10th International DAAAM Baltic Conference
"INDUSTRIAL ENGINEERING -
12-13 May 2015, Tallinn, Estonia

LASER CLADDING TECHNOLOGY IMPLEMENTATION FOR IN-SITU REFURBISHMENT OF SHIP DIESEL ENGINE CRANKSHAFT JOURNALS

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Abstract: *This article provides an overview of state-of-the-art laser cladding technology which can be implemented in the in-situ refurbishment of ship diesel engine crankshaft journals. The envisioned laser cladding system arrangement consists of a carbon dioxide (CO_2) laser, a Neodymium-doped Yttrium Aluminum Garnet (Nd:YAG) laser or a high-power diode laser, a vertical-axis laser cladding powder feeder, a coaxial laser cladding nozzle as well as a process guidance and control system.*

Key words: Laser cladding; lasers; powder feeders; laser cladding nozzle.

1. INTRODUCTION

Laser cladding technology can be implemented for in-situ marine crankshaft renovation by fitting a laser cladding nozzle positioning and guidance device directly onto the crankshaft journal fillets. This novel in-situ concept of applying laser cladding for marine crankshaft repair provides clear economic benefits and many technological advantages.[1;2]

The purpose of this paper is to establish the state-of-the-art technological means of implementing the method to repair damage[1] caused by the gradual degradation of in-service performance of the diesel engine crankshaft journal. This article sets out the most relevant information on the laser cladding equipment and the actual laser cladding process, to be able to define the system specifications used in the in-situ laser cladding refurbishment process.

Laser cladding technology ensures that a thin layer of a desired metal is deposited on a moving substrate using a laser heat source. The material deposition on the substrate can be performed by several methods: powder injection, pre-placed powder on the substrate or wire feeding. Some of these methods and their variants are shown in Fig. 1. The most popular of the aforementioned methods is laser cladding by powder injection. During this process, the laser beam melts the powder particles and a thin layer of the moving substrate to deposit a layer of the desired material on the surface. Different kinds of materials can be deposited on a substrate with laser cladding by powder injection to generate a layer whose thickness can range from 0.05 to 6 mm[2] and width can be as narrow as 0.03 mm.[3]

2. OVERVIEW OF THE LASER CLADDING APPLICATION FOR COMPONENT REPAIRS

Conventional part repair technology relies on destructive, high temperature welding processes. Moreover, error-prone machining processes can have a negative impact on the timely execution of a repair. Laser cladding is a sufficiently safe and accurate technology to repair high-value parts, particularly for critical contact surfaces. The laser cladding repair not only offers complete restoration of the initial quality of a part, but also enhances it, resulting in a longer and more reliable service life. Thus it is possible to restore a high-value product which would otherwise have to be replaced. [4]

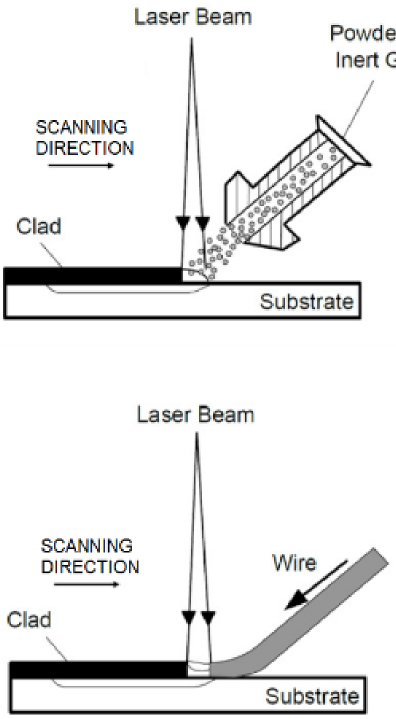

Fig. 1. Material deposition methods in laser cladding [5]

Nonetheless, laser cladding also has its drawbacks. The quality of the laser-cladded layer can vary in different areas due to the complex nature of disturbances in this process. Such occurrences can even be observed between processing cycles performed under the same operating conditions. Even if an optimal set of parameters is found experimentally and is subsequently used in an open-loop process, a surface layer formed may not be of good quality due to the very random or periodic nature of disturbances in the system.

The high investment cost, the lack of laser source efficiency as well as hard-to-control cladding processes are the main drawbacks that hinder a widespread use of this technology in industry.[6]

Laser cladding is used to repair and refurbish high-value components such as tools, turbine blades and military components. Using this process, a part that was over-machined due to an error in the design or manufacturing process can be saved and successfully employed for further operations.

It is possible to use a process such as welding to repair damaged parts, however given that these methods are usually of a destructive nature due to the highly distributed temperature over the area being repaired, the mechanical properties are impaired owing to cracks and pores, leading to a reduction in part life. In contrast to welding, laser cladding can provide a permanent structural repair and refurbishment on alloys that are generally considered unweldable due to the small heat-affected zone, rapid solidification, increased cleanness, lower dilution as well as increased control over the depth of the heat-affected zone.

One of the main areas where laser cladding has gained in popularity is turbine blade repair and refurbishment. Due to their high value and operational importance, these components have become a target for a repair technology application that can maintain their original mechanical and metallurgical features.[6]

3. LASER CLADDING PROCESS PARAMETERS

A large number of operational and physical parameters determine the quality of the obtained clad. A summary of these parameters is given in Fig. 2.

Laser cladding parameters may be defined as dimensionless variables, in terms of the energy balance between the absorbed power Aq and the power used to heat and melt the clad material, in order to successfully establish the operational process window as well as achieve a constant, normalized clad thickness:

Dimensionless beam power:

$$q^* = \frac{Aq}{r_B \lambda (\mathrm{T_m} - t_0)} \tag{1}$$

Dimensionless clad thickness:

$$l^* = \frac{l}{r_B} \tag{2}$$

Dimensionless traverse rate:

$$v^* = \frac{v r_B}{a} \tag{3}$$

Dimensionless volumetric latent heat of melting:

$$L_m^* = \frac{L_m}{\rho c (T_m - T_0)} \tag{4}$$

Dimensionless surface temperature:

$$T_p^* = \left(\frac{1}{\pi}\right)^{\frac{3}{2}} q^* \tan^{-1}\left(\frac{b}{v^*}\right)^{\frac{1}{2}} \tag{5}$$

Thermal diffusivity:

$$a = \frac{\lambda}{\rho c} \tag{6}$$

Where:

A – material absorptivity;

q – beam power $[Js^{-1}]$;

$2r_B$ – beam diameter (spot size) [mm];

l – clad thickness [mm];

v – beam traverse rate $[ms^{-1}]$;

ρ – density of the cladding material $[kg\ m^{-3}]$;

c – specific heat capacity $[J\ kg^{-1}K^{-1}]$;

T_m – melting temperature of the clad [K];

T_0 – initial temperature of the clad $[K]$;

L_m – volumetric latent heat of melting $[Jm^{-3}]$;

λ – thermal conductivity of the clad material $[Js^{-1}m^{-1}k^{-1}]$.[7]

Given the complexity of interactions between the laser beam, the alloy deposition mechanism and the molten region, as well as the fact that no previous knowledge is available for these specific application purposes, further research is needed in order to obtain a successful numerical model of coherent input, process and output parameters. Nevertheless empirical adjustments as well as the consideration of many inflectional factors must be taken into account for the obtained model such that the process result can be predicted, which will offer a direction for further research.[7]

4. MAIN COMPONENTS OF A LASER CLADDING SYSTEM

Of all the numerous laser systems available in the market, those most commonly used for laser cladding are CO_2 lasers, lamp-pumped and diode-pumped Nd:YAG lasers and high-power diode lasers (HPDL).[8]

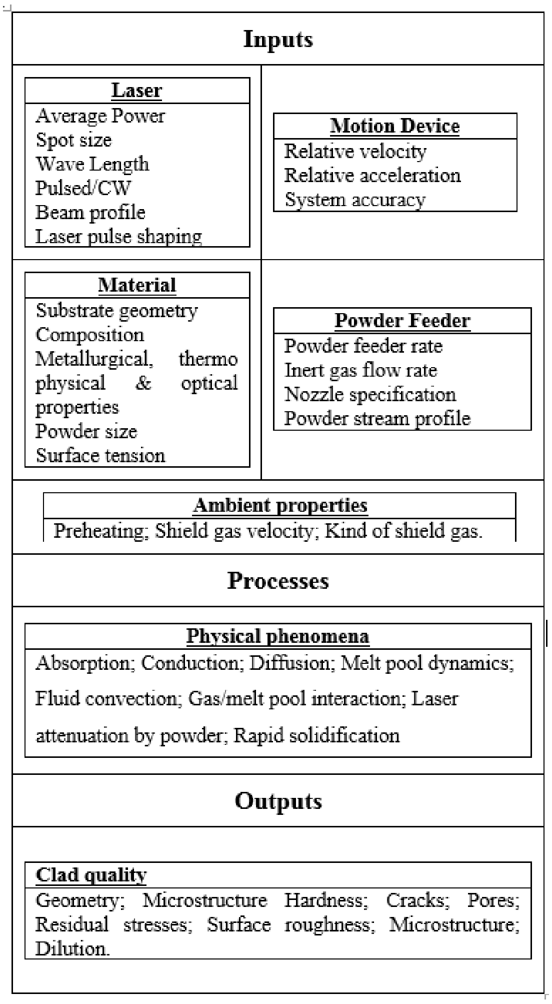

Fig. 2. Laser cladding parameters [7]

Metals are more reflective at 10 µm than at 1 µm, thus Nd:YAG and HPDL lasers which produce light at wavelengths of 1.024 µm and ~0.85 µm respectively are more efficient for metal processing compared with a CO_2 laser (10.6 µm). Aluminium is highly reflective when using a CO_2 beam, whereas the Nd:YAG or HPDL laser is perfectly absorbed. On the other hand, most carbon and stainless steels absorb CO_2 and Nd:YAG beams in a very similar manner. CO_2 laser beams are focused on smaller spots and are more symmetrical, which improves clad width. HPDL lasers provide a wide beam distribution and have a low beam quality, such that HPDL lasers in today’s market cannot be used for materials with a high melting temperature.

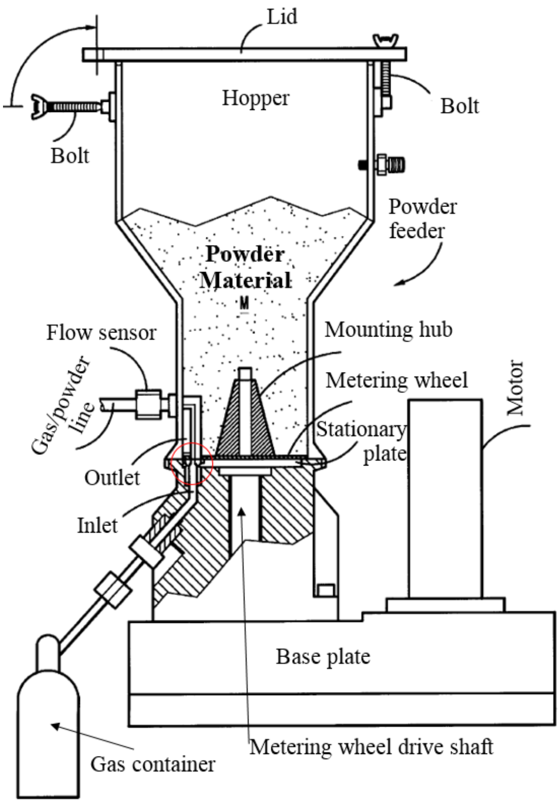

Fig. 3. Cross-sectional view of a potential powder feeder system [9]

Another important issue when selecting a laser for in-situ refurbishment in a confined space is the beam delivery and manoeuvrability of the laser nozzle, which in the case of a CO_2 laser would be very limited, due to the impossibility of transporting a CO_2 laser beam along optical fibre owing to its wavelength of 10.6 µm, which is inappropriate for this technology. Nd:YAG and HPDL lasers on the other hand can be passed along a fibre optic cable and as a result, can be connected to the end effector of a robot with any degree of freedom. However with HPDL, it is necessary to use a standard lens to achieve an appropriate working distance from the focus point. But there is also a very high risk that the protective glass and the lens will quickly become dirty or even damaged by the powder particles. Thus the processing of complex shaped surfaces (such as crankshafts) becomes complicated.[6]

The main components of any type of powder feeder are the powder material hopper with an orifice, as well as a load cell based electronic weighing mechanism, a powder carrier and a supplementary back-pressure gas system for the stability of the powder stream. In order to increase the controllability of gravity-based powder feeders, different devices such as a metering wheel can be integrated into the powder feeder.[6] Fig. 3 illustrates a possible design for a vertical-axis, rotating wheel powder feeder system.

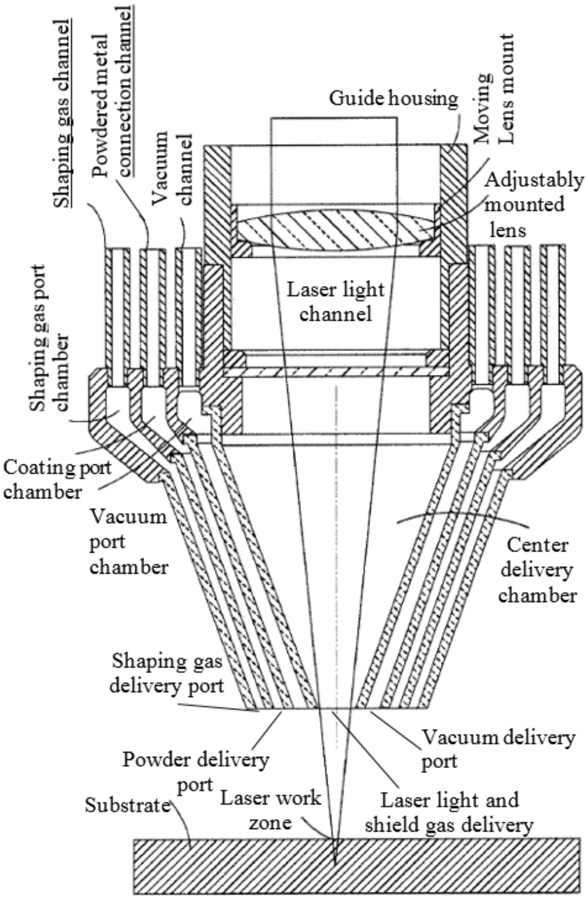

Fig. 4. Possible embodiment of a coaxial laser cladding nozzle [10]

The two basic nozzle configurations for the laser cladding application are coaxial and lateral nozzles.

The coaxial nozzle has gained the most widespread popularity when choosing a nozzle type for a specific laser cladding process, due to various advantages:

- Obstruction of the laser beam is not so critical compared with pre-placed or paste methods, resulting in good bonding formation without the need for binders;

- Deposition is not orientation-dependent, which makes the process omnidirectional and results in stable track formation;
- The combination of material in powder form is relatively easy, which makes it suitable for in-situ alloy deposition.[5]

A possible design for such a nozzle is given in Fig. 4.

In spite of the advantages listed, the integrability of the given component design must be investigated further, to successfully establish all of the limiting factors that pertain to the confined space of the shipboard engine compartment, for the application of in-situ marine crankshaft refurbishment.

5. GENERAL ARRANGEMENT OF A LASER CLADDING SYSTEM

All of the aforementioned laser cladding components can be integrated within a system, the schematic of which is illustrated in Fig. 5. The motion of the laser beam relative to the substrate is provided either by a CNC table, a CNC turning stage or a robotic arm. In such an embodiment the overall system is controlled by a master control computer, which provides coordination information to as well as receiving data from all of the components shown in Fig. 5. Many other secondary control sensors may be integrated within the control system to provide information on various aspects of the laser cladding system's operation to the master control computer.[10]

This system can be implemented for monitoring the marine crankshaft in-situ renovation device. Such a device would allow repairs of a damaged marine crankshaft whilst the ship is at sea far away from on-shore repair facilities, as well as eliminating the need for very complex, time-consuming and a very high-cost crankshaft dismantling from the ship.

The device comprises two guide-ways and two opposite guide-ways to position it on the crankshaft fillets and two frame parts, each of which are fixed to the respective guide-way.

The device also comprises two upper rods, positioned in the upper part of the frame part, and two lower rods in the lower part of the frame part, by means of which both frame parts are rigidly connected to each other (cf. Fig. 6).

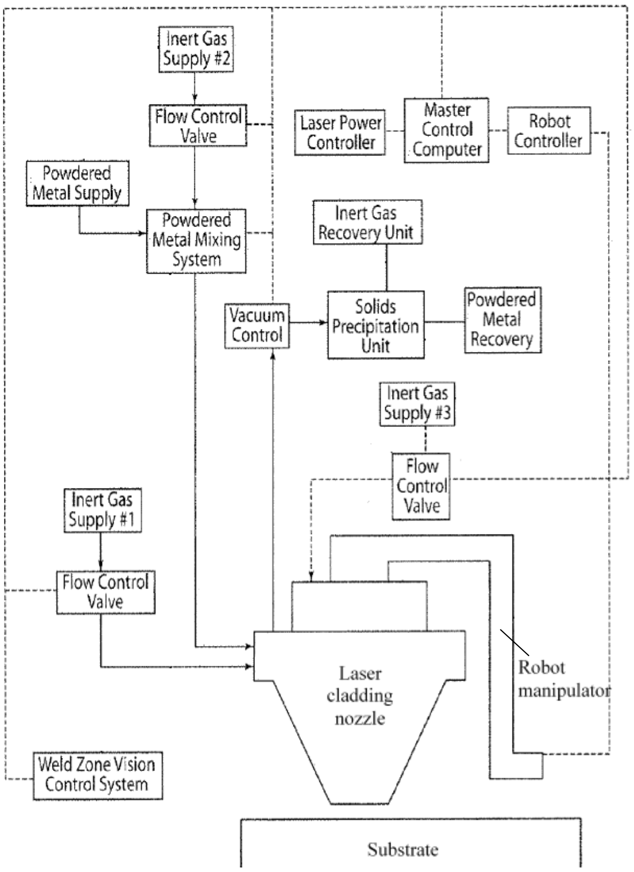

Fig. 5. Block diagram of the overall control system and related components [10]

The device further comprises two carriages which are installed on the upper rods and lower rods so that both carriages can slide along these rods. A laser nozzle is installed operatively between both carriages. The device includes two servo motors, the first of which is installed in the first carriage and is operatively connected to the laser nozzle to control its pivoting angle (see Fig. 6).

A second servo motor is installed on the second carriage and is operatively connected to one of the two lower rods by means of a gearing transmission, to control the laser nozzle's longitudinal position.

To ensure the device's positioning and controlled rotation around the crankshaft journal, it comprises the two aforementioned guide-ways and two opposite guide-ways. Two supporting plates are permanently fixed on the opposite guide-ways. Furthermore, these supporting plates are connected to each other by two opposite rods so that both perpendicular guide-ways are in fixed connection to each other. When installed on the crankshaft journal, the guide-ways and opposite guide-ways are connected and fixed to each other by means of four adjustable arms. The adjustable arms are connected to the guide-ways and opposite guide-ways by eight guidance-screws (cf. Fig. 6).

While the crankshaft is being rotated around its main axis, the laser head top-down position is maintained by eight pneumatic cylinders. These cylinders are connected to the guide-ways and opposite guide-ways by the aforementioned eight guidance- screws. The pneumatic cylinders can rotate freely around these eight guidance-screws.[7]

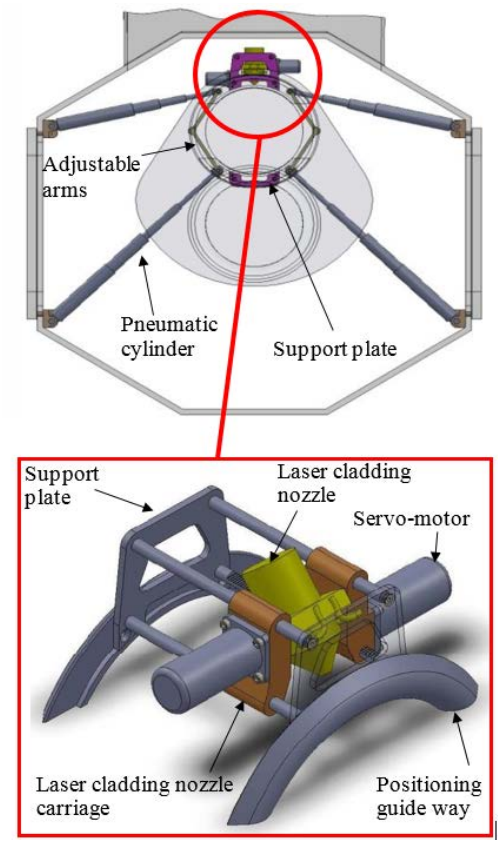

Fig. 6. 3D model of an in-situ marine crankshaft renovation laser cladding device [7]

6. CONCLUSIONS

Laser cladding offers numerous advantages as a repair process, providing complete restoration of a part's initial quality, as well as its overall enhancement, resulting in improved and longer service life. It thus demonstrates sufficient suitability for the refurbishment of a high-value component such as a marine crankshaft.

Further research must be undertaken in terms of establishing input, process and output parameter coherence as well as necessary empirical adjustments that will lead to development of a knowledge-based controller which is of crucial importance for the in-situ marine crankshaft refurbishment process, given its complexity and lack of available information on the subject.

CO2, Nd:YAG and HPDL are the lasers currently used for laser cladding, with Nd:YAG laser displaying the most advantages for in-situ crankshaft refurbishment processes, in terms of compact design and high manoeuvrability potential within the confined working space of a ship engine's housing.

Implementation of current technology for the in-situ refurbishment process requires further identification of all ship diesel engine crankshaft serviceability requirements, as well evaluation of the suitability of the proposed ship diesel engine crankshaft in-situ laser cladding refurbishment process with the identified primary serviceability requirements.

6. ADDITIONAL INFORMATION ON THE AUTHORS

Full title of the Manuscript: Laser Cladding Technology Implementation for the In-Situ Refurbishment of Ship Diesel Engine Crankshaft Journals.

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