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Gap management of stainless-steel Laser Beam Welding with dynamic tailored beam shaping based on Multi-Plane Light Conversion

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Abstract

The increasing automation of the automotive industry has resulted in the widespread use of laser technology, particularly in Laser Beam Welding (LBW) of complex materials like ferritic and austenitic steels used for exhaust systems. However, this may be challenging, and the use of the right beam shape can enhance the process performance and robustness to meet the high-quality standards. This paper focuses on LBW of 1mm steel, and how the Custodian project has developed a methodology to tailor the beam shape to the process. The appropriate shape for this study includes an inner intense spot and a background top-hat shape. A unique dynamic beam shaper based on Multi-Plane Light Conversion (MPLC) has been developed to adapt the shape to the welding bead in real-time. The optical performance of the beam shaper is described, as well as its impact on the quality of LBW with an 8kW 1.07µm laser.

Keywords: Laser; steel; welding; automative industry; beam shaping; dynamic tailored beam shaping

1. Gap management between components

Laser welding consists of joining multiple, generally metal parts using a high-power laser. The heat generated melts the material to form a weld pool. As the weld pool cools, the parts fuse together. One of the major challenges of standard laser welding processes in the automotive industry is assembling parts with a gap, especially interlocking tubular parts. These gaps can lead to functional and structural issues if not addressed appropriately. Currently, to mitigate these problems, expensive mechanical tools are employed to minimize the gaps, but this comes at the cost of reduced process speed and increased overall expenses. Finding innovative solutions that strike a balance between precision and efficiency is crucial to overcome these challenges and streamline manufacturing operations for greater productivity and cost-effectiveness. Beam shaping can facilitate this task while maintaining quality and productivity levels.

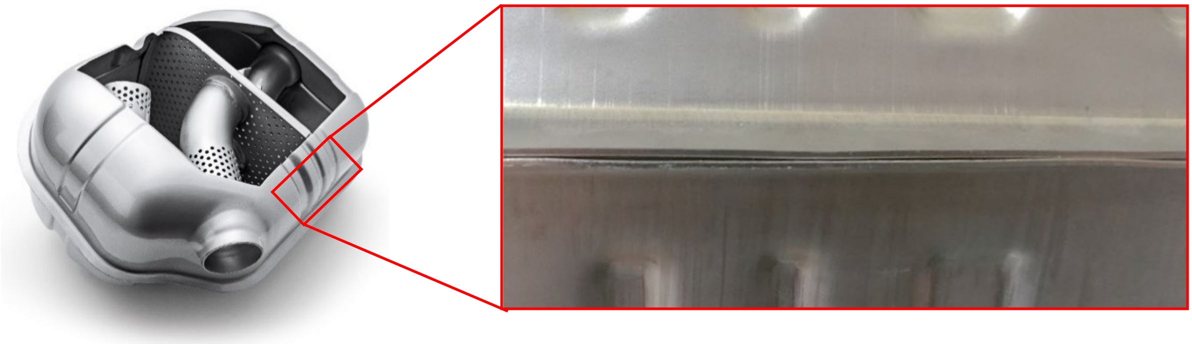

Fig. 1. Example of variable gap between parts to be welded (Automotive exhaust system, Rear muffler).

2. Development of a dynamic beam shaper

2.1. An intense dot and a background rectangle beam-shaping

In the realm of steel welding, a highly effective configuration has been derived through meticulous simulations, consisting of an intense dot to initiate the weld and a rectangular background shape to lower the thermal gradient. This optimal shape is designed to enhance welding performance significantly. The primary beam diameter (d) remains fixed at 0.67 mm, while the secondary beam length (L) is unchangingly set at 1.5 mm. However, the secondary beam width (W) can be dynamically adjusted, allowing for adaptability in different welding scenarios. The relative position between the primary and secondary beams remains constant to maintain consistency. Moreover, the power ratio (P1/P2) between the primary and secondary beams is adjustable, enabling fine-tuning of the welding process to achieve precise and desired outcomes.

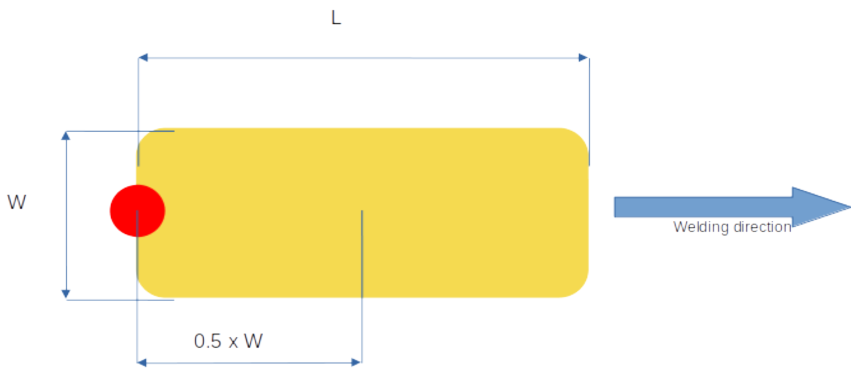

Fig. 2. Beam shape diagram (dot + rectangle)

2.2. Dynamic adjustment through galvo-mirrors

Indeed, the dynamicity of the steel welding configuration is achieved through a well-thought-out principle. The implementation involves two galvo-mirrors that play a pivotal role in the process. These galvo-mirrors contribute to a remarkable dynamicity of up to 300 Hz, allowing for rapid adjustments during welding operations. The width of the secondary beam is modulated by changing the angles of these mirrors, providing flexibility in adapting to varying welding requirements. Furthermore, the power ratio (P1/P2) between the primary and secondary beams is finely tuned by adjusting the linear positions of the galvo-mirrors. This capability ensures precise control over the power distribution during the welding process, optimizing the overall welding performance. To ensure safe and efficient operations, the configuration is designed to operate at a maximum power of 10 kW. This powerful capability empowers the welding system to handle a diverse range of steel welding tasks, catering to both heavy-duty industrial applications and more delicate, intricate projects. The integration of the galvo-mirrors with the overall setup introduces a level of versatility and responsiveness that significantly enhances the welding process, promising improved productivity and superior weld quality for various steel welding applications.

2.3. Integration of the system within an industrial environment

The beam shaping system is seamlessly integrated into a comprehensive welding environment, ensuring optimal performance and compatibility with various components. The first integration takes place with Precitec LBW optics. Mechanical integration with a robot further enhances the system's versatility and manoeuvrability. The robot's capabilities complement the beam shaping system, facilitating precise positioning and movement during welding operations, even in complex workpieces and tight spaces. Additionally, the beam shaping system is coupled to the output of an 8 kW fibre laser with a diameter of 1.07 mm. This integration harnesses the power of the high-performance laser, allowing the beam shaping system to effectively shape and modulate the laser output according to the specific welding requirements. The integration of these components results in a cohesive and powerful welding setup. The beam shaping system's adaptability, combined with the advanced laser technology and robotic precision, ensures unparalleled welding capabilities for various steel welding tasks. This integrated environment promises enhanced productivity, good weld quality, and the ability to tackle a wide range of welding applications with utmost efficiency and reliability.

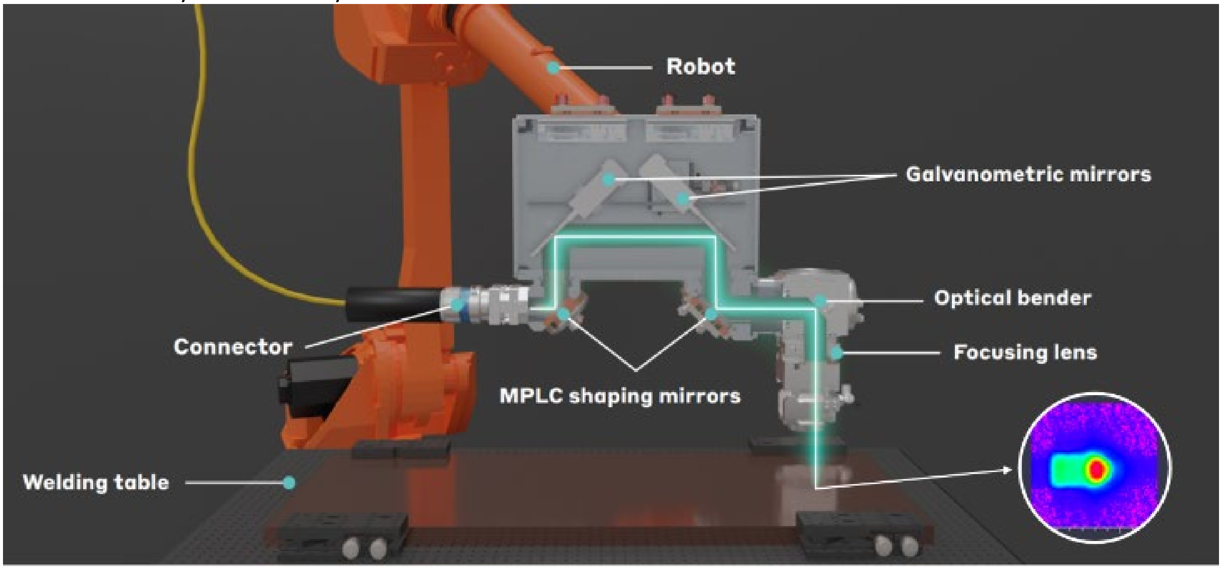

Fig. 3. Dynamic Beam shaper diagram

3. Results obtained with AIMEN.

3.1. Laser welding of tubular parts in AIMEN laboratory

Tubular parts have been chosen to test the performance of the system. To be considered compliant, welding must meet the following industry standards industry compliance standards:

- Minimum interface >0.67 mm
- Lack of penetration <0.2 mm
- Incompletely filled groove <0.2 mm
- Excessive penetration <0.4 mm
- Excess weld metal <0.4 mm
- Undercut <0.1 mm
- Root concavity <0.2 mm

In the absence of beam shaping in Laser Beam Welding, the effects of the gap between sheets are limited to a maximum of 0.2 mm. In such cases, the groove may remain incompletely filled, resulting in a weld that does not achieve full penetration and integrity.

However, with the MPLC system, compliant welds can be achieved even with a gap of up to 0.4 mm. At this gap size, the beam shaping system ensures a filled groove, resulting in a weld joint with improved penetration and structural integrity. This expanded range of gap compliance showcases the system's ability to handle more challenging welding scenarios while still producing high-quality welds with exceptional joint strength and consistency.

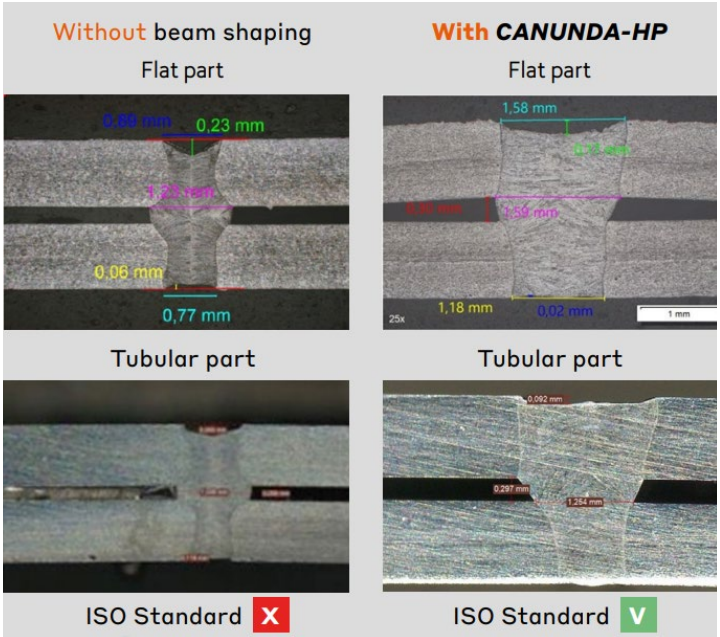

Fig. 4. Comparison of welding results at 0.3mm gap

Mechanical strength tests also show superior performance (see Table 1 and 2) when welded with MPLC beam shaper.

Table 1. Fatigue tests results

Average values		# cycles		difference
		STD	MPLC	%
Gap	0	110401	172647	56
	0,1	63704	116867	83
	0,3	37362	56499	51
	0,4	36870	48537	32

Table 2. Testing conditions table

Testing conditions:		
Load:	245	kg
Arm:	120	mm
Bending moment:	288,12	N/m
Frequency:	10	Hz
Gas T:	550	°C
Skin T:	400	°C

4. Conclusion

This dynamic beam shaper for automotive applications could be a groundbreaking innovation, revolutionizing the welding processes in the automotive industry. The live power and shape adjustment capabilities enable real-time optimization and precision, allowing for enhanced performance and efficiency during welding operations. One of the key achievements is the significant improvement in welding tubular parts with gaps. The dynamic beam shaper effectively manages a 0.4mm gap, surpassing the challenges that were present without beam shaping when limited to a 0.2mm gap. This advancement ensures robust and reliable welds, contributing to the overall quality and safety of automotive components.

Furthermore, the beam shaper has demonstrated remarkable results in fatigue tests, boasting an impressive 83% improvement. This enhancement ensures increased durability and longevity of welded parts, making them more reliable and resilient under demanding automotive conditions.

Overall, the dynamic beam shaper's accomplishments and ongoing developments signify its potential to reshape various industries, not just in automotive applications but also in advanced manufacturing processes and critical sectors. Its adaptability and innovation make it a driving force in modern engineering and a promising technology for the future.

References

[1]: Matthieu Meunier, Avinash Kumar, Aymeric Lucas, Stephane Bernard, Rosa Arias, Jorge Luis Arias Otero, Gwenn Pallier, Guillaume Labroille: “Stainless Steel Laser Beam Welding with a Dynamic Tailored Beam Shaping Laser-Head based on Multi-Plane Light Conversion”, Conference: ICALEO 2023 - Laser Additive Manufacturing (LAM) Track.