THE FUNCTIONING OF SOME TRANSDUCERS AND SENSORS INTENDED FOR ROBOTIZED LASER

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ABSTRACT. The last decade brought an enormous amount of researches in the field of developing and industrial applying of various laser welding processes. The powerful yet sometime too precise tool which is the laser beam needs in practical use sensors and adaptive systems which are able to bring the focused beam at the aimed welding zone. The paper describes contact and scanning transducers for detecting the characteristic points of the seam as well as various sensors (reflected beam, radar a.s.o.) for joint following into the process

Key words: laser, sensors, welding.

REZUMAT. Ultima perioadă a dus la creşterea accentuată a cercetărilor pentru dezvoltarea aplicaţiilor industriale ale diferitelor procese de sudare cu laser. În mod special interesul s-a concentrat pe dezvoltarea echipamentelor necesare pentru cresterea adaptivităţii sistemelor pentru controlarea proceselor din zona de sudare prin folosirea unor senzori cat mai performanţi. Lucrarea descrie traductoarele pentru dedectarea punctelor caracteristice si deverşi senzori necesari procesului de sudare cu laser.

Cuvinte cheie: laser, senzori, sudură.

1. INTRODUCTION

While the welding process is carrying on, sometime one can observe unwanted influences of process parameters, leading to unsatisfactory welds. Most of those problems are duet o operating errors and process malfunctions rather than tot eh robot itself. Thus, the sole replacement of the welder with a robot cannot guarantee quality welds. Defective, dissimilar preparation of joint border, deformation before – or during the process, defective mounting or assembling of the components are some of the possibilities that can cause poor quality robotized welds, sometime worst than those of a human operator.

In order to inform the control system of the robot about the state and changes in its technological environment, some information caption devices, which can also convert these information in comprehensible signals for the robot are necessary. In order to fulfill correctly the welding task, a robot need to know both geometric and process parameter. According to these categories, we speak about sensors and transducers.

The recent development and introduction of modern welding processes like high speed welding, laser welding etc., emphasize the importance of accurate control of the process. The development of new products from advanced materials also implies decreasing of thicknesses. A result of this is a need to be able to work with tighter tolerances.

Thus, the need is increasing for sensors that can meet the requirements from new processes (Fig.1).

The main task of the sensors is to provide the control system with information to generate proper actions, in order to produce a result that corresponds with defined specifications. Even in arc welding this is not as easy as we might think.

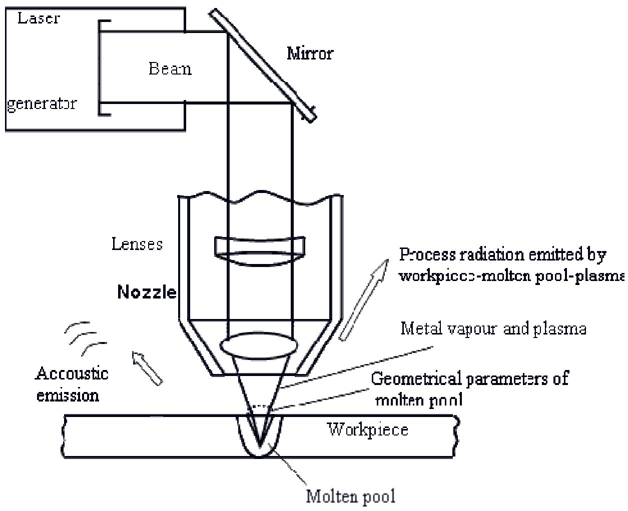

Fig. 1. Process signals during laser welding.

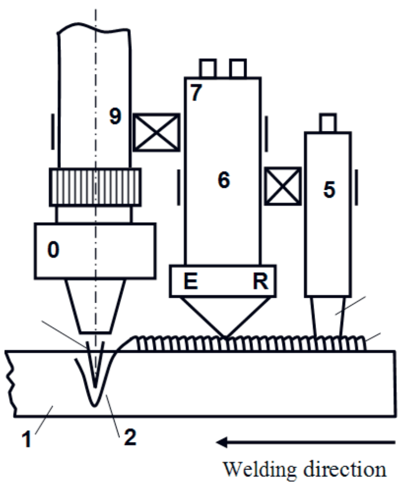

Fig. 2. Complex sensor for determining the relative position towards the workpiece and for controlling and process parameters: *1* – base material; *2* – molten pool; *3* – welded seam; *4* – laser beam for scanning; *5* – low power laser scanning; *6* – IR pyrometer; *7,8* – control circuits for pyrometer; *1* – laser for welding; *10* – air jet blocking curtain; *11* – laser beam.

From a welding process perspective, the process is performed mainly by two subsystems; the welding equipment and the robot (both the torch as well as the workpiece manipulator). The welding equipment includes here the laser power source and the devices that deliver the energy from this, like the laser conduit, the lenses, the welding wire (by LaserHybrid), the torch and so on.

The robot produces the relative positioning of the energy and the work-piece that is to be welded through a weld torch attached to the end effector mounting plate. From a control point of view, both the welding equipment and the robot are important to produce the weld with the specified quality and productivity. They are normally controlled by two different and loosely coupled control systems, controlling the welding power source and the robot arm. As for sensors, they are in most cases used for one of the control systems, either the welding equipment or the robot.

Sensors that measure geometrical parameters are mainly used to provide the robot with seam tracking capability and/or search capability, allowing the path of the robot to be adapted according to geometrical deviations from the nominal path.

Technological sensors measure parameters within the welding process for its stability and are mostly used for monitoring and/or controlling purposes.

As will be discussed later, information from both technological and geometrical sensors provides a basis for a qualitative control of the welding process to make it possible to conform to specifications defined within a WPS (Welding Procedure Specification) concerning quality and productivity measures. Another issue of importance is the mapping problem between observable parameters and controllable parameters with respect to the sensor. In the simple case with a sensor based seam tracking of almost straight welds, the feedback control is straightforward, but applying the sensor data for integrated control related to the WPS will require a more sophisticated model-based control approach.

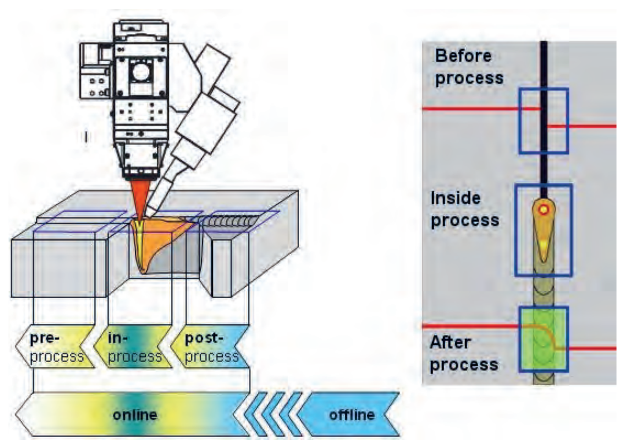

Fig. 3. Categories of sensors according to their the position relatively to the welding head.

The advantages of laser welding over the conventional welding processes in terms of flexibility, speed and weld quality are now well recognized. Indeed many applications of lasers to welding in industry have already been accepted. As more welding systems are being installed by industry, the demand increases for the development of in-process techniques to monitor and control the process quality. This is necessary since weld quality is often affected by the instability of plasma formation during laser welding and instabilities of laser power density.

There are many physical principles already investigated for detecting the weld quality during laser welding, which include:

- The measuring of the retro diffused optical radiation, especially an acoustic mirror which detects the high frequency; component of back reflected laser;
- An acoustic workpiece which detects the workpiece internal stress waves generated during laser welding;
- A photo-electric sensor for detecting plasma intensity;
- A probe laser for detecting melt ripple and plasma diagnosis, as i.e. *(5*) in Figure 2;
- A pyrometer for detecting the temperature near the melt pool, like (*6*) in the a.m. Figure;
- A video camera for monitoring the interaction zone shape.

The laser-material interactions that occur during laser welding emit energy in a variety of forms. Optical and acoustical process signals can be measured from the emissions of the welding using suitable sensors. Since the signals contain information about the beam-material interaction, welding defects can be detected during the process and recorded for each single work piece.

We can distinguish three main categories of sensors according to their the position relatively to the welding head, as shown in Figure 3 :

- the „pre-process" sensors, which proceed the welding head ;
- the „in-process" sensors, placed directly in the interaction zone beam/work piece – or the using of the laser beam itself and/or the generated phenomena ;
- the „post-process" sensors, situated in a rear position according the welding head .

The interactions that occur between the laser and the material during laser welding generate energy in a variety of physical forms.

One can measure either optical or acoustical process signals from the emissions of the welding pool using adequate sensors. These signals contain information about the laser-material interaction : we can therefore on this basis detect welding defects online (during the process) and record them for each workpiece.

Figure 1 is presenting the principal detectable emissions, which can be used as the process signals. The reflected laser is, largely, the amount of the laser source radiation which is not absorbed by the material. A more accurate evaluation is given by the relation (1) :

$$\Phi_{laser} = \Phi_{refl} + \Phi_{retrod} = (1-\eta)*\Phi_{laser} + \Phi_{retrod} \quad (1)$$

We identify two kinds of acoustic emissions : the airborne and the structure-borne emissions. These are generated by the stress waves, which are caused by changes in the workpiece, the surface the metal vapor and from the molten pool. The last ones, together with the metal vapor generate optical radiation in a spectrum which depend on the laser type and application. [For example, in the case of Nd: YAG-laser spot welding, the process emits radiation in the visible and near infrared range.

By welding with CO_2 laser, using the keyhole technique, the plasma emits a light with a wavelength between 190nm and 400 nm. The hot vapor and the spatter are generating optical radiations with λ between 1000nm and 1600 nm. The geometrical parameters of the keyhole and those of the molten pool also contain useful information for determining the width and penetration of the seam.

Thus, they can be used to control online (during the welding operation) the seam parameter.

From the interaction between the intense laser light with the shield gas and the metalic vapor emitted by the molten pool a plasma column is generated. Its optical emission take place in near UV or in the visible spectrum, while the cooler molten pool emits IR radiations. An interesting acoustic emission occurs – something like a buzz – which sounds harmonic when we have a good coupling of the laser beam with the workpiece .

Both the acoustic and the optical specific emissions one register in laser keyhole welding are influenced by the power and intensity of the beam as well as by the shield gas and material characteristics.

Table 1. **Comparison between different sensor, capable of monitoring the laser welding process**

Sensor Type	Complexity	Price	Processing capacity	Signal	Characteristic
Ge/Si Photodiode	Reduced	Low cost	Reduced	Molten pool	1000-1900 nm
In/As/Ga Photodiode	Reduced	Low cost	Reduced	Molten pool	800-1700 nm
Thermistor	Reduced	Low cost	Reduced	Molten pool radiation	UV and IR
Microphone	Reduced	Low cost	Medium	Acoustic emission of the keyhole	20 Hz-20KHz
IR Camera	High	High cost	Good	Base material and seam	Near IR
CCD Camera	High	Medium cost	High	Welding process	Near UV; Near IR
Ga/Ph Photodiode	Reduced	Low cost	Reduced	Emitted plasma	200-525 nm

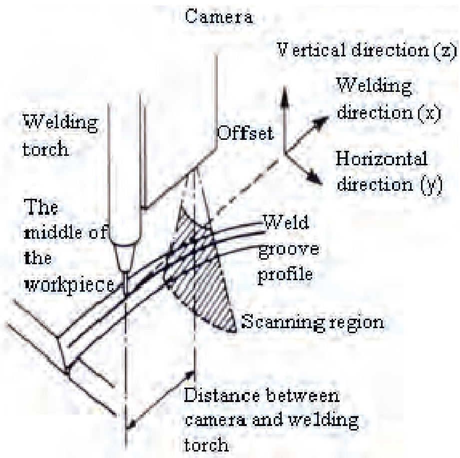

Fig. 4. Working geometry and camera positioning in "look-ahead" configuration (tandem welding) [5].

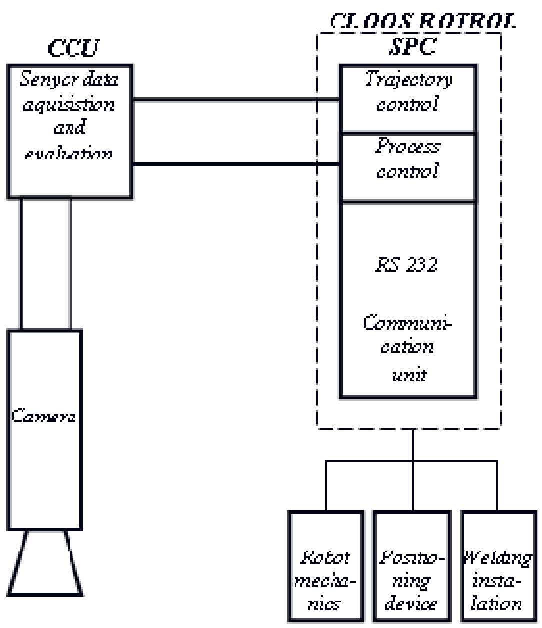

Fig. 5. Schematic of the working principle for laser guided sensors SEAMPILOT [6].

Beside photo diodes and thermal sensors, which detect UV respectively IR optical emissions, CCD or analog type cameras can be used for weld pool monitoring. On their results other geometrical parameter as i.e. penetration can be determined. The sensor described in Table 1 ensure captions of different radiations emitted by the laser welding process where metal vapor fumes and spatter are frequent . Thus the observation windows must be kept clean – by blowing strong gas or air jets. By their aerodynamic effect, these jets obstruct the a.m. impurities to disturb the sensors correct functioning. For the (analog) video cameras we must ensure a scene back lighting – either with laser having quite different wavelength than the welding laser or with stroboscopic light sources.

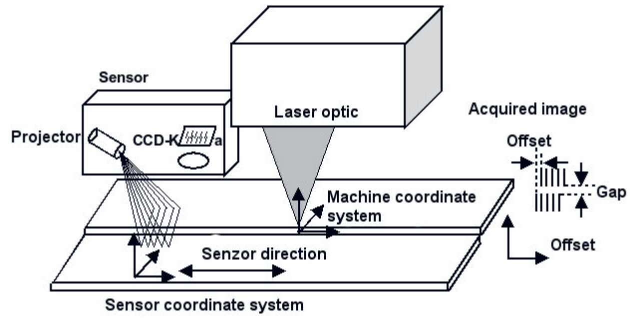

Fig. 6. Design principles and positioning of the CCD camera sensor in accordance with weld seam; explanations of different coordinate systems, according to [7].

A. Analog or CCD video camera based sensors. IR vision cameras do not need the background illumination because plasma emits in the UV spectrum. They generate nevertheless a large amount of information whereas is a need to be processed online. This is the reason for which simpler, CCD based systems prevail for both the seam tracking as well as width pool or seam leg monitoring.

B. Acoustic emission based sensors. During the last decade, many researchers have examined the sensors based on acoustic signals generated during the process (as coherent signals for the quality and of the welded seams.

In the first process phase (till a keyhole is established) the source of the acoustic signals is the vapor emissions trough the keyhole from the pool.

The frequencies of the acoustic signals tend to modify at a higher intensity beam (this generates a deeper keyhole). The acoustic signals are modified by plasma ignition and workpiece surface phenomena too. With established keyhole, the metallic vapor can escape through it, which change the frequency and intensity of the acoustic signal. The positioning of the detector is also important since the strength of the acoustic signal decreases inversely with the square of the distance from the source to the acoustic detector. The acoustic emission is converted into an electric signal which can be measured and used as a process parameter in control loops.

Fig. 7. The key hole, a characteristic for laser welding.

The acoustic signals transmitted through the air has a frequency spectrum of some 16 Hz up to 20,000 Hz. As a sensor special microphones (Fig. 8,*b*) are placed nearby the molten pool or on its vicinity (Fig. 8,*a*). Sometimes concentrators (as the nozzle presented in Fig. 8,*b*) or reflective acoustic mirrors (*5* in fig. 8) are employed.

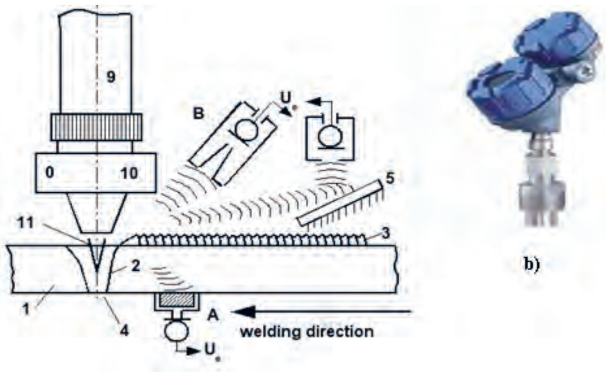

Fig. 8:
a – placement of acoustic sensors in laser welding: *A* – directly on the table; *B* – at the end of a positioning device; *C* – in front of a mirror; *b* – special microphones.

As presented in figures 9-11 one can see the welding seam from above and the weld root from below of some laser welded joints, that were done with help of different type of trajectory guiding and also weld process adaptation capable sensors.

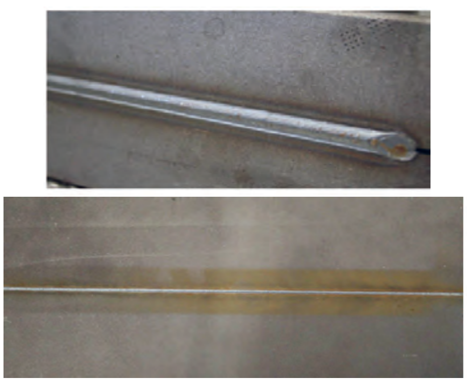

Fig. 9. Front and back side of weld joints, welded using LaserHibrid procedure on 6mm thick plates consisting of the material St 37.1; notice the extreme thin assembling of the weld groove (approx. 20°).

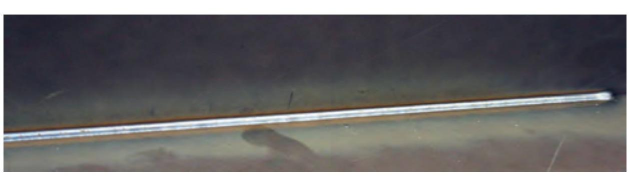

Fig. 10. Aspect of a weld join obtained on steel 1.4541 plate using brazing with CuAl8.

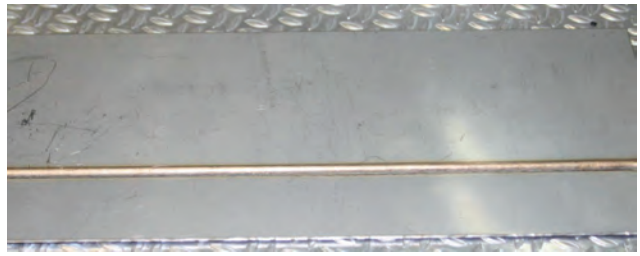

Fig. 11. Butt welds with 2.5 mm thick OL 37.1 plates.

The liability of the shape recognition by optical methods has very much advanced in last two decades. Nevertheless, the use of the laser sensors is still limited : i.e. in multilayer gas shielded welding there is difficult to sense optically the differences between the base metal and the gap. As similarly, the welding of aluminium, stainless steel and highly polished steel surfaces are practically at the limit of a laser sensor. This sensor is much easier to use on dark plates, i.e. those oxidized.

Using high speed [laser] cameras and suitable high speed processors, the laser sensor can follow seam irregularities at welding speeds reaching 12 m/min.

In industrial media with usually imprecise metal structures the use of only one sensor is seldom sufficient : in order to insure an optimal quality is necessary to combine two or more optical sensors as it is presented in Fig. 12.

Fig. 12. Tandem® welding head with two optical sensors : a laser one for the shape (left) and a classical position detector (right).

By using one or more of the above described sensors, one can gather good quality 2D or 3D pictures of the welding gap. Based on the desired measuring criteria the proper captured image is chosen.

Due to the diversification of domains where computers are utilized, the recent breakthroughs in micro processor technology and due to the elaboration of new strategies in signal processing, optical laser sensor technology enjoyed continuous development and perfection.

Object recognition has been much improved lately. But the use of these kind of sensors is still limited, for example, in multilayer welding with gas protection before the final layer when the weld groove is almost at the same level as the margins of the workpiece in some cases groove geometry is very difficult to recognize. As well as in cases were the welding joints surfaces are very smooth and shiny (aluminum or high grade steel) these situations are at the very limit of laser sensor technology. This technology works much better on darker metals (surfaces) for example those covered with slack.

With the use of high speed cameras and fast computers laser sensors were able to function at welding speeds of 12m/min.

In the most cases the use of one sensor is not enough, we need to combine different types of welding sensors to get the optimum quality welds. In the present, progress in robotic laser welding technology is based on the advances made in the fields of groove geometry and seam searching sensors technologies.

BIBLIOGRAPHY

[1] **Dilthey, U.** et al. *Laserstrahlschweissen: Prozesse, Werkstoffe, Fertigung und Prufung*, DVS Verlag GmbH Dusseldorf, Germany 2000

[2] **Seyffarth, P.** and **Krivtsun, I.V.** *Laser-Arc Processes and Their Applications in Welding and Materials*, Treatment, Taylor & Francis, New York, 2002.

[3] *** *Apparatus and method for monitoring laser material processing*, US Patent 5247155 1999, Philadelphia, U.S.A.

[4] Hongping Gu et al: *A statistical approach to acoustic monitoring of laser welding*, 1996 J. Phys. D: Appl. Phys. 29 556-560

[5] **Joni, N., Trif, I.N.** *Sudarea robotizată cu arc electric*, Editura LuxLibris, Braşov, 2005, 300 pagini

[6] *** *Seampilot® Laser Sensor System for Robotic Welding*, 2000, Edited by Carl Cloos GmbH, Haiger, Germany

[7] **** *Pat. 5674015 – Methods and apparatus for realtime weld monitoring*, Un.St. Patent Published 17th October 1999, Chicago. IL.