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Creation of a Mock-up Laser Welding Monitoring System Based on a Photomultiplier Tube

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Abstract— Laser welding is widely used in the different branches of mechanical engineering, mainly consisting of the interaction between the laser beam and the welding material. Online monitoring and quality testing of laser welding processes are important for the manufacturing of quality products. Analysis of scientific papers on this topic showed that there is a relationship between the technological process of laser welding and the recorded signals. The purpose of this work is the creation of a mock-up laser welding processes monitoring system based on a photo sensor. During the design process, a photovoltaic tube was chosen to use with the vacuum photocell. A complete mock-up laser welding monitoring system was developed and tested. The photocell is used with the optical filters, which allows us to record the deviation of the intensity of the torch during the process of laser welding. According to the results of measurement of the intensity of the light emission of the torch of the welding melt bath, the photocell forms a signal. When the photocell is loaded with a strong enough active resistance, it will record a voltage drop sufficient to be recorded by an oscilloscope. Electron-optical version of the layout of the mock-up laser welding monitoring system, based on the analysis of signals taken from photosensors showed good results with potential to implement additional monitoring systems to allow measuring more characteristics of the laser beam.

Keywords—laser welding; monitoring; photomultiplier tube; optical radiation; analogue signal.

I. Introduction

Laser welding is widely used in the different branches of mechanical engineering, such as automotive industry, shipbuilding and bridge laying thanks to its advantages, realizing high productivity, automatic processing and formation of a high-quality welds with a relatively small size of the heat affected zone (HAZ) [1-3]. For this reason, online monitoring and quality testing of laser welding processes are important for the manufacturing of quality products. A lot of scientists have conducted research on detection of the processes in laser welding dating as far back as twenty years ago [4-7]. Analysis of scientific papers on this topic showed that there is a relationship between the technological process of laser welding and the recorded signals; such a relationship manifests itself to some extent regardless of the research method used [8-9]. The reliability of signal recognition and processing depends primarily on the choice of the methodology that takes into account the distribution and interrelation of informative features of the signal [10-13]. However, due to the high cost of sensors, low accuracy of instruments and poor detection efficiency, the experimental results were not widely used in industrial production at the time. At that point of the time, the number of companies using lasers to process products was small, which was considered to be another important factor that limited the further development of the laser welding monitoring processes. As the price of laser devices is now steadily dropping, laser technology is beginning to be widely used in industry. During mass production, real-time monitoring of the welding process can help reduce production costs and improve final product quality.

Laser welding mainly involves the interaction between the laser beam and the welding material. In the welding process, the laser light usually passes through the optical fiber and the lens, though this may vary depending on the laser construction. Accordingly, as most of the sensors used in research are optical sensors, real-time monitoring of the laser welding process is mainly focused on the information, received from optical radiation in the welding zone. Thanks to developments in sensor technology and the introduction of AI technology, the development, detection and recording of real-time signals in laser welding have made significant progress over the past ten years.

The purpose of this work is the creation of a mock-up of the laser welding processes monitoring system based on a photo sensor.

II. DEVELOPMENT OF THE MONITORING SYSTEM

It is a known fact that the use of a photocell can significantly simplify the analysis of video images obtained during welding.

The most common solution to a similar problem in various industries is the usage of semiconductor photovoltaic cells. This solution is used due to their relatively low cost and simplicity of measurement schemes. However, the measuring range of most semiconductor elements is located in the infrared zone. Therefore, during laser welding, these photovoltaic cells will be fully illuminated, producing an output of the maximum value of photo-electromotive force (photo-EMF). Because of that, it will be impossible to distinguish the small value of the useful signal against the background of the maximum value of the photo-EMF. The usage of optical filters to block this background signal will absorb a wide range of potentially useful signals. To this extent, it is not expedient to use a semiconductor element to solve this problem. When using vacuum photocells, optical filters can be used.

However, it is possible to use optical filters when using vacuum photocells. This option is available because the filters reduce the radiation in the infrared range, as well as reduce the light, received from the plasma torch of the melt bath. This is caused by the technical characteristics of vacuum photocells, namely the spectral sensitivity range of 300-600 nm.

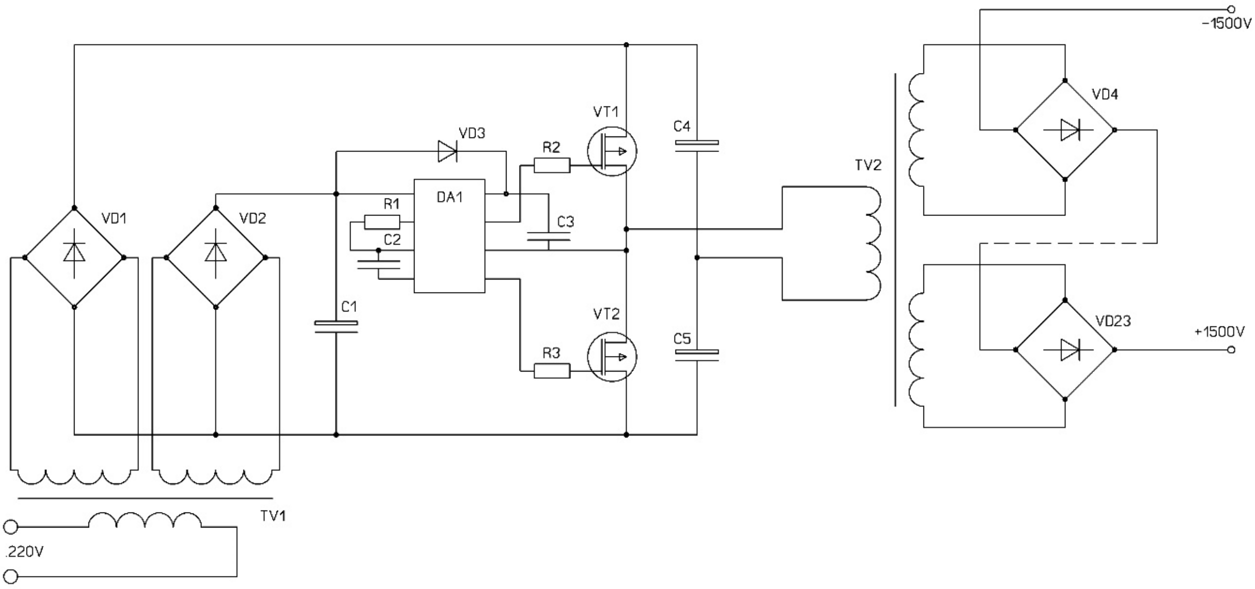
Analysis of the technical characteristics of vacuum photocells allowed us to focus on the photomultiplier tube "FEU-35" shown on the Fig.1, as the one to meet the above-mentioned requirements. Its specifications are presented in Table 1.

TABLE I. SPECIFICATIONS OF THE "FEU-35" PHOTOMULTIPLIER TUBE

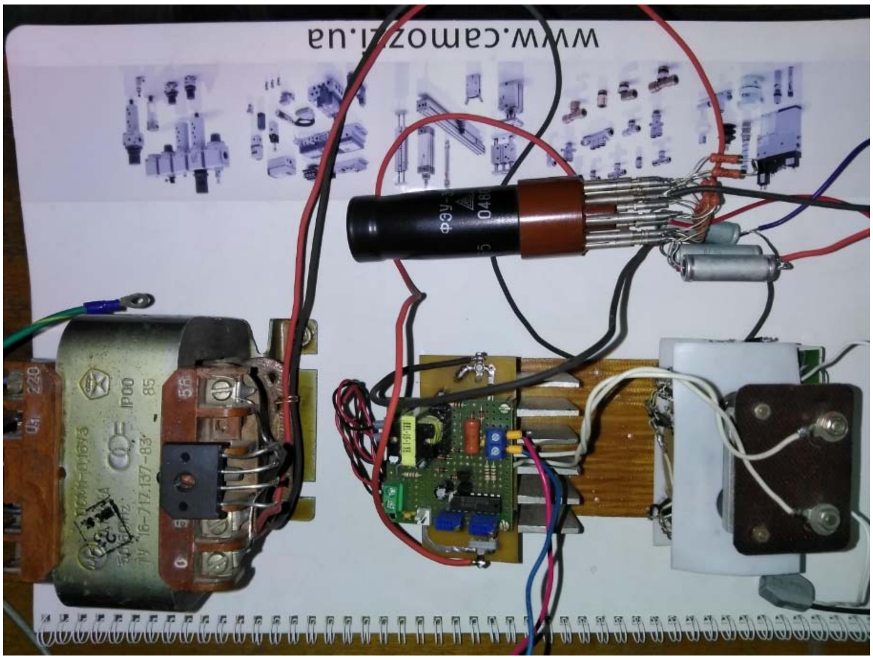
Model of the tube	Location of the entry and [exit] points	Photocathode size, mm	Spectral characteristic type (Δλ, μm) [λ_{max}, μm]	Number of diodes (amplification stages)	S_{phk},mkA/lm, more than	S_a,(under U_p, V), A/lm	$S_{()phk}$,mkA/lm, more than	S_{phk},A/W, more than (when λ, μm is)	U_{pow},W, less than	I, A, less than (when S_a, A/lm is)	I_a, A, less than	F, lm/Hz$^{-1/2}$	Operating temperature range, °C	Dimensions, mm [weight, mm], less
"FEU -35"	front -end [back cap]	Ø25	C×6 (0,3-0,6) [0,38-0,42]	8	40	1(700-900); 10(1050); 30(1250-1750)	2×10^{-2} (0,41 μm)	–	1750	2×10^{-8} (10)	5×10^{-5}		– 60 … +50	Ø30×109 [50]
"FEU -35A"		Ø25	C×6 (0,3-0,6) [0,38-0,42]	8	45	10(1200); 30(1600)			1600	1×10^{-8} (10)				

Fig.1. – "FEU-35" photomultiplier tube

A power supply unit (PSU) with an output voltage of 1500 V DC was created for the connection of the photomultiplier tube, allowing us to reach provided specifications. Fig.2a shows the electronic schematic of the power supply unit (PSU). The layout of the entire mock-up of the laser monitoring system is shown on Fig.2b.



a



b

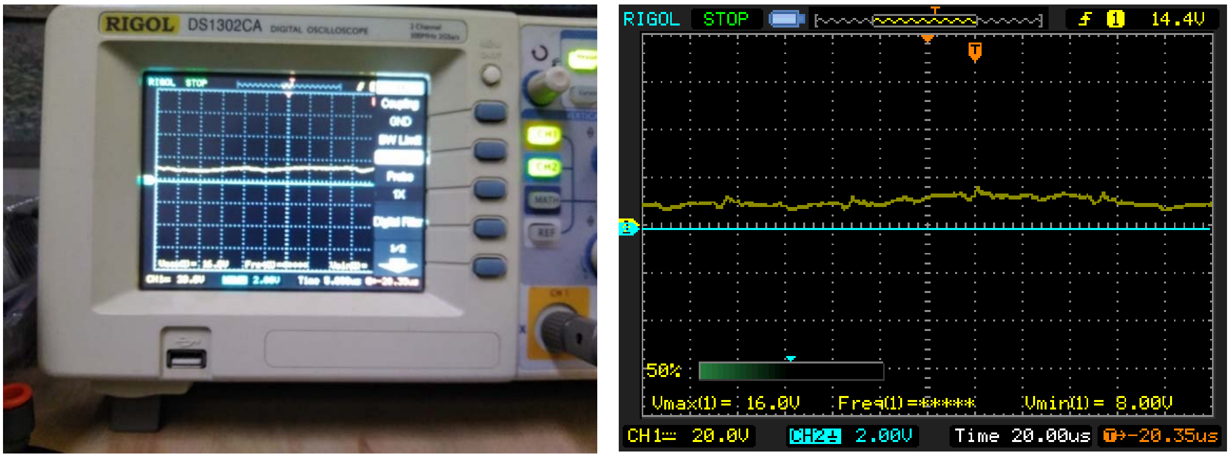
Fig. 2. – Mock-up of the monitoring system, created on the base of the “FEU-35” photomultiplier tube: a – power supply unit principal wiring schematic; б – overall appearance of the mock-up system.

The main element of the circuit is a TV2 high-frequency transformer, which consists of many secondary windings, the outputs of which are each connected to their own VD4… VD23 bridge rectifier. It is possible to obtain about 80 V of voltage from a single (winding and rectifier) section. High-frequency transformer consists of 20 such sections. All of them are connected one by one, which allows to obtain a summary voltage of about 1600 V. The primary winding of the high-frequency transformer is supplied with a rectangular voltage with an amplitude of 60 V and a frequency of about 30 KHz.

This voltage is generated by a half-bridge transistor converter. It consists of two high-voltage VT1 and VT2 field-effect transistors (FETs), N-channel IRF840 structure and two electrolytic capacitors (C4, C5) with a capacity of 470uF and 200V of voltage. Signals for transistor control are generated by a specialized integrated DA1 circuit running on a self-clocking semi-bridge driver IR2153.

To ensure that the output voltage of the power supply does not exceed the recommended values, a step-down TV1 transformer with an industrial frequency of 50 Hz was used, the windings of which form voltages of 56 and 12 V. Bridge rectifiers VD1 and VD2 make these voltages constant for correct work of transistors and chips.

The photocell is used with the optical filters, which allows us to record the deviation of the intensity of the torch during the process of laser welding. According to the results of measurement of the intensity of the light emission of the torch of the welding melt bath, the photocell forms a signal of up to 35 mA. Changing the intensity of the torch glow leads to a change in the magnitude of the signal, which allows for determination of the presence of defects in the weld joint. When the photocell is loaded with an active resistance of 1000 Ohms, it will record a voltage drop within 35 volts. This voltage is sufficient to be recorded with a RIGOL digital oscilloscope, which is shown on Fig.3.



a b

Fig.3. – a - "RIGOL" digital oscilloscope used in testing the layout of the mock-up monitoring system based on the "FEU-35" photomultiplier tube. Fig.3b shows the analogue signal on the oscilloscope screen as well as the already processed signal.

The general scheme of the experiment on testing the layout of the monitoring system based on the "FEU-35" photomultiplier tube is presented in Fig.4.

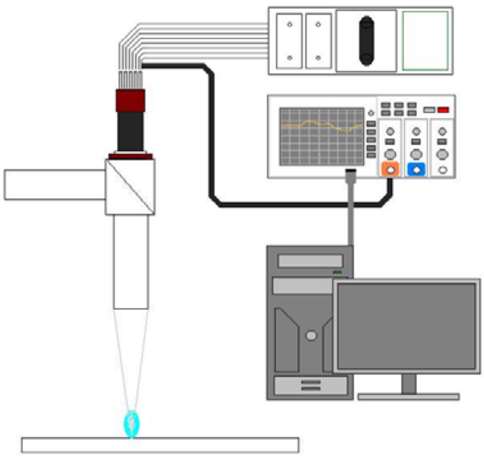


Fig.4. – The general scheme of the experiment on testing the mock-up monitoring system based on the "FEU-35" photomultiplier tube.

The photocell has been installed in place of the video camera. The analogue signal, that forms the element, was sent to one of the channels of the digital oscilloscope. The settings of the oscilloscope and the measuring probe allow the measurement of the signal with an amplitude of up to 30 V on a time interval, proportional to the time of the welding process. This signal can be stored in both the memory of the digital oscilloscope and transmitted via cable to the computer (work station). Data processing is carried out using both the DS1000AE program on a personal computer, which was installed with the RIGOL oscilloscope, as well as the Microsoft Excel program.

III. Conclusions

Processing and recognition of signals, which carry informative features of the technological process of laser welding, namely visual images, various types of radiation or acoustic and electromagnetic emission signals is a complex multilevel task, attempts to solve which are repeatedly described in the scientific literature. However, the construction of a wholistic, universal system for analysis of these signals has not yet been implemented.

Analysis of scientific publications on this topic shows that there is a relationship between the technological process of laser welding and recorded signals; such a relationship manifests itself to some extent, regardless of the chosen research method. The reliability of signal processing and recognition depends primarily on the usage of the method that takes into account the distribution and interrelation of informative features in the signal.

Electron-optical version of the layout of the mock-up laser welding monitoring system, based on the analysis of signals taken from photosensors showed good results. After technological verification, this method can be used to implement inverse communication to determine the power of laser radiation.

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