Method for calculating savings from using a more accurate measuring instruments

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Abstract. Control operations are not related to the creation of material values, so one of the key tasks in economic terms is to reduce the losses arising in the process of control. The article deals with the types of losses that occur during control, as well as losses that are possible in the absence of control, the economic justification of control operations is presented. The result of the control is also affected by the measurement error, so using more accurate measurement tools reduces the loss of internal and external defects due to inconsistency of data and by reducing the number of incorrectly accepted and incorrectly rejected products, but reduces the cost of measurement, while the use of more rough measurement tools reduces the cost of measurement, but increases the loss of internal and external defects. Therefore, when choosing measuring instruments, it is necessary to be guided not only by the permissible error value for this measurement, established in the relevant regulatory documents, but also by the economic component of control. On the basis of the presented material, a method for calculating the savings from using a more accurate measuring tool and the results of evaluating this savings is proposed.

1. Introduction
Quality in a broad sense can and should be the goal of all industries, countries, and markets. The development of the new world order reduces the gap in quality of life between developed countries and the supposed global emerging market [1].

Quality control is an integral part of production processes, which plays an important role as one of the functions of enterprise management. A well-established product quality control system ensures timely detection of defects and their timely elimination. This increases the company's competitiveness and profit [2]. It is known that the leading position in the market is achieved by enterprises that are able to ensure the quality of their products. Control is not connected with the creation of material values, and economic losses arise from its implementation, but losses in the absence of control are usually much greater for both the producer and the consumer.

Issues affecting the relationship between Metrology and Economics are considered in many works of scientists. Thus, in [3], the existence of a direct dependence of the competitiveness of goods and services in the world market on the level of development of Metrology is shown, and it is also proved...
that economic success depends, among other things, on the ability to produce and sell accurately measured and reliably tested goods and services.

Comparisons of measuring instruments in the form of “more expensive – cheaper” or “more precisely – rougher” are not suitable for modern conditions, it is necessary to choose measuring instruments in accordance with economic criteria, taking into account the interests of the manufacturers and consumers [4].

Ensuring the quality of repair of agricultural machinery in modern dealerships of domestic manufacturers is possible only through the introduction of control operations [5]. The standards of the enterprise for metrological support of technical maintenance and repair of equipment should include a list of measures ensuring the uniformity of measurements and the required accuracy [6]. In addition, the necessary accuracy of measuring instruments must be ensured, which is not always implemented in practice [7]. If the measures are successful, the total cost of quality is reduced not only by the amount of losses from internal and external marriage, but also by such cost elements as the costs of measurement and control, especially at the initial stage. The reduction of losses from both internal and external defects is predictable not only due to the detection of inconsistencies and their identification in the first operation, but also due to the reduction of errors of the first and second kind - erroneously accepted and erroneously rejected parts, as a result of the influence of measurement error [8]. As a result of the implementation of the above measures, the efficiency and effectiveness of input and output control at the enterprise will increase significantly. This activity in the quality management system relates to the “Preventive measures” procedure. Namely, preventive measures provide a significant effect and the greatest cost savings.

2. Methodology for estimating savings from using a more accurate measuring instrument

Methods for determining the technical and economic indicators of control operations and methods for determining the influence of measurement error on economic losses have not been fully developed. The main difficulty of such calculations is that the process of measurement and control is not accompanied by the creation of material values, but the economic rationale for control can be reduced to the following expression [1]:

\[ L_{ac} > L_{uc} , \]  \hspace{1cm} (1)

where \( L_{ac} \) – losses of the manufacturer in the absence of control; \( L_{uc} \) – losses of the manufacturer under control.

Losses of the manufacturer of the goods in the absence of control can be divided into two components:

\[ L_{ac} = L_{acc} + L_{aca} , \]  \hspace{1cm} (2)

where \( L_{acc} \) – manufacturer losses in the absence of control, which can be calculated with sufficient accuracy; \( L_{aca} \) – manufacturer losses that cannot be calculated, but can only be assumed.

Losses \( L_{acc} \) can be determined by the formula [1]:

\[ L_{acc} = N \cdot (1 - P_{mr}) \cdot S_{lq} \cdot P_{b} , \]  \hspace{1cm} (3)

where \( N \) – is the number of goods subject to control; \( S_{lq} \) – costs caused by the penetration of low-quality products into production or for the consumer; \( P_{mr} \) – the probability that the product meets the requirements; \( P_{b} \) – the probability of product breakdown due to marriage during the warranty period.

Losses \( L_{aca} \) consist of losses from a decrease in the number of consumers, from the next (as a result of this) decrease in the production or overproduction program, from a loss of reputation as a manufacturer of quality products and the like. This type of loss is quite difficult to determine.

In turn, the manufacturer’s losses during the control \( L_{uc} \) consist of: losses from the purchase, operation of measuring instruments and measurement error \( L_{si} \); losses from a fixable marriage \( L_{fmi} \); losses from incorrigible marriage \( L_{imi} \).
Losses from a recoverable and incorrigible marriage can be determined by the expressions:

\[ L_{fm} = S_{fm} \cdot P_{fm} \cdot N, \]  

\[ L_{im} = S_{im} \cdot P_{im} \cdot N, \]

where \( S_{fm} \) – the cost of correcting the marriage; \( S_{im} \) – the cost of an incorrigible marriage (part) at the time of control; \( P_{fm}, P_{im} \) – the probability of detecting a fixable and incorrigible marriage during control.

The average annual loss in product quality control is calculated by the formula [2]:

\[ L_{qc} = N \cdot (n \cdot L_n + m \cdot L_m). \]

where \( n \) – number of incorrectly rejected products; \( L_n \) – average manufacturer losses associated with false product rejection; \( m \) – number of incorrectly accepted products; \( L_m \) – losses of the consumer and the producer of production owing to non-compliance of production to the established requirements.

Losses from the use of a specific measuring instrument when monitoring a given parameter can be determined by the expression

\[ L_{si} = N_{mi} \cdot \left[ C_{mi}(R_r + S_r) + C_{omi} + L_{qc} + L_o \right], \]

where \( N_{mi} \) – number of measuring instruments (SI) for this parameter; \( C_{mi} \) – one-time costs when using measuring instruments; \( R_r \) – the rate of renovation; \( S_r \) – standard reduction of one-time costs; \( C_{omi} \) – annual operating costs when using measuring instruments; \( L_{qc} \) – losses from using the measuring instruments due to measurement error; \( L_o \) – other costs or losses.

When comparing measuring instruments, it is better to determine the savings over the entire service life. The savings from using a more accurate measuring tool can be determined by the formula

\[ S = \frac{N_{mi2}[C_{mi2}(R_r + S_r) + C_{omi2} + L_{qc2}]}{L_2} \cdot \frac{L_1 - N_{mi1}[C_{mi1}(R_r + S_r) + C_{omi1} + L_{qc1}]}{R_r + S_r}, \]

where indices 1 and 2 refer to the parameters of the 1st and 2nd compared SI; \( L_1 \) and \( L_2 \) – the service life of the compared measuring instruments.

### 3. Results of estimating savings from using a more accurate measuring instrument

The choice of measuring instruments is one of the most important tasks of metrological support of production. The quality of the final product, intermediate and input control depends on its correct solution. Due to a measurement error, some defective products may be considered suitable, and some serviceable parts may be considered unsuitable. Analyzing losses from incorrect product acceptance or rejection is a difficult economic task. The overall cost-effectiveness of the control is also affected by the cost of the measuring device and operating costs, including the cost of annual verification, the inspector’s salary, the consumption of materials and energy for measurements, and so on.

Measuring instruments are selected taking into account metrological and economic factors. The production program also influences the choice of measuring device. In mass production it is more advisable to use special measuring instruments with high productivity and automation, in single and small-scale production it is advisable to use universal measuring instruments.

The measurement error qualitatively affects the measurement result of only those products whose dimensions are close to the boundaries of the tolerance field.

The condition for choosing a measuring instrument according to metrological indicators – the limiting measurement error must be less than or equal to the permissible measurement error:
\[ \Delta \text{lim} \leq \delta, \quad (10) \]

where \( \Delta \text{lim} \) – marginal error of the measuring instrument; \( \delta \) – permissible measurement error.

Consider the methodology of choosing measuring instruments for economic indicators, taking into account the choice of measuring instruments for metrological characteristics for a shaft whose size \( d_n = 20h8 \). By condition (10), for a size of 20h8, we select the following measuring instruments (the first with an error close to \( \delta \); the second is more accurate):

1. Rack C-III with ICH-10 engineers dial
2. Skoba lever SR-25.

Now we evaluate the savings from using a more accurate measuring device and present the results in table 1.

**Table 1.** The results of the assessment of savings from the use of more accurate measuring instruments.

| Indicators      | Means of measurement          |                  |                  |
|-----------------|-------------------------------|-----------------|-----------------|
|                 | Rack C-III with ICH-10 engineers dial | Skoba lever SR-25 |
| Controlled      | 20h8                          | ± 8 mkm         | ± 3,5 mkm       |
| dimension       |                               |                 |                 |
| \( \Delta \text{lim} \) | 4 mkm                         | 1,75 mkm        |
| \( \sigma_{\text{met}} \) | 12,1 %                        | 5,3 %           |
| \( m \)         | 1,67 %                        | 0,65 %          |
| \( n \)         | 4,36 %                        | 1,39 %          |
| \( L_{f\text{m}} \) | 4200 rub.                     | 4200 rub.       |
| \( L_{\text{im}} \) | 25848 rub.                    | 25848 rub.      |
| \( L_{ac} \)    | 413568 rub.                   |                 |
| \( L_{qc} \)    | 154248 rub.                   | 57642 rub.      |
| \( L_{si} \)    | 175492 rub.                   | 84993 rub.      |
| \( L_{uc} \)    | 205541 rub.                   | 115042 rub.     |
| Total           | 92705 rub.                    |                 |

According to the results of the assessment, we see that the use of a more accurate measuring instrument allows us to obtain significant savings by reducing the number of incorrectly received and incorrectly rejected products, with the greatest impact on the magnitude of the effect having a decrease in measurement error.

**4. Conclusion**

Thus, according to the proposed method, it is possible to choose the optimal means of measuring a given parameter, taking into account all technical and economic factors, according to the criterion of achieving the highest value of the economic effect for the entire service life.

**References**

[1] Kvint V L and Okrepilov V V 2014 Quality of life and values in national development strategies *Herald of the Russian Academy of Sciences* **84** 188–200

[2] Petukhova I A and Goncharova E B 2017 Analysis of the product quality control system *Scientific and methodological electronic magazine "Concept»* 2 655–61
[3] Okrepilov V V, Krutikov V N and Elkin G I 2014 The economic component of support for the uniformity of measurements Measurement Techniques 57 109–16
[4] Okrepilov V V 2017 Economics of Metrolog (Saint Petersburg: Saint Petersburg state University of aerospace instrumentation) p 175
[5] Leonov O A, Shkaruba N Zh and Vergazova Yu G 2019 Dermining the tolerances in fitting for joints with interference Russian Engineering Research 39 544–7
[6] Golubev E A, Isaev L K and Chirkov A P 2006 Estimating the quality of verification of measuring instruments Measurement Techniques 49 762–8
[7] Chunovkina A G and Sulaberidze V Sh 2018 On the quantitative expression of the accuracy of laboratory and industrial measurements Measurement Techniques 60 1238–42
[8] Okrepilov V V 2018 Quality and metrology Standards and quality 5 47–51