Ensuring the products quality at the integration of diverse elements into unified technical system (evidence from the technical system "electric actuator - gate valve - operating system")

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Abstract. The current scientific and technical problem of ensuring the product quality at the integration of diverse elements (mechanical, electric, operating) into unified technical system (TS) has been considered. The system "electric actuator - gate valve - operating system" (EA-GV-QS) demonstrates the possibility of using the "system properties" to improve the quality and competitiveness of product. We have formulated basic trends of ensuring quality at design of the TS consisting in establishing "system properties", identifying framework factors, defining conditions and restrictions at technical compatibility of diverse elements. Implying the given trends allows to increase the quality level and competitiveness of technical systems by the correct usage of "system properties".

1. Introduction
The quality of the technical systems (TS) in many respects is defined by the quality of the elements integrated into their structure. But as practice shows, the effect is not always additive. At designing TS most of producers do not consider the system output characteristics variability caused by the appearance of new "system properties" at technical combination of diverse elements (mechanical, electric, operating). "System properties" occurrence is an inevitable stage in formation of the TS [1]. Contingent upon their existence it is possible to succeed functional integration of elements within system, to find new directions for the development of TS, to increase the quality level of the final product. Everything mentioned earlier is possible if we use "system properties" knowledge correctly. Otherwise, technical combination of elements can lead to the destruction of the system [2].

2. Results And Discussion
The quality non-additivity, defining by the difference between system quality and the sum of its elements qualitative characteristics if they do not interact definitely, can be exemplified by the fast-acting TS "electric actuator - gate valve - operating system" (EA-GV-QS).

Systems have a wide scope. They are used for servicing the objects of the oil and gas complex and power (TPS, CHP plant, the NPS, etc.), the enterprises of chemical, petrochemical and oil-refining industries, gas pipelines and disposal facilities [3].

Despite the variety of the modifications considered by TS, the general principle of their design is technical combination of three diverse elements: electric actuator (electromechanical element), gate valve (mechanical part of the system), and operating system (electric element) into a single structure.
Design is carried out by providing the set of the regulated quality criteria established in technical documentation (technical specifications, passports), standards and regulations. Quality indicators nomenclature regulated by technical specifications allow to provide dimensional and functional technical compatibility of elements within the system taking into account requirements to reliability and service environment, but do not consider the "system property" which appears in the deviation of the actual system power characteristics (torques and efforts) from normalized values.

Table 1 explains the results of the experiment with the gate valve NG 26526-065AE-43 using the electric actuator EPAS10.1 as the operating device under various rotation frequency of output shaft (tab. 1).

Table 1. The results of the experiment recorded by the control unit AUMATIC AC 01.2 Non-intrusive within system functioning "gate valve (NG 26526-065AE-43 according to technical specifications 26-07-1407-2008)-the electric actuator (EPAS 10.1)"

| Power pressure under technical specifications 26-07-1407-2008 | Torques of setting for shutdown of the electric actuator EPAS10.1 (\(M_f\)) N\(\cdot\)m |
|---------------------------------------------------------------|---------------------------------------------------------------|
| PN =0 MPa                                                   | 78                89                103                117                                                   |
| PN =2.5 MPa                                                  | 84                98                106                118                                                   |
| during operating the electric actuator EPAS10.1 -14D (output shaft is n=32 rpm) |                                                   |
| PN=0 MPa                                                   | 117               143*                                                   |
|-------------------------------------------------------------------------------------------------------------------|
| *- measured by a torque wrench                                                                                      |

The carried out experiment shows that the torque fixed at a full stop of the TS "EA-GV-QS" considerably exceeds parameters of its setting. Such mismatch is the cause of significant loadings in the system which increases the risk of system output from workable condition.

To establish the factors influencing variability of output characteristics the structural and functional description of the system has been carried out [4]. As a result it has been determined that at functional combination of elements within the TS "EA-GV-QS" the impact is exerted by:
- time lag of an operating system at turning electric motor off;
- inertia of moving elements of the system;
- rigidity of shutoff valves;
- rotation frequency of the electric actuator;
- torque of system setting to shutdown at performing the working cycle "open - closed".

Each of the given factors needs to be considered when optimize and define the sustainable operating conditions of the TS of "EA-GV-QS".

The formula allows to estimate a weightage of factors:

\[
K_i = \frac{M_f}{M_0}.
\]

where \(K_i\) is a relative index of systems quality defining a numerical measure of a ratio of two compared quantities: factual \(M_f\) and calculated \(M_0\) of torques; \(M_0\) is a calculated torque set in the design of system, and used for its setting; \(M_f\) is a factual torque developed by the system.
\( M_f \) value, depending on a stage of life cycle can be determined by two methods: at a stage of tests – experimentally, and at a design stage - by calculation, using a formula:

\[
M_f = M_0 + \Delta M_t + \Delta M_j,
\]

(2)

where \( \Delta M_t \) is torque increment during control lag at engine turning off (time of lag is caused by the time-current characteristics of contactors, power disconnector, microswitch, etc.); \( \Delta M_j \) – is torque increment by means of the energy of inertia system moving elements after engine turning off down to system standstill.

\( \Delta M_t \) value at a design stage can be calculated by the formula:

\[
\Delta M_t = C_{\varphi^o} \cdot n \cdot t \cdot 360^\circ,
\]

(3)

where \( C_{\varphi^o} \) is a torsional stiffness of shutoff valves (Nm/°); \( n \) is electric actuator output speed (rpm); \( t \) is control system time of lag (min.).

Any factor minimization in a formula 3 will significantly reduce the quantity \( \Delta M_t \), reigning in the influence of addend on coherence of system (see a formula 2).

In the designing of the TS "EA-GV-QS" it is necessary to consider the following:
- rigidity \( (C_{\varphi^o}) \) is a constant quantity of GV, and its reducing needs to be changed in construction. In other words, this parameter can be changed only at the design stage of GV, but under technical combination of already-present elements, the adjustment of this parameter is impossible without padding damping devices [5];
- time lag of a control system \( (t) \) is caused by technical capabilities of the operating system object. Decrease in time can be provided only with modernization of QS, that demands additional investment from the operating system organization;
- the rotation frequency of the electric actuator \( (n) \) is also constant value depending on the required response rate of the TS.

Thus, \( \Delta M_t \) value will be a constant for particular TS "EA-GV-QS", and its ponderability will depend only on parameter values of the setting \( M_0 \).

For explanation there are technical specifications of a gate valve Г26524-050MAE with the electric actuator EPAS14.1-11 in table 2.

| Table 2. Technical specifications of electric actuator gate valve |
| --- |
| designations of GV | nominal DN (mm) | Estimated environment pressure (MPa) | Control mode | \( M_0 \), Acc. Tech Spec. (N·m) |
| Г26524-050MAE | 50 | 11 | EPAS14.1-11 | 180 |
| | 50 | 20 | | 230 |

The table shows that the value of \( \Delta M_t \) on pipelines with environment pressure of 11 MPa will be 1.5 times more, than at operation of the same system pressure of 20 MPa.

Torque rise value \( \Delta M_j \) for i of that system can be calculated by a formula:

\[
\Delta M_j = C_{\varphi^o} \frac{n^2}{i \cdot \eta} \cdot \left( J_d + J_1 \frac{m_1^2}{n_1^2} + J_2 \frac{m_2^2}{n_2^2} + \ldots + J_n \frac{m_n^2}{n_n^2} \right) \frac{1}{114.6 \cdot (M_0 + \frac{M_t + M_j}{i \cdot \eta})},
\]

(4)

where \( J_d \) is rotor inertia of a motor and other elements (couplings, gears etc) [6-8], set on an engine shaft; \( J_1, \ldots, J_n \) is an inertia moment of parts do not set on the engine shaft; \( n_1, \ldots, n_n \) is engine shaft speed, (rpm).

Formula (4) presents that \( \Delta M_j \) value can also be minimized by decreasing a torsional rigidity of GV. That is, the GV rigidity in the TS «EA-GV-QS» is the important operating parameter at designing.

Defining the nomenclature of the factors influencing on "system property" of the TS «EA-GV-QS», and their significances allowed to develop methodology for setting correct parameters of considered systems [4].
Using methodology for the TS «EA-GV-QS» allowed to prove decreasing of a system setting torque, including gate valves HG 26526-065AE under technical specifications 26-07-1407-2008 (Veliky Novgorod), and to develop recommendations on a complete set of the mentioned valves EPASunder technical specifications 3791-001-49149890-2003.

Instead of the electric actuator EPAS 10.1-14 D, indicated in technical specifications 26-07-1407-2008 (an output shaft is 32 rpm, power of motor is 0.75 kW, the weight is 26.5 kg, regulating limits of torque restriction coupling is 40 … 120 Nm), we offer to use the electric actuator EPAS07.5-14 D (output shaft rotation frequency is 32 rpm, power of the electric motor is 0.37 kW, weight is 22 kg, regulating limits of torque restriction coupling is 20 … 60 Nm) that reduces system cost in a basic complete set by 22%.

At the moment the work capability of the TS «EA-GV-QS» with reduced power characteristics at the standardized specifications to hermiticity is confirmed by the tests within the specified time in service (3000 cycles).

3. Conclusion

According to the TS "EA-GV-QS" we can formulate three general trends of an integrated TS quality which includes diverse elements:

- comprehensive research of the TS to establish "system properties" and the factors influencing variability of its output characteristics by means of the structural and functional description of the system as well as carrying out full-scale experiments;
- managing the factors, influencing "system properties";
- ensuring effective functional combination of elements in system with the minimum weight, dimensions and power consumption by formation of requirements, conditions and restrictions to technical compatibility of elements.

Implementation of the mentioned trends allows not only to identify "system properties", but to increase the quality level and competitiveness of technical systems by means of their correct usage [9-10].

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