Arc welding Control for Shaped Metal Deposition Process

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Abstract: This paper is focused on the study and the control of a deposition process of robotic arc welding. The process consists of a SMD (Shaped Metal Deposition) system, that is a novel rapid prototyping tungsten inert gas (TIG) welding technique leading to near-net-shape, using a layer by layer deposition technique. An experimental setup has been properly implemented in order to study the system and to develop and tune the parameters of an automatic controller.

Keywords: Industry Automation, Welding Control, Rapid Manufacturing, Control Applications, Industrial production systems, Industrial robots.

1. INTRODUCTION

SMD is an innovative manufacturing process patented by Rolls-Royce; it was developed to produce mechanical parts directly from a CAD model.

The work presented has been carried out in the frame of the RAPOLAC European project (www.RAPOLAC.eu) focussed on the SMD process.

One of the advantages of the process is the substantial reduction of inventory costs, since the only inventory held is wire. As matter of this, the parts could be built to order.

The innovative aspect of the SMD process is a reversed production philosophy. Up to now, the traditional manufacturing methods, such as machining, are based on the material removing from the work piece, in order to obtain a desired final shape. There are several evident drawbacks in this process, like the large waste of material in scraps and the consequent increase of the costs, depending on the material used.

The SMD process works by adding progressively the material to the final workpiece up to obtain the desired shaped component. This is achieved by adding the material required layer by layer, as shown in Fig 1. In this way no process scraps are produced minimizing the material used to the strictly amount required by the final work piece shape (Hensinger et al. 2000, Zhang et al. 2003).

Another significant advantage is reduction of 60% in the lead-time necessary to produce the parts so that it is ideal for use in prototype production as well as in manufacturing.

Finally microstructure analysis of produced parts confirms that there are no disadvantages from the quality point of view (Baufeld et al. 2010).

Several works related to arc welding could be found in literature. However no one concern concrete implementations of control strategies on deposition processes. The papers Bonaccorso et al. 2009, Muscato et al. 2008 and the work presented here are the first, as far as we know, dealing with the study and the control strategies for such a process.

An actual drawback of the process is the need of an operator constantly monitoring and manually acting on the welding process parameters. As a matter of this, one of the aims of the RAPOLAC project is focused on the study of an automatic control system.

In this paper the obtained progress is presented. The paper is organized as follows. Section 2 describes the experimental setup. Section 3 introduces the control law developed while. Section 4 shows the experimental results. Conclusions are reported in section 5.

Fig. 1. A schematic representation of the SMD deposition process.

2. THE EXPERIMENTAL SETUP

2.1 The Hardware architecture

An experimental system has been properly implemented in order to study the system and to develop and test an automatic controller.
The plant has been set up with a six axis industrial welding robot, and a 500A TIG inverter, as is shown in Fig. 2. SMD process prescribes using of a sealed chamber with 99.999% purity argon. However such a chamber has not been used doing this work because of the target, in this case, was the control system, without taking too much attention to the quality of the final pieces.

The implemented system uses different kind of sensors and a software interface.

In particular, the SMD plant has been equipped with a pyrometer and a thermo camera, for analysing both the temperature distribution and the heating and cooling rate over the time during the deposition process. The monitoring system also comprises a welding camera, IR sensors and a microphone.

In particular the operator can monitor in real time the welding machine status (digital data, error code), the principal welding parameters time series like the actual arc voltage and both the imposed and the actual wire feeder rate, from the welding machine, the various sensors time series and the actual torch position that is given by the robot controller.

The interface also permits to change all the main parameters of the welding machine: wire feeder rate, current, etc. and to set the controller parameters.

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2.2 The Software architecture

The block diagram of the architecture used is shown in Fig. 3. It is mainly based on the NI Labview™ real time target architecture.

The interface developed within the NI Labview™ is shown in Fig. 4; there are several windows and buttons that allow to examine and to change all the parameters of the process.

It should be observed that, even if one of the final aims of the RAPOLAC project is to make the SMD process autonomous, in the developing phases the intervention of the operators is fundamental. As a consequence, it is very important to have an user-friendly interface to the process which allows to monitor all the variables and, if needed, to change in real time the process parameters.

![Fig. 2. The arc welding plant for performing SMD using stainless steel 316.](image)

![Fig. 3. Process architecture block diagram of the arc welding SMD.](image)

![Fig. 4. Main interface of the control system for the arc welding SMD.](image)

3. THE SMD PROCESS CONTROLLER

3.1 Control strategy summary

Several tests have been performed in order to study the behaviour of the process. The working variables needed for the control have been identified in four fundamental key parameters: the heat source provided to the process (arc current: I), the injected material mass rate (indicated by the Wire Feeder Rate: WF), the torch speed (indicated by the...
Travel Speed: TS) and the thickness imposed for each layer (indicated by the step height between two subsequent layers: SH), as indicated in Fig. 1.

As it is reported in Bonaccorso et al. 2009 and Muscato et al. 2008 the four parameters act on the dimensions, thickness and width, of the final workpiece.

The basic idea for setting up an automatic controller is to measure the amount of material deposited on each layer $h$ (see Fig. 1). This amount must be equal to the step height imposed for the process, in order to avoid depositing too much or too few material, causing the system to become unstable. Consequently the height of the material deposited $h$ should converge to the prefixed step height $SH$.

According to these information, the wire feeder rate ($WF$) must be controlled in order to adapt the incoming material mass for each layer.

![Fig. 5. Arc length measurement.](image-url)

So the layer height is a key-role parameter of the process and, moreover, is key-role parameter for the different control strategies investigated. But this parameter is not simple to be measured directly, owing to the particular operative conditions.

However another aspect of process like the torch height from the bead, gives indirect information about the material deposited.

There are even different aspects of the process that can be used to measure the gap which are all directly connected to the arc physics such as the arc emitted light (Moore et al. 2009, Tzyh-Jong et al. 2007, Zhang 2001), the arc emitted sound (Sciaky et al. 1966, Ralchenko et al. 2008, Tham 2005) and the arc voltage as shown in Fig. 5.

A good alternative is a vision system (camera, optics, filters): using image processing technique, the arc length estimation can be performed with an optimal level of efficiency (Fig. 6).

![Fig. 6. Vision system for arc length estimation.](image-url)

Several tests have been performed in order to characterize the vision system and to relate the arc length estimation with the arc voltage measurement.

Using the relation in Fig.7 it is possible to directly match the two time series. As showed in Fig. 8, although the both signals must be opportunely filtered, the arc voltage appears more disturbed, especially when the arc is short.
The control strategy is then implemented as described by the following equation:

$$WF = f(I, WF, V - V_{ref})$$  \hspace{1cm} (1)

The wire feed rate $WF$ represents the value corresponding to the stable process working point, in which all the material coming from the wire feeder is deposited in each layer, ensuring the stability of the process. This value is strictly connected to the value of the other parameters: amperage, travel speed and desired step height. $I$ represents the arc current and the $V-V_{ref}$ is the arc voltage error. The function can be a simply linear proportional action, as showed in Fig 7 or more complex solution that permit to take into account the previous layer deposition error.

Fig.7. The linear control strategy characteristic adopted by the controller.

4. EXPERIMENTAL RESULTS

The different control solutions have been performed producing from simpler pieces to more complex structures, using a rotating table as support (Fig 8).

The several trials performed in order to test the SMD controller have achieved very good performance. The trial reported in this paper regards a fundamental comparison between a deposition performed using the SMD automatic controller and the same one performed manually by an operator. The test consists in a deposition of 40 layers Cylinder Ti-6Al-4V in air.
Fig. 8. Various structures deposited (the last one using a 2 axis rotating table).

Fig. 9. Manual: arc voltage and wire feed rate time series.

Fig. 10. Control: arc voltage and wire feed rate time series
Fig. 11. Manual vs. Control test

In Fig. 9 and 10 the arc voltage and wire feed rate time series are shown. As can be highlighted from Fig. 9, during the manual test the operator has to manually correct the wire feed rate several times. In the other case (Fig. 10), the controller tunes the wire feeder rate automatically reaching a steady state condition so that the process can be left unattended. The two structures are shown in Fig 11.

5. CONCLUSIONS

The proposed system has been adopted in many different trials to study the process, to get the best working conditions and the tuning parameters for the controller.

The interface has been also really useful to monitor the process during the experiments, allowing to check in real time most of the parameters and to monitor the outputs.

Different control strategies were investigated. All make use of information coming from different measurements subsystems, in particular using a welding voltage feedback.

The developed controller permits to maintain the process stability condition, so that the process results totally automatic.

The control strategy that has been presented in this work is also part of a patent deposited.

6. ACKNOWLEDGEMENT

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REFERENCES


