LASER SHADOWGRAPH SYSTEM FOR THE ELECTRICAL ARC INVESTIGATION

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Lucrarea prezintă o metodă de investigare a transferului masic din arcul electric de sudare. Pentru investigarea şi monitorizarea procesului, utilizând diferiţi parametri şi în diferite condiţii de lucru, a transferului picăturilor prin arcul electric, a dinamicii acestuia cât şi a topirii sârmei electrod s-a utilizat un echipament care combina filmarea ultrarapidă cu pe un sistem de iluminare cu laser. Imaginile obţinute prin filmare se pot utiliza la validarea modelarilor proceselor de transfer la sudare, la proiectarea unor algoritmi specifici de control a surselor moderne de sudare, cat si pentru dezvoltarea de noi materiale de adaos şi gaze de protecţie..

The present article focuses on a methodology used in metal transfer process investigation, in particular for arc welding processes. The laser shadowgraph combined with a high-speed digital camera technique was applied in order to monitor the filler wire melting and metal droplets dynamics during arc welding process in different conditions and with different parameters. The experimental results obtained after images processing (molten metal drops shape and diameter, drops dynamics and velocity) in different phases of the process can be used for the welding metal transfer modeling, modern power supply control algorithm development and new filler metal development and gas testing.

Keywords: Laser, shadowgraphy, Arc welding, HDRC, Camera, Image processing.

1. Introduction

This paper is elaborated by a group of professors from Department of Manufacturing, Robotics and Welding Engineering from "Dunarea de Jos" University of Galati. One of the team research themes are linked to the development of low power Laser systems used in welding field. During the years, a large number of low-power Laser based systems were developed and includes: shadowgraph system, online tracking system of the weld beads, temperature

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measurement system, welding torch positioning system, polymers friction stir welding system of thin plates.

This article describes one of the above mentioned applications in the arc welding phenomenon investigation, the shadowgraph system respectively. From this point of view, in order to achieve the fundamental research, modern systems for investigation and measurements of the welding parameters are needed. In order to have a complete table of the phenomena, since 2003 a complex system using high speed camera synchronized with the regime processes parameters was developed.

2. Mechatronic system development

The developed system main goal is the investigation and the study of the gas metal arc welding (GMAW) process. The research laboratory is composed of a complex system based on a high dynamic speed camera – HDRC (for filming the welding arc phenomena) synchronized with a welding parameters measurement system (Fig. 1).

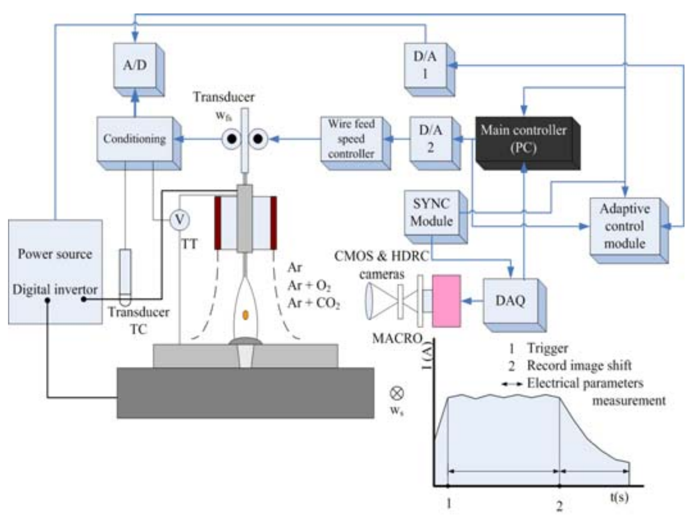

Fig. 1. Arc welding investigation system

The sub-system for analogical parameters measurements contains the following:

- Transducers for arc welding parameters measurements: the welding current, I, arc voltage, U, wire feed speed, - w_{fs} and welding speed - w_s;
- Data acquisition board NI PCI-6070E;
- Connecting the tower linking sensors the acquisition board;
- Data cables;

- The central processing unit.

3. Ultrarapid shooting techniques

For the mass transfer study, in literature three different techniques are usually used:

- with HDRC cameras described in [1];
- with stroboscopic projector;
- “Shadowgraph” or “Back-lighting” method in [2].

3.1. Shooting Systems Requirements

The problem of developing a shooting system for the arc welding investigation that allows the obtaining of clear information of the phenomena not a simple one. Firstly, the images that will result have to be clear and interpretable. This fact requires a proper filtering system, a method for removing the excess of fume and spatters which appears accidentally into the studied area. In order to have a complete image of the process, not altered by its dynamics, the number of frames captured per second must be very high. Depending on the studied process and the proposed main goal, the shooting speed has to be adapted correspondingly. High speed camera should be used for achieving all the above mentioned requirements.

In the case of the gas metal arc welding the frequency of the transferred drops is up to 300 drops/second. For this reason the use of a camera with minimum 1000 frames/second is compulsory for obtaining accurate images of the drops. In conclusion, when developing the shooting system, the aspects that should be considered are the followings:

- corresponding filtering system;
- high dynamic and optic features;
- improved protection of the system (temperature, spatter);
- high shooting speed, correlated with a small exposure time;
- variable macro system and diaphragm and depth of focus;
- external triggering feature;
- increased reliability in hard working conditions (forced cooling system).

3.2. Stroboscopic Projector Alternative

The method consists in the use of a CCD ultra rapid digital camera with shutter and external trigger, together with a very strong stroboscopic projector (5000W). This method is more economical and does not need high security measures (Fig. 2). The disadvantage of the stroboscope projector alternative is that limits the images recording frequency and is impossible to catch the whole transfer cycle.

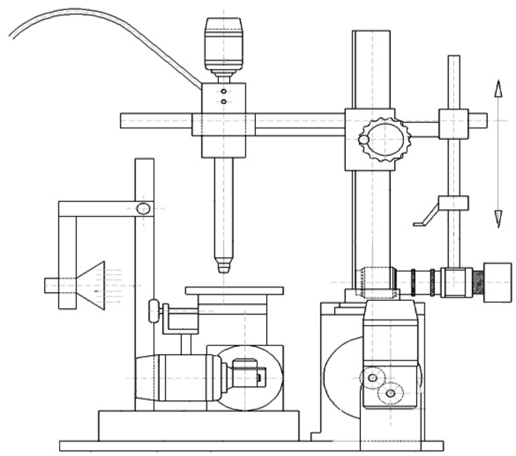

Fig. 2. The variant with stroboscopic projector

3.3. HDRC Camera Alternative

This other method presented in [4] uses a HDRC camera with external triggering. The system consists of a personal computer to record the images synchronized with the recorded welding arc process parameters, the signal processing board, that calculates automatically the welding parameters characteristics and the image processing board for the visual analyse of the mass transfer. Images can be recorded when the triggering is achieved with the additional delay-time. The measurements of the welding parameters start when the trigger signals starts and should be maintained a variable time depending on the welding process period. The shooting part consists of the MACRO optical system, the camera, capture camera and synchronizing block.

4. Shadowgraphy or back-lighting`

The term shadowgraphy has been used when referring to a projected shadow of several elements in the welding region (e.g. torch, electrode, droplets, weld bead and plate) over a flat surface, technique also known as *back-lighting*. Because of the arc excessive brightness and radiation, the use of this method is not possible to obtain the elements shadow. For this reason an additional source of light is needed.

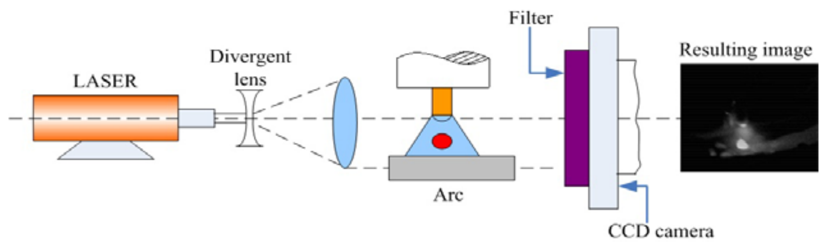

Fig. 3. Shadowgraphy principles used in welding [1,2]

The optical relationships between the main parameters of the Laser beam (Fig. 4) are described as follows:

$$d_{out} = \frac{l_f}{l_{col}} \cdot d_{inp} \tag{1}$$

$$d_{col} = 2 \cdot l_{col} \cdot \tan\frac{\theta}{2} \tag{2}$$

$$d_{\text{int}} = \frac{1}{4} \cdot d_{inp} \cdot \theta \tag{3}$$

Where: l_f – focal length; l_{col} – collimation length; θ – angle of collimation; d_{out} – output focus diameter; d_{inp} – input diameter; d_{col} – diameter of collimation; d_{int} – intermediary Laser beam diameter.

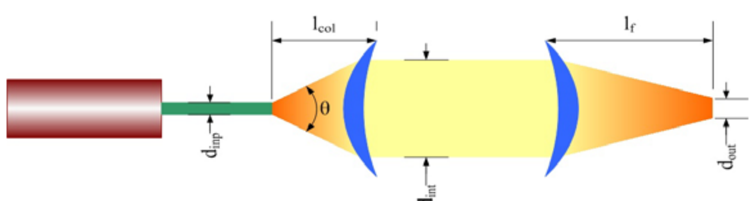

Fig. 4. The optical relationships of the Laser beam

The laser source should be (usually a laser diode) chosen with the following characteristic: a power of 20-100 mW and the emission frequency about 600 and 800 nm. The optical fibbers should be very narrow banded (about 20nm) combined with filters for the light polarization adapted on the laser wave length and of the camera. In order to choose the right filter system, the emitted radiation wave length of the electric arc has to be considered, which is in the range of 380-900 nm.

The video camera is a special one, a CCD speed camera, which acquires a high number of frames per second. In the experiments 1000 frames/second were used and the camera was equipped with a shutter which value is minimum 1/100.000s.

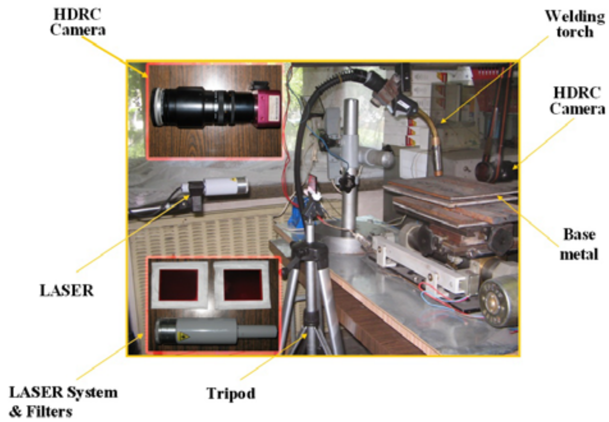

Fig. 5. Experimental system components

5. System components

5.1. HDRC Cameras

The cameras used are: MV-D 1024-160 (Photon Focus), 1M-150-SA (DALSA) and Loglux i5 camera (Kamera Werk) presented in [6]. The camera comprises: the filtering system, MACRO optical system, capture board and a synchronizing module.

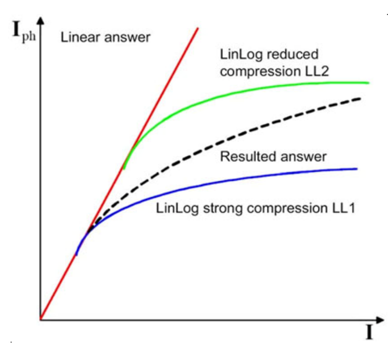

Fig. 6. The characteristic of LinLog 2 sensor [5]

MV-D1024-160 HDRC-Mos Camera is characterized by the CMOS sensor type active pixel LINLOG 2, high resolution (1024 x 1024 pixels), spectral sensitivity 400…900nm, 8 bits monochrome, high optical dynamic range, dynamic response 120 dB global shutter and various trigger possibilities, high shooting speed and ultra rapid data transfer on C-link type lines. The LinLog technology uses a linear response at low illumination levels and logarithmic compression at high intensities. The LinLog 2 principle improves considerably the system behaviour in the transition point.

The camera uses three values: a first threshold for the LinLog compression LL1 strong, another threshold value for the LinLog LL2 reduced compression and an additional parameter COMP, COMP is a value that defines the ratio between the strong compression and the reduced one. The transition point between the linear transition curves, logarithmic, respectively can be changed by the user. Using the corresponding combination between the logarithmic compression and the global diaphragm, in motion objects can be shot (Fig. 6).

5.2. The Laser

In the experiments, the Laser has 650 nm wavelength and a power of 35mW. It is equipped with optical system (divergent and convergent lens) and a collimator. The use of this laser light is due to the fact that its wavelength is 650 nm, which corresponds to a weak region in the arc spectrum (280 to 700 nm). If a selective filtering is chose, almost all of the arc light is eliminated and a shadow of the drop, wire, weld pool and plate can be seen in background.

5.3. Filtering system. Interference Filters

The video systems and those with artificial view are based on the electronic acquisition devices of the images, which usually have a signal-noise ratio in the range 8–12 bit. However, in applications like the welding processes, the increase of this ratio is imposed by filtering optical methods, due to the fact that in the visual field there are extremely light areas.

6. Experimental results

The presented system is used by the authors to study the mass transfer in arc welding processes and appropriate software solutions and algorithms are developed, in order to obtain clear images that show the process evolution. In the resulting images, after the filtering and contrast improving operations, drops contours detection, features and dimensions must be achieved. Using specialized algorithms, the geometrical dimensions and the speed of the drops are determined.

6.1. Image Analysis

Image-processing efficiency is presented in Fig. 7. This shows representative images for different types of drops associated with the mass transfer cycle with arc brightness variation. However, Fig. 7 refers to the steps for visual analysis individual processing. The numeric results are presented in table 1.

Table 1

The geometrical parameters of the drops measured using acquired images

Type	Image 1	Image 2	Image 3
Volume [mm3]	5,58	4,51	2,66
Perimeter [mm]	3,65	3,51	2,88
Ox diameter[mm] d1	1,09	0,93	0,85
Oy diameter [mm] d2	1,11	1,12	0,87

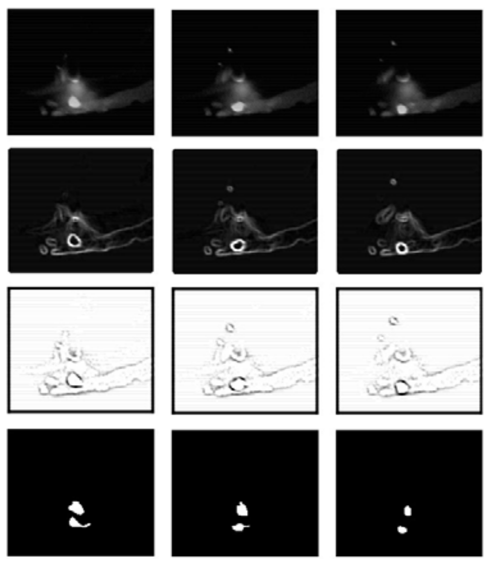

Image 1 Image 2 Image 3

Fig. 7. Visual analysis. a) original image; b) the images resulting after contrast and shadows correction; c) image segmentation; d) object detecting and their classification

All the recorded images (Fig. 8), in the phase of system development, are presented for pulsed gas meal arc welding process, using 1,2mm diameter fill wire. The gas from the experiments was Corgon 18 (82%Ar and 18%CO_2) and the power supply, ESAB Lud-320. Software solutions and optimal algorithms were determined in order to obtain the sharpest images and also to present the entire welding process evolution. For image processing, commercial software's were used, from medicine (e.g. 3D Doctor) or astronomy, in which multi-scale Retinex Image Enhancement algorithms are used.

On the resulting images, from contrast enhancement and improvement operations, contour detection and extraction was performed for detecting the droplets features. The method was presented also in [4] and the feature extraction was achieved using [5], [6]. Initial, because of the extremely high volume information (millions of pictures acquired), the primary operations were performed using commercial image processing programs. Using specialized algorithms, geometrical dimensions and the speed of the droplets were determined.

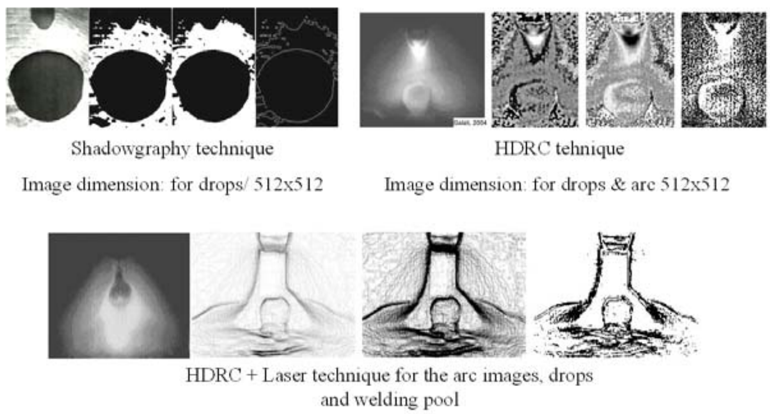

Fig. 8. Resulting images after successive processing using RETINEX algorithm software-based (512x521-584 frames/s)

The specific parameters of the droplets, determined from the mass transfer, coupled with the arc welding current and voltage are processed using various methods and in the end, models and algorithms for welding process monitoring were achieved.

7. Conclusions

In the paper the image acquisition and processing of electric arc welding process is presented with its image processing system components. The methods of image acquirement and the sensorial system are also presented and are highlighted the lighting systems proposed (with incident light, with transmitted light and also with dark and bright field lighting). CCD cameras and CMOS technology are briefly described.

The optical systems used with the referring camera, types of lenses (microlenses, telecentric lens, auxiliary lenses), ring spacers and polarizing filters are presented. A synthetic configuration of the shooting system is based on a lighting unit, a sensory unit (one room), one or more lenses, a capture card with intelligent hardware and peripheral units such as the monitors, printers, card I/O etc.

The originality of the paper consists in the setting up of a system structure that should be considered as an artificial vision one. The key issues regarding image processing such as filtering, restoration, segmentation, contour detection are also set and used in the proposed integrated system.

The images obtained had a contrast that in most of the times is insufficient to view the transfer details, and from this point of view image processing algorithms and techniques are used in order to extract the necessary information for determining the arc and droplet geometry.

The system is still under development and the future key point is to develop the right algorithms for processing the acquired images and also to use the system in other arc welding processed.

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