POSSIBILITIES OF IMPROVING QUALITY MANAGEMENT SYSTEMS IN THE DIGITAL AGE

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Abstract

It was noted that in the digital era, the classical approach to the definition of the concept and the emphasis on quality assurance are fundamentally changing. It is shown that focusing on the current and future needs of consumers requires prompt monitoring and regulation of product quality parameters on a real-time scale. Based on the forecast of the development of quality management systems, the structure of a digital system for ensuring the level of product quality required by the consumer is proposed in the article. Proposals for determining the minimum survey frequency for each of the measured (evaluated) quality parameters have been also developed. A mathematical model for establishing the number of numerical ratios about the value of single indicators of product quality is proposed too.

Keywords: quality consumers require, quality parameters mathematical model, digital quality management system, evaluation frequency measuring quality parameters

Introduction

The quality management systems (QMS) design is regulated by the fundamental standard ISO 9001, which has been revised several times since its inception. The purpose of revision of the standard is constant adaptation to changes in the production sphere in accordance with the development of the scientific and technical revolution. From TQM and lean production, quality management systems have gradually moved to systems that must comply with Industry 4.0, built on smart devices and cyber-physical systems with minimal human involvement [1, p.1-2], [2, p.1]. According to the definition of Quality 4.0: ASQ's (American Society for Quality) definition - Quality 4.0 brings together Industry 4.0's advanced digital technologies with quality excellence to drive substantial performance and effectiveness improvements [3, p.1]. The main tools of Quality 4.0 are the automation and digitization of quality assurance processes, and the ultimate goal of Quality 4.0 is to maintain constant quality using real-time data processing, the Internet of Things, artificial intelligence, and big data analytics [2, p.3]. Thanks to the creation of a European digital economy and society with long-term growth potential, the European Union plans to ensure competitiveness in the market [4, p.2]. This can be achieved through the digital transformation of society with digitization of evaluation processes and quality assurance of products, goods, and services based on the European metrological cloud [5, p.2].

Automation can help optimize quality management processes, reducing time and labor costs. Robotic process automation is a popular example of automation used in quality management. However, it is necessary to determine the polling frequency of the measuring channels.

Proposals to improve methods of product quality assessment

In the conditions of fierce competition, products, goods, services must be evaluated in real time according to an integral indicator, which is determined by the totality of all functional, aesthetic and economic properties, that is, characterized by the totality of consumer value and total costs for its production, sale (supply) and operation [6, p. 56]. It is obvious that in modern conditions, thanks to the high level of microelectronic and information technologies development, we can talk about an attempt to digitize the processes of determining the entire evaluation process in a real time scale of an integral quality indicator. That is, we can already talk about an attempt to build a cyber-physical system of quality assurance, support and evaluation. Thus, in the ideal case, during the construction and implementation of QMS at the current stage of technology development, we can talk about digital management in the quality management system (Fig. 1). The structure of the digital management system in the QMS can be presented as a set of five links that provide digital feedback in the real-time system of ensuring such a level of product and service quality that meets the customer's requirements. Digital measurement and assessment of object quality indicators by analogy with digital management of technical objects will play the role of a bridge connecting the control object with the main link of the QMS, which performs the task of generating control commands in accordance with the current requirements of the customer [7, p .145].

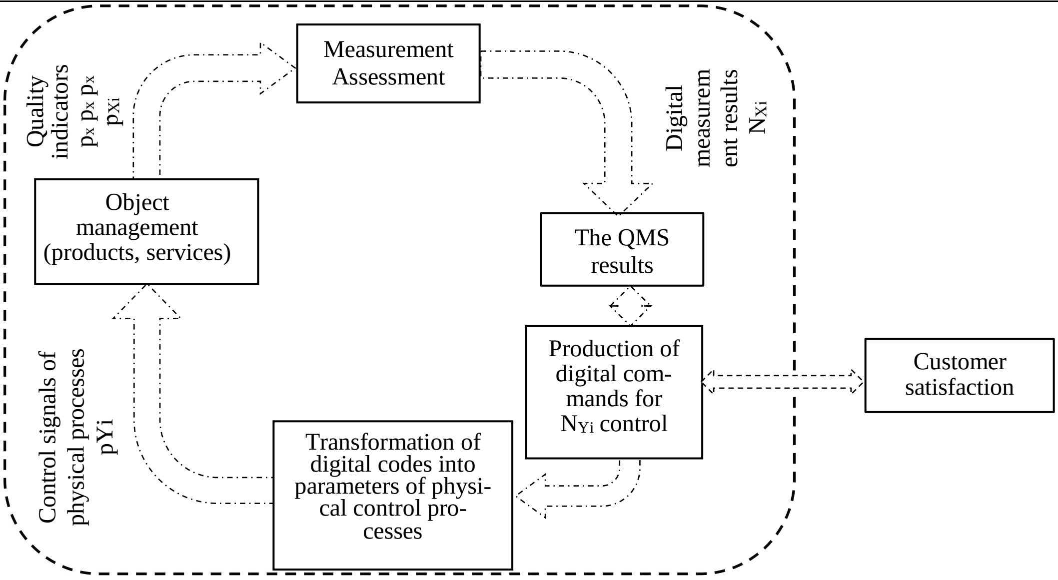

Fig. 1 – The structure of the digital management system in the QMS

The measurement or evaluation link should provide digital information about indicators of the quality of products and services (effectiveness of QMS). This information is compared in real time with the level of consumer satisfaction, and digital facility management commands are produced to maintain consumer satisfaction. This digital information is transformed into a set of control signals for the physical processes of the control object so as to satisfy the current or anticipated needs of the consumer. Digital management will ensure an increase in the objectivity of the implementation of all management processes and principles in the QMS.

Determination of the minimum survey frequency for each of the measured (evaluated) quality parameters

The object of management (products, services) in the general case has an infinitely large number of quality indicators (physical quantities), which in turn are reflected by an infinite number of numerical ratios. A more detailed analysis shows the need to choose such a number of quality indicators and a finite number of numerical ratios about their values that would currently satisfy the customers, as well as the foreseeable and unforeseen impact on the relevant stakeholders. Here we can draw a conclusion about the dynamism of the concept of quality of products and services, which will primarily depend on the foreseeable and unforeseen impact on all interested parties according to ISO 9001:2015. Since the introduction of QMS is a strategic decision of the organization, which can help improve its overall effectiveness and provide a solid basis for sustainable development initiatives, the choice of a certain number of quality indicators by the organization should be constantly changing [6, p.152]. This leads to the establishment of requirements for the flexibility of the structure of the developed QMS and the possibility of operationally changing the number of indicators of the quality of products and services in accordance with changes in the satisfaction of all interested parties. and building an extensible block for measuring/evaluating their values. It is expedient to determine the finite number of numerical ratios about the values of quality indicators of products and services in real time on the basis of ratios that follow from a theorem similar to the counting theorem (Nyquist-Shannon) [8, p.630], [9, p.14]. If the quality indicators can be approximated by a continuous signal x(t) with a spectrum limited by the frequency F_{max}, then it can be unambiguously and losslessly reconstructed from its discrete readings taken at the frequency $f_{dsr}=2F_{max}$, or, in another way, from the readings taken from period $T_{dsr}=1/2F_{max}$.

Then, by analogy with the method of determining the modulation error of the conversion with modulation-demodulation, it is possible to set the minimum value of the time of measurement/evaluation of the values of the quality indicators [10, p.67]: $T_{dsr} \geq (T_0/\pi)\arcsin(\gamma_{max})$ (1)

here $T_\Omega=1/F_{max}$; T_{dsr} the minimum time duration for measurement/evaluation of the quality indicators values;

γ_{max} is the maximum value of the relative modulation error

When determining physical quality indicators, it should be taken into account that the speed of modern ADCs is usually much higher than the change time of these measured quality indicators. When evaluating qualitative quality indicators, one should take into account their very slow change, usually much smaller even compared to labor-intensive and time-consuming expert methods.

Establishing the number of numerical ratios about the value of product quality indicators

In order to guarantee the achievement of the required quality level of goods, products, and services produced with the measuring equipment (ME), modern international regulatory documents recommend systematic and complete control of measurement processes as a separate and long-term procedure. Traditionally, differential, complex and mixed methods are used to assess the quality of any product of the same type. Disadvantages of the differential method include a high degree of subjectivity and low accuracy in determining the quality factor [6, p. 29]. When using the complex method, it is necessary to choose a natural generalized quality indicator for a given type of product and to determine its functional dependence on the main single indicators that, to one degree or another, affect its quality. The mixed method is based on the isolation of a number of separate groups covering the most essential properties of products, for which generalized comprehensive quality indicators are determined, followed by their comparison by the differential method with the corresponding indicators of the basic products [6, p.36].

It is natural to consider the object of measurement as a source, and the ME as a receiver of measurement information. This analog information is transmitted through the communication channel, in which the noise reduced to the input of the ME operates. It is known that the equivalent variance of the input random noise signal is defined as the sum of the variances of individual sources. During its determination, it is necessary to take into account the sources of both thermal and flicker noises. Then it is proposed to determine the amount of measurement information M_x received by the ME during measurement on the basis of the theorem of K.-E. Shannon [9, p.15]:

$$M_x = Ct_x = t_x B\,log_2\left(1+\frac{S_x}{N_n}\right) = t_x B\,log_2\left(1+\frac{U_x^2}{D_{nU}}\right), \quad (2)$$

where C is the performance of the measuring channel; t_x – measurement time;

$B=f_H-f_L$ is bandwidth of the measuring channel;

$S_x = (U_x^2/R_{in})t_{mx}$ is useful signal energy;

$N_n = (U_n^2/R_{in})t_{mx} = (D_n/R_{in})t_{mx}$ is energy of equivalent input noise;

U_x is measured voltage; R_{in} is input resistance of the ME;

U_n, $D_{nU} = D_{1U} + R_x D_{Iin} + 4kTR_x B$ is respectively, the voltage and variance of the equivalent input noise;

D_{n1U}, D_{Iin} is dispersion of equivalent noise by voltage and by current, respectively; k is the Boltzmann constant;

T is the temperature of the internal resistance of the source of the measured voltage.

On the other hand, the main purpose of the measurement process is to obtain measurement information, the numerical value of which is usually determined through entropy (Shannon's measure) or logarithmic measure of uncertainty (Hartley's measure). It is natural to assume that the input uncertainty is equal to the width X_2-X_1 of the ME measurement range, and the uncertainty after the measurements will be determined by the error of discrimination Δ_p of individual measurement results. Then, under the equal probability laws of the distribution of the measured value and the discrimination error Δ_p, the amount of information obtained after measurement can be estimated according to the ratio [11, p. 536]:

$$H_{mx} = log(X_2 - X_1) - log\,\Delta_p = log\frac{X_2 - X_1}{\Delta_p}, \quad (3)$$

here X_2-X_1 is the width of the measurement range of the ME;

Δ_p is the error of distinguishing individual measurement results with the data of the ME.

The coefficient of quality K_x or the efficiency of ME can be presented in the form of the product of both quantities obtained as a result of the measurement of information:

$$K_x = M_x H_{mx} = t_x B\,log\left(1+\frac{X^2}{D_n}\right)log\frac{X_2-X_1}{\Delta_p}, \quad (4)$$

here $X=U_x$; I_xR_{sh}; $I_{sc}R_x$ – input electrical signals when measuring voltage, current, and resistance, respectively.

From the analysis of expression (4), we conclude that, all other conditions being the same, the amount of measurement information obtained with the help of a given ME will be determined by the errors of the measuring circle, which are determined by such factors as the characteristics of the ME, the object, measurement conditions, the qualification of the operator, time, etc. [10, p. 48]. When using a polynomial model, in most practical cases, the expression for the discrimination error can be represented by a quadratic function [10, p.58]. It is clear that at the same time data on the laws of probability distribution of elementary errors are needed to find the distribution of the resulting error based on their composition. According to this distribution, the confidence coefficient k(P) is correctly determined, the value of which depends on the value of the confidence probability P. The analysis of the above leads to the conclusion about the practical difficulty of estimating the value of the discrimination error. In addition, with the passage of time t due to the aging and wear of the ME, its error changes (degrades). Therefore, in order to ensure the metrological reliability of the ME, it is released from production or repair with a certain technological reserve, the value of the coefficient of which is k_{mn}=0.4...0.8 of the permissible error value [10, p.58]. In most practical cases, the expression for the error of the ME $\Delta_{pe}(x, P, \vec{Q}, \vec{\xi}, k_{н}, t)$ in the working conditions of operation and at the moment of time t can be given as:

$$\Delta_{pe}\left(x, P, \vec{Q}, \vec{\xi}, k_{н}, t\right) = \bar{\Delta}\left(x, \vec{Q}, \vec{\xi}, k_{н}, t\right) \pm k\left(P, \vec{Q}, \vec{\xi}, t\right)\sigma\left(x, P, \vec{Q}, \vec{\xi}, k_{н}, t\right) =$$
$$= \Delta_{0pe}(P, \vec{Q}, \vec{\xi}, k_{н}, t) + \delta_s(P, \vec{Q}, \vec{\xi}, k_{н}, t)\cdot x + \varepsilon(P, \vec{Q}, \vec{\xi}, k_{н}, t)\cdot x^2, \quad (5)$$

here $\Delta_0(P, \vec{Q}, \vec{\xi}, k_{н}, t) = \bar{\Delta}_0(\vec{Q}, \vec{\xi}, k_{н}, t) \pm k(P, \vec{Q}, \vec{\xi}, t)\sigma_0$ is the ME additive error component (AEC);

$\delta_s(P, \vec{Q}, \vec{\xi}, k_{н}, t) = \bar{\delta}_s(\vec{Q}, \vec{\xi}, k_{н}, t) \pm k(P, \vec{Q}, \vec{\xi}, t)\sigma_\delta$ is the coefficient of the ME multiplicative error component;

$\varepsilon(P, \vec{Q}, \vec{\xi}, k_H, t) = \bar{\varepsilon}(\vec{Q}, \vec{\xi}, k_{н}, t) \pm k(P, \vec{Q}, \vec{\xi}, k_{н}, t)\sigma_\varepsilon$ is the coefficient of the ME quadratic error component;

$\vec{Q}$ is the ME parameters vector;

$\vec{\xi}$ is the vector of elementary errors;

k_H is the ME nominal coefficient of transmission;

P – confidence probability.

The random component of the AEC will be determined by the noises of the components of the HRT, and thermal noises and noises of the 1/f type should be taken into account. In connection with the divergence of the noise spectrum 1/f in the low-frequency limit, the question of its stationarity arises. However, if the lower limit of the frequency range of the ME is taken to be the frequency f_{kl} of its calibrations (setting of "zero" readings), and the upper frequency f_{hf} of transmission, then its 1/f noise will be frequency limited and, in the first approximation, stationary in a broad sense, the amplitude which are distributed according to the normal law [12, p. 165]. The dispersions D_{nU} and D_{nI} of the noise signal, reduced to the input of the ME, in the frequency band from $\omega_{kl}=2\pi f_{kl}$ to $\omega_{hf}=2\pi f_{hf}$ can be determined by the Wiener-Hinchin theorem according to the relation [10, p.58]:

$$D_n = \lim_{\tau\to 0} D_n(\tau) = A_{0e}(f_{hf} - f_{kl}) + A_{fe} f_{fe} \ln\frac{f_{hf}}{f_{kl}}, \quad 8.6)$$

here A_{0e}, A_{fe}, ω_{fe} is the spectral densities of the equivalent densities of thermal and 1/f noises and the circular frequency of the conjugation of these noises respectively;

$D_n=D_{nU}; D_{nI}$.

Therefore, the device that implements feedback in the system of digital control of the object, from a metrological point of view, will perform the task of a precision multi-channel DAC and must have high metrological characteristics.

Conclusions

In the era of digital technologies, both the classical approach to defining the concept of quality and its provision are changing significantly. Orientation to the current and future needs of consumers requires operational monitoring and regulation of product quality parameters on a real-time scale. Based on the forecast of the development of Quality 4.0 quality management systems, the structure of a digital system for ensuring the level of product quality required by the consumer is proposed. Proposals for determining the minimum frequency of surveys for each of the measured (evaluated) quality parameters have also been developed. A mathematical model for establishing the number of numerical ratios in relation to the value of individual indicators of product quality is also proposed.

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