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MONITORING AND ANALYSIS OF PGMAW

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Abstract: In this paper a monitoring system that simplifies the finding of optimal welding parameters, the analysis and the optimisation of pulsed gas metal arc welding is described. The system allows the visual online observation of all states of the process, including the droplet transfer, without an additional lighting unit. Additionally, the measurement of electrical welding parameters during image recording and the extraction of characteristic parameters are possible. Furthermore, the system allows the visual analysis of the images. For an analysis and optimisation of the process the systems computes statistical data of all collected and calculated visual and electrical data.

Keywords: sensor systems, on-line, monitoring, signal processing, visual pattern recognition, statistical analysis

1. INTRODUCTION

The pulsed gas metal arc welding (PGMAW) process is an important component in many industrial and manufacturing operations. It is highly suited to a wide range of applications. Due to the complex processes, the extreme brightness of the welding arc, the high number of different welding tasks, etc., the finding of optimal parameters, the test of new welding parameter combinations or the analyses by process errors is difficult.

For the solution of the problems the visual observation of the droplet transfer in combination with the measurement of electrical welding parameters is an approach. Typically, the droplets should be even and in uniform size and the droplet transfer should be splashless.

The visual observation of the material transition has been used extensively. Normally digital Charge-Coupled-Device (CCD) high-speed cameras in combination with an optical laser are used. Due to the extreme brightness these approaches are using the shadowgraphing technique, described by Allemand *et al.* (1985).

For the mentioned problems the systems are unsuitable due to a set of disadvantages. The most important are:

- The necessity of the lighting unit and the limited possibilities of observation caused by this (shadow graphing technique).
- The acquisition and maintenance costs are very high.

2. SYSTEM

The monitoring system consists of a High-Dynamic-Range-CMOS camera (HDRC) with an external trigger input, an intelligent measuring board for the triggering of the image recording and the synchronized and simultaneous measurement of electrical welding parameters, a signal processing unit for the automatic calculation of characteristic welding process parameters, an image processing unit for the automatic visual analysis of the droplet transfer images and a statistical unit. Due to the properties of the HDRC camera the system requires no additional lighting unit. The basic set-up of the system is shown in figure 1.

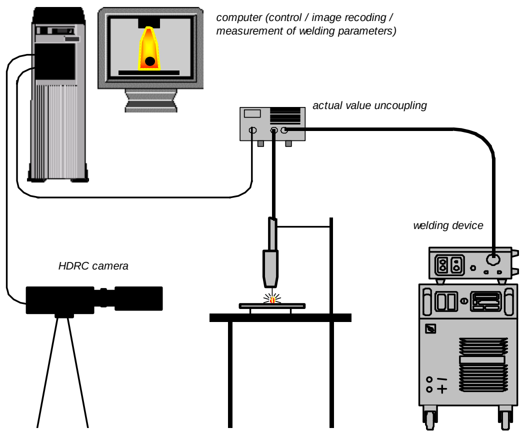


Fig. 1. Experimental set-up

2.1 *High-Dynamic-Range-CMOS camera (HDRC)*

HDRC cameras use an image sensor with a brightness dynamic of approximately 10^6:1. This corresponds approximately to the intensity difference of the welding process. HDRC cameras are therefore able to observe all states of the droplet transfer in all welding positions without an additional lighting unit.
The principle of HDRC cameras can be described as follows. The level of intensity, i.e. the grey values of an object, is essentially dependent on the exposure rate and the material properties of the object with its reflection properties. The information of an object is essentially dependent on the contrast. A CCD camera maps the absolute grey values caused by respective irradiation in the image. As opposed to the CCD camera the HDRC camera maps the contrast, which is caused by different reflections. I. e., brightness conditions (grey values of the object) are independently represented by the intensity of illumination as constant number differences. Before further processing, this high intensity dynamic is compressed logarithmically in every cell of the image sensor just like in the human eye. Due to this compression, the information content of the image that is included in the contrast is not reduced.
A further advantage of HDRC cameras is, that at every time each sensor cell can be accessed independently of all others. The constraint of CCD cameras that must read out complete images does not apply for HDRC cameras. This property of HDRC cameras allows the selection of sub areas of the image sensor instead of the complete image. Considerably higher image recording frequencies become possible.

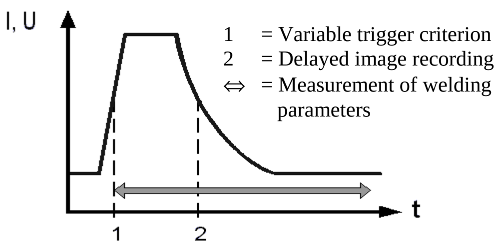


Fig. 2. Procedure of image and electrical welding parameter recording

2.2 *Principle of Image Recording and Measurement of Electrical Welding Parameters*

The system uses the periodicity of the droplet transfer of the PGMAW process. For the observation of the regularity of such processes it is sufficient to take one picture per period of the same process phase. In order to observe the exactly same process phase in each case (also at period times varying), the image recording is synchronized on an electrical welding parameter and is not carried out in fixed time intervals. The image recording starts after a trigger criterion is detected and an additional variable delay time (see figure 2).
Due to the variable trigger criterion and the variable delay time, every state of the welding process (the melting of filler wire through the arc, the detachment of the drop and finally the immersion of the drop into the welding bath) can be observed in online mode, even if this state itself has no unambiguous trigger criterion.
With periodically recorded images, the virtual picture of a quasi-stationary process, i.e. of a stationary drop is generated. Irregularities within the welding process are immediately recognized as different images in a series. The influence of varying welding parameters on the process is immediately visible.
Furthermore the variable delay time between the trigger criterion and the trigger impulse for the camera in one recording series can be continuously enlarged. In this case a virtual picture of a continuous process, i.e. of a virtual droplet transfer through the sequence of the different consecutive drops, is recorded.
Simultaneous to the image recording the welding current and voltage are measured. The measurement starts at the trigger criterion and holds after a variable time within the period of the process (see figure 2).

2.3 *Signal Processing*

The signal processing unit allows the automatic calculation of the following typical characteristic PGMAW process parameters from the measured current and voltage signals (see figure 3).

- Pulse current I_p and voltage U_p
- Background current I_g and voltage U_g

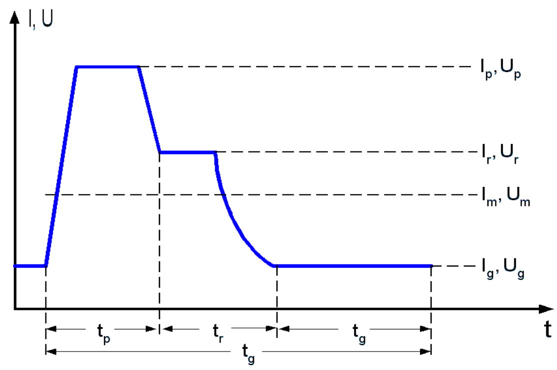


Fig. 3. Calculated typical characteristic electrical pulsed gas metal arc welding parameters

- Mean value (of the period) of current I_m and voltage U_m
- Pulse t_p and background t_g time
- Period time t_{ges} and frequency f_{ges}

Additionally, the unit calculates specific parameters of the used welding supply (EWM HIGHTEC Welding GmbH). The supply generates current and voltage signals that contain a so-called 'backpack' in the falling edge of the pulse (see figure 3). The calculated special parameters are:

- Backpack current I_r and voltage U_r
- Backpack time t_r

2.4 Image Analysis

For further conclusions onto the process the droplet transfer images are analysed visually. The image preprocessing unit allows the automatic detection and geometric measurement of all objects in the images and their classification. The unit is divided into the classical image processing parts preprocessing, segmentation, feature extraction and classification.

Due to the extreme brightness conditions and the characteristics of the HDRC camera, objects within the arc differ only by few grey levels from the background and objects outside of the arc clearly visible against the background (see figure 4a). The images cannot be analysed with standard image processing techniques. Preprocessing is essential. For preprocessing a procedure is necessary, which is robust against varying image contents (e.g. arc brightness).

A procedure was developed, which enables the „recognition" of the high-contrast areas that have to be maintained and low-contrast areas that have to be improved. Additionally pre-processing contains a compensation of the locally varying lighting influences, so that the result image of the preprocessing only shows the contrasts with the interesting information. The segmentation is carried out region-oriented by the calculation of an optimal grey level threshold for each image. The feature extraction part detects the objects and measures their geometry (volume, size, width, height, perimeter, among other things). With a statistical classification procedure, which characterizes the object classes by distribution densities, the objects are assigned to the given object classes („drops", „splashes" or „unknown") according to the criterion of the maximal probability. Figure 4 demonstrates the steps of the image analyse.

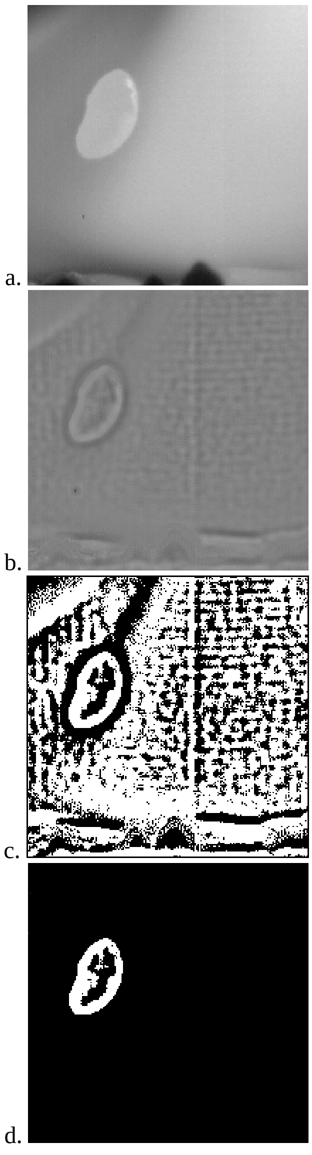


Fig. 4. Image processing: a.) Original image b.) Image with contrast enhancement and shading corrections c.) Image after threshold segmentation d.) Image with detected and classified object

2.5 Statistical Analysis

The statistical unit computes the following data of all measured and calculated visual and electrical parameters of a recording sequence.

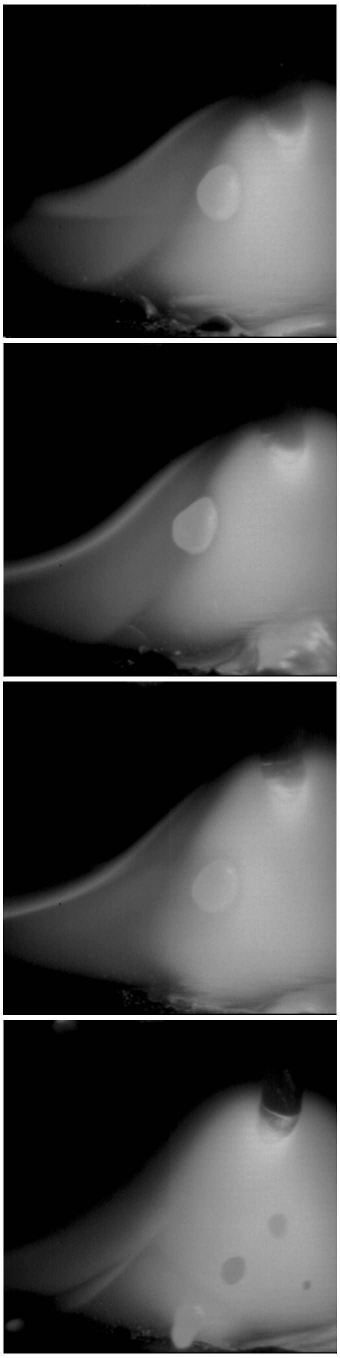
- Minimum, maximum and range
- Mean and median
- Standard deviation and variance
- Linear deviation dimension
- Coefficient of variation
- Histogram chart
- Modal value(s) of the histogram chart
- Skewness and kurtosis
- Regression line (trend analysis)

The unit also performs sequential analysis, which allows the user to analysis and optimizes the process.

2.6 Results

The efficiency of the system is illustrated by experimental data[1]. Figure 5 presents the quasi-stationary

[1] All data were recorded during weld-surfacing of unalloyed steel with a thickness of 4 mm and a diameter of the welding wire of 1,2 mm. Welding was carried out using a EWM HIGHTEC Welding GmbH Inverter power supply "Integral Inverter MIG 350 Pulse (Update 2.0)" (EWM HIGHTEC Welding GmbH) and with a vertical position of the welding torch in tub position. The protective gas consists of 82% argon and 18% carbon dioxide.



a.
b.
c.
d.

Fig. 5. Quasi-stationary drop with irregularities

Table 1 Results of the visual analysis of figure 6b

Object	drop
Width [mm]	1,41
Height [mm]	1,49
Size [mm^2]	1,57
Perimeter [mm]	4,77

Table 2 Results of the signal processing of figure 6c

	Current [A]	Voltage [V]
Mean	121,7	25,8
Peak	434,6	40,0
Backpack	152,7	29,5
Background	36,3	20,3

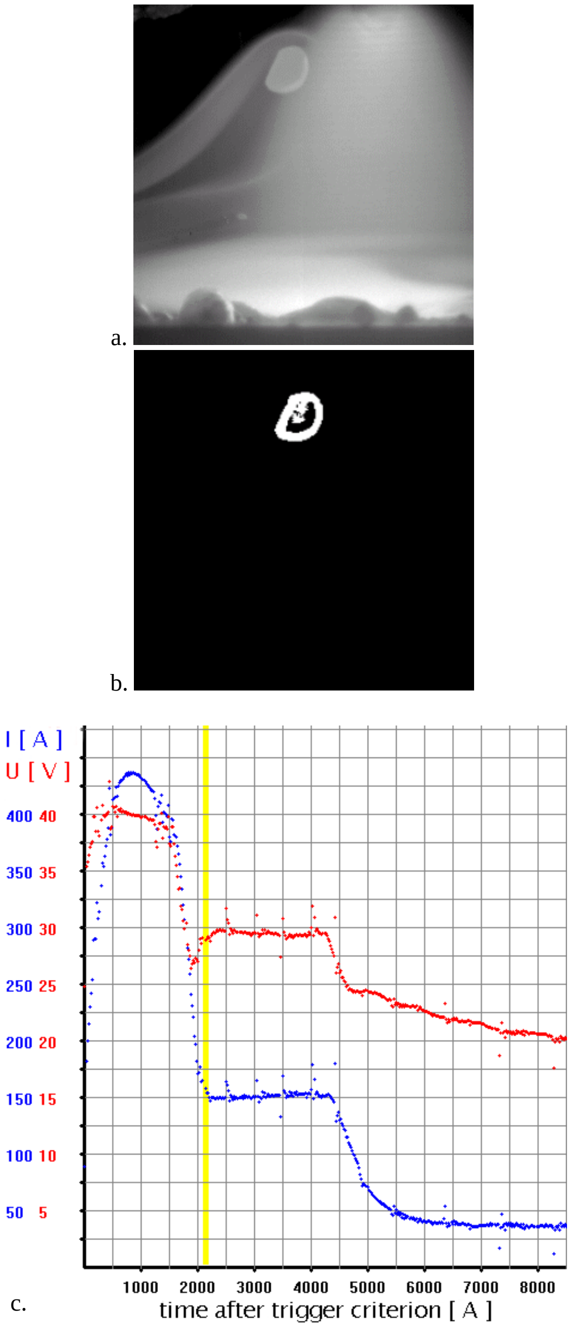
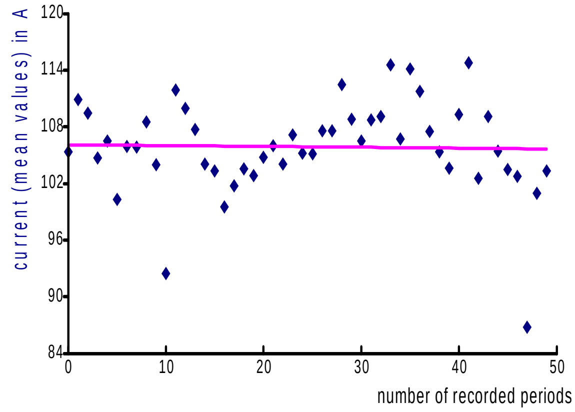


Fig. 6. Common representation of recorded and calculated data of one period a.) Image of the droplet transfer b.) Result image of the visual analysis c.) Synchronized and simultaneously measured electrical welding parameters current and voltage including the time of the image recording (vertical line)

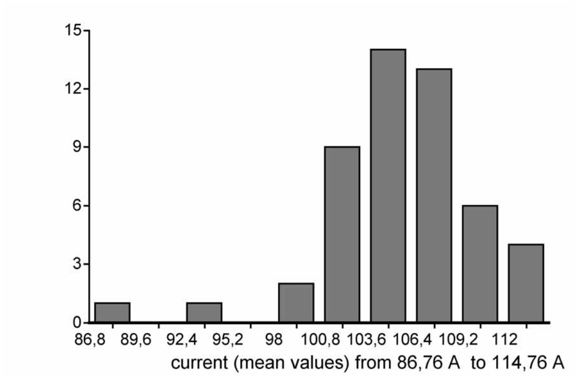
process through the recording of several different drops at the same states of the process.

The first three images (figure 5a, 5b and 5c) of the sequence show an even droplet transfer. The drops have approximately the same size and shape and are nearly at the same position. Image 5d shows the consequences of irregularities. The droplet transfer splits up into several little drops.

Figure 6, table 1 and table 2 illustrate an example for all measured and calculated data of a period. The figures and tables show an image of the droplet



a.



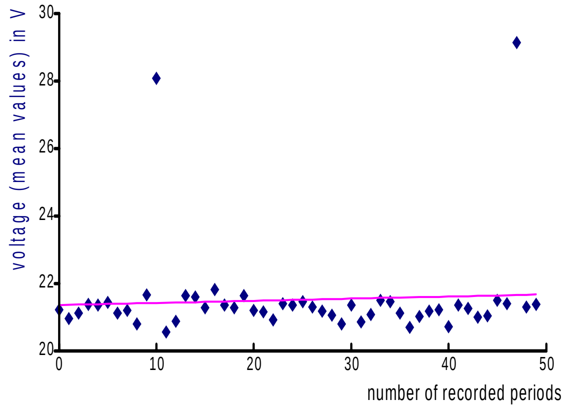
b.

Fig. 7. Mean values of the individual periods of the welding current of a recorded sequence and its calculated statistical data a.) Mean values including regression line b.) Histogram chart

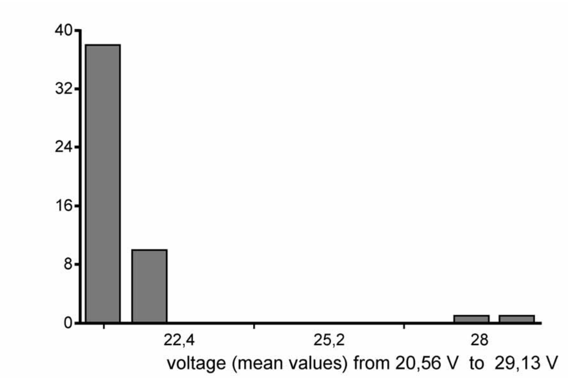
Table 3 Statistical data (selection) of mean values of the individual periods of the welding current of the recorded sequence of figure 7a

Statistic value	[A]
Mean	105,87
Median	105,88
Modal	104,96
Variance	24,42
Standard deviation	4,94
Minimum	86,76
Maximum	114,76
Range	28,00
Coefficient of variation	0,04
Linear deviation dimension	3,43

transfer, results of the visual analysis, synchronized and simultaneously recorded electrical welding parameters current and voltage and calculated characteristic electrical welding process parameters. Figure 7, figure 8, table 3 and table 4 present examples for the statistical unit. The figures and tables show the mean values of the individual periods of the welding current and voltage of a sequence as well as its calculated statistical data. The image recording quality of the system is demonstrated by figure 9. The figure shows the starting of the weld arc, which is another important phase of the welding process.



a.



b.

Fig. 8. Mean values of the individual periods of the welding voltage of a recorded sequence and its calculated statistical data a.) Mean values including regression line b.) Histogram chart

Table 4 Statistical data (selection) of mean values of the individual periods of the welding voltage of the recorded sequence of figure 8a

Statistic value	[V]
Mean	21,50
Median	21,25
Modal	20,98
Variance	2,22
Standard deviation	1,49
Minimum	20,56
Maximum	29,13
Range	8,57
Coefficient of variation	0,59
Linear deviation dimension	0,06

In spite of the missing additional lighting unit all details of the welding process including the droplet transfer are visible.

2.7 *Specifications*

The capability of the system is dependent on the employed components (model of the processor, the main memory of the computer, etc.), the size of the image area and the monitoring modes (online/offline observation and display and online/offline analysis).

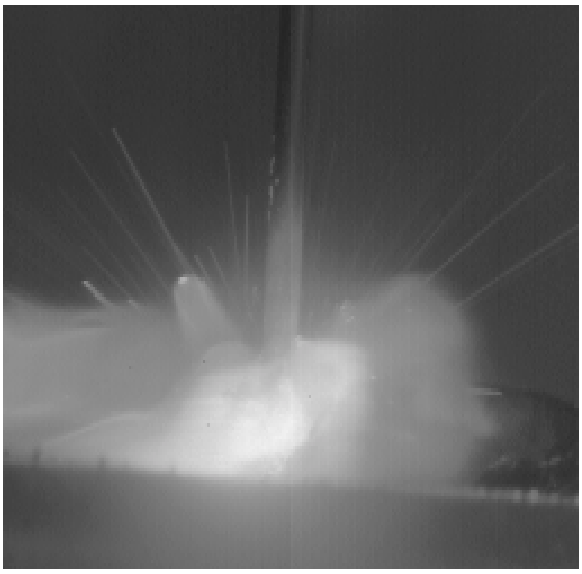


Fig. 9. Starting of the weld arc

On a computer with a Dual Pentium III 850 MHz, an image area size of 256 x 256 pixel and the operating system Windows NT 4.0 for example

- a visual online observation and display of the droplet transfer with 160 pictures per second,
- a simultaneous and synchronized measurement of the welding current and voltage with offline display,
- offline analyses (visual, characteristic process parameters and statistical data)
- and the saving of all data in the main memory.

are possible.

3. CONCLUSION

The sensor system described in this paper allows the online visual observation of all states of the PGMAW process, including the droplet transfer, without additional lighting. The image recording is synchronized to an electrical welding parameter.

Additionally, with the system the simultaneous and synchronized measurement of electrical welding parameters and the calculation of characteristic process parameters is possible.

Furthermore, the system is featured with an image processing unit for the automatic detection, geometry measurement and classification of the droplet transfer. With this unit, visual 2-D features of the droplet transfer can be directly assigned to the electrical welding parameters.

For an analysis and optimisation of the process the systems computes statistical data (extreme values, mean values, standard deviation, etc.) of all measured and calculated visual and electrical data of a recording sequence.

Presently, the optimisation is restricted to the online observation of the images of the droplet transfer and the offline analysis of all measured and calculated data.

The system can be used

- for the fast and economical adjustment of suitable welding parameters prior to manufacturing,
- to test different combinations of parameter settings, filler metals, inert gases, etc.
- and the development of welding devices.

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