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Comparative research of quality indicators of measuring instruments: practical aspects

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Abstract

The main purpose of modern measuring instrument MI is to perform accurate and reliable measurements in order to obtain complete and reliable measurement information. The MI must be of proper quality, which must be reliably assessed. For technical means, traditional quality indicators have been established, some of which are common to MI. The metrological characteristic is unique to a MI and can be considered one of the most important of MI indicators.

The quality of MI is characterized by a certain system of quality indicators. Depending on MI group, the system of quality indicators can differ. The target indicators are specific for each type of product. These indicators require additional analysis. The main metrological characteristics should be referred to the target indicators of MI. For some MI categories, additional indicators can be established, and for others, they are excluded.

The methodology of evaluation of MI quality indicators and algorithm of its realization are offered. The digital multimeters as category of MI have been selected for practical comparative evaluation of MI quality indicators. The ten indicators for this category of MI have been refined. Comparative expert evaluation of quality indicators of 12 multimeters was carried out with the involvement of a group of 34 metrology experts. The weight of each of the 10 selected MI quality indicators was determined. The results of expert evaluation of multimeter are presented.

Keywords: measuring instrument; metrological characteristic; quality indicator; expert evaluation; metrological traceability.

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Introduction

The measuring instrument (MI) is a device used for making measurements, alone or in conjunction with one or more supplementary devices in accordance with the International Vocabulary of Metrology (VIM, 3.1) [1]. The main purpose of modern MI is to perform accurate and reliable measurements in order to obtain complete and reliable measurement information. The MI must be of proper quality, which must be reliably assessed [2].

The product quality, in particular MI, is the basis of its competitiveness. For technical means, traditional quality indicators have been established, some of which are common to MI. Such indicators of the quality of technical means include, in particular, manufacturability, design, functionality, standardization and unification, ergonomics, aesthetics, and efficiency. Quantitative characterization of one or more product properties that make up its quality is traditionally called the product quality indicator [2–5].

The metrological traceability is a property of the measurement result, and the concept of measurement uncertainty is used for it [6, 7]. If metrological traceability is a requirement or an essential element of assuring confidence in the reliability of measurement results, then special requirements are set for the state of MI [8]. The metrological characteristic means a characteristic that can influence the measurement result, as defined in the international standard ISO 10012 [9]. The metrological characteristic is unique to a MI and can be considered one of the most important of MI indicators. MI, as a rule, can have several metrological characteristics.

Research has been carried out on one of the quality indicators of MI metrological reliability: the algorithm for assessing the individual metrological reliability of MI is considered in [10], and the system for ensuring the metrological reliability of MI is considered in [11]. In the literature, there are no results of research of other important MI quality indicators. Therefore, the task of practical evaluation of the MI quality indicators as a system of indicators remains relevant.

The problem statement, purpose and objectives of the study

The purpose of the article is to highlight the results of practical evaluation of MI quality indicators, in particular:

- to study the basis for setting special MI quality indicators;

• to establish a methodology for evaluation MI quality indicators;

• to conduct a practical evaluation of MI quality indicators for one of MI categories in order to establish the most preferable MIs.

The research and setting of quality indicators of measuring instruments

The quality of MI is characterized by a certain system of quality indicators, which are generally divided into functional, resource-saving, environmental, etc. Functional MI indicators include indicators that reflect consumer properties of products, include technical effect; reliability (durability); ergonomics, and aesthetics. Depending on MI group, the system of quality indicators can differ. The main groups of MI indicators are considered in detail in [2].

In general, the system of MI indicators can be based on the following basic principles:

• maximum use of quantitative characteristics expressing certain indicators;

• the use of a qualitative characteristic only in cases where an important MI characteristic cannot be expressed numerically.

For specific items of the MI categories, the range of quality indicators can be much less than considered in [2].

The target indicators are specific for each type of product, therefore these indicators require additional analysis. The main metrological characteristics should be referred to the target indicators of MI.

In general, MI indicators can be the following groups of metrological characteristics [1]:

1) for the indication of MI:

• indication interval (VIM 4.3);

• nominal indication interval (nominal interval) (VIM 4.4);

• range of a nominal indication interval (VIM 4.5);

2) for the measurement range and accuracy of MI:

• measurand (VIM 2.3);

• measuring interval or measuring range (VIM 4.7);

• accuracy class (VIM 4.25);

• maximum permissible error (VIM 4.26);

3) for MI measurement conditions:

• rated operating conditions (VIM 4.9);

• limiting operation conditions (VIM 4.10);

4) for the sensitivity and selectivity of MI:

• sensitivity of a MI (VIM 4.12);

• discrimination threshold (VIM 4.16);

• dead band (VIM 4.17);

• selectivity of a MI (VIM 4.12);

• resolution of a displaying device (VIM 4.15);

5) for the stability and transient characteristics of MI:

• stability/instability of a MI (VIM 4.19);

• instrument drift (VIM 4.21);

• step response time (VIM 4.23).

This list of MI indicators is long, but not exhaustive. For some MI categories, additional indicators can be established, and for others, they are excluded. This may be due, in particular, to the designation of specific categories of MI or the envisaged operating conditions of the MI.

The algorithm for calculating the integrated MI quality indicator is as follows:

• definition of the nomenclature of the MI quality indicators;

• definition of the nomenclature of the grouped MI quality indicators;

• determination of the weight coefficients of the MI quality indicators;

• calculation of the grouped MI quality indicators as weighted average of corresponding MI quality indicators;

• calculation of the integrated MI quality indicator as the average of all grouped MI quality indicators.

The numerical value of the integrated MI quality indicator QI_{IMI} is determined by the expression

$$QI_{\text{IMI}} = \sum_{i=1}^{M} QI_{\text{GMI}i} \Big/ M, \tag{1}$$

where $QI_{\text{GMI}i}$ is i-th grouped MI quality indicator; M is total number of the grouped MI quality indicators.

The numerical value of the i-th grouped MI quality indicator QI_{GMI} is determined by the expression

$$QI_{\text{GMI}i} = \sum_{j=1}^{N} w_j QI_{\text{MI}j} \Big/ N, \tag{2}$$

where $QI_{\text{GM}j}$ is j-th MI quality indicator; w_j is weight of j-th MI quality indicator; N is total number of corresponding MI quality indicators.

The value of the weight of the j-th MI quality indicator w_j (range from 0 to 1), as well as the values of the j-th MI quality indicator $QI_{\text{MI}j}$ itself, are determined by the expert method.

In some cases, there is no need to group MI quality indicators and then the numerical value of the integrated MI quality indicator is determined by the expression

$$QI_{\text{IMI}} = \sum_{j=1}^{Q} w_j QI_{\text{MI}j} \Big/ Q, \tag{3}$$

where Q is number of all MI quality indicators.

Results of research of quality indicators of measuring instruments

The multimeters as category of MI were selected for practical comparative evaluation of MI quality indicators. The ten indicators ($QI_{\text{MI1}} - QI_{\text{MI10}}$) for this category of MI have been refined:

M1 is measuring range (by main value);

M2 is limit of permissible error (the main value);

M3 is normalized working conditions;

Table 1

The evaluation results of the weight of MI quality indicators

Indicators	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
w_j	1.00	0.89	0.64	0.85	0.29	0.96	0.58	0.27	0.55	0.20

M4 is sensitivity or resolution (basic value);

M5 is stability (instability) or drift (the main value);

M6 is number of measured values and ranges;

M7 is automation of measurements;

M8 is presence of self-diagnosis;

M9 is availability of memorization of results;

M10 is availability of data transmission channels.

In this case, the integrated IM quality indicator was determined by expression (3) for $Q = 10$.

Comparative expert evaluation of quality indicators of 12 digital multimeters [12] was carried out with the involvement of a group of 34 metrology experts. Each metrology expert had at least 5 years of metrological work experience. At the same time, with the help of metrology experts, the weight of each of the 10 selected MI quality indicators was determined.

The evaluation results of the weight of MI quality indicators are shown in Table 1 and in Fig. 1. On the petal diagram of Fig. 1 red dashed line shows the average value for all MI indicators. The value of the weight of all MI indicators varies from 0.20 to 1.00. The largest value is the indicator M1 – 1.00, and the smallest – the indicator M10 – 0.20.

The group of 12 MIs was evaluated by 34 experts on 10 MI quality indicators (M1 – M10) using a scale from 1 to 9 scores. The results of the expert evaluation of the selected MI are shown in Table 2 without taking into account the weight of the selected MI quality indicators, and in Table 3 taking into account the weight of the MI quality indicators.

The results of the expert evaluation of the selected MI are shown in Fig. 2 with (solid line) and without (dashed line) taking into account the weight of the selected MI quality indicators. The result of the expert evaluation the average scores for MI. The values of the evaluation of indicators for MI are reduced by the weight of the indicators as can be seen from Fig. 2.

The average scores of expert evaluations of MI with and without taking into account the weight of the MI indicators is given in Table 4. The difference between these two expert evaluations is insignificant and does not change the priorities obtained for the selected 12 MIs. This difference varies from 0.82 (for MI5) to 1.91 (for MI1) scores.

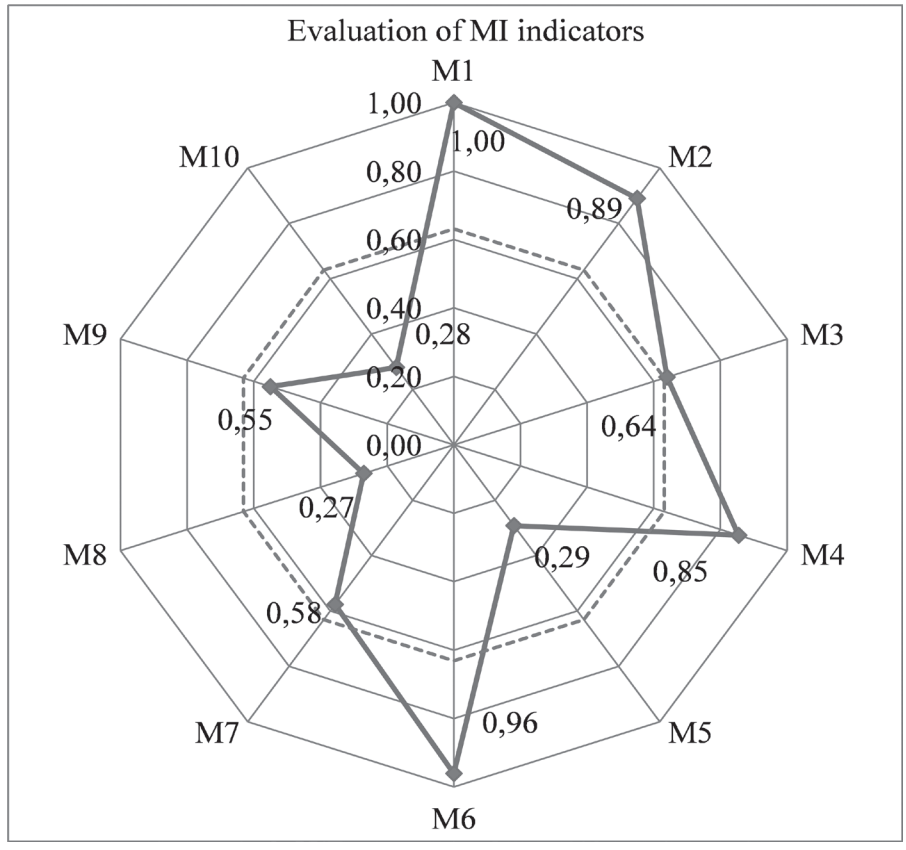

Fig. 1. The weights of MI quality indicators

Table 2

The results of the expert evaluation of the selected MI without taking into account the weight of the selected MI quality indicators

	MI1	**MI2**	**MI3**	**MI4**	**MI5**	**MI6**
M1	8.71	7.97	6.91	7.26	6.79	4.76
M2	8.68	7.41	5.59	6.76	4.88	3.53
M3	4.18	4.74	2.47	3.29	3.24	4.24
M4	7.88	7.47	4.74	4.79	4.79	4.74
M5	2.44	2.26	2.00	1.97	1.71	1.41
M6	8.68	7.88	4.94	5.91	5.91	5.88
M7	5.59	3.41	3.03	2.56	2.53	5.24
M8	2.06	1.91	1.50	1.50	1.56	1.62
M9	7.82	2.79	2.82	2.85	2.91	2.44
M10	7.44	1.15	1.00	1.00	1.00	1.09
	MI7	**MI8**	**MI9**	**MI10**	**MI11**	**MI12**
M1	4.29	3.79	7.29	6.29	8.00	7.26
M2	3.35	3.50	6.82	6.68	7.79	5.62
M3	4.21	4.21	4.35	4.50	5.71	5.65
M4	4.62	4.76	5.12	7.06	6.91	4.91
M5	1.41	1.41	2.06	2.03	2.44	2.03
M6	6.41	3.88	6.24	6.47	7.62	6.38
M7	5.21	5.24	3.68	3.56	2.94	2.76
M8	1.65	1.88	1.59	2.32	1.97	1.88
M9	2.41	2.71	5.50	5.65	2.88	2.85
M10	1.09	1.47	2.56	2.15	1.12	1.12

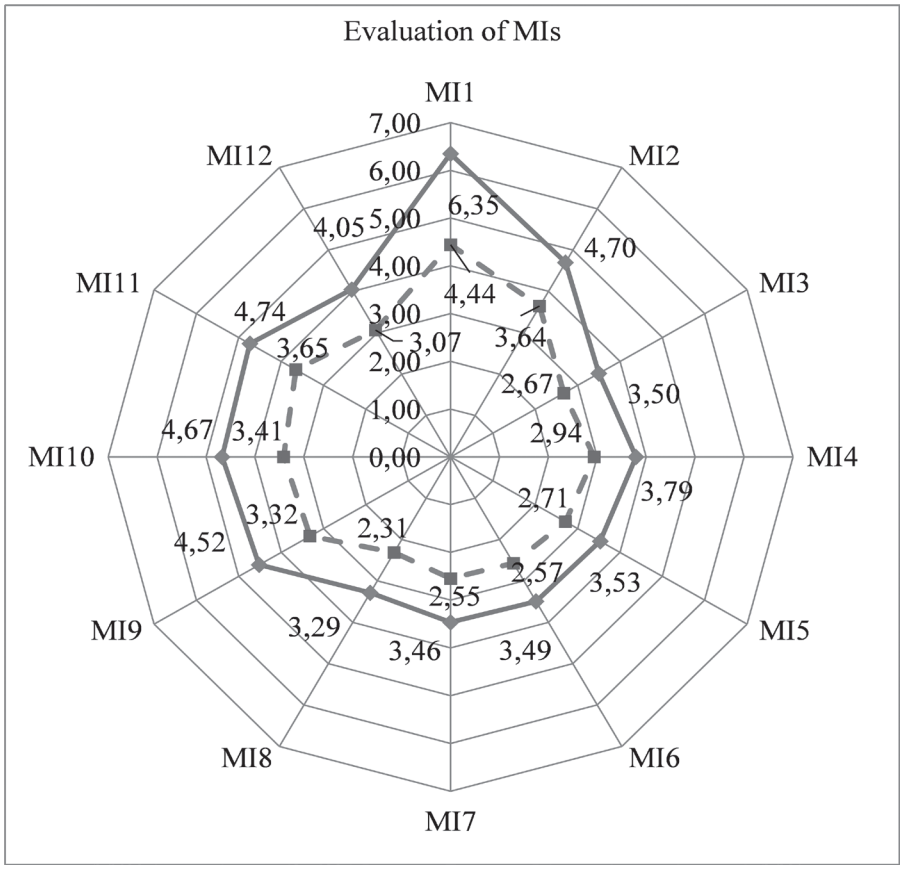

Fig. 2. The results of the expert evaluation of the selected MI

Table 3

The results of the expert evaluation of the selected MI with taking into account the weight of the selected MI quality indicators

	MI1	**MI2**	**MI3**	**MI4**	**MI5**	**MI6**
M1	8.71	7.97	6.91	7.26	6.79	4.76
M2	7.72	6.60	4.97	6.02	4.35	3.14
M3	2.67	3.03	1.58	2.11	2.07	2.71
M4	6.70	6.35	4.03	4.08	4.08	4.03
M5	0.71	0.66	0.58	0.57	0.49	0.41
M6	8.33	7.57	4.74	5.68	5.68	5.65
M7	3.24	1.98	1.76	1.48	1.47	3.04
M8	0.56	0.52	0.41	0.41	0.42	0.44
M9	4.30	1.54	1.55	1.57	1.60	1.34
M10	1.49	0.23	0.20	0.20	0.20	0.22
	MI7	**MI8**	**MI9**	**MI10**	**MI11**	**MI12**
M1	4.29	3.79	7.29	6.29	8.00	7.26
M2	2.98	3.12	6.07	5.94	6.94	5.00
M3	2.69	2.69	2.79	2.88	3.65	3.61
M4	3.93	4.05	4.35	6.00	5.88	4.18
M5	0.41	0.41	0.60	0.59	0.71	0.59
M6	6.16	3.73	5.99	6.21	7.31	6.13
M7	3.02	3.04	2.13	2.06	1.71	1.60
M8	0.44	0.51	0.43	0.63	0.53	0.51
M9	1.33	1.49	3.03	3.11	1.59	1.57
M10	0.22	0.29	0.51	0.43	0.22	0.22

Table 4

The results of the expert evaluation of the selected MI

Average scores	**MI1**	**MI2**	**MI3**	**MI4**	**MI5**	**MI6**
Without w_j	6.35	4.70	3.50	3.79	3.53	3.49
With w_j	4.44	3.64	2.67	2.94	2.71	2.57
Difference	1.91	1.06	0.83	0.85	0.82	0.92
Average scores	**MI7**	**MI8**	**MI9**	**MI10**	**MI11**	**MI12**
Without w_j	3.46	3.29	4.52	4.67	4.74	4.05
With w_j	2.55	2.31	3.32	3.41	3.65	3.07
Difference	0.91	1.19	1.20	1.26	1.09	0.98

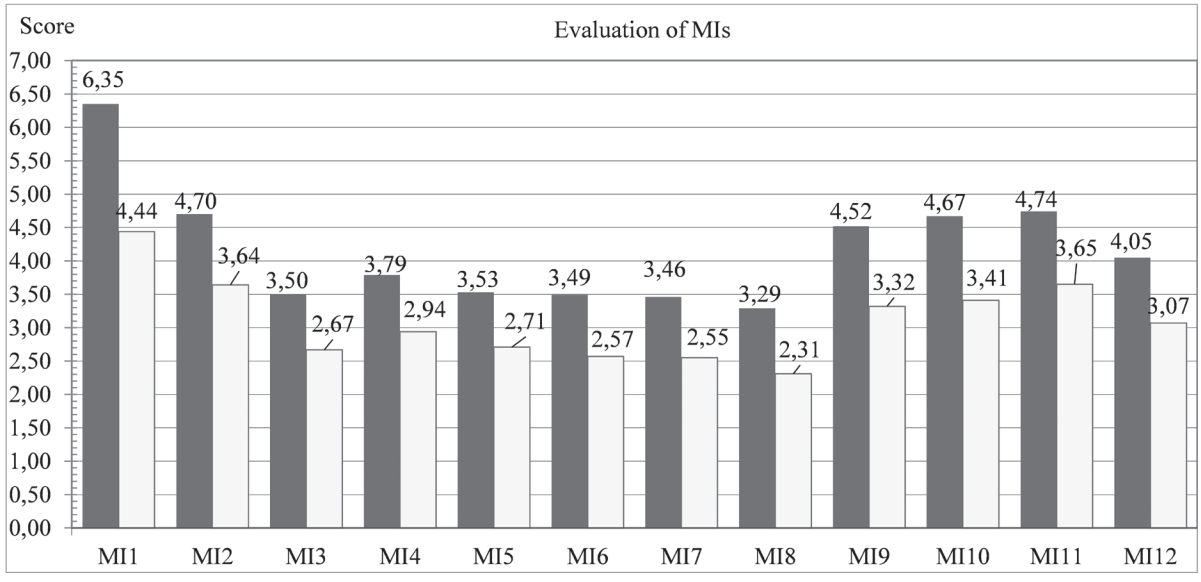

Fig. 3. Histogram of average scores of expert evaluations for MI

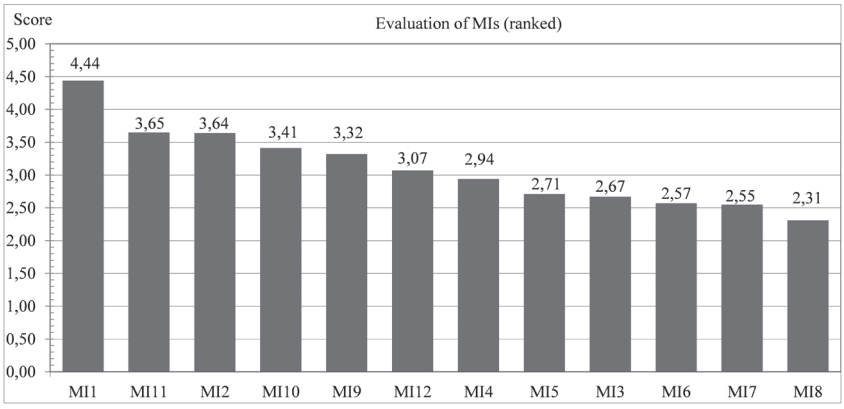

Fig. 4. Histogram of ranked average scores of expert evaluations for MI

Histogram of average scores of expert evaluations for MI with (light column) and without (dark column) taking into account the weight of the MI indicators is given in Fig. 3. Histogram of ranked average scores of expert evaluations for MI with taking into account the weight of the MI indicators is given in Fig. 4.

The obtained expert evaluation shows the following advantages of MI from the group of 12 MIs:

MI1>MI11>MI2>MI10>MI9>MI12>MI4>MI5>MI3>MI6>MI7>MI8.

Summary

The proposed methodology for expert evaluation of MI quality is used for practical evaluation of quality indicators of multimeters as a category of MI. A comparative expert evaluation of quality indicators of digital multimeter was carried out with the involvement of a group of 34 metrology experts. The presented results of expert evaluation of multimeters showed the full suitability of the proposed methodology.

Порівняльне дослідження параметрів якості засобів вимірювальної техніки: практичні аспекти

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Анотація

Основною метою сучасного засобу вимірювань (ЗВ) є проведення точних і надійних вимірювань з метою отримання повної та достовірної вимірювальної інформації. ЗВ повинен бути належної якості, що має бути достовірно оцінено. Що стосується технічних засобів, були встановлені традиційні показники якості, деякі з них є спільними і для ЗВ. Метрологічна характеристика є унікальною для ЗВ і може вважатися одним із найважливіших показників ЗВ. ЗВ, як правило, може мати кілька метрологічних характеристик.

Якість ЗВ характеризується певною системою показників якості, які загалом поділяються на функціональні, цільові, ресурсозберігаючі, екологічні тощо. Залежно від групи ЗВ, система показників якості може відрізнятися. Цільові показники є специфічними для кожного виду продукції, тому потребують додаткового аналізу. Основні метрологічні характеристики слід віднести до цільових показників ЗВ. Для деяких категорій ЗВ можуть бути встановлені додаткові показники, а для інших – виключені. Це може бути пов'язано, зокрема, із цільовим призначенням конкретних категорій ЗВ або передбаченими умовами експлуатації ЗВ.

Наведені результати вивчення основи для встановлення спеціальних показників якості ЗВ. Запропоновано методологію оцінки показників якості ЗВ та алгоритм її реалізації. Цифрові мультиметри як категорія ЗВ були обрані для практичної порівняльної оцінки показників якості ЗВ. Запропоновано 10 показників якості для цієї категорії ЗВ. Порівняльну експертну оцінку показників якості 12 мультиметрів було проведено із залученням групи з 34 експертів-метрологів. Водночас за допомогою цих експертів-метрологів було визначено вагу кожного з 10 обраних показників якості ЗВ. Наведені результати експертної оцінки показників якості мультиметрів і встановлені найбільш переважні для вибору споживача мультиметри.

Ключові слова: засіб вимірювання; метрологічна характеристика; показник якості; експертна оцінка; метрологічна простежуваність.

Сравнительное исследование параметров качества средств измерительной техники: практические аспекты

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Аннотация

Основным назначением современного средства измерений (СИ) является проведение точных и надежных измерений с целью получения полной и достоверной измерительной информации. СИ должно быть надлежащего качества, которое необходимо надежно оценивать. Для технических средств установлены традиционные показатели качества, некоторые из них являются общими и для СИ. Метрологические характеристики уникальны для СИ и могут считаться одними из наиболее важных показателей СИ.

Качество СИ характеризуется определенной системой показателей качества. В зависимости от категории СИ система показателей качества может различаться. Основные метрологические характеристики следует отнести к целевым показателям СИ.

Предложена методология экспертной оценки показателей качества СИ. Цифровые мультиметры как категория СИ выбраны для практической сравнительной оценки СИ. Предложены 10 показателей для этой категории СИ. Приведены результаты сравнительной экспертной оценки 12 мультиметров с привлечением группы из 34 экспертов-метрологов.

Ключевые слова: средство измерения; метрологическая характеристика; показатель качества; экспертная оценка; метрологическая прослеживаемость.

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