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Optimization of babbit milling processing methods using a machine module for big bearings treatment

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Abstract. This article describes optimization of babbit milling processing methods under conditions of reduction treatment of sliding surface area of big bearings using a special machine module. The aim of the optimization is to increase efficiency while maintaining target quality of the treated surface. Optimizable parameters include feed per hob tooth and cutting speed expressed in terms of the mill rotation rate which have the greatest impact on the treatment time and surface quality parameters. The linear programming method is used, and the following engineering constraints are taken: surface roughness, set tool life, main motion drive power, treatment time relevant for the efficient life, allowable cutting temperature. The optimization is performed in two stages: a set of inequalities is solved at the first stage, and the obtained values are adjusted at the second stage.

1. Introduction

Big sleeve bearings are widely used in construction and mining as components of such units as autogenous mills, semi-autogenous mills, drum driers, trommels and other large-sized rotating equipment.

The traditional technology of remedial treatment of big sleeve bearings, which is generally carried out at the operational site, has some significant disadvantages. In particular, these are hand scraping applied as the final method of the sliding surface area treatment, which is characterized by low efficiency, high cost and unstable quality depending on the qualification of a worker [1].

A special machine module (figure 1) is designed for enhancement of the efficiency of the large bearings sliding surface area treatment [2]. The movement over the radial surface of a segment of a big sleeve bearing is the design feature of such a machine module. The line feed motion is kinematically implemented by means of the four-bar crank-and-slot mechanism. The rotary motion is transmitted to the crank from the electric motor through the reduction gear. The link and the rocker arm convert the rotary motion of the crank into the swinging motion of the rocker arm shank, on which the cutting tool is located. There is one cutting run and one idle run of the cutting tool with return to the initial position in one complete rotation of the crank. Cross feed motion occurs at the end of the full operation cycle of the mechanism – the operating and idle runs. Tool withdrawal and cross feed are carried out by means of stepping motors, which are activated when the mill crosses the laser sensor beam. The main motion – axial rotation of the mill – is driven by the asynchronous motor [3].

The design of supporting structures in the form of special grooves, matching grooves of a sleeve bearing, allows matching the axis of the sleeve bearing sector and the rotational axis of the swing frame, which ensures the treatment accuracy.

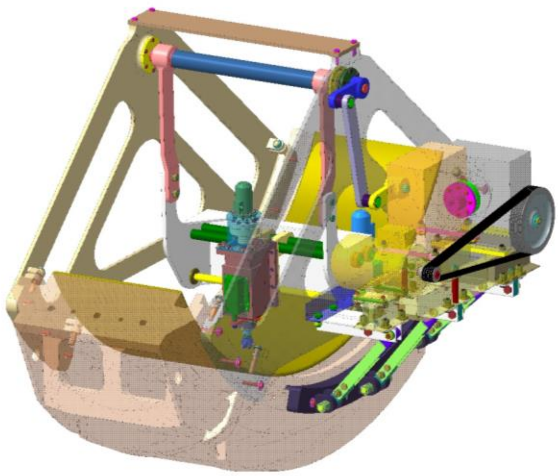

Figure 1. Overall view of a special machine module for big bearings treatment.

2. Materials and methods.

Efficient use of the suggested equipment requires the optimization of process parameters in order to ensure its maximum performance while maintaining the set parameters of treatment quality [4].

Feed per hob tooth and cutting speed are taken as optimized parameters since these parameters have most impact on processing performance. Moreover, feed significantly affects surface roughness and cutting power, while cutting speed determines the tool life. Figure 2 shows the optimization structural elements diagram. The input parameters include cutting conditions (material grade, mill diameter, a number of teeth, milling width, cutting depth) and structural parameters of the treated bearing segment (diameter and width), which have impact on the overall treatment length on a pass. The following technical restrictions are assumed: an allowable cutting temperature, set roughness to be achieved on a pass, main motion drive power, set tool life [5]. The output parameters include: treatment time, efficient cutting power, an actual cutting temperature.

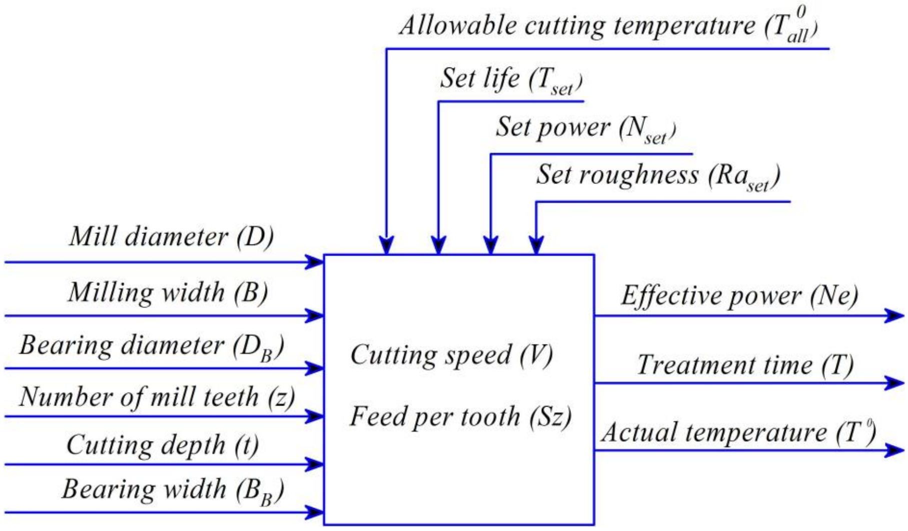

Figure 2. Optimization structural elements diagram.

Figure 3 shows the optimization algorithm which consists of two main stages. Once the initial data are determined and the process restrictions are set, the primary optimization problem is solved at the first stage, subject to the set restrictions without regard to the surface roughness restriction. The set tool life, allowable temperature and cutting power serve as the restrictions [6]. The values of the

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optimized modes, which ensure compliance with the set restrictions, are obtained as the output parameters.

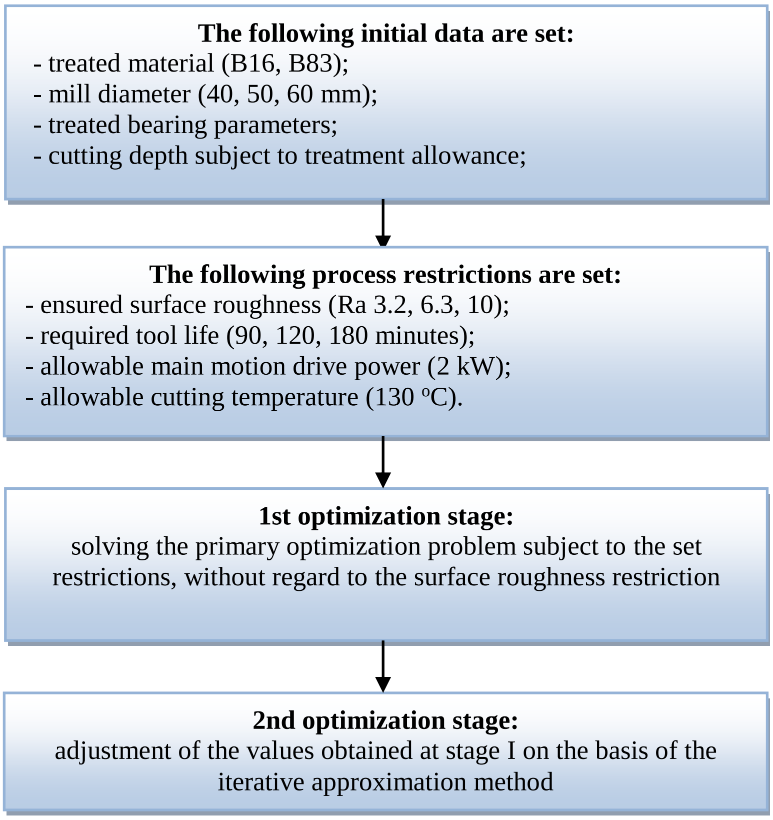

Figure 3. Optimization algorithm.

The obtained values are adjusted at the second stage subject to the surface roughness restriction; the optimized cutting speed is fixed since it does not significantly affect roughness value. The required surface roughness value is achieved by the feed adjustment using the iterative approximation method. The second stage is necessary since the function of the surface roughness of the process parameters is a function of second order having quadratic and pairing terms. Therefore, it is characterized by the complex linearization unlike other restrictions set by power functions.

3. Results.

The optimization requires establishing of mathematical relations between the optimized parameters and the target function, as well as the system of process restrictions.

The cutting power restriction establishes the relation between the power consumed by the cutting process and the optimized parameters (feed and cutting speed) [7, 8]. The mathematical expression of the main motion drive power during milling has the following form:

$$Ne = \frac{Pz \cdot V}{1020 \cdot 60} \tag{1}$$

where P_z is tangential cutting force, H; V is cutting speed, m/min.

The following empirical dependence obtained during the experimental studies is taken as tangential cutting force:

$$Pz = 336\,\frac{t^{0.85} \cdot Sz^{0.75} \cdot B^{1}}{n^{0.1} \cdot D^{0.8}}, \tag{2}$$

where t is cutting depth; S_z is feed per hob tooth, mm/tooth; B is milling depth, mm; n is mill rotation rate, mm/r; D is mill diameter, mm.

After the conversion of equation (1) subject to (2), having expressed the cutting speed in terms of the mill rotation rate and transferred the optimized parameters to the left side, we obtain:

$$Sz^{0.75} \cdot n^{0.9} = \frac{Ne}{1.72 \cdot 10^{-5} \cdot t^{0.85} \cdot B \cdot D^{0.2}} . \quad (3)$$

Equation (3) is transformed into the linear form by taking the logarithm, multiplying the feed by 100 in order to obtain values of the same order:

$$0.75 \ln(100 \cdot Sz) + 0.9 \ln n = \ln(\frac{Ne \cdot 100^{0.75}}{1.72 \cdot 10^{-5} \cdot t^{0.85} \cdot B \cdot D^{0.2}}) . \quad (4)$$

The following notations are introduced:

$$\ln(100Sz)=x_1 , \ \ln(n)=x_2 , \quad \ln(\frac{Ne \cdot 100^{0.75}}{1.72 \cdot 10^{-5} \cdot t^{0.85} \cdot B \cdot z \cdot D^{0.2}}) = b_1 . \quad (5)$$

The linear inequality is obtained which is the restriction that establishes the relation between the optimized parameters and effective cutting power:

$$0.75 \cdot x_1 + 0.9 \cdot x_2 \le b_1 . \quad (6)$$

Other restrictions are formed similarly. The restriction related to the cutting capabilities of a tool:

$$0.4 \ln(100 \cdot Sz) + \ln(n) = \ln(\frac{3.1 \cdot 10^5}{D^{0.75} \cdot T^{0.2} \cdot t^{0.1} \cdot B^{0.15} \cdot z^{0.1}}) , \quad (7)$$

where T is a tool life, min; z is a number of mill teeth.

In light of the notations ln(100Sz)=x_1, ln(n)=x_2, the logarithm of the right side of equation (7) - b_2 the second restriction will take the following form:

$$0.4 \cdot x_1 + x_2 \le b_2 . \quad 8)$$

The treatment time restriction is required for the regulation of mill operating time in the course of a single process step within the efficient life duration:

$$\ln(100 \cdot Sz) + \ln(n) = \ln(\frac{H \cdot L \cdot 100}{T \cdot z \cdot B}) , \quad (9)$$

where H is width of the treated bearing, mm; L is length of the arc of the treated bearing segment, mm.

In light of the notations ln(100Sz)=x_1, ln(n)=x_2, the logarithm of the right side of equation (9) - b_3 the third restriction will take the following form:

$$x_1 + x_2 \ge b_3 . \quad (10)$$

The cutting temperature restriction is introduced for temperature control within the allowable values and prevention of such negative phenomena as build-up forming. The empirical dependencies obtained in the course of the experimental studies are used as cutting temperature functions [9].

The cutting area temperature during milling of B16 babbit:

$$Tr = 4.22 \frac{t^{0.29} \cdot Sz^{0.5} \cdot B \cdot n^{0.6}}{D^{1.08}} . \quad (11)$$

The cutting area temperature during milling of B83 babbit:

$$Tr = 33 \frac{t^{0.47} \cdot Sz^{0.57} \cdot B^{0.95} \cdot n^{0.38}}{D^{1.08}} . \quad (12)$$

According to equation (11), the cutting temperature restriction for B16 babbit:

$$0.5 \cdot \ln(100 \cdot Sz) + 0.6 \cdot \ln(n) = \ln(\frac{Tr \cdot D^{1.08} \cdot 100^{0.5}}{4.22 \cdot t^{0.29} \cdot B}) . \quad (13)$$

According to equation (12), the cutting temperature restriction for B83 babbit:

$$0,57 \cdot \ln(100 \cdot Sz) + 0,38 \cdot \ln(n) = \ln(\frac{Tr \cdot D \cdot 100^{0,57}}{33 \cdot t^{0,47} \cdot B^{0,95}}). \quad (14)$$

In light of the notations ln(100Sz)=x_1, *ln*(n)=x_2, the logarithm of the right side of equation (13) - b_4 the fourth restriction for B16 babbit will take the following form:

$$0.5 \cdot x_1 + 0.6 \cdot x_2 \le b_4. \quad (15)$$

In light of the notations ln(100Sz)=x_1, *ln*(n)=x_2, the logarithm of the right side of equation (14) - b_4 the fourth restriction for B83 babbit will take the following form:

$$0.57 \cdot x_1 + 0.38 \cdot x_2 \le b_4. \quad (16)$$

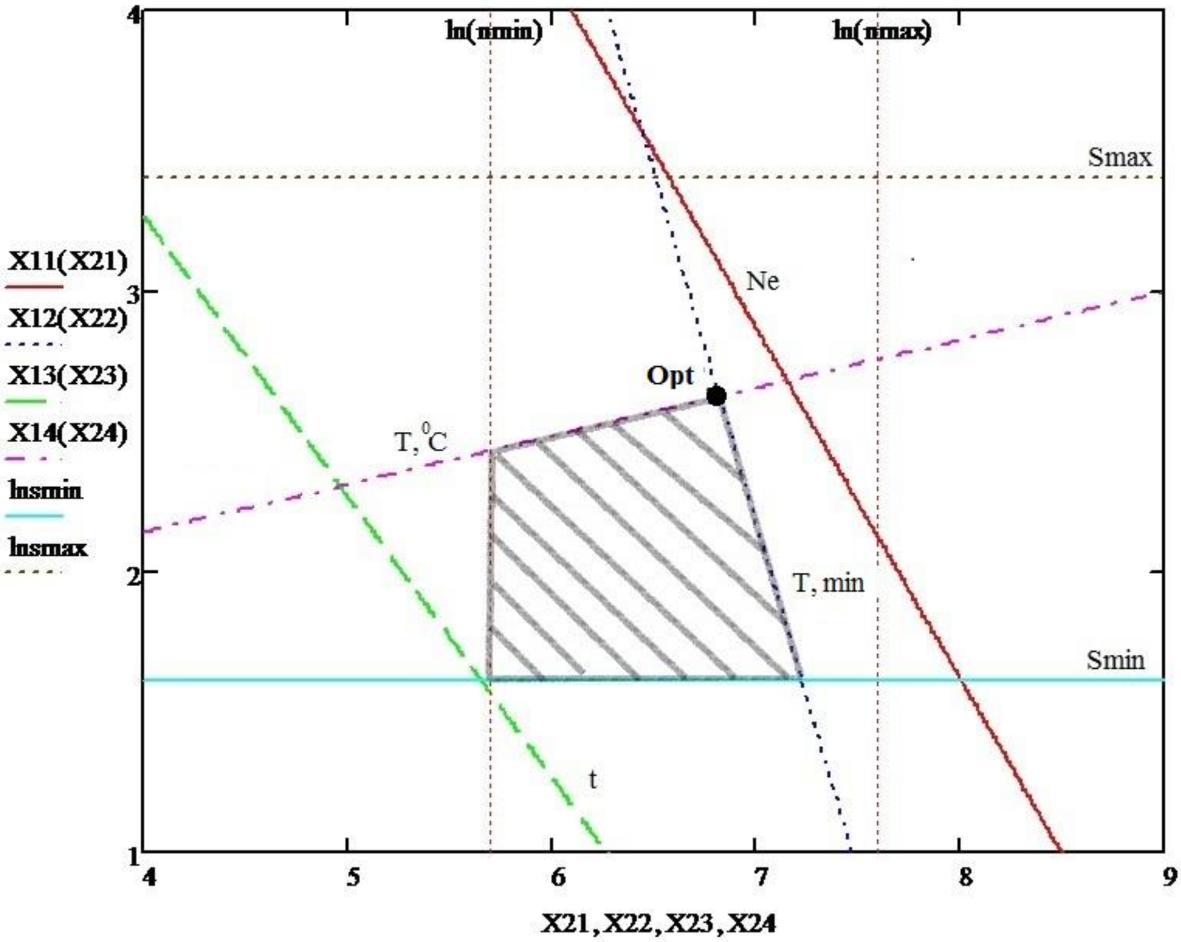

Figure 4. Graphical representation of maximization of the target function subject to the restrictions.

By means of the obtained restrictions (6), (8), (10) and (15), the optimization model for B16 babbit milling can be written in the form of a system of inequalities with the addition of the restriction on the optimized parameters limits in a logarithmic form:

$$\begin{cases} 0.75 \cdot x_1 + 0.9 \cdot x_2 \le b_1 \\ 0.4 \cdot x_1 + x_2 \le b_2 \\ x_1 + x_2 \ge b_3 \\ 0.5 \cdot x_1 + 0.6 \cdot x_2 \le b_4 \\ \ln(Sz\min \cdot 100) \le x_1 \le \ln(\text{Szmax} \cdot 100) \\ \ln(n\min) \le x_2 \le \ln(\text{nmax}) \end{cases} \quad . \tag{17}$$

By means of the obtained restrictions (6), (8), (10) and (16), the similar optimization model for B83 babbit milling can be written as follows:

$$\begin{cases} 0.75 \cdot x_1 + 0.9 \cdot x_2 \le b_1 \\ 0.4 \cdot x_1 + x_2 \le b_2 \\ x_1 + x_2 \ge b_3 \\ 0.57 \cdot x_1 + 0.38 \cdot x_2 \le b_4 \\ \ln(Sz\min \cdot 100) \le x_1 \le \ln(\text{Szmax} \cdot 100) \\ \ln(n\min) \le x_2 \le \ln(\text{nmax}) \end{cases} \quad . \tag{18}$$

The systems of inequalities (17), (18) are solved for the target function that has the following form:

$$f(x_1, x_2) = x_1 + x_2 \to \max \, . \tag{19}$$

Figure 4 shows the graphical representation of the optimization results subject to the above restrictions.

The region of feasibility lies within the bounded polyhedron formed by crossing of the set restrictions. Since one of the smaller bearing typical sizes is taken in the initial data, the treatment time restriction is virtually not involved in the solution; all values satisfy such a restriction within the assumed range. The cutting temperature and tool life restrictions form limiting restrictions: the optimum is located at their crossing. The optimal values are: x_1=2.622 и x_2=6.825, which corresponds to natural values of the optimized parameters: feed per tooth 0.14 mm/tooth, rotation rate 920 rpm, cutting speed 145 m/min. The obtained values ensure maximum performance subject to the set restrictions [10].

The obtained values are adjusted at the second optimization stage ensuring surface roughness by means of the iterative approximation method. Since the cutting speed achieved during the milling of babbits has no significant impact on roughness, the adjustment will be based on changing the value of feed per tooth. The following experimentally obtained dependencies are used for the adjustment.

For B16 babbit:

$$Ra(s,v,t) = 8.35 - 6.7 \cdot 10^{-3} v + 11.26s - 3.8t + 3.33 \cdot 10^{-2} vs - 6.1 \cdot 10^{-1} st + 3 \cdot 10^{-4} v^2 + 8.2s^2 + 1.3t^2 \, ; \tag{20}$$

For B83 babbit:

$$Ra(s,v,t) = 12.625 - 7.8 \cdot 10^{-1} v + 10.5s - 5.3t + 5.4 \cdot 10^{-2} vs - 9.5 \cdot 10^{-3} vt + 3.8 \cdot 10^{-4} v^2 + 7.1s^2 + 1.4t^2 \, . \tag{21}$$

4. Conclusions.

The suggested optimization algorithm and optimization model allow one to determine the process modes of babbit milling during the reduction treatment of large bearings sliding surface area through a special machine module, which ensures achieving of effective technical and economic parameters: the maximum capacity subject to the set quality parameters of a treated surface. The suggested algorithm can be used for various typical sizes of bearings, while the optimization model allows for making calculations with different initial data related to treatment conditions.

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