Method of control position of laser focus during surfacing teeth of cutters

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Abstract. Providing the quality laser of surfacing the edges of teeth requires control not only the energy of the radiation parameters, but also the position of the focal spot. The control channel of position of laser focus during surfacing, which determines the parameters of quality of the deposited layer, was calculated in the work. The parameters of the active opto-electronic system for the subsystem adjust the focus position relative to the deposited layer with a laser illumination of the cutting edges the teeth cutters were calculated, the model of a control channel based on thermal phenomena occurring in the zone of surfacing was proposed.

1. Introduction
The main role in the development of the industry belongs to tool production, which determines the level of the productive forces of the entire industry. To meet the needs of mechanical engineering, metalworking and other industries in the metal cutting tools necessary to significantly improve the quality, improve operating techniques. The quality of the tool depends on the design, material, manufacturing technology, the type of surface thermal treatment. Modern technologies of tool manufacture are: the use of powder metallurgy; automation of technological processes, the use of automatic line laser technological complexes; application of methods of thermal and thermo-chemical treatment, wear-resistant coating; extension of the scope of thermal processing methods. These areas, ultimately, contribute to the solution of the main tasks of increasing efficiency of production and quality.

2. Automatic control system of the laser technological complex
Stabilization of energy parameters in the zone of interaction of laser radiation (LR) to the metal during surfacing and improving the accuracy of positioning its focus with respect to the cutting edges of teeth cutters, is the best way of building automation systems, laser technological complex (ACS LTC). This leads to the challenge in meeting the requirements for the quality of the technological process (TP) surfacing [1, 2].

Tracing the trajectory LR accurately focus movement provides non-contact methods, in particular, based on measuring as the light flux of the thermal radiation of metal, as well as reflected from the
plane cutters teeth [3]. The solution of the control focus position LR is it possible with the help of photodetectors line (PL) [8].

On the basis of the energy balance:

\[ W_{LR} + W_{Boost} + W_{Light pressure} = W_{Melting} + W_{Mechanical} + W_{Reflections} + W_{Kinetic}, \]

where \( W_{LR} \) - energy is supplied to the treatment zone LR, J; \( W_{Boost} \) - energy shielding gas pressure, J; \( W_{Light pressure} \) - mechanical energy of the impact on the metal surface of LR, J; \( W_{Melting} \) - the energy expended on melting metal; \( W_{Mechanical} \) - the energy of the mechanical oscillations in the metal, J; \( W_{Reflections} \) - reflected energy from the interaction zone LR metal, J; \( W_{Kinetic} \) - the energy expended on the flight of the molten metal particles, J.

It can be stated that \( W_{Reflections} \) is about 10% of the \( W_{LR} \) energy as the metal temperature exceeds the melting point and the co-absorption coefficient LR melt is 0.9.

Providing high accuracy of the trajectory of the laser head, it requires a clear boundary illumination sites photodetectors, to this end, we make the calculation laser illumination channel. Area illumination diameter of 10 mm is formed in the channel laser illumination at a distance of 150 mm from the lens by a semiconductor laser \( \lambda = 0.84 \) m with an angle of divergence of the laser beam is then 40° [4].

In laser illumination channel illumination area of this size is relatively large and so it does not require such a high quality in image forming optical systems, the lens is made of a single lens [5-6].

The distance from the front surface to the first focus lens is 22.3 mm. The calculated wavelength is 0.84 microns. The focal distance is 25.1 mm.

Select channel optical parameters of the photodetector for the reflected total radiation requires accounting for such requirements and constraints as:
- the linear dimension of the subject area (plane cutters teeth) quality image which is to be formed in the photodetector plane - 10 mm;
- aberration circle diameter (maximum) - 10 microns;
- image size PL element in the plane of the teeth cutters - 20 microns;
- the number of sensitive elements in the line PL (minimum) - 500;
- the distance from the lens to the plane of the cutter teeth - 150 mm;
- adequacy of PL exposure level of sensitive elements of the illuminated laser tooth plane (power rating, see below);
- use AF type DALSA line with the size of the sensor 14x14 microns or 13x13 microns.

The required focal distance \( f' \)’s lens and the distance from the lens to the PL to obtain a first approximation of geometric optics formulas for thin lenses.

\[ s' = f' + x' = 150, \]
\[ \Gamma = x'/f' = f/x = s'/s = 1.5, \]

here \( s = 100 \) mm, \( f' = 60 \) mm.

These requirements for the optical system PL channel implemented in three lens. The design parameters of the lens are shown in Fig. 1.
Figure 1. Progress beams and structural parameters of the channel OP: 1, 2, 3 - lens; 4 - mirror.

The calculated wavelength is 0.84 microns. The focal length of 71.3 mm. The distance from the focus F to the front surface of the first lens, 85.5 mm. Distance from the PL to the first surface of the lens 133 mm. The distance from the last surface of the lens to the back focus F' = 42.8 mm.

Flat-breaking mirror installed between PL and lens will reduce the size. With similar mirrors can be optimized size of the PL optical channel. Flat mirror does not affect the image quality [7-8].

Calculation of indicators of the quality of the lens, made in the program «Zemax». Diagram of scattering spots was created in the plane of the tooth for the field of views corresponding to a deviation from the optical axis 0, 3, 8 and 5 mm. Scattering circle diameter does not exceed 5 microns.

Energy assessment will show sufficient irradiance PL sensor elements at the chosen parameters of the laser optics channel and photodetector channel [4].

Initial data for calculation:
- power laser, \( P_l = 0.2 \) W;
- laser lens channel transmission \( \tau_l \), not less than 0.8;
- threshold exposure of photodetector at \( \lambda = 0.84 \) m, \( N_{thr} = 13 \times 10^{-12} \) W · s/ cm\(^2\);
- exposure of photodetector saturation at \( \lambda = 0.84 \) m, \( N_p = 23 \times 10^{-9} \) W · s/ cm\(^2\);
- transmission of lens of photodetector channel with mirrors, \( \tau_{ph} = 0.8 \);
- coefficient of the metal reflectance in the tooth plane, \( \rho = 0.7 \);
- laser spot area at the tooth plane \( S_l = 0.8 \) cm\(^2\);
- half aperture angle of lens of photodetector channel, \( \alpha = 2.86^\circ \);
- bodily aperture angle lens of photodetector channel \( \Omega = 2 \pi (1 - \cos \alpha) = 0.0078 \) cp;
- linear increase lens in the direction from the photodetector to the tooth plane, \( \Gamma = 1.5^\circ \).

The calculation is as follows. Power illumination (irradiance) of the laser in the plane of the tooth:

\[
E_s = P_l \tau_l / S_l = 0.2 \times 0.8 / 0.8 = 0.2 \text{ W/cm}^2.
\]

Energy brightness laser spot:

\[
B = E_s \rho / \pi = 0.2 \times 0.7 / 3.14 = 4.45 \times 10^{-2} \text{ W/(cm}^2 \cdot \text{sr)}.
\]

Irradiation in the plane PL:

\[
E_{ph} = B \Omega \tau_{ph} \Gamma^2 = 4.45 \times 10^{-2} \times 0.0078 \times 0.8 \times 1.52 = 0.6 \times 10^{-3} \text{ W/cm}^2.
\]

In the case of a standard charge accumulation photodetector \( t_n = 25 \) microseconds threshold
irradiance of photodetector

\[ E_{\text{thr}} = N_{\text{thr}} / t_n = 13 \times 10^{-12} / 25 \times 10^{-6} = 0.5 \times 10^{-6} \text{ W/cm}^2. \]

This implies that the signal / noise ratio will be

\[ E_{\text{fp}} / E_{\text{thr}} = 0.6 \times 10^{-3} / 0.5 \times 10^{-6} = 1200. \]

Limit charge accumulation time must not exceed

\[ t_{\text{max}} = N_p / E_{\text{fp}} = 23 \times 10^{-9} / 0.6 \times 10^{-3} = 38 \times 10^{-6} \text{ c}. \]

3. Conclusion

It can be concluded that the calculation of the energy assessment of laser illumination of the weld shows sufficient irradiance sensor elements of the photodetector line (PL) at the chosen parameters of the laser optics channel and photodetector channel.

The presented method of controlling the position of the laser focus relative to the plane of the tooth with considering calculated geometry can significantly improve the quality of welding.

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