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Powder flux regulation in the Laser Material Deposition Process

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Abstract

In the present research work a powder flux regulation system has been designed, developed and validated with the aim of improving the Laser Material Deposition (LMD) process. In this process, the amount of deposited material per substrate surface unit area depends on the real feed rate of the nozzle. Therefore, a regulation system based on a solenoid valve has been installed at the nozzle entrance in order to control the powder flux. The powder flux control has been performed based on the machine real feed rate, which is compared with the programmed feed rate. An instantaneous velocity error is calculated and the powder flow is controlled as a function of this variation using Pulse Width Modulation (PWM) signals. Thereby, in zones where the Laser Material Deposition machine reduces the feed rate due to a trajectory change, powder accumulation can be avoided and the generated clads would present a homogeneous shape.

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1. Introduction

The Laser Material Deposition (LMD) is a process that is gaining relevance thanks to the advantages that the process offers: High flexibility and the possibility to repair damaged parts with a minimum heat affected zone.

However, there are many points in the LMD process that need to be solved when relatively complex geometries are to be generated. One of the most critical points in the LMD process is obtaining a constant layer height. Due to

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the variations of the substrate geometry, the heat dissipation through the base material is variable, what results in changes in the melt pool size and consequently in the generated clad geometry. Furthermore, due to geometrical restrictions, when the machine reduces the feed rate in order to change the deposition direction or sharp edges are to be generated, a non-uniform machine feed rate is obtained. A non-uniform feed rate leads to variations in the amount of deposited material and in the energy introduced to the substrate per surface unit area; and generates instabilities in the process when overlapping the subsequent layers.

In LMD, process monitoring and control is essential to reduce the amount of rejects and improve the process reproducibility (*Pavlov et al., 2010*). Therefore, during the last decade several authors have focused their efforts on monitoring the laser processes. With the aim of presenting an overview of the non-contact methods used for in-process monitoring of laser processes, *Purtonen et al.* did a review of the latest works in this field (*Purtonen et al., 2014*).

Most authors focus their efforts when monitoring and controlling the LMD processes on the laser power and the amount of heat introduced to the base material. The LMD process control is done in two different ways: a pyrometer can be used for measuring the melt pool temperature and adjust the laser power according to a reference value (*Bi et al., 2006a, Bi et al., 2006b*). Other authors have developed different feedback controls that based on the generated melt pool size, are able to adjust in real time the laser power and keep the melt pool size constant during the deposition process (*Hofman et al., 2012, Ocylok et al., 2014, Ding et al., 2016*). Moreover, authors like *Bi et al.* have gone one step beyond and they have developed a specific laser cladding head that, in addition to different sensors to check the components of the nozzle in real time, includes a CCD camera for monitoring the melt pool size and shape and also an IR signal sensor for temperature measurement (*Bi et al., 2007*).

Nevertheless, when complex geometries are to be obtained, the kinematics of the machine has a big influence in the process, especially when abrupt direction changes are required due to the final shape of the part. At those points, even the melt pool size and temperature can be adjusted by means of a close loop that regulates the laser power, the amount of material that is added to the substrate is increased substantially and therefore the height of the clad is also increased.

This phenomenon was discussed by *Nenadl et al.* and they concluded that the ratio between the powder feeding rate and the scanning speed is directly related to the height of the clad (*Nenadl et al., 2014*). But it was done nothing to correct it. *Boisselier et al.* presented in the LANE-2014 International Conference a trajectory smoothing method that ensured a stable processing (*Boisselier et al., 2014*). But when sharp edges are to be manufactured there is no option for smoothing trajectories.

During the LMD process, the powder flow is controlled by the powder feeder. Usually a powder feeder based on a rotatory disk is used, where the powder flow is regulated by means of the rotation speed of the disk. Some authors have developed a sensing and control system of the powder flow by using an optoelectronic sensor (*Ding et al., 2016*). As it is stated in that article, the key element for achieving a powder delivery control is to measure the powder flow rate in real time. However, although the powder feeder can regulate the amount of powder, usually the response of a conventional powder feeder is not fast enough and no instantaneous powder flux regulation can be carried out using this kind of setup. Furthermore, to gain quick response, the powder flow regulation has to be done once the powder leaves the powder feeder and almost reaches the cladding nozzle. This obliges to use a step-forward control system that is able to predict and anticipate powder variations and actuate before powder accumulation happens.

With the aim of controlling the deposited layer height and eliminate the effect of the powder accumulation due to the machine feed rate reduction, a solenoid based control system has been designed, developed and validated.

2. Experimental setup

The first step when designing the powder flux control system was the analysis of the different alternatives and possible solutions. Two different solutions have been discussed:

1) *Online control*. The machine real feed rate is taken out of the machine drive modules instantaneously and compared with the set-point value send by the machine CNC in order to regulate the powder flux.
2) *Offline control*. The LMD program is run once without switching on the laser nor the powder feeder and a vector of the machine real feed rate regarding to the runtime is obtained from the machine CNC