NEW IMAGE PROCESSING BASED METHOD FOR AUTOMATED WELDING TECHNOLOGY

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ABSTRACT
In this paper the use of the Digital Image Correlation Technique (DICT) for automatic settings of welding parameters in Pulsed Gas Metal Arc Welding (P-GMAW) technology is approached. The proposed technique use recorded digitized video images of droplet detachment and an image correlation computer routine to measure the correlation between the acquired images and standard images established as models for different parameters settings. New methods for image acquisition and image processing were proposed and evaluated. The results of calculations were used for establishing a look loop automation system for welding process. This system is capable of overcoming the known limitations of current used welding technology, and in addition is capable to assess its performance.

KEYWORDS: Advanced materials welding, Pulsed GMAW, Parameter selection, Automation, Image processing.

1. INTRODUCTION
In order to overcome the limitations regarding the control of metal transfer of conventional Gas Metal Arc Welding (GMAW) process, in the last years new developments in electronic controls have resulted in the introduction of several new types of welding systems. These new developments include advanced high switching rate (compact) inverter power sources and controls for implementation of GMAW-P (pulsed GMAW), STT (surface tension transfer) GMAW, GMAW-VP (variable polarity GMAW), and the CSC (controlled short circuit) GMAW. These new developed GMAW methods and equipments provide an array of new possibilities for controlling heat input and deposition rate and also combine good fusion characteristics and cosmetic appearance with negligible spatter. Among them, the Pulsed Gas Metal Arc Welding (P-GMAW) is probably the most promising technology in advanced materials welding field.

Pulsed GMAW can be described technically as a modified spray transfer process. In the GMAW spray transfer mode, droplets of molten metal are continuously being transferred across the arc. In pulsed transfer mode, the power source rapidly switches the welding output from high peak current to low background current. The peak current pinches off a spray-transfer droplet and propels it toward the welding pool for good fusion. The background current maintains the arc, but is too low for metal transfer to occur. Because there is no metal transfer, the weld puddle gets a chance to cool and freeze slightly. Because the heat input is lower, pulsed GMAW eliminates or minimizes burn-through, distortion, heat-affected zone size and loss of mechanical properties as it can be observed in figure 1a and 1b.

A faster-freezing weld puddle also provides better control on overhead and vertical welds so that the puddle doesn’t "roll out" of the joint when welding out of position. Pulsed GMAW produces little, if any spatter (unlike SMAW or short circuit GMAW). As a result, finishing costs may be reduced or eliminated. The high level of control over metal deposition, with consequently very low spatter, and good cosmetic appearance, makes these GMAW systems suitable for welding a wide range of alloys in multiple product forms from castings, forgings and extrusions, to sheet and plate products.
These characteristics, with the associated high weld integrity, result in GMAW-P being a serious contender to all the other welding methods, especially for mechanized, robotic and automated welding operations in the aerospace market. When the additional potential productivity gains are considered, these systems are gaining interest across a broad range of materials, including stainless steels, nickel-based alloys, aluminium alloys, and titanium alloys.

However, along with its advantages, the P-GMAW process brings also some challenges. The most serious is the properly setting and control of new parameters in addition to those already existing in GMAW. Each pulsed GMAW "wave" is composed of four variables - peak current, background current, pulse width and pulse frequency and in addition the process itself came with some other variables as wire feed speed, trim (arc length) and shielding gas composition, see figure 2 [3].

![Figure 1: Welded joints produced using a) GMAW –spray transfer mode; b) GMAW –P (one pulse one droplet).](image)

The optimum settings for these variables change for a given wire size, alloy, shielding gas type, design, welding position and gun technique. It is quite difficult for the end user to know which settings will provide the optimum arc for a given application and which are the influences of changing one of the variables on the welded joint. Although some procedures and recommendations for calculation and selection of the pulse parameters (peak current, background current, pulse width and pulse frequency) as a function of some variables (electrode diameter and material and shielding gas type) could be found in literature [1, 2 and references therein], for suc-
cessfully implementation of P-GMAW technology in advanced materials field where a wide range of welding conditions could exist, it is highly desirable to have a method for settings the welding parameters in an automated way. Such a method will bring additionally the possibility to avoid control difficulties due to some eventual unpredictable impurities in the welded material, filler material or shielding gas.

Attempts for the automation of P-GMAW process have been already made through the design of algorithms that contemplate calculation routines and a database with the involved material information. There are already on the market power sources with a command system built into their circuits by which a significant pulse parameter is automatically amended in function of an operational parameter (wire feed speed or average current) in such a way that a stable condition is maintained over a range of wire feed speed and average current level /3/. However, the systems employed in these equipment’s have presented some simplifications that could lead to limitations: the first one is the assumption that there is a linear relationship between wire feed speed (WFS) and mean current (Im). A second simplification is related to the output electrical signal format, usually assumed as perfectly rectangular. The use of linear equations and not actual signal format in the algorithms may lead to errors in the predicted setting parameters, especially in higher currents. A third limitation would be the setting (command) parameter, which is the wire feed speed in most conventional power sources. In this case, current becomes a consequence of the value set for wire feed speed, making it more difficult to set the power source at the desired heat input.

2. PROPOSED ARCHITECTURE OF AUTOMATA SYSTEM

The challenge is to develop a system capable to control in an efficient manner the GMAW-P process. In the present study I have tried to overcome the above mentioned limitations using a different approach. The most common premise in order to obtain good quality welds is to detach during each pulse one droplet of a size approximately the same as that of the electrode, for which the effect of the base parameters on the droplet formation is neglected. Therefore, I have chosen to use as information the image of the droplet. The process output (the image of the droplet of molten material) is compared with a reference, and if there is a deviation, the controller takes action according to the control strategy. In the proposed automation system, in the forward path of the feedback control system, I have used a system of correlation filters. The most difficult part was to establish a pattern in the modification of the droplet shape and the variation of the welding parameters. The architecture of automata is presented in figure 3.

![Figure 3: Control system for GMAW-P welding process.](image-url)
3. EXPERIMENTAL RESULTS

A series of experiments was carried out using a Lincoln Electric Power Wave 455M /STT – Robotic, with adaptive control capabilities. The software Wave Designer provided by the same company was employed to select the optimum parameters for the current pulse /3, 4/. The visualization system composed of a laser, a high speed camera and an interface to synchronize the current and voltage signals with the camera images. A high resolution CCD multi spectral, digital camera, MS 4000 type and a continuous emission Nitrogen laser were used for recording the imagery, see figure 4 /5/.

![Diagram](image)

**Figure 4:** The overall layout of the experimental equipment for setting the optimal parameters of current pulse and recording the detachment of droplets.

The correlation, which determines the degree of correspondence between a pattern and an image, is used for identifying priori known shapes. Depending on the size of the pattern, the matching operation is implemented either in the image or in the transform domain.

The proposed system allowed determining with precision the regions in which a stable one pulse one droplet transfer for the used materials is achieved. The parameters of the current pulse generated by the power supply for the optimum transfer of the droplet were: 300A peak current, 100A background current, 5ms pulse width and 40 Hz pulse frequency. The recorded image of the optimum droplet detachment is presented in figure 5a. It is very difficult to establish a pattern of droplet detachment considering that all the parameters of the current pulse are varying. In order to simplify the work it was considered that parameters such as background current, pulse width and pulse frequency that are less probable to be affected by variations and are constant.

In order to establish a pattern in the droplet detachment modifications due to the variations of pulse amplitude I have decreased gradually the amplitude of the current pulse from 300A to 290A where I have observed that the droplet did not detach properly and become elongated increasing the risk of short circuit as it is presented in figure 5b. With the lower limit established, I have increased gradually the amplitude of the current peak above 300A and I have observed that above 310 A the filler material is detaching in multiple droplets very similar to the spray mode as presented in figure 5c.
These experiments provided the opportunity to record master images that represent whole patterns in droplet detachments. Image correlation is a technique by which the new image and the master image will be searched for the maximum correlation coefficient. The reference images used for defining the three classes that correspond to the three situations possible during the GMAW-P welding are presented in figures 5a, 5b, and 5c.

The autocorrelation of the established reference images is presented in figure 6. Figure 7 shows the correlation between each two reference images. In figure 7a the image of
optimum detachment is correlated with image of spray transfer. In figure 7b the image of optimum detachment is correlated with image of the elongated droplet and in figure 7c the image of the elongated droplet is correlated with the image of spray transfer.

This exercise has been done in order to verify if attempted matching with templates that represent whole patterns is possible. Scaling and orientation of the template must match that of the unknown if classification by correlation is to be effective. However, there are several problems that have to be considered using this method. The location of the maximum and the choice of the best fitting class sometimes may become unreliable. The normalization of the correlation must also be carefully chosen so that the correlation response is not misleading, for example, a weak correlation by a large mask being chosen as the best fit because the size of the large mask dominates the result.

4. CONCLUSIONS

A method based on Digital Image Correlation Technique (DICT) was proposed in this study for automated setting of welding parameters in Pulsed Gas Metal Arc Welding (P-GMAW) technology.

The implementation of a more efficient control system for P-GMAW is possible using information extracted from the image of filler material droplet detachment. The process output - the image of the droplet of molten material - is compared with a reference, and if there is a deviation, the controller takes action according to the control strategy. In the proposed automation system, in the forward path of the feedback control system, it was used a system of correlation filters.

The correlation filters could provide an effective method of classification by correlation. It is recommended to use a system of three parallel filters in order to provide a faster feedback. Using a digital video sensor (CCD camera) and a binary filter (multiple levels of gray does not provide useful information) the time required for correlation coefficient calculus is shorter. To improve the speed of data processing a mask window can be used but its dimension has to be carefully chosen.

However, it should be noted that only variations of current pulse amplitude were considered. Modifications of background current, pulse width and pulse frequency would affect the process in an unpredictable manner. Therefore, in order to establish a reliable pattern in droplet detachment correlated with modifications of those parameters more experiments are remaining to be done.

5. REFERENCES

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