SYSTEM OF VIDEO OBSERVATION OF THE PROCESS OF TIG WELDING OF TITANIUM STRUCTURES

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A system for video observation of the process of narrow-gap TIG welding of titanium structures at currents of up to 500 A was developed. Video observation system is equipped with the means for automatic control of photoreceiver sensitivity, depending on the intensity of welding arc radiation.

Keywords: *titanium welding, video observation, light radiation of the arc, digital videocamera, sensitivity control, automatic regulator*

Recently, the scope of application of titanium alloys in different industries has considerably increased, particularly in aircraft construction and shipbuilding. In shipbuilding industry the process of narrow-gap multilayer MIAB welding of 20–100 mm thick titanium structures became widely accepted. In order to control this welding process, the welding machine operator requires feedback devices, ensuring visual observation of the welding zone, which is difficult because of small dimensions of the gap, and varying intensity of light radiation of the arc. As a consequence, in this case it is rational to use machine vision means for realization of visual observation. Standard systems of video observation are not suitable for solving this task, as the functions of automatic adjustment of signal amplification or final adjustment of lens aperture cannot provide an adequate solution of the problem of photoreceiver oversaturation at a high level of external light radiation.

PWI developed a system of video observation of the process of TIG welding of titanium structures, fitted with elements of adaptation to the level of light radiation of the welding arc. The system is a monochromatic digital videocamera with an integrated microprocessor controller. Special light filters are mounted between the videocamera lens and photoreceiver matrix. Standard TV signal in PAL format is used as the output signal. Microprocessor controller is applied for analysis of the obtained images, automatic fine tuning of operating mode of photoreceiver matrix and generation of output TV signal. Also realized is the scaling function, allowing selection of a region in the image that corresponds to the welding zone, and representing it in the form of full-screen frames.

Digital images, generated using the photoreceiver matrix, have a limited dynamic range of pixel intensity, dependent on the digit capacity of analog-digital converters of photoreceiver cells. At insufficient level of external lighting the images can have zero or extremely low brightness. Here, pixel intensity will be in the vicinity of the dynamic range lower limit. At the same time, exceeding the photoreceiver matrix saturation limit can be observed at a high level of lighting, i.e. pixel intensity will correspond to the upper limit of the range. In both the cases, visual quality and information content of the generated images are extremely low. Thus, stabilization of visual quality of output TV signal requires maintaining a high brightness of images, while avoiding any significant oversaturation of photoreceiver matrix.

Light radiation of the weld pool in TIG welding of titanium structures is characterized by considerable fluctuations of intensity, reduction of which requires controlling videocamera operation mode. Videocamera exposure time e, which determines the total sensitivity of the photoreceiver, was selected as the control signal. Maximum intensity of any of image pixels, $i_{\max}$, depends on the level of photoreceiver lighting L and value of parameter e, assigned in the previous cycle of videocamera operation:

$$\begin{gathered} i_{\max}[n] = l_{\max}[n]e[n-1]k_1, \\ I_{\min} \le i_{\max}[n] \le I_{\max},\ \ l \ge 0,\ \ E_{\min} \le e[n] \le E_{\max}, \end{gathered} \tag{1}$$

where n is the cycle number; $l_{\max} \in L$ is the maximum level of lighting of one of the photoreceiver cells; $k_1 > 0$ is the videocamera gain factor; $l_{\max} > 0$, $I_{\min} \ge 0$ are the upper and lower limits of the general dynamic range of pixel intensity; $E_{\max} > 0$, $E_{\min} > 0$ are the limits of exposure variation, respectively.

If the value in the right-hand part of equation (1) is equal to or exceeds $I_{\max}$, this leads to saturation of photoreceiver matrix pixels. The quantity of pixels with maximum intensity can be assigned in the following form:

$$m_{\max}[n] = i_s[n]k_2[n],\ i_s \ge 0, \tag{2}$$

where $i_s[n] = l[n]e[n-1]k_1 - I_{\max}$; $k_2[n] \ge 0$ is the coefficient dependent on distribution of light radiation intensity of the observed object.

From expressions (1) and (2) it follows that the videocamera is a non-linear object, for automatic control of which it is rational to apply an optimum or adaptive approach [1]. Parameters $I_{\max}[n]$ and

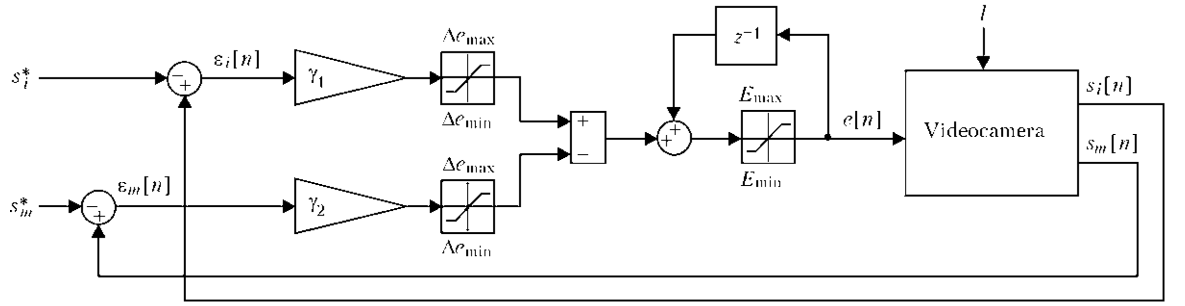

Figure 1. Schematic of automatic regulator for stabilization of image visual quality (for designations see the text)

$m_{max}[n]$ are independent. Therefore, regulator feedback should be represented by two signals, one of which characterizes the current brightness of the image, and the other — the saturation level of the photoreceiver. Brightness index is calculated as

$$s_i[n] = \frac{I_{max} - i_{max}[n]}{I_{max}}. \quad (3)$$

Level of photoreceiver saturation is determined as follows:

$$s_m[n] = \frac{m_{max}[n]}{M}, \quad (4)$$

where M is the total number of image pixels.

Quality control criteria for minimizing the instant value of errors, has the following form:

$$J(e) = \varepsilon^2[n] + \varepsilon_m^2[n] = (s_i[n] - s_i^*)^2 + (s_m[n] - s_m^*)^2 \to \min, \quad (5)$$

where s_i^*, s_m^* are the setting impacts.

At zero s_i^*, s_m^* values and fixed aperture, minimization of error by brightness index is achieved by extension of videocamera exposure, while minimizing the error by saturation level, contrarily, is achieved by its lowering. To find an optimum solution, a gradient method was selected [2], in keeping with which the equation of discrete regulator will be written as follows:

$$e[n] = e[n-1] + \nabla J(e) = e[n-1] + \gamma_1\varepsilon_i[n] - \gamma_2\varepsilon_m[n], \quad (6)$$

where $\gamma_1 > 0$, $\gamma_2 > 0$ are the error gain factors.

Schematic of synthesized automatic regulator is shown in Figure 1. Value of gain factor γ_1, γ_2 was pre-determined by simulation in MatLab environment, and was additionally precised experimentally. Minimizing of control error was taken as the main criterion of regulator setting up, as considerable over-regulation can lead to oscillatory process (image blinking). Additional limitations from Δe_{min} up to Δe_{max} are also imposed on the amplitude of the change of control signal $e[n]$.

Logic of regulator operation at $s_i^* = 0$, $s_m^* = 0$ is illustrated using Figure 2. At the initial moment of time at $l[0] > 0$ an error by brightness index $\varepsilon_i[n]$ arises. In subsequent steps exposure $e[n]$ increases up to reaching the upper limit of brightness range

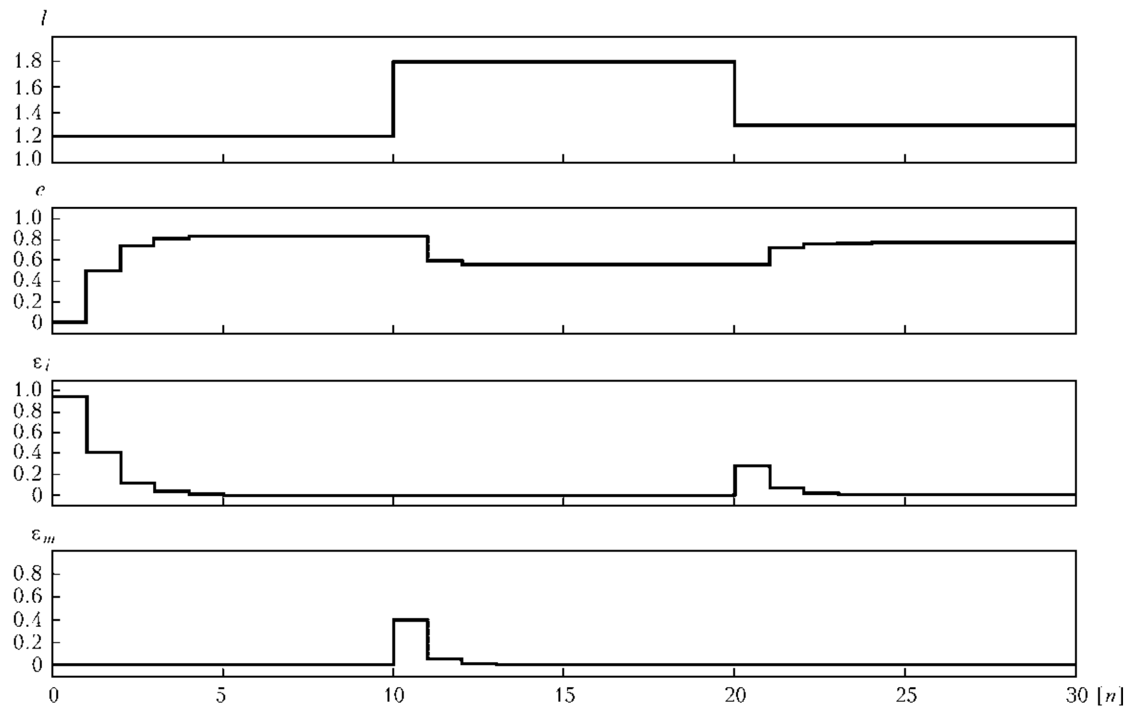

Figure 2. Behaviour of automatic regulator at variation of external lighting of photoreceiver

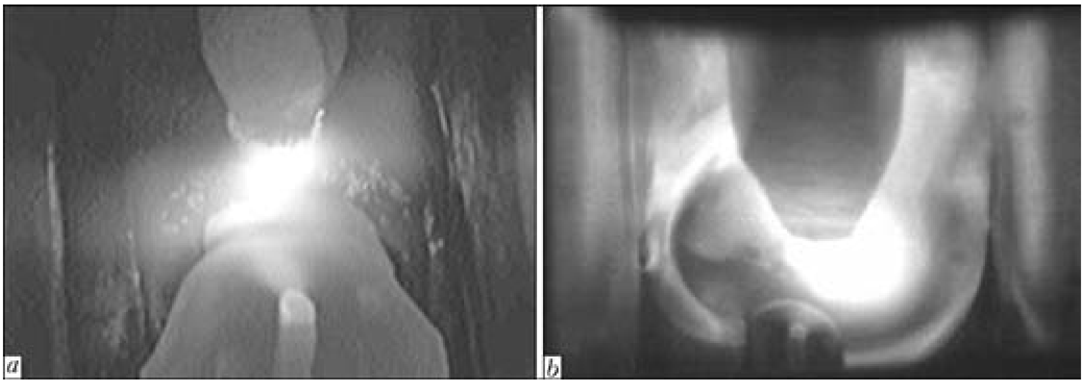

Figure 3. Examples of generated images of TIG welding zone at welding current of 100 (*a*) and 500 (*b*) A

($i_{max}[n] \to I_{max}$). At saturation of photoreceiver matrix ($\varepsilon_m[n] > 0$) videocamera exposure gradually decreases and so on. Thus, stabilization of visual quality of the image near the saturation boundary is ensured. If required, assigning $\Delta e_{min} = 0$, $s_i^* > 0$ and/or $s_m^* > 0$, we can provide a certain zone of regulator insensitivity to variation of external lighting.

At zero or low external lighting the exposure increases up to reaching the upper level E_{max}, and at the same time it is possible to increase the total image brightness to the maximum. The range of effective stabilization of image visual quality can be adjusted using the lens aperture.

To improve visual perception of the TV signal, gamma-correction of output images is applied elementwise. Increase of gamma-correction coefficient allows enhancing the contrast and intelligibility of image dark areas, not making the light details of the frame too contrast or bright.

During experiments it was established that the developed video observation system provides an acceptable level of detalization of output TV signal for the entire range of welding currents (110–500 A), and allows the welding operator a sufficient degree of control of the welding process. All the necessary objects are clearly visible in Figure 3: electrode, welding arc, groove walls, liquid metal region.

The video observation system was introduced as standard equipment of the machine for TIG welding of titanium of VT20 and VT6 grade. The proposed approach to control of photoreceiver sensitivity can be applied for development of systems of video observation of any objects, which are characterized by a considerable range of variation of light radiation intensity.

1. Aleksandrov, A.G. (1989) *Optimal and adaptive systems*. Moscow: Vysshaya Shkola.
2. Tsypkin, Ya.Z. (1968) *Adaptation and training in automatic systems*. Moscow: Nauka.