УДК 535.3

MODERN MODELS OF THE EXTENDED UNCERTAINTY AND THEIR APPLICATION IN INDUSTRIAL METROLOGY

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At present, in the practice of accredited laboratories, attention is being paid to identifying and assessing risks, and hence to calculating increased uncertainty, because according to ISO 9000 [1], the risk is the impact of uncertainty. The analysis of the last published works allowed to identify and formulate the main approaches to calculating the expanded uncertainty and to show their effectiveness.

The most general approach is outlined in GUM, where a z-model is presented, based on the product of total uncertainty and coverage factor:

$$U = z_{95}\sigma[\bar{q}] = z_{95}\frac{\sigma[q]}{\sqrt{n}}, \qquad (1)$$

where z_{95} – coverage ratio for the 95 % confidence level under the assumption of a normal distribution; $\sigma[\bar{q}]$ – the experimental standard deviation for $\bar{q}$; $\sigma[q]$ – the experimental standard deviation fo q.

However, depending on the measurement tasks, variations of this model are used – such as the Student's t-model, the Bayesian Z-model, the Craig model and the Monte Carlo method, which does not use the coverage factor.

In work [1] three models are considered – Student, Bayes and Craig. The main difference between these models is the different values of coverage factors.

The Student's model (t-model), developed in 1908, looks like this:

$$U_s = t_{95} \times s[q], \qquad (2)$$

where t_{95} – coefficient with 95 % coverage interval; s[q] – standard deviation.

The Craig model (1927), developed in the works of Hening Huang (2010), is presented below:

$$U_s = \frac{z_{95}}{c_4} \times s[\bar{q}], \qquad (3)$$

where t_{95} – coefficient with 95 % coverage interval; c_4 – function of the sample size, which is calculated as follows:

$$c_4 = \sqrt{\frac{2}{N-1}} \times \frac{\Gamma\left(\frac{N}{2}\right)}{\Gamma\left(\frac{N-1}{2}\right)}. \qquad (4)$$

In this case, Γ is introduced as a gamma function.

In addition, when the conditions of the central limit theorem are satisfied, but the reliability condition is not fulfilled, the probability distribution of the measurement result is described by the Student's distribution (t-distribution) with effective degrees of freedom ν_{eff}:

$$U_s = \nu_{eff} \times s[q]. \qquad (5)$$

Estimation of effective degrees of freedom ν_{eff} for standard measurement uncertainty $u_c(y)$ is carried out with the help of the Welch-Sutterswain formula:

$$\nu_{eff} = \frac{u_c^4(y)}{\sum_{i=1}^{N}\frac{u_i^4(y)}{\nu_i}}, \qquad (6)$$

where $u_i(y)$ $(i=1,2,\ldots,N)$ – contributions to the standard uncertainty of the measurement, which corresponds to the estimate y output quantity; ν_i – the effective degree of freedom of contribution to uncertainty $u_i(y)$.

In [2] the expression (5) is decomposed into components of uncertainty, estimated by type A and by type B:

$$\nu_{eff} = \frac{[\sum(\theta_i\sigma_i)^2 + \sum(\theta_i\beta_i)^2]^2}{\left[\sum\left(\frac{(\theta_i\sigma_i)^4}{\nu_i^A}\right) + \sum\left(\frac{(\theta_i\beta_i)^4}{\nu_i^B}\right)\right]}, \qquad (7)$$

where σ – standard uncertainty estimated by type A; β – standard uncertainty estimated by type B; θ – contribution to total uncertainty.

The Z-model The Bayesian model looks like:

$$U_s = \frac{z_{95}}{\sqrt{1+\frac{1}{\gamma^2}}} \times [g] \qquad (8)$$

or

$$U_s = \frac{z_{95}}{\sqrt{1+\gamma^2}} \times s_p[q], \qquad (9)$$

where γ is the ratio of the previous value of the standard uncertainty $s_p[q]$ to the experimental standard uncertainty of the current measurement $s[q]$:

$$\gamma = \frac{s_p[q]}{s[q]}. \qquad (10)$$

In 1998, Phillips suggested that the coverage factor be equal to z_{95}, based on the post-a priori information.

Today, another method for estimating uncertainty is known to modern science – the Monte Carlo method (hereinafter MCM), which is a kind of estimation of type A uncertainty. This method has been known since 1949, from the publication of the article by Nicholas Metropolis and Stanislav Ulam «The Monte Carlo Method». The difference between this model and the above is that the calculation does not use the coverage factors, but calculates the coverage interval. The method can be applied to practically all models having a single input value in which the input quantities can be characterized by any probability distribution functions. Often this method is called a statistical test method because of the need for a large number of test results.

The author of the article [2] in his work compared the application of the MCM method to the previously considered methods of estimating uncertainty. Student's model, in the analysis of measurements, has a very high probability of a random error, when using this method on arrays of small volumes. And also, the model has a significant shift from the true value of uncertainty.

The Student's model is recommended to be used when the standard deviation is unknown, and the number of observations in the series is less than 30.

The next model of comparison with MCM was the Craig model. The simulated errors are also scattered, but the scattering range is much smaller in comparison with the Student's model. Also, it can be noted that the average value of simulated uncertainties almost coincides with the true value of uncertainty. And, consequently, the risk of assuming subsequent errors associated with the procedure for calculating uncertainty is reduced. Therefore, when comparing the model of Craig and Student, it is reasonably recommended to use the Craig model.

The Bayesian model, of all the considered, has the smallest dispersion of uncertainty values. A distinctive feature is that the final uncertainty value is less than the true uncertainty value. This is due to the fact that the true value is related to the average value from the array of observations. Therefore, when calculating the uncertainty in this method, it is necessary to take into account this feature and introduce a correction factor. The calculation of MCM in the Bayesian Model is equated to the value of the standard uncertainty and is felt in the calculation.

The analysis is assisted by a graphical interpretation of the scattering results of the simulated extended uncertainty.

At the present stage, three models are available in the literature for calculating expanded uncertainty using standard deviation. When comparing these models by the Monte Carlo method and by studying a possible random error or a shift in the calculated extended uncertainty, several recommendations were made for using models. The student model is the least accurate. The Craig model is more accurate than the student model, and it is recommended to use it when a priori (preliminary) information is not available. The model is the most accurate and preferred, but only with sufficient preliminary information.

Comparing the models presented above, it can be noted that, unlike the t Student model and the Craig Model, in calculating the uncertainty, the Bayesian model is not related to the current average value of the measurements. Based on the received a priori information about the models, we can talk about the recommendation of using the Bayesian model in estimating the uncertainty.

The Conclusion. A review of the extended uncertainty models showed that they differ in the specific component of the experimental data in the combined uncertainty budget. The GUM z-model and Monte Carlo model are used in measurements with a large number of observations while the z-model is used for the normal distribution of measurement results, the Monte Carlo model is more universal. The Student’s and Craig models are applied for a small number of observations of less than 30, and the Bayes model based on the Welch-Suttersweit equation is applied at the combined budget and performance of the Central Limit Theorem. In addition, approaches to the description of measurement results in discrete systems (e. g. ISO 15530) and for nonparametric systems are currently being developed.

References

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УДК 006.91

СОВЕРШЕНСТВОВАНИЕ МЕТРОЛОГИЧЕСКОГО ОБЕСПЕЧЕНИЯ КОНТРОЛЯ КАЧЕСТВА ПРОДУКЦИИ В ОАО «КРИНИЦА»

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В соответствии с [1] качество пива оценивается более чем 20 показателями качества, а именно физико-химическими, органолептическими, показателями безопасности, микробиологическими показателями.

Основными физико-химическими показателями качества пива являются – объемная доля спирта и массовая доля сухих веществ в начальном сусле, которые определяются по ГОСТ 12787.