QUALITY ASSURANCE OF MACHINE REPAIR IN PRODUCTION PLANTS

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Abstract
The paper considers the problem of the assurance of the quality of machine repair in production plants. The primary quality repair index has been described analytically with the help of the arithmetic matrix in which the relationship between the production capacity and the structural and organizational factors of the quality of repair is taken into account. Ratios of input variables and the output relationship with the primary factors of the quality of machine repair were determined using matrix equations that reflect the relationship between design, process and organizational factors, and the basic quality ratios. It has been concluded that the quality of machine repair depends on proper diagnosis, the wear and tear of individual connections of elements, and the technological processes leading to the restoration of the damaged parts and reassembling the machine.

Keywords: machine repair problem, machine failure, machine reliability, wear

1 Introduction

The quality index is considered to be the "production capacity of the repair", or the susceptibility to repair conditions. Nevertheless, we still do not have exact numerical values for the machine, as well as ways to determine them, which will give a representation of the time of the repair and the level standard to which the repair was carried out. Numerical examples given in work done by Ke et al. [1] have demonstrated the effectiveness of computational analysis of the machine repair problem with unreliable multi-repairmen. The process of repairing a machine requires more than one phase. In each phase, the repair time is exponentially distributed and more than one operator may be required to repair a damaged machine [2]. A one-phase repair model to deal with the problem of interference between the phases of the machine repair has been considered by Eben-Chaime [3].

The diagram presented in **Fig. 1** shows the mutual relations of factors during machine repair. It predicts complex features: diagnosis, the technological process of repair. The diagram also defines the basic quality index of the repaired machine.

Most existing investigations of the machine repair problem make the restrictive assumption that repairs are only carried out when a machine breaks down, i.e. preventive maintenance is ignored [4]. Bunday and Scraton [5] showed that the steady-state probabilities for the number of machines operating could be calculated by means of the failure and repair distributions alone. A review of multiple machine reliability and maintenance in general has been provided by Cho and

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Parlar [6] while Stecke and Aronson [7] give particular attention to papers on the machine repair problem.

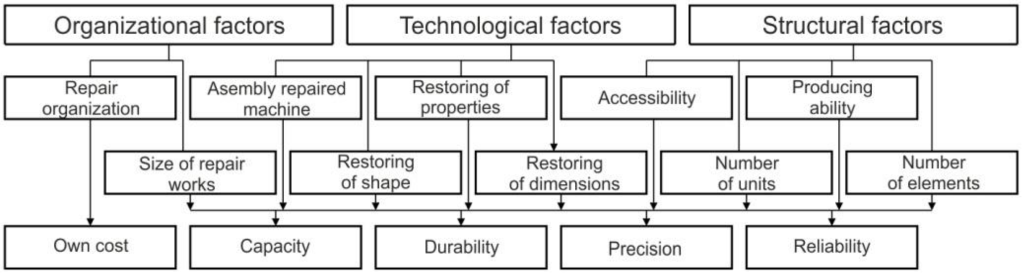

Fig. 1 Diagram of mutual connections of input and output factors during machine repair

The wear and tear processes start from discrete contact with the hard surface [8-10]. Elastic and plastic resistance in materials, microcutting, the destruction of layers and base material are basic types of such imperfections. The most characteristic reasons for the wear and tear process are high contact pressure (causing phase changes, and often also leading to the melting of metal), thermo-chemical processes (leading to oxidizing of the superficial layer, dissolving one of the components, brittleness of the superficial layer), influence of lubricant (which after getting into the micro-cracks can cause material to wedge out and an increase in wear and tear), moving material from one surface to another, internal stresses of different signs (+,-).
In this paper a primary repair quality index has been described analytically with the help of an arithmetic matrix. This matrix takes into account the relationship between production capability, structural and organizational factors and the quality of machine repair.

2 Quality machine repair

All kinds of wear and tear can be divided into three groups [11, 12]: mechanical (abrasive wear - microcutting, scratching), molecular (formation and destruction of adhesive joints), corrosive (oxidation, fretting). Primary parameters determining wear and tear are [13, 14]: unit pressure and the speed of the relative dislocations, the mechanical characteristics of friction couples (structure, kind of friction, lubrication properties).
The degree of wear and tear is determined using special computer programs, or is measured using various methods for example: micrometry, according to the content of wear and tear products, or using superficial activation. Outward signs of the classical destructive process are [15-17]: chipping (brittle and ductile), plastic deformation, creep, bending, change of material properties (structure, mechanical properties, chemical composition), corroded areas (corrosion, erosion, cavitations), formation of cracks, accretion, changing of properties of the superficial layer (roughness, hardness, flexibility), wear and tear (abrasion, crushing, material transfer), changing of contact conditions (contact surface, size of micro cavities), lubrication condition.
The extent of wear and tear of the machine components during diagnosis according to one of the known methods is taken into account. Other cases of failure (fractures, cracks, breakage, etc.) [18-20] have been also considered. Based on the results of analyses the machine components have been classified as: subjected to repair and subjected to change. When any part of a machine is partly worn (i.e. it still works), then this can also be reproduced.
A diagram of mutual connections describing the basic index of machine repair (**Fig. 2**) takes into consideration the influence of the ten variable input factors (X_1 - X_{10}) which are divided into

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three groups: structural, technological and organizational, as output variables (Z_1 - Z_5): precision, reliability, capacity, durability, own cost, that are primary factors in the quality of machine repair.

3 Model description and results

Based on the diagram of mutual connections of input and output factors during machine repair it was found that every input variable has its influence on all the output variables. Using the principle of superposition, each variable is considered as a linear combination of indexes and this can be described according to the matrix equation:

$$\begin{vmatrix} (Z_1\,K_1)^2 \\ (Z_2\,K_2)^2 \\ (Z_3\,K_3)^2 \\ (Z_4\,K_4)^2 \\ (Z_5\,K_5)^2 \end{vmatrix} = \begin{vmatrix} k_{11}^2 & k_{12}^2 & k_{13}^2 & k_{14}^2 & \cdots & k_{1\,10}^2 \\ k_{21}^2 & k_{22}^2 & k_{23}^2 & k_{24}^2 & \cdots & k_{2\,10}^2 \\ & & & & \cdots & \\ & & & & \cdots & \\ k_{51}^2 & k_{52}^2 & k_{53}^2 & k_{54}^2 & \cdots & k_{5\,10}^2 \end{vmatrix} \cdot \begin{vmatrix} (X_1\,Kx_1)^2 \\ (X_2\,Kx_2)^2 \\ \\ (X_{10}\,Kx_{10})^2 \end{vmatrix} \quad (1.)$$

where: k_{ij} – coefficients of reduction taking into account the influence of input variables on the output variables or correlation coefficient,
K_i – spread coefficient of output variable,
Kx_i – spread coefficient of input variables.

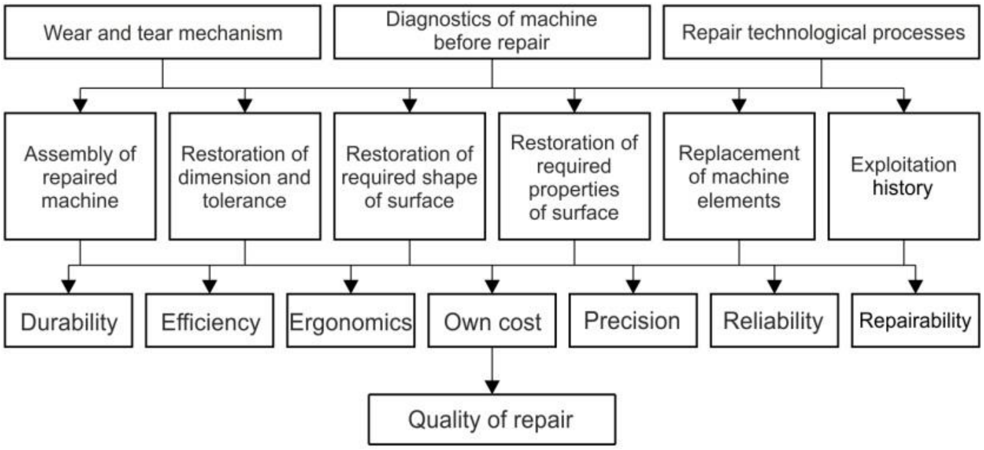

Fig. 2 Diagram of mutual connections during the definition of the primary factors affecting the quality of machine repair

Let us assume that the system which is described by the linear dependence is stabilised and describes its static properties. For a nonlinear relationship, which we meet in reality, we cannot use the principle of superposition, but we can use linearization of a system by changing nonlinear equations into a linear equation under given variation sections of input and output variables:

$$Z_1 = F_1(mx_1, mx_2, \ldots, mx_{10}) + \sum_{j=1}^{10} \left(\frac{\partial Z_1}{\partial X_j}\right)^{*} (X_j - mx_j) \quad (2.)$$

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$$Z_5 = F_5(mx_1, mx_2, \dots, mx_{10}) + \sum_{j=1}^{10} \left(\frac{\partial Z_5}{\partial X_j}\right)^{*} (X_j - mx_j)$$

where: $F_1 - F_5$ - differential functions combining output variables Z_j and input variables,
X_j and mx_j - the mathematical expectation of the random variable of input errors and the converting arrangement,
$\left(\frac{\partial z_5}{\partial x_j}\right)^{*}$ - values of partial derivatives after putting the mathematical expectation of a random variable in place of each argument.

For simplification we should consider linear or linearised values. From in Eq. in (2) above, which tie input and output variables, output variables are described as:

$$Z_1 = K_1^{-1} \sqrt{X_1^2 Kx_1^2 K_{11}^2 + X_2^2 Kx_2^2 K_{12}^2 + X_{10}^2 Kx_{10}^2 K_{110}^2}$$

$$\dots \tag{3.}$$

$$Z_5 = K_5^{-1} \sqrt{X_1^2 Kx_1^2 K_{51}^2 + X_2^2 Kx_2^2 K_{52}^2 + X_{10}^2 Kx_{10}^2 K_{510}^2}$$

In the Eq. (3) the determination of the matrix of reduced correlation coefficients is the most complicated. We can consider them as linear operators of transforming input variables into output variables:

$$K_K = \begin{vmatrix} K_{11} & K_{12} & K_{13} & \dots & K_{110} \\ K_{21} & K_{22} & K_{23} & \dots & K_{210} \\ K_{51} & K_{52} & K_{53} & \dots & K_{510} \end{vmatrix} \tag{4.}$$

Elements of the main matrix diagonal correlation coefficients of basic link k_{ij}, j = i, and the remaining elements of the matrix are cross linked. When there are no relationships in the matrix, we put 0 in the right location. As this kind of matrix describes the relationship between the number of input and output variables, the matrix can be square, linear, diagonal or rectangular like in the case considered here. Study of the matrix reduces the number of numerical values of the correlation coefficients searched for. We can do this in two ways [2]. If we know the functional relationship, we can calculate them analytically using the partial derivative from the differentiation of the function to input variables and the transformed arrangement. The analysis of the results has been carried out by the least square method [3]. The whole equation system can be described in the form of a matrix for defining the correlation coefficients as below:

$$K = W \cdot Q \tag{5.}$$

where: K – square matrix, whose elements are correlation moments kz_jx_j,
W – quasidiagonal complex matrix, in which the square matrix is set along the main diagonal and the remaining elements are equal to 0,
Q – square matrix, whose elements are searching for the correlation coefficient.

Thus, for any correlation coefficient the Eq. (5) takes the form:

$$K_{ij} = \frac{1}{\Delta} \sum_{i=1}^{n} Ax_j \cdot x_i \cdot Kz_j x_i \tag{6.}$$

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where: Δ – matrix determinant *W*,
n – the total number of observations,
Ax_j - algebraic complements of adequate elements Kz_jx_i and the matrix determinant.

Considering the fact that we have a lot of calculations, they should be carried out using appropriate computer programs. To carry out an analysis of the degree of influence on the repair quality input variable, we can consider a simplified structural variant, which is shown in **Fig. 3**. It describes the mutual (influence) connection between structural, technological and organizational factors on reliability, durability and the own cost repair index, by the dispersion equation:

$$\begin{vmatrix} D_{z1} \\ D_{z2} \\ D_{z3} \end{vmatrix} = \begin{vmatrix} K_{11}^2 & K_{12}^2 & K_{13}^2 \\ K_{21}^2 & K_{22}^2 & K_{23}^2 \\ K_{31}^2 & K_{32}^2 & K_{33}^2 \end{vmatrix} \cdot \begin{vmatrix} Dx_1 \\ Dx_2 \\ Dx_3 \end{vmatrix} + \begin{vmatrix} D^*x_1 \\ D^*x_2 \\ D^*x_3 \end{vmatrix} \tag{7.}$$

where: D_{z1}, Dx_i - dispersion of input and output variables accordingly,
D^*x_i, - part of dispersion conditioned by the influence of factors which were not taken into account.

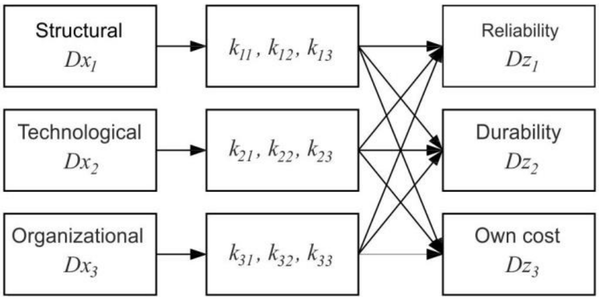

Fig. 3 Influence diagram of three groups of input coefficients on three basic coefficients of the quality of machine repair

The system correlation matrix and dispersion of input and output variables were determined based on the experimental data from the repair machines division of industrial enterprise. The matrices of input data D_{xi} and output data D_{zi} in a form of correlation coefficients K_{ij} and determinant coefficients K_{ij}^* describe the mutual connection between input factors and output factors shown in **Fig. 3**.

The system correlation coefficient matrix was found as:

$$K_K = \begin{vmatrix} 0.95 & 0.54 & 0.87 \\ 0.77 & 0.99 & 0.92 \\ 0.52 & 0.45 & 0.67 \end{vmatrix} \tag{8.}$$

To define the searched input value, the mean deviation of reliability was evaluated using the equation below:

$$Dz_1 = 0.9025\,Dx_1 + D^*x_1 + 0.2916\,Dx_2 + 0.1569\,Dx_3 \tag{9.}$$

$$\text{where: } Dx_i = \begin{vmatrix} 8.95 \\ 10.2 \\ 13.1 \end{vmatrix} \cdot 10^{-4} \text{ and } D^*x_i = \begin{vmatrix} 5.05 \\ 9.7 \\ 6.1 \end{vmatrix} \cdot 10^{-4} \tag{10.}$$

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The columnar matrix of dispersion input variables is conditioned by conditional and unconventional coefficients.
For the numerical example $Dz_1 = 2.6\cdot 10^{-3}$ shown, the changes of the constructional factor about ±20% ($D^{+}x_1 = 1.074\cdot 10^{-3}$ and $D^{-}x_1 = 7.16\cdot 10^{4}$) causes a change of reliability dispersion accordingly of about +6.15% and -6.21% which can be seen as a linear relation presented in **Fig. 4**.

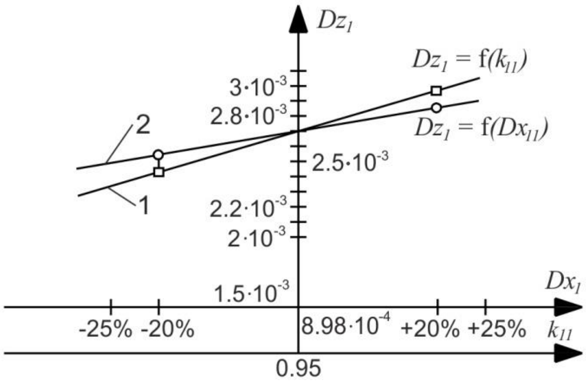

Fig. 4 Changing of dispersion reliability to correlation coefficient dispersion (line 1) and structural coefficient k_{11} (line 2)

Comparing the result obtained with the analogical change Dz_1 depending on the same changes (±20%) of the correlation coefficient $k_{11} = 0.95$, we can affirm almost the same linear relationship, but steeper. Hence the conclusion, that the correlation coefficients are more influential on the output variables than the oscillation of the input variables. This is the general result concerning the relationship identified from equation Eq. (10).

Conclusions

In this paper, the problem of assurance of machine quality was analysed. The main conclusions drawn are as follows:

1) The quality of repair of the machine is influenced by existing wear and tear mechanisms on individual elements of wear and tear, proper diagnosis, technological processes leading to the restoration of damaged parts and reassembling the machine.
2) The primary quality repair index can be described analytically with the help of matrix arithmetic, in which the relationship between production capacity, structural and organizational factors, and primary factors is taken into account.
3) In the case of a need for more detail, the number of input and output variables can be increased or decreased, nota bene it is only then that the technological influence of factors on the limited number of quality indexes is interesting.

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