Ensuring compatibility as an element of a technical system life cycle management

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Abstract. The article considers the issue of ensuring compatibility in the implementation of the life cycle processes of technical systems. A logical diagram is given explaining the reasons for the decline in the quality of objects due to insufficient attention to the requirements for technical compatibility. On the basis of static calculations, the possibilities of improving the quality of systems of electric shut-off valves are presented due to the correct provision of technical compatibility of the form “product - lubricant”. Alternative options for combining valves and electric drives with reduced power and weight characteristics are proposed.

1. Introduction
The majority of mining equipment are complex technical systems characterized by a wide range of quality indicators. The nomenclature of indicators is determined by the purpose of the equipment, its operating conditions, improvement trends in order to meet consumer requirements and ensure competitiveness. The implementation of quality indicators in the technical system and ensuring their compliance with consumer expectations is carried out at each stage of the life cycle (LC) of systems [1, 2].

The basic set of stages of the life cycle of technical systems includes six main stages:
1. Assess the new capabilities of the system, develop preliminary system requirements and ongoing design decisions - the stage of conception.
2. Create a system that meets the requirements of the consumer and can be tested, evaluated and applied as intended - the development stage.
3. Produce the system and test it; produce corresponding supporting systems - the production stage.
4. Use of the system in the given operation conditions and guarantee of its effectiveness - the stage of application.
5. Material and technical supply, maintenance and current repair - the stage of application support.
6. Ensure the removal of the system under consideration - the stage of termination of application and decommissioning.

The above stages divide the life cycle into manageable phases: development, implementation and completion, the effectiveness of which depends on a set of interconnected processes.

In the life cycle of technical systems, four groups of processes can be distinguished:
- agreement processes that determine the actions necessary to reach an agreement between organizations involved in the implementation of the LC technical system;
- enterprise processes that provide the resources and infrastructure necessary for the implementation of projects and guarantee the achievement of goals and the fulfillment of obligations;
of organizations under agreements;  
- project processes used to establish and implement plans, evaluate actual achievements and project progress in accordance with plans, and to monitor project implementation until its completion;  
- technical processes, including a set of works, allowing the profits to be optimized and risks to be reduced within the framework of the tasks.

Thus, ensuring the quality of technical systems is, first of all, ensuring the quality of processes, each of which should be aimed at meeting the requirements for technical compatibility [3].

Technical compatibility should be understood as the compatibility of elements of a technical system, their components, structural, fuels and lubricants, manufacturing and control processes [4].

The issue of ensuring technical compatibility at each stage of the life cycle is relevant for all technical systems [5–11], since non-compliance with the requirements for technical compatibility can lead to significant deviations of processes and a decrease in the quality.

2. Discussion
Here is a logical diagram explaining the decline in the quality of the technical system due to insufficient attention to the requirements of technical compatibility in the implementation of life cycle processes.

![Figure 1. Logical scheme of quality formation in the implementation of the life cycle of technical systems](image)

The following conventions are used in the diagram (Figure 1): \( P_1, P_2, P_3, \ldots, P_n \) are processes of the LC system; \( Q^p_1, Q^p_2, Q^p_3, \ldots, Q^p_n \) is potential (possible) quality of the TS in the implementation of the relevant processes; \( Q^f_1, Q^f_2, Q^f_3, \ldots, Q^f_n \) is the actual quality of the TS in the implementation of the relevant processes; \( \Delta Q_1, \Delta Q_2, \Delta Q_3, \ldots, \Delta Q_n \) are deviations of the real quality from possible one; \( \Sigma P \) is a set of sequential processes; \( Q^p \) is potential (possible) level of quality of the TS in the implementation of a set of processes \( \Sigma P \); \( Q^f \) is the achieved quality level of the TS during the implementation of the set of processes \( \Sigma P \) or the share of the acquired quality criteria.

In this case, to calculate the achieved level of quality, one can use the mathematical dependence known from the theory of reliability, which describes the probability of obtaining defect-free products, interpreting it within the framework of the problem under consideration:

\[
Q^f = (1 - q_1) \cdot (1 - q_2) \cdot \ldots \cdot (1 - q_n)
\]

where \( q_1, q_2 \ldots q_n \) are the proportions of quality indicators that are present in the technical system but not implemented in the final product due to a violation of the principles of technical compatibility.

The potential of the system, not realized in the final product, will affect the value of the object, but not be of value to the consumer. For the manufacturer, the unrealized potential of the system will be a lost competitive advantage.

3. Results
As an example, we present the results of the process of designing systems that include an electric drive and shutoff valves from the position of ensuring technical compatibility of the form “product -
lubricant”. This type of technical compatibility characterizes the suitability of a certain type of lubricant for use in the product in question, ensuring the required quality indicators.

The selection of elements in the systems under consideration is based on the results of a static calculation of valves. Modeling the required operating conditions, the generally accepted methods determine the power characteristics of valves and the corresponding characteristics for selecting an electric drive: \( M_X \) is idle torque (N-m); \( M_O \) is opening torque (N-m); \( M_C \) is closing torque (N-m). In accordance with the results obtained, an electric drive is selected and, after a set of tests, the "electric shut-off valve" system is supplied to the facility.

As an object of study, valves intended for operation as shut-off devices in gas pipelines were selected (Figure 2). Valve production is carried out by one of the Russian manufacturers in accordance with TU 3742-041-49149890-2009 for nominal bore DN (mm) 65; 80; 100 and medium pressure PN 8.6; 9.2; 11; 12; 14 MPa.

![Figure 2. System of the electric shut-off valve](image)

In accordance with the technical specifications, an electric drive is used as a control device for all modifications of this shut-off valve with the limits of regulation of the torque limiting clutch 400-1000 N-m; drive power is 3 kW.

The reason for choosing this version of the electric drive is the results of the static calculation, partially presented in Table 1.

| Nominal valve DN (mm) | Pressure medium PN (MPa) | 9.2 | 11 | 14 |
|----------------------|--------------------------|-----|----|----|
|                      | Estimated values of the output characteristics of the system: \( M_X \) is idling torque (N-m); \( M_O \) is opening torque (N-m); \( M_C \) is closing torque (N-m) | \( M_X \) | \( M_O \) | \( M_C \) | \( M_X \) | \( M_O \) | \( M_C \) | \( M_X \) | \( M_O \) | \( M_C \) |
| 65                   | 152                      | 279 | 368| 178| 326| 425| 221| 400| 523 |
| 80                   | 169                      | 451 | 550| 200| 527| 641| 247| 653| 793 |
| 100                  | 173                      | 596 | 724| 203| 711| 860| 252| 880| 1000|

The results of static calculations of the power characteristics of the specified type of valve (see Table 1) are for high-temperature grease VNII NP-275 (TU 38.101891-81), designed for power screw pairs and threaded connections. This type of lubrication provides an increased coefficient of friction \( \mu = 0.2 \), which for manual valves allows the self-braking condition of the power pair (screw-nut) to be ensured.

When used to control the valve of the electric drive, the use of lubricants with a high coefficient of friction is not a prerequisite, since the self-braking effect is provided by the electric drive. This
removes a number of limitations and allows the manufacturer to expand the field of research on optimizing the system parameters within the framework of ensuring the type of technical compatibility “product - lubricant”. It should be noted that at the moment the manufacturer does not use the indicated potential.

As an explanation, we present the results of a static calculation for the same system when using the VNII NP-232 lubricant (GOST 14068-79), which provides a friction coefficient \( \mu = 0.14 \) and presents an analysis of the results. The calculation results are summarized in Table 2.

**Table 2.** The calculated values of the output characteristics of the system at a working medium pressure of 9.2; eleven; 12; 14 MPa, the friction coefficient of high-temperature grease \( \mu = 0.14 \)

| Nominal valve DN (mm) | Pressure medium PN (MPa) |
|----------------------|--------------------------|
|                      | 9.2          | 11      | 14      |
| Estimated values of the output characteristics of the system: \( M_X \) is idling torque (N·m); \( M_O \) is opening torque (N·m); \( M_C \) is closing torque (N·m) |
|                      | \( M_X \) | \( M_O \) | \( M_C \) | \( M_X \) | \( M_O \) | \( M_C \) | \( M_X \) | \( M_O \) | \( M_C \) |
| 65                   | 114         | 178     | 280     | 135       | 207       | 326     | 166       | 253       | 400       |
| 80                   | 120         | 253     | 390     | 141       | 294       | 451     | 174       | 364       | 559       |
| 100                  | 135         | 398     | 561     | 156       | 468       | 656     | 189       | 581       | 800       |

For the analysis, let us compare the results obtained (Tables 1-2). The comparison can be simplified by the graphs of changes in torque for the same technical system when using two types of lubricant VNII NP-232 (GOST 14068-79) and VNII NP-275 (TU 38.101891-81) (Figures 3-5).

It can be seen from the graphs (Figure 3-5) that the use of VNII NP-232 lubricant (GOST 14068-79) reduces power characteristics by 20-40%, and the lubrication efficiency is higher, the lower the pressure of the medium. In this case, there is no need to assign 400-1000 N·m of torque limiter to control the valve of the electric drive with the limits of regulation of the torque limiter.

The analysis allows offering alternative options for the technical combination of the electric actuator and the shut-off valve in the system (Table 3).

The proposed options (Table 3) in terms of weight, power, overall dimensions and cost will be significantly more beneficial for the consumer. The cost of alternative options is more than 60,000 thousand rubles lower. The manufacturer, in turn, will receive an additional competitive advantage and the opportunity to increase market share.

**Figure 3.** Graphs of torque changes when using greases VNII NP - 232 (GOST 14068-79) and VNII NP-275 (TU 38.101891-81) for DN = 65 mm
Figure 4. Graphs of torque changes when using greases VNII NP - 232 (GOST 14068-79) and VNII NP-275 (TU 38.101891-81) for DN = 80 mm

Figure 5. Graphs of torque changes when using greases VNII NP - 232 (GOST 14068-79) and VNII NP-275 (TU 38.101891-81) for DN = 100 mm

Table 3. Actual characteristics of the system and possible characteristics of the system for alternative options for technical alignment of the electric actuator with a shut-off valve after solving the problem of technical alignment of the form “product - lubricant”.

| DN (mm) | Actual specifications | Possible specifications |
|---------|-----------------------|-------------------------|
|         | PN (MPa) | Me [N·m] | M_{min}-M_{max} [N·m] | N (W) | m (kg) | Me [N·m] | M_{min}-M_{max} [N·m] | N (W) | m (kg) |
| 65      | 14       | 523      | 400-1000              |       | 400    |       |
| 80      | 11       | 641      | 400-1000              | 93    | 451    | 200-500  | 1.5   | 55     |
| 9.2     | 550      |          |                       |       |        |          |       |        |

where \( M_{min}-M_{max} \) are the limits of regulation of the torque limiter of the electric drive (N·m); \( m \) is...
the weight of the electric drive (kg); N is the electric motor power (W).

4. Conclusion
Regardless of the type of technical system, the processes of each life cycle stage must be considered as a set of processes for ensuring technical compatibility.

Technical compatibility requirements will affect both the quality of the process and the quality of the final product.

To realize the full potential of the system, together with the tasks of quality assurance, it is necessary to solve the problems of quality management, which consist in determining the control factors that can provide predetermined properties of the system and increase the value of products for the consumer.

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