Automatic control system of high precision welding of workpieces in mechanical engineering

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Abstract. In this paper, based on the conducted patent research, the system of laser welding control with different geometry of weld and shapes of parts is developed. The method of monitoring the position of the spot of laser radiation in relation to the curved weld is worked out; it is based on the tracking the edges of the welded parts by low-power laser radiation reflected from the surface of the parts. It allows to make the positioning of the focus of laser radiation in relation to the juncture of the welded parts automatically.

1. Introduction

One of the trends of modern engineering is the widespread use of automated system of laser welding as one of the effective ways to reduce the costs of production by increasing the ratio of utilization of materials [1]. Provision of stability of properties and quality of weld, as well as high economic indicators, requires the application of automatic control system in the technological process (TP). Elaborated and currently used technological methods do not allow to solve fully all the problems of automation of the welding process in mechanical engineering.

2. Basic part

The quality of the obtained product has a complex dependence on the technological parameters of the process (radiation power density, speed of the movement of laser radiation, gaseous atmosphere, etc.) that causes the need to control the process by maintaining those parameters within the required limits. [2] This necessitates the use of new approaches to the control of the process of high-precision laser welding and improvement of automatic control system (ACS) TP.

To control the position of the focus of laser radiation (LR) in relation to the workpiece is possible using 4 - quadrant photo detector (PD) [3]. A sensitive layer of the multi-element coordinate photo detector (MCP) consists of several individual elements enclosed in a single housing. MPC application simplifies the construction of certain types of opto-electronic converters, as it excludes the mechanical scanning. Receiving information from the platforms of multi-element coordinate photo detector is performed with the help of high-speed commutators, which allow to determine the locus of the spot of LR in relation to the weld [4]. Fig. 1 shows the location of the spot of LR on the photosensitive platform.
Fig. 1. The location of the light spot on the platforms of 4-quadrant photo detector.

When you change the curvature of the weld, there is a change in the ratio between the internal resistance of the illuminated and unilluminated surfaces of MCP platforms. This leads to a change in the differential values of resistance of platforms. Rotation of MCP to the angle $\Delta \phi$ allows to balance these ratio, as well as to calculate the control signal to the drive of MCP by the worked out algorithm, taking into consideration the spatial positions of MCP and the optical system LTC [5].

Linearity region of the output signal $V_x(x)$ and $V_y(y)$ is defined by the inequalities:
$$x < l \quad \text{and} \quad y < l.$$ 

As it can be seen, when there is a quadratic light spot and parallelism of diagonals of the square to the axes $x$ and $y$, the mutual influence of axes is absent.

The calculation of active resistance of the photosensitive layer of photo detector shows its dependence on the area of illumination:
$$R_{\phi_{p}} = \frac{\rho_{n}\rho_{o}l^{2}}{dl[(x-\Delta x)\rho_{n} + \Delta x\rho_{o}]} = \frac{\rho_{n}\rho_{o}l^{2}}{dl[(S_{n} - S_{o})\rho_{n} + S_{o}\rho_{o}]}.$$ 

where $R_{pc}$ - resistance of the photosensitive layer, $\rho_{N}$, $\rho_{O}$ - resistivity in accordance with unlit and lit sites of photo detector;
1 - length of the photosensitive platform;
$S_{n}$, $S_{o}$ - area of the photosensitive layer, according to unlit and lit surfaces of photo detector.

As follows from the calculations, correction of MPC drive of the remote measurement of LR focus position on regard with the angle displacement between the optical axes of MCP and the tangent of the weld at the point of LR interaction with metal is defined by the following formula [6]:
$$\Delta \phi = f \left( R_{\phi_{In}} - R_{\phi_{Il}} \right),$$

where $\Delta \phi$ is increment of the angle displacement between the optical axis of the photo detector and the tangent of the weld at the point of interaction of laser radiation with metal; $R_{PD_{p}}$, $R_{PD_{n}}$ is a resistance of the photosensitive layer according to the complete and unlit surfaces of the photo detector.

However, the focal length of the laser backlight changes for the parts of complex shapes, which leads to an increase of the spot on the 4 - quadrant PD. To exclude this effect, it is necessary to create a parallel beam; it can be provided with the help of the collimator.

When submitting laser radiation on the weld, it’s displacement in relation to the curved juncture and parts of complex shape is possible. To reduce the positioning error of LR,
channel is introduced; it is based on the backlight of the juncture by the low-power laser and reception of the reflected radiation by the four-quadrant photo detector [7]. After processing on the corresponding units of ACS LTC, the error signal arrives to MCP, where the processing of received information according to the given algorithm takes place, and the error signal is issued through the NC on the appropriate drive. As the focal length of the low-power laser with a certain divergence of laser radiation will change according to the distance of the optical system to the part surface, it is necessary to apply the collimator, which converts the divergent beam of LR into a parallel one. Therefore, the diameter of the reflected radiation, which reaches a four-quadrant photo detector, remains practically unchanged, it reduces the positioning error of the beam of LTC. Correction of the positioning is carried out by the drives. Flowchart of the worked out ACS LTC is shown in Figure 2.

\[
T = \frac{h \nu}{4\pi} \cdot \frac{Ag}{Z} \cdot Ni \exp\left(-\frac{E}{KT}\right),
\]

where \(\nu\) - frequency; \(E\) - power of drive; \(g\) - statistical weight of level; \(A\) - transition probability; \(h\) - Planck constant; \(k\) - Boltzmann constant; \(T\) - temperature; \(Z\) - statistical sum; \(Ni\) - ion concentration.

When using this formula, the temperature of the investigated zone of the source of spectrum of radiation is estimated [9], it determined a definite value of the ratio of line intensities \(I_1 / I_2\), according to which it is equal to:

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Fig. 2. Flowchart of ACS LTC of laser welding of metals.
Using the known PD, providing the combination of plane of analysis of polarizer of one of the photosensors with the plane of polarization of the analyzed radiation \([10]\), it is possible, by measuring the voltage of photosignal from the sensors, to determine the degree of linear polarization of the incident radiation by the formula:

\[
P = \frac{S_1}{S_0} = \frac{J_{y=0} - J_{y=90}}{J_{y=0} + J_{y=90}} = \frac{U_{y=0} - U_{y=90}}{U_{y=0} + U_{y=90}},
\]

using the well known PD, one can determine the degree of linear polarization of radiation, azimuth of which coincides with the plane of the analysis of one of the polarizers of PD.

Measuring voltage of photosignal, we can calculate the degree of polarization \(P\) and azimuth of polarization \(\psi\) of the analyzed radiation:

\[
P = \sqrt{S_1^2 + S_2^2}, \quad S_0 = \frac{\sqrt{(U_{y=0} - U_{y=90})^2 + (U_{y=45} - U_{y=-45})^2}}{U_{y=0} + U_{y=90}},
\]

\[
\psi = \frac{1}{2} \arctg \frac{S_2}{S_1} = \frac{1}{2} \arctg \frac{U_{y=45} - U_{y=-45}}{U_{y=0} - U_{y=90}},
\]

3. Conclusions

The method of monitoring the position of the spot of laser radiation in relation to the curved weld is worked out; it is based on the tracking of the edges of welded parts by low-power laser radiation reflected from the surface of parts. This allows to conduct the positioning of the focus of laser radiation in relation to the junction of the welded parts automatically. As a result, it reduces the impact of vibration of the welded parts and the laser head on quality indicators of TP.

3. References

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