In modern mining and processing industries, ore-grinding mills are widely used for crushing rock mass. Gearboxes are one of the most loaded and responsible elements of the mill, which determines the reliability and durability of the equipment as a whole. The analysis of damage of gear wheels shows that their premature failure is caused mainly by the processes of destruction in the surface layers of the teeth.

One of the most promising areas for the development of modern production is the introduction of intensive surface hardening technologies for large-scale gears using concentrated energy sources [1]. Particularly advantageous for massive parts is the plasma surface hardening (PSH), due to the high thermal power and the possibility of obtaining hardened layers of considerable thickness (up to 5 mm) [1-3]. However, the properties of the hardened layers after surface plasma-arc hardening have not been sufficiently investigated, and rational ways to conveniently regulate the specific power in the plasma arc heating spot have not been proposed, as a consequence, it is not possible to use the large electrical power required to improve the heat.

The purpose of this work is to improve the technology of production of mining machines, namely – the development and optimization of the parameters of the process of surface hardening of large-modulus gear wheels to increase the durability, longevity of gear drives of ore mills. The stated purpose of the work necessitated the solution of such problem as optimization of technological parameters of the regime of surface plasma-arc hardening by mathematical modeling in order to identify their influence on the relative lifetime of large-modulus gears.

In the conditions of PSH, the efficiency of the plasma arc, as a source of heating, depends significantly on the ratio of the size of the thermal source, its speed and thermal power; it is rational to consider such a ratio in which the temperature of the
heated surface at the back boundary of the heating spot reaches, but does not exceed, the melting temperature for the material.

The analysis of the features of the operation of open gears made it possible to conclude that it is advisable to use economic indicators to determine the optimal service life.

The minimization of the economic criterion associated with the specific costs of maintenance and repair, taking into account the cost of manufacturing gears when using PSH, made it possible to estimate the optimum operating time of open gears. In order to investigate the influence of the gears of the gears on the speed of movement of the heating source and the current of the plasma arc, an active experiment was organized by using a sequential simplex method, which made it possible to isolate the optimal surface area of the response surface.

A nonlinear stochastic model described by a second-order polynomial was used to study the area of the optimum response surface. The use of composite rotatable experiment planning made it possible to synthesize a mathematical model. Subsequent statistical analysis of the simulation results allowed the Student's criterion to filter out the insignificant coefficients of the mathematical model and to establish its adequacy by applying the Fisher test.

A detailed study of the optimum region found by constructing the isolines indicated the presence of many solutions located on the optimal isoline (Fig. 1). To find the optimal solution, an economic criterion was proposed that determines the total costs associated with the magnitudes of the movement of the heat source and the plasma arc current. The minimization of this criterion within the limits of the optimum insulation made it possible to determine the best values of the speed of movement of the heating source and the current of the plasma arc to ensure the optimum life of the gear wheel, the surface of which is subjected to PSH.

![Fig. 1. Isolines of the response surface](image)

Analysis of the graphs (Fig. 2), shows that the minimum economic losses occur at $t = 0$, i.e., at the left end of the optimal line:

$$
\begin{align*}
V &= 350 + 73.4t, \\
I &= 246.25 + 3.75t \quad (0 \leq t \leq 1),
\end{align*}
$$

where:

$V$ – the speed of the source movement; $I$ – the current strength; $t$ – Student’s $t$ test.
Thus, the optimal values of the factors in the process of PSH are $V_{opt} = 350 \text{ mm/ min}$, $I_{opt} = 245 \text{ A}$.

Conclusions. As a result of mathematical modeling, the influence of the parameters of the surface plasma-arc hardening mode on the relative lifetime of large-modulus gear wheels $x$ is revealed. This made it possible to obtain optimum ratios of process parameters that provide the best performance with respect to the wear resistance of the working surfaces of large-scale gears ($V_{opt} = 350 \text{ mm / min}$, $I_{opt} = 245 \text{ A}$).

References: