

REVIEW OF SYNCHRONOUS POWDER FEEDING TECHNOLOGY FOR LASER CLADDING

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Abstract

Laser cladding is a key technology for remanufacturing metal part. Forming quality and rate have relations with the feeding technology of cladding material. In practice, synchronous powder feeding is a popular way because it has some advantages such as easy alloying, good processability of cladding material and satisfying the requirements of full dense functional gradient metal components and high processing flexibility. According to the position between powder stream and laser beam, there are three approaches now: off-axis powder feeding, conventional coaxial powder feeding and powder feeding inside a hollow beam. The different synchronous powder feeding methods need different structures of powder feeding head that is a main apparatus of the system, which are introduced in detail in the paper.

Keywords: laser cladding, synchronous powder feeding, powder feeding head

1 Introduction

Cycle economy is a sustainable growth pattern, which takes the resources highly effective use and the circulation use as a core, “reducing, reuse, remanufacturing and recycle” as the principle, low emissions and high efficiency as the basic characteristics. And it can efficaciously solve the contradiction between the resource shortage and the economic development^[1]. Laser cladding is a key technology for remanufacturing engineering. This technology has some especial advantages, such as little heat affect zone, high properties, excellent forming accuracy and so on. It is capable of achieving/exceeding the properties of the new product. Moreover, near net-shape can come true.

Laser cladding materials can be delivered by powder or wire/ribbon, corresponding feeding methods called powder feeding or wire feeding. Using powder feeding, the superior advantages are wide raw material sources, easy alloying, good processability and high forming accuracy. However the main disadvantages are low powder using efficiency, low build rate and dust pollution of powder. Wire feeding solves the problems, which has the following remarkable excellences: almost 100% powder using efficiency, easy controlling process of feeding and good feeding precision. Nevertheless, if cladding material that can't be made into wire because of poor ductibility, the method is limited. Thus, powder feeding is extensively researched and applied.

The laser cladding process can be performed in two different ways of powder feeding: the preplaced feeding and synchronous feeding. Firstly, the cladding material is

preplaced on the base metal before scanning. This process is difficult to adapt on full dense functional gradient metal components and high processing flexibility. Secondly, the cladding material is delivered into a molten pool. It overcomes before-mentioned problem, and is popularly investigated.

According to whether powder stream axis and laser beam axis are the same, synchronous powder feeding can be divided into off-axis and coaxial. The structure of powder feeding head that is a main apparatus of the system depends on powder feeding approach, which is introduced in detail in the paper.

2 Off-axis powder feeding

Under off-axis powder feeding condition, there is an angle between the powder stream axis and the laser beam axis, i.e. the powder stream is injected off-axis from laser beam.

The structure of off-axis powder feeding head is simple relatively, usually, it is designed into coaxial double pipes. Inside passage and outside passage serve to transport metallic powder and shield gas respectively. The shield gas is employed in order to not only prevent from oxidation of molten pool, but also increase stiffness of the powder stream and powder using efficiency. If the shape of powder passage exit is circular, the problem that the opening filled by melting powder would hardly occur. However, if the shape of powder passage exit is rectangular for wide-band laser cladding, the preceding problem easily takes place because of large area of reflected laser beam absorption. Furthermore, uniformity of the powder stream is unsatisfied. Therefore, it can be replaced by arranging powder streams in a row^[2].

In practice, off-axis powder feeding cladding confronts a challenge that the variation of scanning direction leads to change cladding geometry. To get the excellent formability, the powder feeding angle must be kept a constant, namely, the powder stream direction must be adjusted to the scanning direction. Theoretically, there are two effective measures: maintaining the scanning direction using scanning path planning and weaving nozzle for fixed angle between the powder stream direction and the scanning direction. Notwithstanding, substantial problems would appear simultaneously, such as the increase of the amount of work of scanning path planning, high system performance, the change of scanning velocity and on-off/ of laser beam and so on^[3]. It is obvious that, off-axis powder feeding technology is unsuitable for producing high-quality and complex components.

3 Coaxial powder feeding

Under coaxial powder feeding condition, the powder stream axis and the laser beam axis are perpendicular to cladding surface, which eliminates existing problem in off-axis powder feeding. There are two performable approaches. Firstly, an annular powder stream that is coaxial with a single laser beam converged on the focus of the laser beam, which is named conventional coaxial powder feeding by reason of prior studying and using. Second, an annular laser beam that is coaxial with a single powder stream converged and intersected with the powder stream, which is named powder feeding inside a hollow beam. Comparing with the off-axis powder feeding, the structure of nozzles is complex.

3.1 Conventional coaxial powder feeding

There are two fashions of the annular powder stream required conventional coaxial powder feeding: hollow ringed converged or symmetric converged (uniformity, symmetric multiple powder streams focused). From the powder stream convergence viewpoint, it requires powder flow from all directions is uniform firstly. However, the later fashion ensures fluidity of every powder streams are similar. Therefore, the symmetric powder stream is generally adopted.

A schematic diagram of conventional coaxial powder feeding head is given in Figure 1^[4]. It is shown that, basal structure of this nozzle is multilayer coaxial taper cylindrical, there are four paths from center to outer boundary such as laser beam path, powder path, gas path and water path. Laser beam path is positioned in apparatus center. Inner shield gas that is introduced into the path takes away dust and heat during processing, which prevents focus lens from being polluted and damaged. Powder path is at an angle off-normal some paths on circle orientation of laser beam with uniformity and symmetry. Outer shield gas that is delivered from outside of powder path builds a gas wall, it serves to prevent from cladding oxidation, increase powder stream stiffness and blow away superfluous powder around processing place in order to avoid disbenefit effect on formability. Water path was fabricated in nozzle end, which protects nozzle from the spatter and reflected laser beam during the cladding process.

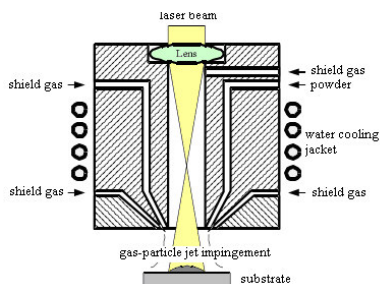


Figure 1 Schematic diagram of conventional coaxial powder feeding head

Based on mentioned above, some novel design inspirations are pointed out. For example, inner shield gas often blows down along laser beam axis, whose size affects convergence of powder stream at laser beam focus. To ensure powder stream stability, the gas flux is

lower, so protecting focus lens is insufficient. Therefore, transverse shield gas is discussed in literature^[5]. That is to say, gas entry and gas exit fabricated on opposite both sides of laser beam path below focus lens, which is resulted in transverse flow of inner shield gas. Usually, the bottom of outer shield gas path is ringed and tilted. If its design is outward, the direction of the gas flow also is outward, which is easy to remove superfluous powder around processing place^[6]. Considering the working distance between the nozzle and the molten pool is short and the surface of the nozzle's end is also large, it is impossible to operate the nozzle for a long time since the spatter obstructs powder stream exit. Thus, the nozzle's end is changed into several off-axis powder feeding nozzles (Figure 2)^[4]. In addition, owing to absorption coefficient of metal to laser radiation is very low and surface of liquid metal is specular, best part of laser beam is reflected during cladding process. The reflected laser beam that has great energy damages surrounding equipment frequently. For ensuring safety of cladding process and reusing the reflected laser beam energy, Zhong ML et al were design the looking-glass reversed cone surface for the nozzle's bottom^[7], Yang JX et al were install reflection cover with concave mirror on the nozzle's bottom^[8]. In that way the reflected laser beam was returned to laser processing region again.



Figure 2 A novel conventional coaxial powder feeding head

It is well known that forming accuracy and cladding rate were conflicted. Forming accuracy increased with decreasing cladding thickness, but forming time is obviously extended. Experimental and theoretical researches show that the use of outline cladding technique allows an increase in the cladding rate without compromising the forming accuracy. The core of the technique is described as follows: for one thing, external deposited features is formed using small laser beam spot and low powder feeding speed that provides thin cladding, which ensures/increases forming accuracy; subsequently, internal deposited features is filled using large laser beam spot and high powder feeding speed that provides thick cladding, which decreases forming time. Optemec Design Company (USA) achieves this technique using multiple beams and nozzles deposition apparatus (Figure 3), which consists of the four parallel laser beams focused onto the deposition substrate and the ten powder nozzles which create a converging powder stream to the deposition region^[9]. During forming external outline a laser beam and 2~4 powder passages

are employed, during filling internal region 2~4 laser beams and 4~10 powder passages are turned on. From the user standpoint, insuring uniform powder flow rate, feeding direction and injection force from every powder tubes etc. was not easy. At the same time, keeping powder stream stability and position between processing surface and feeding head would be greatly difficult because cladding parameters, such as the powder flow rate, the carrier gas flow rate and laser beam focus etc., was not constant during the cladding process, which influence on cladding quality and decreasing powder using efficiency. For that reason, actual coaxial powder feeding (the powder stream is perpendicular to substrate) was explored.

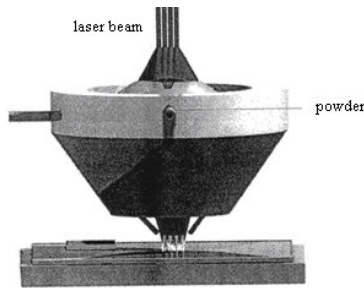


Figure 3 Multiple beams and nozzles deposition apparatus

3.2 Powder feeding inside a hollow beam

Under powder feeding inside a hollow beam condition, there are two fashions of the annular laser beam: hollow ringed converged or symmetric converged (uniformity, symmetric multi-laser beam focused). For obtaining fine convergence and uniformity of focused laser spot, a symmetric converged laser beam requires good optical path quality, but a hollow ringed converged laser beam is simple than others, it is an attractive methodology and the subject of this section.

Schematic diagrams of powder feeding inside a hollow beam head are given in Figure 4^[10, 11]. It shows the nozzle also includes optical path, powder path, gas path and water path. The hollow ringed converged laser beam is achieved by various means. For example, reflection with opening-focusing technology is used in Figure 4a. In this case, a hole processed on the central region of the plane mirror (11). When incoming laser beam (1) is irradiated the plane mirror surface, that laser beam which passes the hole will be absorbed by absorber (9), others will be reflected, and forms the hollow ringed converged behind the focusing mirror (4). Enlarging beam-focusing technology is selected in Figure 4b. A pair of the tapered mirror (13) and the toroidal focusing mirror (12) are assembled in optical path, their surface are face to face and their axes agreed with incoming laser beam. Thus it can be seen, the central free laser region from enlarging beam-focusing technology is larger than reflection with opening-focusing technology. Its powder path is simple than conventional coaxial powder feeding, so that a pipe (3) purely utilized from outside into inside of the laser beam. Worthy of notice, when the feeding pipe or other

metal part are meeting the laser beam in optical path, suitable technique must be adopted to prevent those parts from being damaged. The reflection with opening technology is continued in Figure 4a. A gap joined with the hole on the central region is processed along radius of the plane mirror (11), thus free laser region (6) is formed for setting up powder feeding pipe (3). Screening by tapered mirror and absorbing by coating absorbing material on part surface has been used in Fig 4b. The structures of gas path and water path are the same to the structure of conventional coaxially powder feeding respectively.

Powder feeding inside a hollow beam really eliminates scanning direction problem, and enhances powder stream stability. The advantage of this process is that operation is easy and coupling accuracy is higher because the coupling between the laser beam spot and the powder spot is independent on focal point position. Laser beam spot bigger than powder spot or outline cladding procedure can be achieved by adjusting their size, which can increase the powder using efficiency and improving cladding quality. The laser beam spot diameter is changed using the axial distance between powder nozzle and part, co-axial (Figure 4a) or parallel double feeding pipes are utilized for the powder spot diameter.

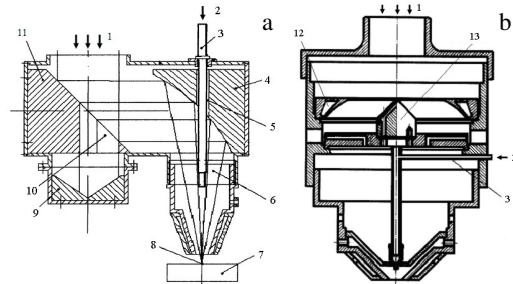


Figure 4 Schematic diagrams of powder feeding head inside a hollow beam

1-laser beam; 2-powder stream; 3-powder feeding pipe; 4-focusing mirror; 5-hole; 6-free laser region; 7-part; 8-focus; 9-absorber; 10-opening; 11-plane mirror; 12-toroidal focusing mirror; 13-tapered mirror

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