Quality assessment of modernization projects of heavy duty drives

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Abstract. The article presents an approach to improving the quality of modernization projects of drives of heavy duty machines by solving the problem of the quality assessment of design solutions. The problems in the assessment of the complex technical projects, such as the project for the heavy technological machines drives modernization, have been defined. A system of technical and technological parameters of such drives which determines the quality of design solutions has been developed. A method for the complex quality assessment of modernization projects of heavy machine drives is proposed. The developed method takes into account the entire life cycle of the product including aftersales service and disposal.

1. Introduction

Constantly escalating competition demand from manufacturers to reduce production costs continuously increases productivity and quality of products, reduces the time gap between the product planning and its appearance on the market, uses the environmental friendly production processes and technologies based on the efficient use of raw materials, labor, financial and energy resources. To achieve these goals, continuous optimization of all production processes, as well as modernization and improvement of technological systems, should take place. In this regard, the successful modernization of various systems is an important task for enterprises to achieve uninterrupted work and financial well-being.

The current state of Russian industry is characterized by high wear of the equipment and low energy efficiency. This problem is especially acute for such industries as cement, mineral, mining etc., where heavy machines characterized by high energy consumption are used [1]. Within the modernization process, special attention should be given to the electric drives of heavy stationary machines. They include the main drives of high-power metal cutting machines, steel rolling mills, compressor units, high-power pumps, drill rigs, generators, cement and coal mills, rotary kilns, grinding mills and self-grinding mills, drum dryers, separators, mixers, roller presses, belt conveyors and others.

The process of modernization of the complex technical equipment, the problem of analyzing design decisions always arises. The complexity of the assessment of the design solutions for modernization is based not only on the complexity of the technical analysis and evaluation of the project from the point of view of its design features affecting the operation of the equipment, but also on the necessity to assess the associated expense and risks related to modernization, for example, the project implementation time, the warranty period, energy efficiency, the ability to provide spare parts for the whole life of equipment, etc. Thus, various enterprise departments with different objectives are
involved in the decision making, and a strategy is needed that takes into account the quality criteria of the proposed project meeting the requirements of all participants in the process.

2. Features of heavy duty drives

Heavy machines include many machines involved in the technological processes of production. Heavy technological machines are classified primarily in terms of their mass and power of drive motors. The mass of such machines exceeds 10 tons, and the total power of the drive engines is tens and thousands of kW. The group of the process equipment includes rotary kilns, opposing compressors, crushers, high-power metal cutting machines, steel mills, high-power pumps, drill rigs, generators, drum dryers, separators, mixers, roller presses, belt conveyors and various kinds of mills and crushing machines, designed to produce fine fractions of the material, i.e. cement and raw mills, grinding mills and self-grinding mills. For example, ball mills are widely used in the enterprises of non-ferrous and ferrous metallurgy, chemical industry, alumina production, cement industry, brick factories, coal thermal power stations, mining enterprises. In most cases, an electric drive is used as a drive of such heavy machines. It is necessary to mention the main features of heavy duty drives:

1. High transmitting power and torque. Transmitted power in such electric drives reaches hundreds or even several thousand kilowatts. For example, the rated power of a cement mill ∅4x13.5 m is 3150 kW.

2. Significant weight and size characteristics of the whole drive and its individual components. For example, the mass of the drive for a cement mill ∅4x13.5 m is about 140 tons. In this regard, it is necessary to prepare not only the design of the operating elements of the drive, but also in accordance with it – the project for the building the production site.

3. The various variants of the arrangement of heavy duty drives within the production site and the mutual arrangement of the elements are possible. Even for heavy machines of the same application, there are various modifications of them leading to their different arrangement on the production site and imposing limitations on possibilities of the applicable drive arrangements. So it affects to the layout of the production site.

4. Long lifetime of the equipment of the heavy duty drives. Thus, the average life of cement mill drives is about 30 years. At the same time, the current scientific and technological progress is such that for the years that have passed since the commissioning of the equipment, there have been significant changes in technic and technology that make it possible not only to achieve greater efficiency, but also bring significant changes in the design and arrangement of the drive. Therefore, the process of modernization of the drive requires to take into account the production site layout and to assess the amount of construction work to install the new drive.

To look deeper into features of the heavy duty drives, we need to classify them. The most of the considered heavy machines have rotating elements and the first classification criterion is related to the axis of rotation of the drive. For example, a mill has a rotated drum or a grinding table, a kiln - the case, a crusher - an axis of rotation of a shaft of a rod, etc. From the point of view location of the axis of rotation of the heavy machine [2], all drives can be divided into vertical [3] and horizontal ones. Depending on the heavy machine, some of the variants of the drive arrangement may be more or less common.

Horizontal drives due to the mutual arrangement of their components can be divided into:
- co-axial (or central) drives [4, 5], when the axis of rotation of the machine (the input part of the machine) coincides with the axis of rotation of the drive;
- non-central drives [5], when the axis of rotation of the machine (the input part of the machine) is located higher, lower, or has left or right shift from the axis of rotation of the drive;
- peripheral (lateral or side) drives [6], when the drive is located by the side of the machine.

Depending on the variant of the mutual arrangement of the components of the drive and the machine, the requirements for the production site, the location of the foundations and their height are defined.

There are three categories of the heavy duty drive due to a number of motors: drive systems with one, two or many motors.

Drives are divided according to the integral elements:
- direct drives [7], when the motor is directly connected to the machine;
- gear drives with the gearbox between the motor and the machine;
- girth drives [6] with the girth gear on the machine and the girth pinion connected to the motor or with a gearbox;
- integral drives [8] (with gear-motor drive) where the gearbox and the motor is integrated in one case;
- belt drives [5], with the belt to transmit the power from the motor to the machine (can be also with a gearbox);
- drives with cardan shafts (can be also with a gearbox) [9].

The girth drives include the following categories:
- with the girth gear on the machine and the girth pinion that does not integrated with the gearbox (if it is applicable);
- with the lateral gearbox, when the gearbox has an open case and located by the side or lower of the central plane of the machine.

The gear drives due to the type of the gearbox can be divided into three groups:
- with a cylindrical gearbox;
- with planetary gearbox;
- with gearbox with a power flow split.

Based on this classification, it is possible to analyze how effective the modernization from the point of view preparation work, including construction work on the site, is. In addition, some types of drives can be excluded from consideration if the heavy machine itself is not replaced. Thus, the vertical drives can’t be replaced by horizontal ones. Moreover, the replacement of peripheral drives with coaxial ones is associated with considerable difficulties and can be chosen only if considerable advantage of the replacement according to other parameters is proven.

In other words, when considering the quality assessment of the modernization project, one of the parameters of the design solutions is the amount of construction work to modernize the production site.

3. Approach to the quality assessment of the project for the modernization of heavy duty drives

When assessing the quality of complex technical systems, it is necessary to consider this problem in a comprehensive manner, considering solutions in the system of interrelations between the manufacturer of the drive system and the plant where it will be used. The manufacturer of the drive system provides not only a drive, but also an additional set of services, including warranty service, provision of spare parts, delivery, real-time condition monitoring of equipment and so on.

The presence or absence of services from the above list influences on the final quality of the project. In addition, it is necessary to assess the quality not only of the product, but also of the manufacturer, since the heavy duty drives are operated for a long time (more than 20 years), and the possibility to have a support during the entire operation period or within disposal of the product is one of the criterion of choosing a supplier company.

Thus, to evaluate not only the technical component, but also to analyze the information about the supplier, the most convenient way is to use the quality assessment method 4P [10]. The basis of this technique is the division of all quality criteria into 4 groups:

- Product – quality criteria relating to the product characteristics. To identify the main quality criteria for the Product group, the GOST 4.124-84 "System of product quality indicators. Reducers, geared motors, variators” can be considered as the base.
- Price – quality criteria relating to economic efficiency;
- Place – quality criteria relating to the location of the manufacturer respectively to the end user of the equipment
- Promotion – quality criteria relating to the means of informing the customer about the products, as well as to the reliability of the supplier.

The results of the definition of the criteria are presented in the form of the “fishbone” diagram in Figure 1.
The task of choosing the optimal drive option for a heavy machine, taking into account the features of the production site, can be formulated as follows:

\[ z(4P) = \sum_{i=1}^{n} (T_i \cdot w_i) \cdot w_{p1} + \frac{P_{\text{min}}}{P} \cdot w_{p2} + \left( \sum_{i=1}^{n} T_i \cdot w_i \right) \cdot w_{p3} + \left( \sum_{i=1}^{n} T_i \cdot w_i \right) \cdot w_{p4}, \quad (1) \]

where \( T_i \) – the value of the \( i \)-th drive indicator, \( w_i \) – weight coefficient of the \( i \)-th drive indicator, \( n \) – total number of indicators used for analysis, \( w_{p1} \ldots w_{p4} \) – weight coefficients of the groups Product, Price, Place and Promotion respectively, \( P_{\text{min}} \) and \( P \) – the minimum price among competitive alternatives and the price of the current alternative respectively.

The functions have some limitation related the applicability of the solution according to the classification mentioned above. Moreover, \( g \geq g_{\text{Cl}} \) – the warranty period for the equipment should be not less than required; \( P \leq P_{\text{Cl, max}} \) – the price should be lower than maximum defined the client; \( z1(fw) \rightarrow \min \) – the works for foundation modification should be minimized [11] and the solution should meet all requirements in technical specification.

The general method of the quality assessment of the heavy duty drives is as follows:

1. Collection of the data required for the assessment, namely: the parameters of the existing drive, the parameters of the heavy machine and the layout of the production site, the purpose of modernization, financial constraints on the modernization project, and other requirements for the project.
2. Based on the initial data, verification of the applicability of the quality indicators for the drive of the specified heavy machine.
3. Evaluation of the significance of the criteria of the modernization project quality.
4. Creation morphological table. Tables are formed as follows (Table 1).

### Table 1. Rules for the creation of a morphological table

| Parameter values for the current alternative | Parameter values for the current alternative | ... | Parameter values for the current alternative |
|---------------------------------------------|---------------------------------------------|-----|---------------------------------------------|
| Indicators                                  |                                              |     |                                              |

5. For each row of the morphological table, the values of significance of the indicators for estimating alternatives are determined by the method of pairwise comparisons.

6. Determining the values for each alternative for each indicator.

7. If it is necessary to evaluate the different possible solutions for modernization, then design solutions for the modernization of the drive are generated (as a set of different variants of alternatives for each indicator) and their evaluation is carried out. Then there is implementation of clauses 9-11, 13a.
8. If it is necessary to evaluate the proposed by different manufacturers solutions, then according to the morphological table the offers of producers are evaluated. To do this, it is necessary to perform the preparation work, namely, to form tables for structuring information for comparison [12]. Then the implementation of clauses 9-11, 13b.

9. Estimation of efficiency of replacement of the type of the drive and the scope of foundation works [18].

10. Evaluation of the remaining technical quality indicators by comparison with the base.

11. Estimation of economic efficiency of drive modernization by the formula:

\[
TC = C_b \cdot (1 - \frac{D}{100}) + (C_{el} + C_o \cdot (V_o \cdot n_o + V_{ol}) + n_m \cdot C_m + \sum_{i=1}^{m} C_{spi} \cdot n_{spi} + C_o + n_r \cdot C_r + \\
+ C_{ss} \cdot (t_o \cdot n_o + t_m \cdot n_m + t_r \cdot n_r) \cdot T_{op} + C_{dm} - C_{dp}
\]

(2)

where \(TC\) – total costs; \(C_b\) – initial costs; \(C_{el}\) – electric energy costs; \(C_o\) – lube oil costs; \(C_m\) – maintenance costs; \(C_{spi}\) – cost of purchase of the \(i\)-th name of spare parts; \(m\) – number of different names of spare parts; \(C_{ss}\) – costs for storage spares and expendable materials; \(C_r\) – costs for repair; \(C_{ss}\) – costs from standstill; \(C_{dm}\) – costs for dismounting; \(C_{dp}\) – money get from disposal some parts; \(D\) – discount in percent; \(V_o\) – volume of lube oil; \(V_{ol}\) – volume of oil loss; \(n_o\) – number of oil changes; \(n_m\) – number of maintenance of the drive per year; \(n_{spi}\) – number of the spares of the \(i\)-th name; \(n_r\) – number of repairs of the drive per year; \(t_o\) – time for the oil change, if the oil is changing during the scheduled maintenance, it can be considered as 0; \(t_m\) – time for maintenance; \(t_r\) – time for the emergency repair; \(T_{op}\) – lifetime in years.

12. Estimation of the indicators from the groups Place and Promotion by the method of pairwise comparisons.

13a. Define the function \(z(4P)\) and maximization.

13b. Define the function \(z(4P)\) and calculate the parameter for every solution provided by manufacturers.

4. Conclusion

The article analyzes the main parameters of the heavy-duty drives, which influence the process of the modernization. A method of the complex quality assessment of the modernization project is proposed. The method includes not only an assessment of the technical parameters of the project, but the parameters related to the supplier reliability.

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