Deliverable D1.2: Laser deburring station

Automated robotic system for laser deburring of complex 3D shape parts

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1 Introduction

The overall objective of the project is to design and set up an automated robotic station for laser deburring of metal casting 3D high quality complex parts. In particular, it is intended to develop a flexible, low-maintenance and environmentally friendly prototype, able to improve the quality, cost and cycle time of finishing operations (deburring, etc) of aluminium injected components. The system could potentially be applied to different light casting alloys (Mg, AlZn, etc.) and sectors (automotive, railway, electronics, furniture, electric appliances, etc.)

This Deliverable contains the main results concerning the conceptual design and set up of different laser systems for the laser deburring of 3D metal castings. For the moment, two process approaches remain under consideration, gas-assisted cutting and remote cutting (we consider deburring as a cutting process). Although both are based in a laser source to produce the separation of the parts, they rely on different physical mechanism, and therefore require distinct machine configurations, particularly concerning the beam guiding device.

2 Laser system for conventional gas assisted laser deburring

2.1 Laser source

A fibre laser has been selected as the source for gas assisted deburring. Fibre lasers are cutting edge technology and offer significant advantages when compared to other laser generating techniques such as high beam quality, compact size and reliability. In this case the source is also single-mode, which is the highest beam quality available in the market today. It is air cooled and it is guided through an optical fiber of 5 m length (see Fig. 1). It is a laser source which has a very good beam quality ($M^2 < 1.1$) and also allows modulating its emission, by emitting pulses of up to 10 µs. It is portable and of easy automation, therefore, its integration on different machines such as machining centres, robots, etc. is possible. Given the high quality of the laser beam, the laser is ideal for joining, micro-machining, cutting and welding applications. The main properties of the laser source are summarized below on Table 1.

Table 1. Laser source specifications

Maximum Power (W)	200
Operating wavelength (nm)	1070
Beam quality (M^2)	< 1,1
Fibre optic length (m)	5
Pulse repetition frequency (kHz)	0 - 100
Maximum pulsed energy (mJ)	2,0 @ 100 KHz
Pulse duration (ns)	>10
Power stability (%)	<0.5
Weight (Kg)	45
Dimensions W x L x H (mm)	483 x 507 x 221

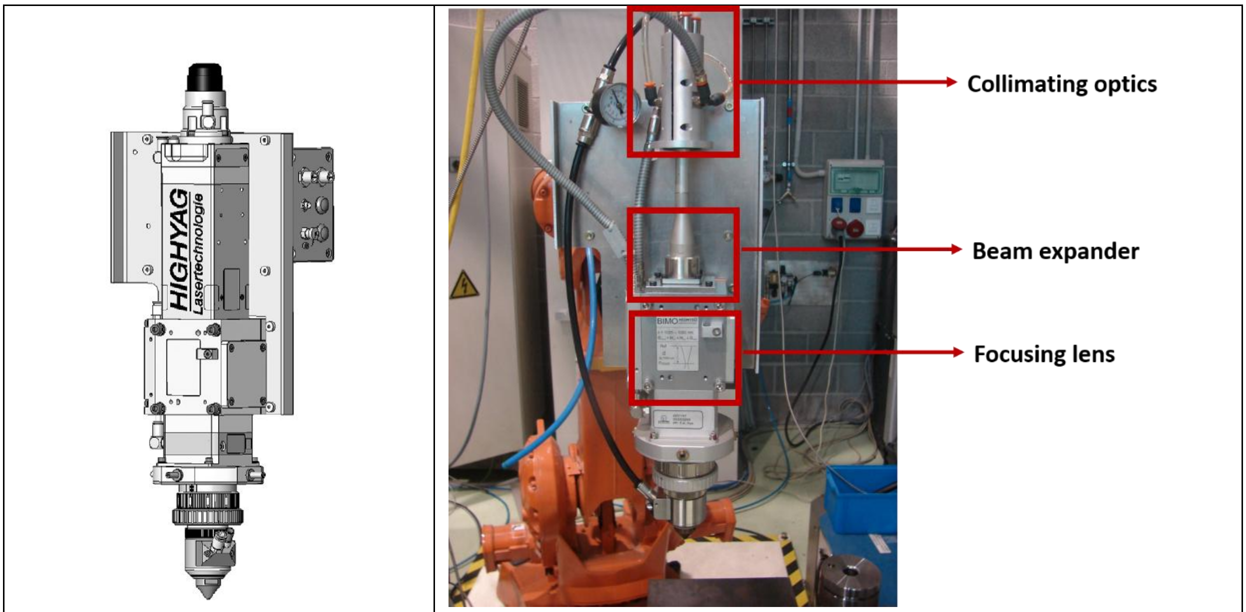
The radiation is generated inside the active fibre, which is inside the housing, and then coupled to another optic fibre, in order to guide the radiation to the work piece. This fibre has a diameter of 10µm and is in turn connected to the cutting head. It must be mentioned that a signal to trigger the laser has been implemented into the robot control. This way the on/off instruction for the laser is available when writing the robot program.

Fig. 1. Laser source

2.2 Optical system

Gas assisted laser cutting relies on the effect of a gas to evacuate the molten metal from the interaction area and produce the effective separation of the pieces, in this case the burrs from the final part. Therefore, the cutting head must be very close to the part because the gas stream needs to be tightly focused to be effective. A typical stand-off distance is around 1mm. The selected model is shown in Figure 2a.

The guiding fibre, which is connected to the cutting head, comes already with a collimating unit. In its original configuration, the cutting head contains another collimating module and a focusing module. In order to increase the process efficiency, both in terms of speed and energy, a modification to the original optical system of the cutting head has been designed and implemented, so as to obtain a smaller spot size. In this way it is possible to concentrate the incoming laser radiation in a smaller area and increase the feed rate. This is done by removing the collimating unit of the cutting head and placing a beam expander module between the collimator of the fibre and the focusing lens of the cutting head. The result of this modification can be seen in Figure 2b, where the areas highlighted in red show the different modules of the optical system.

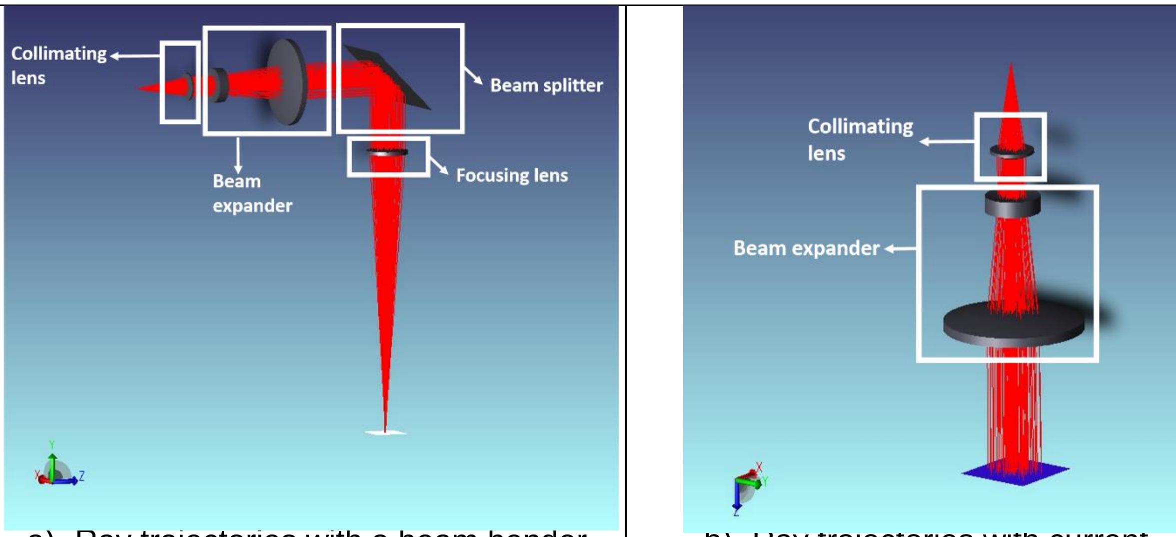


a) Original configuration   b) Modified configuration

Fig. 2. Cutting head for gas assisted processing

By using optical design software, the trajectories of rays all along the optical path can be computed and plotted. This is extremely useful when designing new optical systems and also to evaluate the potential of modifications to already existing systems. In this case, the commercial software code ZEMAX has been used to evaluate and optimize different possibilities.

As previously stated in other documents, one of the goals of the DEBUR experiment is to optimize the process productivity. In order to maximize velocity it is necessary to implement some kind of closed loop control, which must be fed with certain information, coded in the signals generated during the interaction of the laser and the metal in the substrate zone. With the current cutting head configuration, it is not possible to record any signal. Therefore, another optical design has been considered, which includes a beam bender to collect radiation from the interaction area and guide it to a window where different sensors can be placed. A beam bender is an optical element that is normally placed at a 45º angle with the incoming radiation. It is made of a mirror with a special coating, which reflects the operating laser wavelength but can transmit radiation of other wavelengths, such as UV, other IR bands, visible, etc., which can then be used as the basis for a control. The biggest change when compared with the current configuration is the need of the radiation to impinge at 45º, as can be seen in Fig. 3a. In this figure, the first lens is the collimator from the fibre. Then come two more lenses, which comprise the beam expander module, followed by the beam bender mirror and finally the focusing lens. An extra connecting part is needed, to link the beam expander and the beam bender. This part has been designed and is currently being manufactured. In Fig. 3b the ray trajectories with the current optical configuration are shown (focusing lens not included).

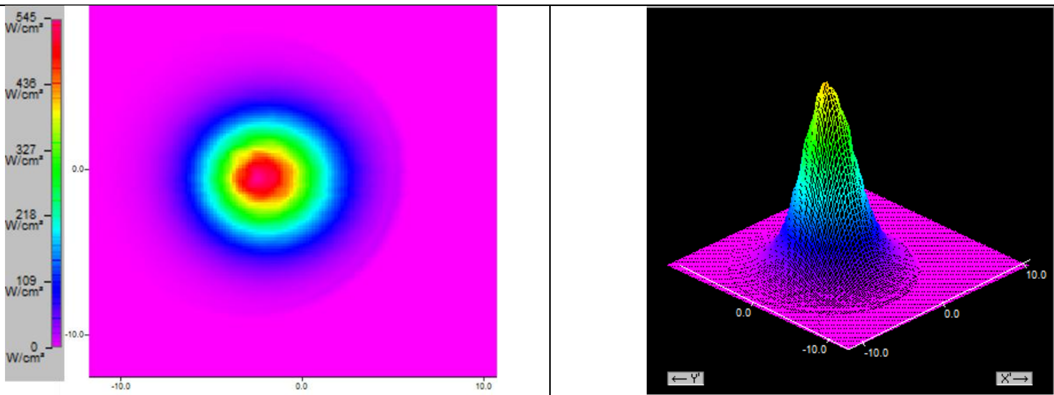


a) Ray trajectories with a beam bender

b) Ray trajectories with current configuration

Fig. 3. Ray tracing simulations

In order to locate the lenses at their optimum positions it is very useful to have an experimental characterization of the beam irradiance and divergence at different positions along the optical path. However, in this case, given the high beam quality, the spot size at the focus position is too small to be measured experimentally with the available devices. Therefore, the beam has been measured after the beam expander module. The results can be seen in Fig. 4.



a) Beam irradiance after the beam expander

b) 3D representation of the beam irradiance

Fig. 4. Experimental characterization of the laser beam

From the irradiance measurement it can be seen that the radius at exit of the beam expander module is of 5.25mm, and that the peak value is around 545W/cm^2.

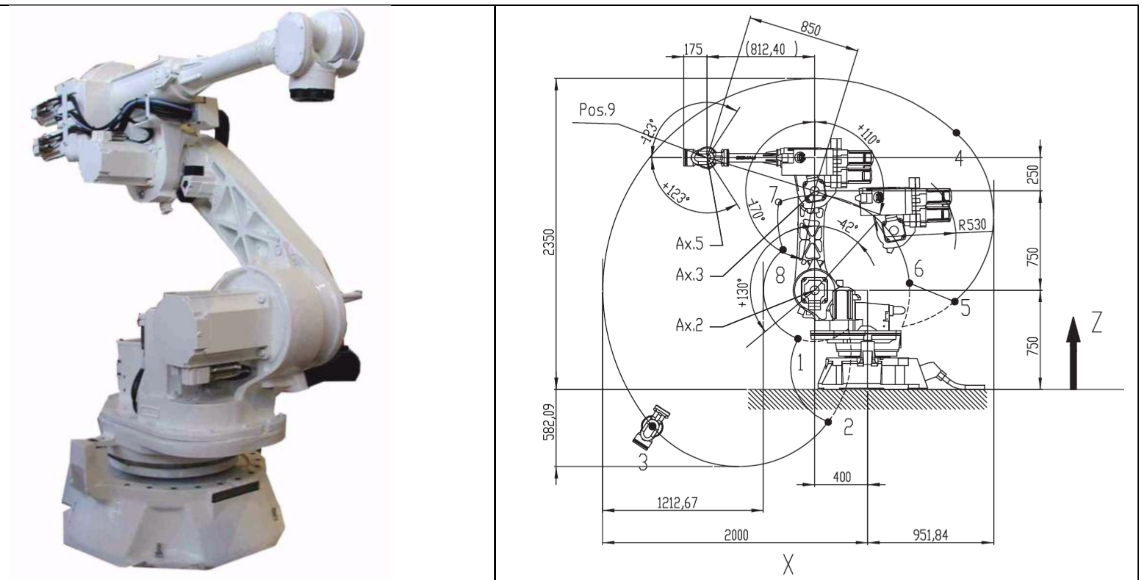
2.3 Robot

The robot plays a key role in the DEBUR experiment, since it is responsible of the part movement during the laser deburring process. Considering the weight of the parts and other needs, a 6 axis robot has been selected, the main characteristics of which are listed in Table 2.

Table 2. 6-Axis robot specifications

VERSION		NM 45-2.0 (*)
Structure / n° axes		Anthropomorphous / 6 axis
Load at wrist		45kg *99.20 lb(1)*
Additional load on forearm		40kg *88.18 lb(2)*
Torque axis 4		176,58Nm
Torque axis 5		176,58Nm
Torque axis 6		117,72Nm
Stroke /(Speed)	Axis 1	+/-180°(160°/s)
	Axis 2	+130°/-53°(150°/s)
	Axis 3	+110°/-170°(160°/s)
	Axis 4	+/- 2700° (250°/s)
	Axis 5	+/-123 °(250°/s)
	Axis 6	+/-2700 °(340°/s)
Repeatability		+/- 0,06 mm *0.00236 in*
Robot weight		680kg *1499.14 lb*
Tool coupling flange		ISO 9409-1-A100
Motors		AC brushless
Position measurement system		with encoder
Total power installed		12 kVA / 18,5 A
Protection class		IP65 /IP67
Working temperature		0 ÷ + 45[°C
Storage temperature		- 40 [°C] ÷ + 60[°C]
Colour of robot (standard)		Red RAL 3020
Assembly position		On the floor; from the ceiling; sloped (45° max)

Although in the final configuration of the demonstrator the laser head is fixed and the part is moved by the robot, for the preliminary tests on test samples the cutting head will be mounted in the robot and the parts remain fixed. In the final configuration the robot will also hold the 3D vision system for burr detection.



a) ABB robot for laser deburring

b) Working range

Fig. 5. 6-Axis robot

3 Laser system for remote laser deburring

3.1 Laser source

The same laser source is planned for this process variant. It must be noted that the use of a single mode laser is mandatory for remote cutting/deburring.

3.2 Optical system

Laser remote cutting is based on the combination of high brilliance sources and a high speed beam deflecting device, such as a scanning system, normally composed of two mirrors, which quickly scan the beam and focus it onto the substrate by means of an F-Theta lens. The low mass and low inertia of this solution are translated into high speed processing, which can exceed 10m/s. Furthermore, the trajectory remains very accurate despite the high velocities. The material to be cut is evaporated on a layer by layer fashion, until the parts are effectively separated.

Regarding the mirror head, besides the characteristics mentioned in Table 3, several other particularities can be mentioned, such as the possibility of expansion (for example, to add a third optical axis) and the digital circuitry, which algorithms that are designed to improve dynamic performance and processing quality. It also has different options for diagnosis and communication between the scanner head and the control PC. Furthermore, the integrated firmware comes with several predefined options predefined, some of which are fine tuned for speed, other for accuracy and other offers a balanced solution. It is also possible to switch between a set of parameters and other "on-line" during processing, which add great flexibility. Finally it must be noted that, like the laser generator, the scanning head offers the possibility to be serviced remotely, to speed up maintenance operations.

Table 3. Scanning head specifications

Aperture (mm)	20
[1]Typical marking speed (m/s)	1
[1]Typical positioning speed (m/s)	11
Weight without objective (kg)	5.8

(1) with F-Theta objective, f=163mm

Fig. 6. Scanning head

3.3 Robot

Same as for conventional gas assisted cutting.

4 Conclusions

- Two different set-ups have been conceived for the gas assisted and remote laser deburring processes.
- The most appropriated laser source, optical system and robot have been selected for each case.
- Some modifications to the optical system have been designed and implemented, in order to maximize process productivity and allow signal recording from the interaction area.