of 3D parts
Welding shift fork	SODECIA	S420 steel	
Cutting aerospace component	GEL	Ti6Al4V titanium	
Cladding shift fork	SODECIA	S420 steel	

The event was promoted mainly through social media and using the below banner to support (Figure 1). A platform to keep track of registrations and engagement was also used, Eventbrite. The event counted with 21 external participations from industry.



Figure 1 Final Event Promotional Banner.

Figure 2 shows a screenshot of a group picture from the event.

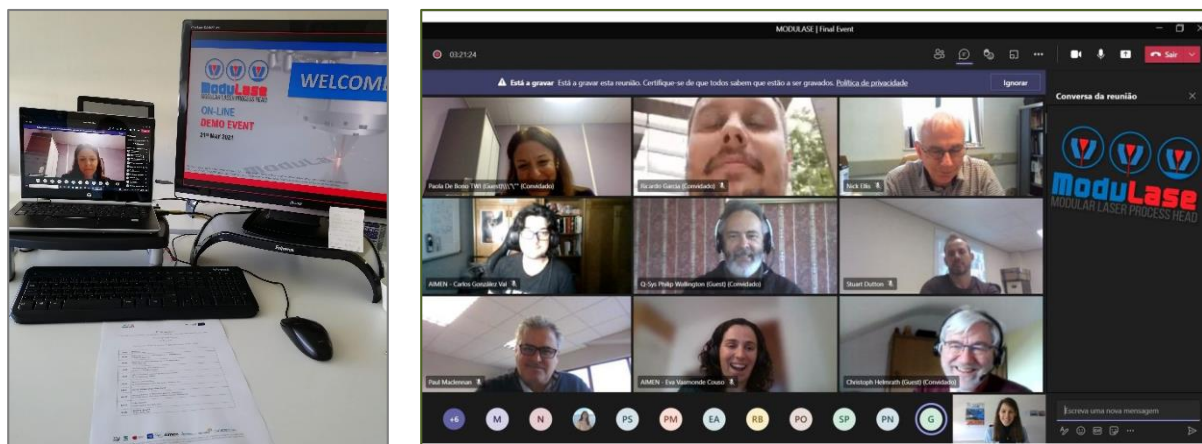


Figure 2 Group picture of Final Event participants and speakers

The annex of this document reports screenshots of the presentations given at the event, for each of the topics covered. Full version of slides can be found on the ModuLase website (<https://www.modulase.eu/documents.html>).

Demo videos, showcasing the capability of the ModuLase system in an industrial environment, were recorded at GEL laser pilot cell, where the ModuLase system was ultimately integrated. All recorded videos can be found on the ModuLase website (<https://www.modulase.eu/documents.html>). Screenshots of the demos are shown in Figure 3 to Figure 6.



Figure 3 Operator at GEL laser cell, handling ModuLase end-effectors.

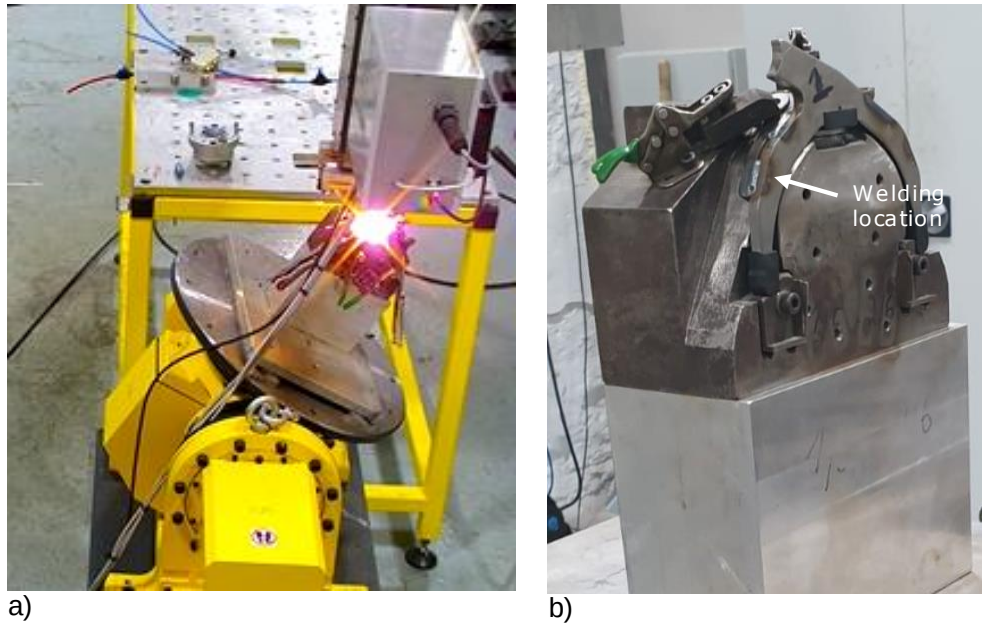


Figure 4 Laser welding process demonstrated on SODECIA shift fork automotive case study – laser processing (a) and resulting welded component (b).

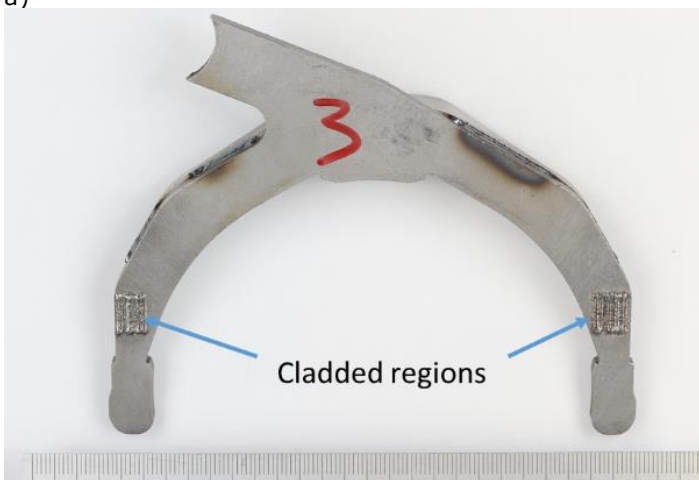
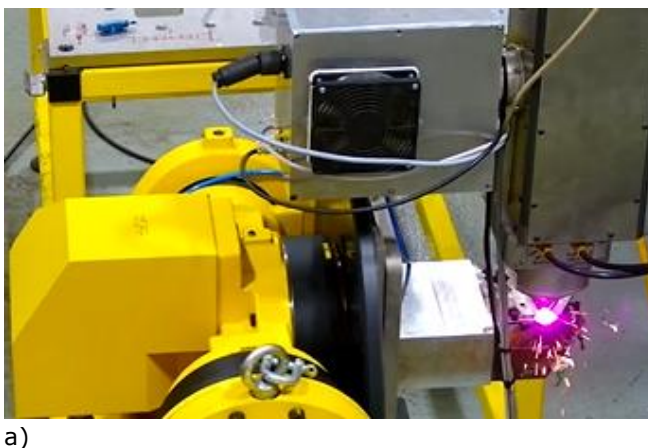
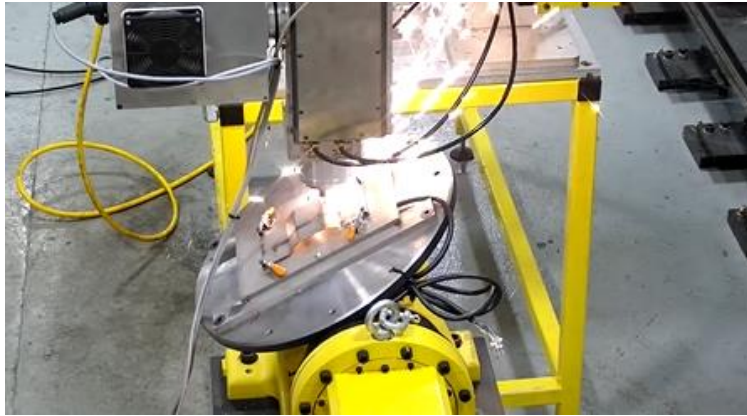


Figure 5 Laser cladding process demonstrated on SODECIA shift fork automotive case study – laser processing (a) and resulting cladded component (b).



a)



b)

Figure 6 Laser cutting process demonstrated on GEL aerospace case study – laser processing (a) and resulting cut component (b).

4

Summary

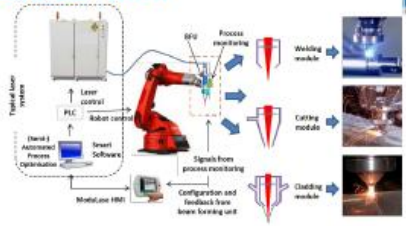
An online final event was successfully held on 21st May 2021, delivered to an industrial audience (external to the ModuLase project) and showcasing the capability of the ModuLase system in a manufacturing environment, at GEL pilot laser cell. The concept of flexible manufacturing was demonstrated across three laser process: welding, cutting and cladding.

The event was promoted through social media and attracted 21 external participations from industry. Full version of presentations and demo videossides can be found on the ModuLase website (<https://www.modulase.eu/documents.html>).

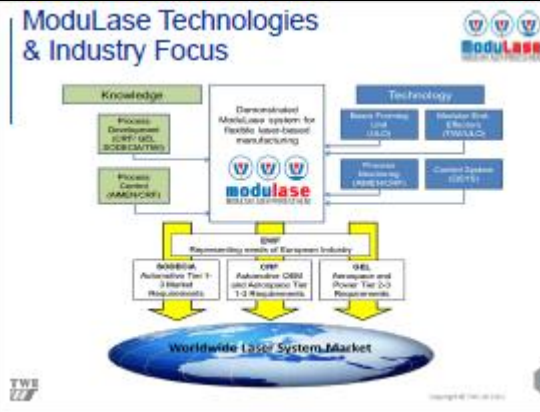
Annex

Screenshots of presentations given at the ModuLase workshop

ModuLase Overview: Main Objectives vs. Achievements - by Paola De Bono, TWI (slides can be found on the ModuLase website <https://www.modulase.eu/documents.html>).

 Development and Pilot Line Validation of a Modular Re-Configurable Laser Process Head ModuLase Workshop with Industry 21st May 2021 ModuLase Overview: Main Objectives vs. Achievements 	Contents - Overview of the project - Introduction of Consortium scientific objectives - Achievements for the project																
Introduction to the Project - H2020-FOF-13-2016 call - Factories of the Future: Photonics Laser-based production - Start date: 1st September 2016 - Duration: 57 months - Received EC funding: €2,458,465 (€2,184,565 Grant) - Programme directly focused on "Rapid individualised laser-based production"  The ModuLase project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. H2020-FOF-2016- 723945-ModuLase. The project is an initiative of the Photonics and Factories of the Future Public Private Partnerships	Business Need  - Develop a processing head covering welding, cladding and cutting, through the use of three modular end-effectors and re-configurable optics - Include intelligent sensor technologies for in-process monitoring - Be linked to an intelligent user interface system, to achieve adaptive process control, quality assurance, and semi-automated process parameters configuration																
Expected ModuLase Outputs Reduced capital investment costs: - End-users will save as much as 59% when installing the ModuLase head (1xprocess head with three end-effectors considered in this project) - Higher savings possible for organisations adopting more end-effectors Maximise laser equipment utilisation rates by reducing down-time: - Anticipated changeover time of <1 minute for the proposed ModuLase process head - Improved utilisation rates Reduced running costs: - Reconfiguring the BFU to match the required beam configuration will save time and cost - The integrated process control and monitoring system also helps minimise, if not eliminate, defects and therefore save on re-work or scrappage 	The ModuLase Consortium 8 participants from 4 countries 50% RTO, 25% SMEs and 25% LEs - End users within the power, aerospace and automotive sectors <table border="1"> <thead> <tr> <th>Activities</th> <th>Consortium</th> </tr> </thead> <tbody> <tr> <td>Beam Forming Unit</td> <td>ULO Optics</td> </tr> <tr> <td>End Effectors</td> <td>Q-Sys, SODECIA</td> </tr> <tr> <td>Process monitoring and quality control</td> <td>Jülich</td> </tr> <tr> <td>Laser processing development and validation</td> <td>TWI</td> </tr> <tr> <td>User friendly Operating/User Interface</td> <td>Q-Sys</td> </tr> <tr> <td>Training, Dissemination & Exploitation</td> <td>AIMEN</td> </tr> <tr> <td>Automotive and Aerospace applications</td> <td>Q-Sys, SODECIA</td> </tr> </tbody> </table> 	Activities	Consortium	Beam Forming Unit	ULO Optics	End Effectors	Q-Sys, SODECIA	Process monitoring and quality control	Jülich	Laser processing development and validation	TWI	User friendly Operating/User Interface	Q-Sys	Training, Dissemination & Exploitation	AIMEN	Automotive and Aerospace applications	Q-Sys, SODECIA
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ModuLase Technologies & Industry Focus



Objectives of the Project

1. Develop a Beam Forming Unit (BFU) for Tailoring Laser Beam Energy Distribution

- Re-configurable collimating and focusing optics (by mounting them on automated drives) to allow tailored beam caustics to be produced for welding, cladding and cutting applications

2. Develop End-Effectors for Welding, Cladding and Cutting Applications

- A range of rapidly interchangeable end-effectors designed and built for welding, cladding and cutting
- Each having the same 'plug and play' connection method to the BFU
- End-effectors will provide the additional functionality for each process (for example, cutting assist-gas, wire/powder-feed and plume control)

Objectives of the Project

3. Develop a Co-Axial In-Process Quality Assurance System

- Commercial in-process monitoring systems exist for laser cladding, welding and cutting applications
- However, the systems are not currently compatible for all three processes. In ModuLase, quality monitoring unit to be suitable for welding, cladding and cutting applications

4. Develop Software Package and Integrate with Process Head

- User-friendly software package required to interface with other parts of the wider laser processing system and for human interface

Objectives of the Project

6. Validate the Flexibility of the ModuLase system for Welding, Cladding and Cutting at a Pilot Facility

- End-user applications targeted for the ModuLase system:

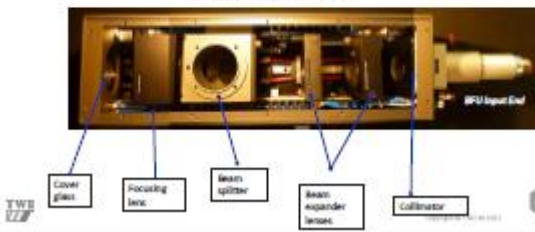
End-user	Application	Process(es)
SODECA	Shift forks for automotive gearbox components, constructed from steel-based material	Welding, Cladding
GEL	Titanium aerospace parts (eg gas turbine components)	Welding, Cutting
CMF	Galvanized steel door frame parts	Welding, Cutting

Achievements

Beam Forming Unit (BFU)

- Adaptable optical elements capable of delivering a wide range of laser beam energy distributions, suitable for welding, cutting and cladding applications

Hardware - BFU



Achievements - BFU

- Power handling capability up to 10kW, and compatible with 1µm wavelength laser sources
- Capable of providing focus spot sizes varied by a factor of 3 (fibre diameter is benchmark)
- Reduce optical configuration changeover from current 1-2 hours to <1 minute, minimising down-time
- Positional accuracy of 0.05mm of optical component drives, to ensure accurate beam caustics
- Optical compatibility with co-axial process monitoring technology

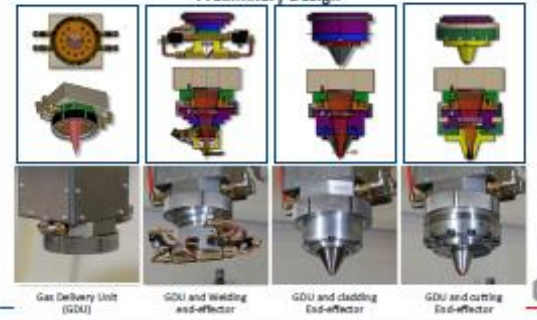


Achievements – End Effectors

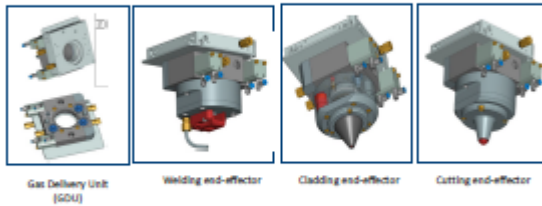
- Three rapidly interchangeable end-effectors to cover welding, cutting and cladding applications
- Plug and play system to allow them to be changed on the end of the process head within a time of 1minute

Achievements – End Effectors

Preliminary Design



Achievements – End Effectors Optimised Design



Achievements – Quality Assurance

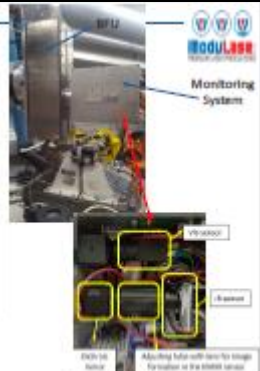
- A process monitoring system suitable for welding, cladding and cutting processes developed
- Embedded into the ModuLase system, in order to assure process stability, reduce scrap rate, enabling to reduce additional time and costs involved in the process



TWI

Achievements Quality assurance

- Effective and compatible with the three different laser processes
- Arrangement includes camera-based sensors which cover different spectral bands from visible (VIS) to infrared (IR) embedded electronics and optical components
- Molten pool is monitored in real time
- Deviations from stable reference conditions are captured, localized and identified as anomalies of the process



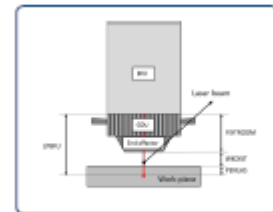
Achievements - Friendly User-interface

- The ModuLase system will comprise an user friendly HMI interface, enabling to input the material grade, its thickness and the laser process required
- Both the Quality Assurance System and BFU shall adjust vision and optical configurations and deliver the beam accordingly with minimal user contact

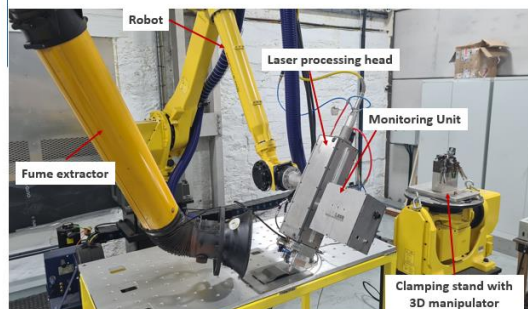
✓ Quick process configuration



✓ Reducing the expertise required to optimise the laser processes



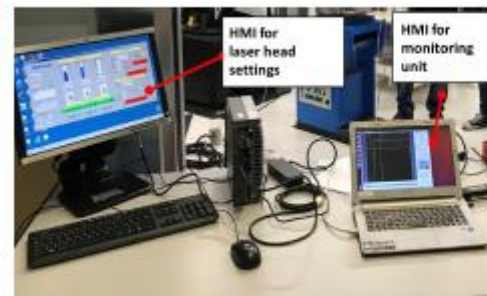
System Set-up and Validated at GEL Pilot Cell



TWI

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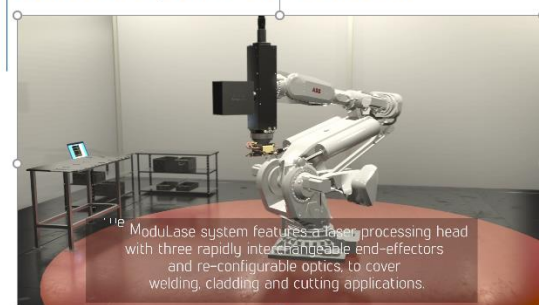
System Set-up and Validated at GEL Pilot Cell



TWI

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ModuLase System – CGI Animation



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Summary

- The Modulase system has been designed and manufactured to be flexible and accommodate three different laser processes: welding, cutting and cladding
- The system comprises, monitoring unit, on board intelligent algorithms for setting the optical configuration and help the user in the selection of process parameters
- The capabilities of the system have been proved across three different technologies, welding, cladding and cutting. Results are aligned with users' requirements

TWI

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Summary

- System validated in lab environment at TWI and, subsequently at GEL's pilot laser cell on-going
- 40% Investment saving (1xBFU) ✓
- Up to 40% Space saving ✓
- Up to 20% Production time saving ✓
- < 1 min changeover of end effector ✓

Contact

Further information available at:
<http://www.modulase.eu/>

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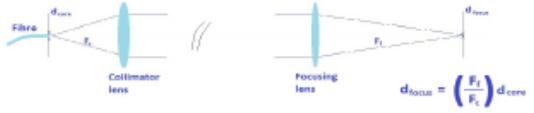


Beam Forming Unit implementation and advantages - by Nick Ellis, ULO (slides can be found on the ModuLase website <https://www.modulase.eu/documents.html>).



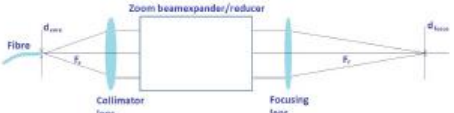
Beam Forming Unit (BFU)

- Basic fibre laser processing head layout – Collimator lens & Focusing lens (& protective window – not shown).
- Focus is an image of the fibre core end.
- Diameter of focus is determined by the ratio of the focal lengths (the magnification).
- BFU has $F_c = 100\text{mm}$ & $F_f = 173\text{mm}$.



Beam Forming Unit (BFU)

- To vary the focus diameter to suit the different processes, we needed to vary the focal length of either the collimator (F_c) or focusing lens (F_f). A zoom beam expander/reducer will do this.

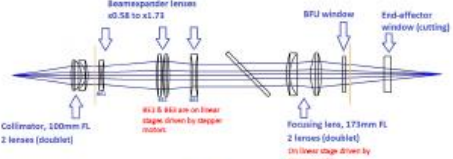


Beam Forming Unit (BFU)

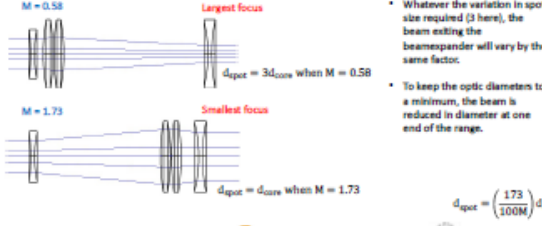
- Addition of a beamsplitter so monitoring cameras can view the process.
- Beamsplitter allows the laser beam through but reflects the visible light and other near IR wavelengths.



Beam Forming Unit (BFU)



Beam Forming Unit (BFU)



- Whatever the variation in spot size required (3 here), the beam exiting the beam expander will vary by the same factor.
- To keep the optic diameters to a minimum, the beam is reduced in diameter at one end of the range.

Beam Forming Unit (BFU)

Labels in diagram: Beam expander BE3, Beam expander BE2, Collimator, Fiber receiver QD/CBH/QB, Beam expander BE1 in end plate, Water cooling pipes, Stepper motor with Electronic brake, Beamsplitter housing & mount for cameras, Focusing lens.

Beam Forming Unit (BFU)

Beam Forming Unit (BFU)

Beam Forming Unit (BFU)

Original end-effector shown

Beam Forming Unit (BFU)

Acoustic and power measurements by IGS

Beam Forming Unit (BFU)

- Some specs:
- Dimensions: L x W x H = 510 x 150 x 150mm, excluding collimator (80mm) and fibre receiver.
- Weight: 22kg, excluding end-effectors.
- 0.15 NA fibre at 86% power level (has been used with 0.2 NA fibre).
- Water-cooling connectors – essential to use at the powers required.
- Connector for gas purge.
- Collimator 100mm FL. Focusing lens 173mm FL. Beam expander x0.50 to x1.73.
- Factor of 9 variation in focused spot intensity.

The modularity of the end-effectors - By Ricardo Garcia, SODECIA (slides can be found on the ModuLase website <https://www.modulase.eu/documents.html>).

ModuLase
MODULAR LASER PROCESS HEAD

Final Event
The modularity of the end-effectors
Presenter: Ricardo Garcia, SODECIA

SODECIA, ULD Optics, Synt, amon, EWF

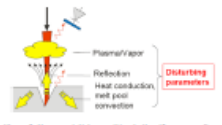
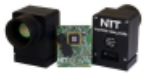
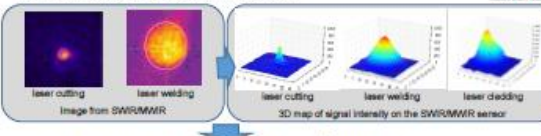
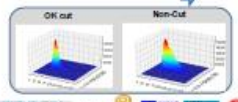
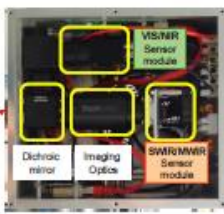
The ModuLase project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101019144-PPP-2020-ModuLase. The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101019144-PPP-2020-ModuLase. The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101019144-PPP-2020-ModuLase.

End-effectors

- Welding
- Cutting
- Cladding

Welding End-effector Attach	Welding End-effector Detach
Cutting End-effector Attach	Cutting End-effector Detach
Cladding End-effector Attach	Cladding End-effector Detach
The ModuLase project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. H2020-FoF-2016-723945-ModuLase. The project is an initiative of the Photonics and Factories of the Future Public Private Partnerships. www.modulase.eu	

Why to include a monitoring tool in the system? - By Eva Vaamonde, AIMEN (slides can be found on the ModuLase website <https://www.modulase.eu/documents.html>).

 ModuLase MODULAR LASER PROCESS HEAD Why to include a monitoring tool in the system? Eva Vaamonde, AIMEN     The ModuLase project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101017544. T2000. ModuLase: The project is an initiative of the Processes and Production of the Future Public Private Partnership.	Summary • Laser process monitoring • Introduction • MWIR/VIS imaging • ModuLase cases of study • Cutting process • Welding process • Cladding process    
Laser process monitoring     	Why laser process monitoring? The main goal of process monitoring is to get information on the process to: • Improve the understanding of the occurring phenomena • Enhance process reproducibility and traceability • Enhanced Productivity • Assure process reliability and quality • Reduction of scrap • Reduction of defects on components • Maintenance of installations. • Systems examine laser-to-metal interaction to infer the quality of the weld/deposit/cut itself, according to process quality signals. • Methods based on acoustic, electric and optical signals. • Optical methods are the most commonly used due to low noise and relative ease collected. • Main Sensors: Photodiodes, Spectrometers, CCD and CMOS cameras, Acoustic sensors, Pyrometers     
Main considerations for ModuLase monitoring system: • Commercial process monitoring systems: mainly for one specific process. • Multi-sensor approach increases the complexity of the processing head. • Low-cost alternatives (microbolometers or pyroelectric devices): low response time. • High frame rate is required to enable fast process control. IR sensors → Uncooled PbSe Sensors • High speed Infrared Imaging • Low cost     	Main considerations for ModuLase monitoring system:  Low signal in the IR sensor for the laser cutting process → VIS sensor     
Main considerations for ModuLase monitoring system: ModuLase process monitoring system: suitable for welding, cladding and cutting processes      	Modulase cases of study     

Modulase monitoring system set up

To set up the quality control or RT control for each process, we need to complete these steps:

1. Sensor calibration.
2. Training dataset acquisition.
3. System training.
4. RT System validation.

Welding process: Sodecia welding case of study

Cutting process: Graham cutting case of study

Cladding process

- Location and dimensioning of defects is complex
- SWIR/MWIR sensor enables measuring the melt pool geometry
- Correlation between melt pool geometry/dilution/ laser power was establish through algorithms (based on real trials).

Kp, Ki Adjustment:
 - Actuation over laser power. Other parameters are static.
 - Controller maintain parameters within a valid range.

Real-Time control results

Conclusions

- The machine learning solution able to automatically identify welding defects has been tested. Accuracy higher than 90% is achieved on detection of lack of penetration on laser welding process with the MWIR sensor.
- According to results from laser cutting trials, an accuracy higher than 95% is achieved on detection of non-cut defect with the VIS sensor
- For cladding process, a RT control system based on MWIR Images of the melt pool was implemented. The system is able to improve the geometry stability of the laser metal deposition tracks. Dilution decreases and becomes more uniform along the cladding process.
- Higher number of trials are required for system training. The accuracy of the system is highly dependent on number of trials.

Thank you for your attention

The Modulase project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101019044-4P-2019-120809 Modulase. The project is an initiative of the Principles and Technologies of the Future Public Private Partnership.

System User Interface - By Philip Wallington, Q-sys and Stefano Tedeschi, TWI (slides can be found on the ModuLase website <https://www.modulase.eu/documents.html>).

ModuLase
MODULAR LASER PROCESS HEAD

Development and Pilot Line Validation of a Modular Re-Configurable Laser Process Head

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Contents

- Modulase System User Interface

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System Architecture

- Defining software modules, overall architecture specified and how the data will be structured and stored

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User Interface Structure

The Knowledge Database Implementation

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User categories

- Basic user (Level 1):** Enabling the user to gain access to the knowledge database in order to retrieve the process parameters needed for the laser process operation choice.
- Intermediate user (Level 2):** Enabling the user to set process parameters independently (without the need to rely on data in the knowledge database).
- Administrator user (Level 3):** Provides full control of the interface. This user can perform modification to the current interface and add process parameters.

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Interface Screen Features

Human Machine Interface (HMI)

- Communication panel which includes: Date and time, Command and response signals, COM port selection, STOP Motor and EXIT bottom.
- Brake switches and home buttons.
- Knowledge database for retrieve process parameters or directly set process parameters.

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Basic User Controls

Basic User level

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Intermediate User Controls

Intermediate User level

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Administrator/ Advanced User Controls

Administrator User level

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Controls Comparison

Basic User level Intermediate User level Administrator User level

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Thanks for Your Attention
Any Questions?

