Establishing compatibility of technical elements for electric isolation valve systems

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Abstract. This research addresses the issue of technical compatibility of elements. It demonstrates that violation of technical compatibility principles when engineering products are designed reduces the quality and increases energy intensity of systems. It is established that for electric isolation valves, the main performance indicator of element compatibility is as follows: the ratio of energy flows expended on deformation of isolation and force-measuring springs. To meet the requirements for compatibility of technical elements in electric isolation valve systems, it is recommended to expand the number of indicators in project documentation. Key indicators should include variations of output characteristics by different combinations of such parameters, as the electric drive rotational speed, control system lag time, stiffness of the force-measuring spring and isolation valves.

1. Introduction
For a major part, manufactured engineering products are complex multi-element systems. Given the variety of elements interaction of which is required for a system to function, one of the main issues for improving the quality of engineering products is to ensure compatibility of its elements.

This term stands for compatibility of backbone, systemically important elements and their components, structural, fuel and lubricants, manufacturing and control processes.

Requirements for element compatibility should be laid down at the product design stage and further ensured and evaluated at all stages of a product life cycle [1].

The nomenclature of technical elements compatibility requirements is determined by the system structure and operating conditions. For each type of product, nomenclature has a separate set of indicators.

2. Results and Discussion
Here, we will use results of studies that contain the main provisions for technical compatibility in the electric isolation valve systems.

A system consists of an electromechanical drive subsystem, an isolation valve, an electric drive control system. All these elements are combined at the product assembly stage [2].

When design documentation is developed for this type of systems, design engineers take into account dimensional compatibility of elements, reliability requirements compatibility, functional compatibility, etc.

Nomenclature requirements for technical compatibility allows for various combinations of elements in one system, their performance capabilities are confirmed by acceptance testing that aim to verify isolation valve leak tightness. Ensuring leak tightness is a key function of isolation valve systems. The
control parameter is important; however, the results of theoretical and experimental studies show that one parameter is still insufficient for quality assessment of the whole system [3].

This research relies on results of experimental studies of typical electric isolation valve systems designed to ensure safety of nuclear power facilities. Fast-response electric drive valve systems make up more than 40% of this type of equipment operated at nuclear power plants [4].

The permissible torque deviation for such systems is $\pm 10\%$ of the maximum torque of the electric drive setting.

Figure 1 demonstrates actual torque changes when NG 26526-065AE isolation valve system was running by different electric drive parameters. System I: electric drive SA 10.2–14, output shaft rotational speed of the electric drive is 32 rpm, output shaft rotational speed of the electric engine is 1500 rpm ($\omega = 150 \text{ s}^{-1}$). System I: electric drive SA 10.2–16, output shaft rotational speed of the electric drive is 63 rpm, output shaft rotational speed of the electric engine is 3000 rpm ($\omega = 300 \text{ s}^{-1}$).

It is clear from Figure 1 that in real life conditions, output torque deviation does not fit tolerance limits specified in technical documentation. For System I, the actual output torque value exceeds the limit approximately by 2 times. For System II, the actual output torque is 3 times the limit value.

Figure 2 demonstrates results of the second series of tests. A common element for Systems I and III (Figure 2) is the electric drive SA10.2-14 (output shaft rotational speed is 32 rpm). However, in System I the operating device is the isolation valve NG 26526-065AE, while in the System III, it is isolation valve NG26524-050MAE. As in the previous case, the graphs demonstrate significant deviation of the actual torque values relative to the torque specified at the system setup.

Given that in both cases the same electric drive was used to conduct tests, it can be concluded that the cause for different actual blocking moments is different stiffness of NG 26526-065AE and NG26524-050MAE isolation valves.

Therefore, when requirements for technical compatibility of the electric drive and isolation valves are determined, a set of parameters "System stiffness" and "Rotational speed of the output shaft of the electric drive" play a significant role. Analysis of specifications and nomenclature catalogs of different manufacturers allows for the following conclusion: neither a set of parameters (rotational speed of the electric drive; stiffness of electric isolation valves), nor their impact on the output characteristics of the system are listed in the documentation. In the list of performed system tests for electric isolation valves, the requirements for and methods of assessing the actual power characteristics of the system are also are
absent. Compliance of electric drive torque values to the tolerance limits specified above (±10%) is confirmed by the bench tests of the drive, when load is modeled without taking into account valve stiffness variations. Results of the existing approach are illustrated in Figure 1 and 2.

Thus, it is established that the deviation of the actual torque value from one specified in system settings represents systemic effect. The reason for this system effect is that different technical elements are combined into a single system: an electric drive, valves and motor control system.

Most specialists that design such complex technical systems believe that the time interval of 20–60 ms (control system lag time) can not lead to significant errors. However, as results of experiments show [2], during this short period of time the actual deviations can be so significant that it is necessary to raise the issue of safe operation.

Energy equation allows for explaining the reason for such inconsistencies, since ensuring energy balance is a key criterion of compatibility of technical elements in system:

\[
\sum E = \sum E_{P1} + \sum E_{PII} + \sum E_{PIII},
\]

where \(\sum E\) is the total energy of the electric drive (ED), spent on the working cycle execution (open – closed); \(\sum E_{P1}\) is the potential energy at Stage I (work performed by the system to ensure leak tightness of valves; Stage I ends when system shutdown settings are reached); \(\sum E_{PII}\) is potential energy at Stage II (work performed by the system from the moment a microswitch is activated and signals that a systems needs to be shutdown, to the shutdown of the electric drive); \(\sum E_{PIII}\) is potential energy at Stage III (work performed by the system under the force of inertia).

To explain the equation (1) given above, principles of operation are considered using a simplified kinematic diagram of a typical electrical isolation valve system (Figure 3).

The electric engine 1 converts electric power into a mechanical rotational motion, which through the output shaft 2, a clutch and a worm-reduction gear is transmitted to the output shaft of the electric drive 6. The power pair 8 located in the body frame converts rotational motion of the output shaft of the electric drive into a translational motion of the isolating valve unit 10. When the end position is reached, the isolating valve unit 10 thrusts against a seating 11 and stops. Then the worm wheel 5 stops. As the electric motor continues to work, the worm 3 rotates and, given the locked worm wheel 5, moves along its X axis. By doing so, it compresses the force-measuring spring 4. When the drive develops a target torque for valve closing, a small lever that is moved by a worm 3 flank, reaches a torque microswitch 12. From it, a signal is transmitted to the control panel.
It should be taken into consideration that after a seating 11 comes into contact with the isolating valve unit 10, a rotor of the electric engine 1, which is kinematically connected to them, slows down its rotation up to a full stop. The electromagnetic field of the rotor lags if compared to the stator field, the current increases, the motor's rotary moment increases and the torque of the electric drive steeply increases [4]. This process is similar to starting torque, but if the stop is abrupt, it runs harder [5]. A time interval between microswitch 12 activation to engine 1 shutdown is the control system lag time. It depends on the total hysteresis (delay) of components that make up the control and power circuits (microswitches, relays, etc.) During this lag time, the system accumulates such amount of energy that is enough for manifold increase of the resulting electric drive torque if compared to a target value used to set up system shutdown [6].

After the engine is no longer powered, moving parts of the system (a rotor, worm, forcing screw, nut, etc.) continue to operate under the force of inertia. That is, during the stopping period, due to the inertia moment, the torque of the electric drive output shaft also increases [7, 8]. Thus, at the moment of a system full stop, the actual output torque value significantly exceeds the value specified in settings.

The conclusion is as follows: the energy balance principle should be maintained for compatibility of different technical elements within a separate valve system. Implementation of this principle at the system design stage is possible only if parameters of each element are taken into account (the stiffness of valves units, stiffness of a force-measuring spring, inertia of all components, the control system lag). Otherwise, energy accumulated in the system will result in excessive loads from the electric drive, or it will dissipate in the system creating additional strain [9]. Both of these variants are negative and increase the risk of performance loss of the system and the objects it handles [10].

The described approach to ensure compatibility in electric isolation valve systems can be used to develop nomenclature requirements for the quality of the system and its elements.

Next, we will address the issue of improving the electric isolation valves through improving compatibility efficiency of its elements.

In the system under consideration, two main elements can be identified: their rigidity has a direct impact on the energy efficiency of the whole system. These are isolation valves and a force-measuring spring. A combination of these elements forms a force-measuring system. After the isolation valve unit
comes into contact with a seating, kinetic energy of the engine is divided into two parallel flows. The first flow compresses the spring ($E_{SP}$), the second one aims to deform the valve unit ($E_{VA}$).

The energy ratio can be calculating using this formula:

$$K_c = \frac{E_{SP}}{E_{VA}} = C_{is} \frac{k_{sp}}{C_{sys}}$$

(2)

where $C_{is}$ is rigidity of isolation valves; $k_{sp}$ is rigidity of a force measuring spring; $C_{sys}$ is a constant coefficient that defines a ratio of forces in system equilibrium conditions. This coefficient depends on the following parameters: worm wheel radius, worm gear efficiency factor, efficiency factor of the isolation unit screw pair, torque arm in the trapezoidal screw thread.

Thus, for the electric isolation valve system, the coefficient $K_c$ will be a unique indicator of compatibility effectiveness and will have a constant value ($K_c \rightarrow \text{const}$).

Ensuring rigidity balance, for this case, and assessment of efficiency of combined elements performed when the electric isolation valve system is designed, can reduce the system's energy consumption.

If a value coefficient is in the range $0<K_c<1$, then most of the energy accumulated in the system is spent on ensuring the leak tightness of a pipeline and such combination of elements is be effective. In case it is close margin value $K_c=1$, the energy will be distributed in equal shares, i.e. the required amount of energy two times as large. By $K_c>1$, most of the energy will be spent on performing force-measuring function or damped by the force-measuring spring, i.e. the combination of elements within the system will be inefficient.

It should be concluded that the possibility to use rigidity of system elements as an additional control parameter is currently ignored when systems are designed. Taking this parameter into the account will allow for effective functional compatibility of elements, correct assessment of accumulated energy, danger minimization for dynamic overloads that influence reliability and safety of the objects handled by a system.

3. Conclusion

When an electric drive, isolation valves and the electric motor system control are combined into a single system, in order to ensure consistency of power characteristics, the energy balance should be taking into account, as well as the stiffness balance between isolation valves and the force-measuring spring.

Compatibility requirements should be established when a system is designed. Further, at all stages of the system life cycle, they should be ensured and evaluated. To meet these requirements, nomenclature of indicators for electric isolation valve systems in technical documentation for each element of the system should include stiffness factors and variations of output characteristics by different combinations, such rotational speed of the electric drive, control system lag time, stiffness of the force-measuring spring and isolation valves.

For electric isolation valves, the key performance indicators for element combination in the system will be the ratio of energy flows spent on deformation of isolation and force measuring springs. Generic approach to quality assurance of electric isolation valve systems requires significant revision: it is necessary to change standard power-based calculation methods and take into account compatibly of technical elements to ensure the balance of energy and stiffness in systems.

References

[1] Rudenko A A, Antipov D V, Iskoskov M O 2015 IOP Conf. Ser.: Mater. Sci. Eng. 6 012071
[2] Plakhotnikova E V, Vasin S A, Malikov A A 2018 IOP Conf. Ser.: Earth Environ. Sci. 6 062028
[3] Anikeeva O, Ivakhnenko A, Erenkov O 2018 MATEC Web of Conferences
[4] Plakhotnikova E V 2016 IEEE Conf. on Quality Managem., Transport And Inform. Security, Informat. Technol. (IT&MQ&IS)
[5] Maksarov V V, Krasnyy V A, Viushin, R V 2018 IOP Conf. Ser.: Mater. Sci. Eng. 2 022047
[6] Maksarov V, Zlotnikov E, Olt J 2017 Annals of DAAAM and Proc. of the Int. DAAAM Symposium 0209-0215
[7] Ivakhnenko A G, Kuts V V, Altukhov A Yu, Ivakhnenko E O 2015 *Chem. and Petrol. Eng.* **51**(7) 445-451
[8] Maksarov V V, Gabov V V, Zadkov D A, Martyushev N V 2018 *IOP Conf. Ser.: Earth Environm. Sci.* **194**(7) 012001
[9] Zakirnichnaya M M, Kulsharipov I M 2017 *IOP Conf. Ser.: Earth Environm. Sci.* **87** 082055
[10] Sytin A, Babin A, Vasin S 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **233**(1) 012045