Estimation technique of corrective effects for forecasting of reliability of the designed and operated objects of the generating systems

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Abstract. In the present article researches of statistical material on the refusals and malfunctions influencing operability of heat power installations have been conducted. In this article the mathematical model of change of output characteristics of the turbine depending on number of the refusals revealed in use has been presented. The mathematical model is based on methods of mathematical statistics, probability theory and methods of matrix calculation. The novelty of this model is that it allows to predict the change of the output characteristic in time, and the operating influences have been presented in an explicit form. As desirable dynamics of change of the output characteristic (function, reliability) the law of distribution of Veybull which is universal is adopted since at various values of parameters it turns into other types of distributions (for example, exponential, normal, etc.) It should be noted that the choice of the desirable law of management allows to determine the necessary management parameters with use of the saved-up change of the output characteristic in general. The output characteristic can be changed both on the speed of change of management parameters, and on acceleration of change of management parameters. In this article the technique of an assessment of the pseudo-return matrix has been stated in detail by the method of the smallest squares and the standard Microsoft Excel functions. Also the technique of finding of the operating effects when finding restrictions both for the output characteristic, and on management parameters has been considered. In the article the order and the sequence of finding of management parameters has been stated. A concrete example of finding of the operating effects in the course of long-term operation of turbines has been shown.

The technique is based on theoretical developments and results of the researches presented in articles [1, 2]. The stated technique allows to consider active corrective actions during creation of expensive objects and by that solves in active statement a problem of management of process of enhancement of a product in case of directed improvement of its characteristics.

As desirable dynamics of change an output characteristic (a reliability function) the distribution law of Veybull is adopted, the law is considered to be universal as in case of various parameter values of distribution it turns into other types of distributions (for example, in exponential or normal distribution).

The output characteristic for the adopted law is:
\[ y(t) = P(t) = e^{-\lambda t}. \] (1)

Then the set conditions of change of the output characteristic in the process of working off can be written down as the solution of the differential equation
\[ \frac{dy(t)}{dt} = \lambda y, \] (2)

where \[ y = \alpha t^{\alpha-1} e^{-\lambda t}. \]

These conditions shall be provided as a result of the choice of corrective actions, i.e. the choice of a management vector \( u(t) \). Practice shows that success in a program implementation of the working off set in the form of the equation (2) is provided thanks to certain increments \( \Delta u(t) \) a management vector, i.e. the desirable control law is pro rata to integral from change of the output characteristic. It should be noted that the choice of the desirable control law allows to determine necessary parameters of management with use of cumulative change of the output characteristic and at the same time to consider total impact of all parameters of the managements operating to straight lines and indirectly on total change of the output characteristic in general.

We will determine dependence of rejections of the output characteristic of \( y(t) \) on parameters of management in a regression form by a linear ratio [4,5]
\[ B[u(t) - u^0] = \int_0^T y(t) dt \] (3)

or in an expanded form
\[ y_1(t) = b_{11}(u_1(t) - u_1^0) + b_{12}(u_2(t) - u_2^0) + \ldots + b_{1m}(u_m(t) - u_m^0), \]
\[ y_2(t) = b_{21}(u_1(t) - u_1^0) + b_{22}(u_2(t) - u_2^0) + \ldots + b_{2m}(u_m(t) - u_m^0), \]
\[ \ldots \ldots \ldots \ldots \]
\[ y_n(t) = b_{n1}(u_1(t) - u_1^0) + b_{n2}(u_2(t) - u_2^0) + \ldots + b_{nm}(u_m(t) - u_m^0), \] (4)

where \( y_i(t) = \int_0^T y(t) dt. \)

The solution of the equation (3) is an expression:
\[ [u(t) - u^0] = B^* y(t) \] (5)
or
\[ \begin{bmatrix} u_1(t) - u_1^0 \\ u_2(t) - u_2^0 \\ \ldots \\ u_m(t) - u_m^0 \end{bmatrix} = \begin{bmatrix} b_{11} b_{12} \ldots b_{1m} \\ b_{21} b_{22} \ldots b_{2m} \\ \ldots \\ b_{m1} b_{m2} \ldots b_{mm} \end{bmatrix}^+ \begin{bmatrix} y_1(t) \\ y_2(t) \\ \ldots \\ y_n(t) \end{bmatrix}. \] (6)

Thus, the operating effects for the set dynamics of development of the output characteristic expressed in the form of Veybull's distribution are found, using the expression:
\[ u(t) = u^0 + \frac{1}{\lambda} \left(1 - e^{-\lambda t}\right) B^* y(t) \] (7)
or in an expanded form
and we tabulate, having written down the equations (4) for every line (tab. 1).

The third step. We write down on the basis of basic data of tab. 1.

\[
\begin{bmatrix}
   y_{11} \\
   y_{21} \\
   \vdots \\
   y_{n1}
\end{bmatrix} = 
\begin{bmatrix}
   \begin{bmatrix}
   u_{11} - u_1^0 \\
   u_{12} - u_2^0 \\
   \vdots \\
   u_{n1} - u_1^0
\end{bmatrix} \\
   \begin{bmatrix}
   u_{12} - u_2^0 \\
   u_{22} - u_2^0 \\
   \vdots \\
   u_{n2} - u_2^0
\end{bmatrix} \\
   \vdots \\
   \begin{bmatrix}
   u_{n1} - u_1^0 \\
   u_{n2} - u_2^0 \\
   \vdots \\
   u_{nm} - u_m^0
\end{bmatrix}
\end{bmatrix} 
\begin{bmatrix}
   b_{11} \\
   b_{12} \\
   \vdots \\
   b_{1m}
\end{bmatrix} 
= 
\begin{bmatrix}
   y_{11} \\
   y_{21} \\
   \vdots \\
   y_{n1}
\end{bmatrix}.
\]

The first step. We take the first equation from ratios (4):

\[
y_{11}(t) = b_{11}(u_1(t) - u_1^0) + b_{12}(u_2(t) - u_2^0) + \ldots + b_{1m}(u_m(t) - u_m^0).
\]

The second step. We take experimental or settlement data for \( y_{11}(t) = y_1 \) and we tabulate, having written down the equations (4) for every line (tab. 1).

**Table 1.** Tabular form of the basic data' record of the first equation

| \( y_1 \) | \( u_1 - u_1^0 \) | \( u_2 - u_2^0 \) | \( \ldots \) | \( u_m - u_m^0 \) | \( y_{ij} \) |
|------------|----------------|----------------|-------|----------------|----------|
| \( y_{11} \) | \( u_{11} - u_1^0 \) | \( u_{12} - u_2^0 \) | \( \ldots \) | \( u_{1m} - u_m^0 \) | \( y_{11} = b_{11}(u_{11} - u_1^0) + b_{12}(u_{12} - u_2^0) + \ldots + b_{1m}(u_{1m} - u_m^0) \) |
| \( y_{21} \) | \( u_{21} - u_1^0 \) | \( u_{22} - u_2^0 \) | \( \ldots \) | \( u_{2m} - u_m^0 \) | \( y_{21} = b_{11}(u_{21} - u_1^0) + b_{12}(u_{22} - u_2^0) + \ldots + b_{1m}(u_{2m} - u_m^0) \) |
| \( \ldots \) | \( \ldots \) | \( \ldots \) | \( \ldots \) | \( \ldots \) | \( \ldots \) |
| \( y_{n1} \) | \( u_{n1} - u_1^0 \) | \( u_{n2} - u_2^0 \) | \( \ldots \) | \( u_{nm} - u_m^0 \) | \( y_{n1} = b_{11}(u_{n1} - u_1^0) + b_{12}(u_{n2} - u_2^0) + \ldots + b_{1m}(u_{nm} - u_m^0) \) |

The third step. We write down on the basis of basic data of tab. 1.

\[
y_1 = \begin{bmatrix}
   y_{11} \\
   y_{21} \\
   \vdots \\
   y_{n1}
\end{bmatrix} = \begin{bmatrix}
   \begin{bmatrix}
   u_{11} - u_1^0 \\
   u_{12} - u_2^0 \\
   \vdots \\
   u_{1m} - u_m^0
\end{bmatrix} \\
   \begin{bmatrix}
   u_{12} - u_2^0 \\
   u_{22} - u_2^0 \\
   \vdots \\
   u_{2m} - u_m^0
\end{bmatrix} \\
   \vdots \\
   \begin{bmatrix}
   u_{n1} - u_1^0 \\
   u_{n2} - u_2^0 \\
   \vdots \\
   u_{nm} - u_m^0
\end{bmatrix}
\end{bmatrix} \begin{bmatrix}
   b_{11} \\
   b_{12} \\
   \vdots \\
   b_{1m}
\end{bmatrix} = [u - u^0] b_1.
\]
The fourth step. We find a vector by the method of the smallest squares

\[ b_1 = \begin{bmatrix} b_{11} \\ b_{12} \\ \vdots \\ b_{1m} \end{bmatrix} = \begin{array}{c} [u - u^0] \\ [y_{12}] \\ [y_{21}] \\ \vdots \\ [y_{n1}] \end{array} \]

The first step. We will consider the second equation from a ratio (4).

The second step. We tabulate the obtained experimental or settlement data for \( y_2(t) = y_2 \) having written down the equation (4) for every line (Table 2)

**Table 2. The Tabular Form of Record of Basic Data of the Second Equation**

| \( y_{ij} \) | \( u_1 - u_1^0 \) | \( u_2 - u_2^0 \) | \( \ldots \) | \( u_m - u_m^0 \) |
|---|---|---|---|---|
| \( y_{12} \) | \( u_{11} - u_1^0 \) | \( u_{12} - u_2^0 \) | \( \ldots \) | \( u_{m1} - u_m^0 \) |
| \( y_{22} \) | \( u_{21} - u_1^0 \) | \( u_{22} - u_2^0 \) | \( \ldots \) | \( u_{m2} - u_m^0 \) |
| \( \ldots \) | \( \ldots \) | \( \ldots \) | \( \ldots \) | \( \ldots \) |
| \( y_{n2} \) | \( u_{n1} - u_1^0 \) | \( u_{n2} - u_2^0 \) | \( \ldots \) | \( u_{nm} - u_m^0 \) |

The third step. We will write down on the basis of basic data of table 2

\[ y_2 = \begin{bmatrix} y_{12} \\ y_{22} \\ \vdots \\ y_{n2} \end{bmatrix} = \begin{bmatrix} (u_{11} - u_1^0)(u_{12} - u_2^0) \ldots (u_{m1} - u_m^0) \\ (u_{21} - u_1^0)(u_{22} - u_2^0) \ldots (u_{m2} - u_m^0) \\ \vdots \\ (u_{n1} - u_1^0)(u_{n2} - u_2^0) \ldots (u_{nm} - u_m^0) \end{bmatrix} \begin{bmatrix} b_{21} \\ b_{22} \\ \vdots \\ b_{2m} \end{bmatrix} = [u - u^0]b_2. \]

The fourth step. We will determine a vector by method of the smallest squares

\[ b_2 = \begin{bmatrix} b_{21} \\ b_{22} \\ \vdots \\ b_{2m} \end{bmatrix} = \begin{bmatrix} y_{12} \\ y_{22} \\ \vdots \\ y_{n2} \end{bmatrix}. \]

We find vectors similarly \( b_3, b_4, \ldots, b_m \):
Further we find the matrix assessment $B$:

$$
\hat{B} = \begin{bmatrix}
    b_{11}^T \\
    b_{21}^T \\
    \vdots \\
    b_{m1}^T
\end{bmatrix}
\begin{bmatrix}
    y_1^T \\
    y_2^T \\
    \vdots \\
    y_m^T
\end{bmatrix} = [u - u^0]^T [y]^T.
$$

On the basis of the received matrix $B$ by the standard Microsoft Excel functions $t$ we define an assessment of the pseudo-return matrix

$$
\hat{B}^+ = [u - u^0]^T \begin{bmatrix}
    y_1^T \\
    y_2^T \\
    \vdots \\
    y_m^T
\end{bmatrix} = [u - u^0]^T [y]^T.
$$

In that specific case, when the output characteristic is defined for the fulfilled product in general, the transposed matrix $[y]^T$ is written down in the form of a vector $y^T$. At the same time the assessment of the pseudo-return matrix is also presented in the vector form $\hat{B}^+$. If working off of all executive knots, mechanisms, panels and other elements of a product is carried out as a part of a product, then estimation of the pseudo-return matrix becomes simpler and as follows a little. We will choose $n$ time points $t_i$, having presented a ratio (6) for these moments as:

$$
\begin{bmatrix}
    u_1(t) - u_1^0 \\
    u_2(t) - u_2^0 \\
    \vdots \\
    u_m(t) - u_m^0
\end{bmatrix}
\begin{bmatrix}
    b_{11} b_{12} \ldots b_{1m} \\
    b_{21} b_{22} \ldots b_{2m} \\
    \vdots \\
    b_{n1} b_{n2} \ldots b_{nm}
\end{bmatrix}
\begin{bmatrix}
    y_{11} & y_{12} & \ldots & y_{1m} \\
    y_{21} & y_{22} & \ldots & y_{2m} \\
    \vdots & \vdots & \ddots & \vdots \\
    y_{n1} & y_{n2} & \ldots & y_{nm}
\end{bmatrix}.
$$

Using a method of the smallest squares, we will find $B$ matrix assessment on a formula

$$
\hat{B} = [y]^T [u_j(t_j) - u_j^0]^T.
$$

Further we will define an assessment of the pseudo-return matrix by the standard Microsoft Excel functions

$$
\hat{B}^+ = [y]^T [u_j(t_j) - u_j^0]^T.
$$
In this case for receiving an assessment of a matrix of \( B \) everyone use the skilled data of \( u_j(t) \) and received on background. According to the desirable law of management proportional to integral from change of the output characteristic, \( y_j(t) \) value approximately are calculated by a formula
\[
y_j(t_i) = \int_0^{t_i} y_j(t) \, dt \approx \frac{y_{11} + y_{21}}{2} \Delta t_1 + \frac{y_{31} + y_{32}}{2} \Delta t_2 + \ldots + \frac{y_{n-1} + y_{n}}{2} \Delta t_n,
\]
where \( j = 1, m; \; i = 1, n; \; \Delta t_i = t_i - t_{i-1} \).

Every line \( u_j(t_i) \) is received from the corresponding column, i.e. transposing of a matrix of basic data. Каждую строку \( u_j(t_i) \). For finding of an assessment of the pseudo-return matrix similarly we define the transposed matrix \( [u_j(t_i) - u^0_j]^T \), at the same time the line is received from the corresponding column in which each element can be defined as a difference between the following and the first elements of this column. The received assessment of the pseudo-return matrix is used further as a constant matrix for determination of parameters of managements, having set up its in (8).

Now we will consider a case when working off of a product is carried out quickly, i.e. the output characteristic of \( y(t) \) changes in proportion to acceleration of change of parameters of management and is defined in a regression form by a linear ratio of [6,7]
\[
y(t) = B\dot{u}(t), \quad \frac{d^2 u(t)}{dt^2} = \ddot{u}(t) \tag{10}
\]
or in an expanded form
\[
y_j(t) = b_{i1}\dot{u}_1(t) + b_{i2}\dot{u}_2(t) + \ldots + b_{im}\dot{u}_m(t). \tag{11}
\]
The solution of a task for the desirable law of the management expressed by a formula (10) has a view
\[
\ddot{u}(t) = B^+ y^{\text{tp}}(t). \tag{12}
\]
At an exponential distribution of the output characteristic
\[
\ddot{u}(t) = B^+ e^{-Dt} y^{\text{tp}}(t). \tag{13}
\]
Integration (13) gives the equation
\[
\dot{u}(t) = u_1^0 + B^+ \int_0^T e^{-Dt} y^{\text{tp}}(t) \, dt, \tag{14}
\]
where \( u_1^0 \) — initial value of speed of change of parameter of management;
\[
\int_0^T e^{-Dt} y^{\text{tp}}(t) \, dt = \frac{1}{D} \left[1 - e^{-Dt}\right] y^{\text{tp}}(t).
\]
After integration (14)
\[
\dot{u}(t) = u_1^0 + \frac{1}{D} \left[1 - e^{-Dt}\right] y^{\text{tp}}(t). \tag{15}
\]
For finding of a management vector we integrate (15)
\[
u(t) = u^0 + u_1^0 t + B^+ \int_0^T \frac{1}{D} \left[1 - e^{-Dt}\right] y^{\text{tp}}(t) \, dt, \tag{16}
\]
where \( u^0 \) — initial value of management parameter.

Integration (16) leads to the equation
\[
u(t) = u^0 + u_1^0 t + B^+ \left\{ t - \frac{1}{D} \left[1 - e^{-Dt}\right] \right\} y^{\text{tp}}(t). \tag{17}
\]
At the set working off term $T$ expression (17) will be transformed as follows:

$$u(t) = u^0 + u_1^0 t + B^+ T \left[ t - T \left( 1 - e^{-\frac{t}{T}} \right) \right] y^{\text{TP}}(t).$$

(18)

The considered mathematical model of working off can be used also when imposing restrictions both for the output characteristic, and on management parameters (8). When imposing restrictions for the output characteristic for the desirable law of the management proportional to the speed of change of parameters, the operating influences define from the system of the equations

$$u(t) = u^0 + T \left( 1 - e^{-\frac{t}{T}} \right) B^+ y^{\text{TP}}(t);$$

$$u'(t) = u^0 + T \left( 1 - e^{-\frac{t}{T}} \right) C^+ y^{\text{TP}}(t),$$

(19)

where $T$ – the set period of working off (tests); $B^+$ – pseudo-return matrix of management parameters; $y^{\text{TP}}(t)$ – the required value of the output characteristic; $u^0$ – the initial value of management parameter on restrictions ; $C^+$ – pseudo-return matrix of restrictions' parameters .

For finding of the operating influences when imposing restrictions directly for managements use a ratio as

$$u(t) = u^0 + (C^+ B^+) T \left( 1 - e^{-\frac{t}{T}} \right) C^+ y^{\text{TP}}(t).$$

(20)

The technique of finding of the operating influences at a stage of creation of difficult systems is as follows:

1) we make a matrix $u = [u_{ij}]$ of basic data – design, technological and operational parameters $u_{ij}$, time between failures or failure rate, or probability of no-failure operation for the set time $t$ for relevant $i$- product life stage;

2) according to the chosen law of management and the set desirable dynamics of development of the output characteristic the transposed matrixes of parameters of managements and the output characteristic by an initial matrix are determined $[u^T], [y^T]$;

3) by the known formula with the use of the standard Microsoft Excel functions the transposed pseudo-return matrix are determined $[y^+]^T$;

4) we count assessment of the pseudo-return matrix $\hat{B}^+ = [u^T][y^+]^T$, which in the subsequent is applied as a constant;

5) the final stage – the definition of the operating influence on the formula received according to the chosen desirable law of management and the set dynamics of development of the output characteristic Example 1. In use turbines refusals of components of the turbine which reduced reliability of the turbine have been recorded. The results of operation of turbines in the form of change of the corresponding parameters are shown in the table 3.
Table 3. The Basic Data

| $u_1$ | $u_2$ | $u_3$ | $u_4$ | $u_5$ | $y_1$ | $y_2$ | $t, \text{ year}$ |
|-------|-------|-------|-------|-------|-------|-------|------------------|
| 0.09  | 0.05  | 0.04  | 0.026 | 0.05  | 0.33  |       | 1                |
| 0.09  | 0.06  | 0.04  | 0.039 | 0.05  | 0.33  |       | 2                |
| 0.1   | 0.06  | 0.08  | 0.116 | 0.05  | 0.33  |       | 3                |
| 0.15  | 0.06  | 0.11  | 0.116 | 0.07  | 0.49  |       | 4                |
| 0.17  | 0.13  | 0.14  | 0.259 | 0.12  | 0.82  |       | 5                |
| 0.25  | 0.17  | 0.51  | 0.441 | 0.13  | 0.83  |       | 6                |
| 0.27  | 0.47  | 0.65  | 0.505 | 0.45  | 0.15  | 0.85  | 7                |

It is required to determine the optimum parameters of management in the form of change of distribution of a stream of refusals of $u_i(t)$, confirming the required values of the output data of mornings: parameter of a stream of refusals $y_1 = 0.15$; coefficient of not planned repair of $y_2 = 0.85$ during operation of $T_0 = 7$ years.

**Solution**

1. We will be set by desirable dynamics of development of the output characteristic in the form of exponential dependence

$$y(t) = e^{-\lambda t} y^0 = e^{-\frac{t}{T}} y^0.$$  

2. We will choose the desirable law of management proportional to integral from change of the output characteristic:

$$B[u(t) - u^0] = \int_0^T y(\tau) d\tau = \int_0^T e^{-\lambda \tau} y^0 d\tau.$$  

3. The results of the statistical data obtained at operation of the turbine are shown in the table 3.

4. According to the chosen desirable law management we will transform the table of basic data to initial matrixes at the same time

$$u = u(t) - u^0$$

and

$$y_j(t_i) = \frac{y_{1j} + y_{2j}}{2} \Delta t_1 + \frac{y_{2j} + y_{3j}}{2} \Delta t_2 + \cdots + \frac{y_{i-1} + y_{ij}}{2} \Delta t_i,$$

where $j = 1, m = 1, 2; i = 1, n = 1, 2, \ldots, 7.$

As a result of transformation we will receive

$$u = \begin{bmatrix} 0 & 0.01 & 0 & 0.02 & 0.01 \\ 0.01 & 0.01 & 0.04 & 0.04 & 0.09 \\ 0.06 & 0.01 & 0.07 & 0.06 & 0.09 \\ 0.08 & 0.08 & 0.1 & 0.08 & 0.23 \\ 0.16 & 0.12 & 0.47 & 0.11 & 0.42 \\ 0.18 & 0.42 & 0.61 & 0.46 & 0.42 \end{bmatrix}.$$
5. We will transpose the initial matrices

\[ u^T = \begin{bmatrix} 0 & 0.01 & 0.06 & 0.08 & 0.16 & 0.18 \\ 0.01 & 0.01 & 0.01 & 0.08 & 0.12 & 0.42 \\ 0 & 0 & 0.1 & 0.1 & 0.5 & 0.6 \\ 0 & 0 & 0.1 & 0.1 & 0.5 \\ 0.01 & 0.09 & 0.09 & 0.23 & 0.42 & 0.42 \end{bmatrix}, \]

\[ y^T = \begin{bmatrix} 0.05 & 0.1 & 0.16 & 0.26 & 0.38 & 0.52 \\ 0.33 & 0.66 & 1.07 & 1.73 & 2.55 & 3.39 \end{bmatrix}. \]

6. For the initial matrixes which have a number of the equations more or equally to number of unknown and the number of lines are more than number of columns, the pseudo-return matrix can be found by means of the standard MS Excel functions on a formula

\[ A^* = \left( A^T A \right)^{-1} A^T, \]

where \( A \) – the initial matrix.

For the matrix \( y^T \) we will find the transposed pseudo-return matrix \( \begin{bmatrix} y^+ \end{bmatrix}^T \).

\[ \begin{bmatrix} y^+ \end{bmatrix}^T = \begin{bmatrix} 0.93 & -0.13 \\ 1.87 & -0.25 \\ -14.19 & 2.19 \\ -46.76 & 7.14 \\ -44.42 & 6.83 \\ 61.23 & -9.11 \end{bmatrix}. \]

7. Using a method of the smallest squares, we will find an assessment of the pseudo-return matrix \( \hat{B}^* = u^T \begin{bmatrix} y^+ \end{bmatrix}^T \):

\[ \hat{B}^* = \begin{bmatrix} -0.66 & 0.15 \\ 16.53 & -2.42 \\ 10.88 & -1.49 \\ 18.96 & -2.78 \\ -4.46 & 0.81 \end{bmatrix}. \]

8. For the set desirable dynamics of development of the output characteristic and the chosen desirable law management we will determine the operating influences by a formula

\[ u_j(t) = u_j^0 + T \left( 1 - e^{-\frac{t}{T}} \right) \hat{B}^* y^p, \]
which we will transform, having accepted the operation period \( T_0 = 7 \text{ лет} \) and \( T = T_0 / 7; \)

\[
u_j(t) = u_j^0 + \frac{T_0}{7} \left( 1 - e^{-\frac{t}{T_0}} \right) \hat{B}^\top \mathbf{y}^{\text{np}} = u_j^0 + \left( 1 - e^{-\frac{t}{T_0}} \right) \hat{B}^\top \mathbf{y}^{\text{np}}.
\]

The expanded view of this vector:

\[
\begin{bmatrix}
  u_1(t) \\
  u_2(t) \\
  \vdots \\
  u_n(t)
\end{bmatrix} = \begin{bmatrix}
  u_1^0(t) \\
  u_2^0(t) \\
  \vdots \\
  u_n^0(t)
\end{bmatrix} + \left( 1 - e^{-\frac{t}{T_0}} \right) \begin{bmatrix}
  b_{11} & b_{12} & \cdots & b_{1n} \\
  b_{21} & b_{22} & \cdots & b_{2n} \\
  \vdots & \vdots & \ddots & \vdots \\
  b_{n1} & b_{n2} & \cdots & b_{nn}
\end{bmatrix} \begin{bmatrix}
  y_1^{\text{np}} \\
  y_2^{\text{np}} \\
  \vdots \\
  y_n^{\text{np}}
\end{bmatrix}.
\]

9. Having substituted the basic data \( u_j^0, \hat{B}^\top, y_i^{\text{np}} \) and \( t = 1, 2, \ldots \), we will receive the corresponding values of parameters of managements (table 4)

\[
\begin{bmatrix}
  u_1(t) \\
  u_2(t)
\end{bmatrix} = \begin{bmatrix}
  0.09 \\
  0.05 \\
  0.04 \\
  0.043 \\
  0.026
\end{bmatrix} + \left( 1 - e^{-\frac{t}{T_0}} \right) \begin{bmatrix}
  -0.66 & 0.15 \\
  16.53 & -2.42 \\
  10.88 & -1.49 \\
  18.96 & -2.78 \\
  -4.46 & 0.81
\end{bmatrix} \begin{bmatrix}
  0.15 \\
  0.85
\end{bmatrix}.
\]

**Table 4.** Calculated Values of Parameters of Management in Relative Shares

| Parameter of management | Operation period, year |
|-------------------------|------------------------|
|                         | 1         | 2         | 3         | 4         | 5         | 6         | 7         |
| \( u_1(t) \) – distribution of turbines' failures | 0,1101   | 0,1175   | 0,1203   | 0,1213   | 0,1216   | 0,1218   | 0,1218   |
| \( u_2(t) \) – distribution of a rotor's refusals | 0,3195   | 0,4187   | 0,4552   | 0,4686   | 0,4735   | 0,4754   | 0,4754   |
| \( u_3(t) \) – distribution of working blades' failures | 0,2718   | 0,3571   | 0,3885   | 0,4001   | 0,4043   | 0,4059   | 0,4064   |

**Continuation of table 4**

|                         | Operation period, year |
|-------------------------|------------------------|
| \( u_4(t) \) – distribution of bearings' failures | 0,3501   | 0,4631   | 0,5047   | 0,5200   | 0,5256   | 0,5277   | 0,5284   |
| \( u_5(t) \) – distribution of an oil system's refusals | 0,0378   | 0,0421   | 0,0437   | 0,0443   | 0,0445   | 0,0446   | 0,0446   |

The analysis of the received management parameters' values (figure 1) demonstrates that with increase in number of refusals the parameter of a stream of refusals \( \lambda \) and coefficient of not planned repair is increased. It corresponds to physical sense. The results of the obtained data allow to predict change of a parameter of a stream of refusals \( \lambda \) and coefficient of not planned repair of KN.P at further operation. Apparently from table 4, at admissible value of a stream of refusals \( \lambda_{\text{np}} = 0,15 \) and coefficient of not planned repair of KN.P = 0,85 distribution of turbines' failures, a rotor, working blades, bearings and an oil system will grow by years for the next seven years of operation.
Conclusions
1. The technique of an assessment of management parameters on the basis of mathematical model of change of output operational characteristics of heat power installations taking into account the operating influences has been developed.
2. In the technique the tasks of management both of speed, and of acceleration of change of the output characteristic without restrictions and taking into account the restrictions for the output characteristic have been solved.
3. The order of finding of the operating effects on a concrete example has been stated.

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Figure 1. Dependence of management parameters on the operation period
