Uncertainty in type approval and verification

H. Morinaka
National Metrology Institute of Japan / AIST, Tsukuba, Japan
Central 3, 1-1-1 Umezono Tsukuba, Ibaraki, 305-8563,
tel. +81-29-861-4058, fax +81-29-861-4055, hiroaki-morinaka@aist.go.jp

Abstract

Cet article étudie comment présenter le concept de l'incertitude dans les critères de la conformité dans l'homologation et la vérification. Ce qui suit sont les résultats obtenus à partir de cette étude:
(1) l'incertitude dans l'homologation est différente de l'incertitude dans l'exécution des instruments de mesure.
(2) dans l'homologation, si l'incertitude est égale à ou moins d'un tiers des erreurs permises maximum, l'incertitude devrait être incluse dans les critères de la conformité. Si les valeurs de mesure incluses de l'incertitude sont dans les limites des erreurs permises maximum, on le décidera comme conformé, et s'il est en dehors des erreurs permises maximum, décidé comme non-conformé.

This paper investigates how to introduce the concept of uncertainty in the criteria of conformity in type approval and verification. The following are the results obtained from this study:
(1) The uncertainty in type approval is different from the uncertainty in the performance of measuring instruments.
(2) In type approval, if the uncertainty is equal to or less than one-third of the maximum permissible errors, the uncertainty should be included in the criteria of the conformity. If the measurement values inclusive of the uncertainty are within the maximum permissible errors, it will be decided as conformed, and if it is outside the maximum permissible errors, decided as non-conformed.

1. Introduction

Measuring instruments for commercial transactions and certifications are regulated by the Measurement Law of Japan and called "specified measuring instruments". The legal regulatory system demands that they pass type approval tests and be subject to verification before they enter the market. In this report, the criteria for deciding conformity of measuring instrument in type approval and verification will be discussed. In the current type approval tests and verification, evaluation is only based on whether or not the test results fall within the maximum permissible error (MPE) specified by the Measurement Law, and the uncertainty of measurement is not considered at all. The current criteria for deciding conformity is not wholly reliable because of the uncertainty of measurement about test results. To improve the reliability, the measurement uncertainty needs to be taken into account. Research institutes in several countries begun to consider how to introduce the concept of the measurement uncertainty into the criteria for deciding conformity1)-8).

The purpose of this report is to study methods of calculating the measurement uncertainty based on the statistical interpretation on type approval tests and verification specified by the Measurement Law, and then propose criteria with the uncertainty of measurement for deciding conformity to legal metrology.

As a specific example, type approval tests on non-automatic weighing instruments (NAWIs) will be discussed in this report, since the number of applications submitted for type approval of this category is the largest among all specified measuring instruments.

2. the uncertainty in type approval tests and verification

2.1 Test requirements of type approval and verification for weighing instruments

Tests of type approval and verification on NAWIs stipulated in the current Measurement Law are shown in Table 1.

MPE is specified in each test. If the measurement errors are within the specified MPE in every test, the test result is decided as conforming. If the errors exceed MPE, it is decided as nonconforming. Thus, only a NAWI that passes all test will be accepted, and one that fails to pass any one of the test will be rejected.

Table 1. Test requirements of type approval and verification

<table>
<thead>
<tr>
<th>Type approval</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrumental error test</td>
<td>Instrumental error test</td>
</tr>
<tr>
<td>Eccentricity test</td>
<td>Eccentricity test</td>
</tr>
<tr>
<td>Tilting error test</td>
<td>Discrimination test</td>
</tr>
<tr>
<td>Temperature characteristics test</td>
<td>Zero error test just after switching-on</td>
</tr>
<tr>
<td>Zero error test just after switching-on</td>
<td>Repeatability test with series of loading (about 5 items)</td>
</tr>
<tr>
<td>Span stability test just after switching-on</td>
<td></td>
</tr>
<tr>
<td>Repeatability test with series of loading</td>
<td></td>
</tr>
<tr>
<td>Indication limit test</td>
<td></td>
</tr>
<tr>
<td>Creep characteristics</td>
<td>(about 30 items)</td>
</tr>
</tbody>
</table>


2.2 Definition of type approval and verification

In this report, type approval and verification will be defined respectively and the uncertainty of measurement will be discussed based on these definitions.

In type approval tests, a design of a new type of specified measuring instrument is examined in order to decide the conformity to technical requirements. Type approval tests consist of tests on the characteristics that solely depend on the design. Therefore, one or a few samples of measuring instrument are submitted to type approval tests. When type approval is obtained, the design of this type of instrument shall meet the requirements of legal regulation and perform adequately under the conditions of practical use.

Verification is carried out in order to decide the conformation of individual items of type-approved specified measuring instrument to the requirements for performance. Verification tests consist of the tests on characteristics that depend on each item. If each item makes a major instrumental error, some of the tests performed in type approval could be applicable to verification as well. Actually, the test results of type approval can be substituted in verification.

2.3 Uncertainty in type approval tests and verification

There are various methods for estimating the measurement uncertainty. This paper shows two ways of estimating the measurement uncertainty as follows:

[1] Uncertainty of performance of NAWIs (see Equation(1))

\[ u = \sqrt{V_r + V_d + V_s + (V_e + V_t) \times W^2} \] \hspace{1cm} \text{Equation(1)}

[2] Uncertainty in type approval tests on NAWIs (see Equation(2))

\[ u = \sqrt{V_d + V_s} \] \hspace{1cm} \text{Equation(2)}

where:
- \( u \): standard uncertainty in each test
- \( V_r \): dispersion of repeatability
- \( V_d \): dispersion of rounding error
- \( V_s \): dispersion of the mass of weight
- \( V_e \): relative dispersion by eccentric load
- \( V_t \): relative dispersion by temperature characteristic
- \( W \): load on a receptor

Regarding “[1] uncertainty of performance of NAWIs”, each term of Equation (1) is chosen from major factors of the measurement uncertainty in type approval tests. This information is what users will need as well as the satisfactory performance of NAWIs.

In this paper, the measurement uncertainty in type approval tests and verification is discussed. In type approval tests, every factor of errors related to the performance of NAWIs is tested one by one. Other factors are small enough to be ignored when estimating the total uncertainty under the standard condition. As shown in Equation (2), error factors of the uncertainty of NAWIs are the dispersion of rounding errors and that of the mass of weights.

The reason why the dispersion of rounding errors should be considered as a factor of the measurement uncertainty is as follows: If six times of measurement gave the same values. Each value might fall in one scale interval but spread within the interval. Therefore the dispersion within one scale interval should be considered. In this respect, dispersion of rounding errors should be included in the factors of the uncertainty of the type approval test. However, if all the values measured 6 times are totally different, rounding errors are naturally included and they do not need to be included in the uncertainty of the type approval test. Here, assuming that all the values are almost equivalent, rounding errors should be included in the factors of uncertainty of the type approval test.

Regarding the specified measuring instruments whose conformity is decided based on the average of measurement results or standard deviation, the dispersion of repeatability is included in the factors of the uncertainty. But concerning NAWIs, it is not included due to the following reason: Regarding repeatability test on NAWIs, a series of six times of measurement is taken and the results of each time are assessed separately. In other words, if one of the six measurement result fails to pass the test despite the passed five, the instrument will be rejected as a nonconforming item. Thus the average or standard deviation of measurement results is not used for assessment of NAWIs. This is why the dispersion of repeatability is not included as a factor of the measurement uncertainty here.

Type approval tests and verification are basic rules provided by the Measurement Law and related regulation. If the enforcement of requirements are tightened, it will increase production costs and retail prices of the specified measuring instruments, which would finally act against the public interests. Setting stricter standards should be left to the voluntary control of the manufacturing industry, since their requirements in general are stricter than those of national regulation. If the national law is tightened, they will make their standards stricter than ever. This situation could increase the cost endlessly and never benefit the public.

The uncertainty of verification can also be evaluated in the following way:

1. Estimate the uncertainty by the same way as type approval.
2. Not consider the uncertainty because the main purpose of verification is to ensure that the structure of each instrument conforms to the design.
3. Not consider the uncertainty in view of time, cost and public interests.

3. Criteria of conformity in type approval

3.1 Criteria of conformity in type approval and verification

Figure 1 shows an example of the relationship between measurement result, uncertainty, maximum permissible error and criteria of conformity.
CASE 1: both measurement result and uncertainty lie within the MPE. In this case, the result is obviously conforming.

CASE 2: measurement result lies within the MPE but the uncertainty outside. In the current legislation, the result is conforming, since the conformity is decided only by the measurement value. If the measurement uncertainty is considered, however, the result can be decided as nonconforming.

CASE 3: measurement result lies outside the MPE and the result is nonconforming in the current legislation. But if the measurement uncertainty is considered, the measurement result lies within the MPE, and it is decided as conforming.

CASE 4: both measurement result and uncertainty lie outside the MPE. In this case, the result is obviously nonconforming.

Regarding CASE 2 and CASE 3, a question about how to decide the conformity considering the measurement uncertainty would arise.

In the ISO14253-1\(^3\), the criteria for deciding conformity of measurement result including the measurement uncertainty is provided as follows: First, discuss how to consider the measurement uncertainty and achieve a consensus about the standard of acceptance among the parties involved. If a consensus cannot be achieved, accept only CASE 1 as conforming for consumer protection. In type approval and verification, the relevant parties are the government (or organizations designated by the government) and private companies that apply for type approval. Their relationship is not equal, as the position of the applying customer tends to be weaker. Since it should be difficult to reach a consensus through discussion between them, only CASE 1 will be accepted according to the ISO14253-1.

Regarding the maximum permissible error (MPE), it is a concept which was introduced at the time when the uncertainty of measurement had not been considered. To introduce the concept of the measurement uncertainty, the MPE should also be reviewed. It is possible to extend the range of the MPE in accordance with the measurement uncertainty. Nevertheless, the measurement uncertainty will be reduced by the development of technology in the future. It is not a worthwhile idea to feature the range of MPE periodically in accordance with the measurement uncertainty. In this paper, discussion will be based on the premise that MPE should not be changed.

A market surveillance was carried out focusing on the performance of the NAWIs which are practically in use, not on the needs of users.

Classes of NAWIs are shown in Table 2. The accuracy is classified from class 1 to class 4. A NAWI of class 1 has the narrowest range of MPE, whereas one of class 4 has the largest. As to NAWIs of class 3 and class 4, the range of MPE is larger, while the measurement uncertainty is quite small. Therefore, the measurement uncertainty does not affect conformity decision on the instruments of class 3 and class 4. The measurement uncertainty will greatly affect the conformity decision on NAWIs of class 1. By the way, a scale interval of a NAWI of class 1 is specified to be equal to or more than 0.01g in Japan while that in some of EU countries is 0.001g. Therefore the measurement uncertainty will significantly affect NAWIs of class 1 in those countries.

In Japan, there are several manufactures of NAWIs of class 1. By a voluntary cooperation of three companies among them, the instrumental error tests in type approval were carried out on the NAWIs of class 1 of some of EU countries and the NAWIs of class 1 and class 2 of Japan. The relationship between the measurement results, measurement uncertainty and the MPE is shown in Figures 2-7.

On the horizontal axis of each figure, the mass of weights loaded on the NAWIs are shown. On the vertical axis, the deviation between the indication of the NAWIs and the mass of a weight. The dashed line in each figure shows the range of the MPE. If the deviation is within the dashed lined range, the instruments will be decided as conforming.

In the case of Figure 2, weights of 50 g, 100 g, 150 g and 200 g were loaded. When a weight of 50 g was loaded, the indication was 50.001 g and when 100 g was loaded, it was 100.001 g, with a deviation of 0.001 g.

It was confirmed that the test result of domestic NAWIs of class 1 and class 2 lay well within the range of MPE, even inclusive of the measurement uncertainty (Figures 2-5). The test results of NAWIs of some of EU countries of class 1 also lay within the range of MPE inclusive of the uncertainty, whereas one of them gave a little larger degree of uncertainty (Figures 6 and 7). In fact, for these manufacturers, it is acceptable that the measurement uncertainty is introduced into conformity decision in type approval and verification.

Accordingly, this report proposes that only CASE 1 should be accepted in type approval tests for NAWIs.

As CASE 2 is also accepted under the current legislation, the demerits of rejecting CASE 2 shall be discussed. The demerits would be as follows: an increase of defective fraction at the manufacturers before shipping, an increase of time for inspection and an increase of retail...
price. If these demerits exceed the merit of improvement in performance, the revision of the Measurement Law would not be preferable. Conversely, the revision would be desirable when the merit exceeds the demerits. However, in the case of NAWIs, the above demerits would be impossible. They will not occur because manufacturers have improved the designs and quality of products and realized automatic/unmanned inspection in-house. Even if CASE 1 became the only case that would be accepted in type approval tests, no problem would arise due to the advances in manufacturing technology.

Table 2. Relationship between accuracy class of domestic NAWIs and uncertainty

<table>
<thead>
<tr>
<th>Accuracy class</th>
<th>Scale intervals</th>
<th>Number of scale intervals (maximum capacity)</th>
<th>Example: Incidation value of NAWI with maximum capacity 500g</th>
<th>Degree of influence of uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$0.01g \leq e \leq 0.05g$</td>
<td>$50,000 \leq n \leq 100,000$</td>
<td>$0.09g$, $0.1g$, $0.11g$, $0.12g$, $0.13g$, $0.14g$, $0.15g$, $0.16g$, $0.17g$, $0.18g$, $0.19g$, $0.2g$, $0.21g$, $0.22g$, $0.23g$, $0.24g$, $0.25g$, $0.26g$, $0.27g$, $0.28g$, $0.29g$, $0.3g$, $0.31g$, $0.32g$, $0.33g$, $0.34g$, $0.35g$, $0.36g$, $0.37g$, $0.38g$, $0.39g$, $0.4g$, $0.41g$, $0.42g$, $0.43g$, $0.44g$, $0.45g$, $0.46g$, $0.47g$, $0.48g$, $0.49g$, $0.5g$</td>
<td>large</td>
</tr>
<tr>
<td>2</td>
<td>$0.1g \leq e \leq 2g$</td>
<td>$100 \leq n \leq 10,000$</td>
<td>$0g$, $0.01g$, $0.02g$, $0.03g$, $0.04g$, $0.05g$, $0.06g$, $0.07g$, $0.08g$, $0.09g$, $0.1g$, $0.11g$, $0.12g$, $0.13g$, $0.14g$, $0.15g$, $0.16g$, $0.17g$, $0.18g$, $0.19g$, $0.2g$, $0.21g$, $0.22g$, $0.23g$, $0.24g$, $0.25g$, $0.26g$, $0.27g$, $0.28g$, $0.29g$, $0.3g$, $0.31g$, $0.32g$, $0.33g$, $0.34g$, $0.35g$, $0.36g$, $0.37g$, $0.38g$, $0.39g$, $0.4g$, $0.41g$, $0.42g$, $0.43g$, $0.44g$, $0.45g$, $0.46g$, $0.47g$, $0.48g$, $0.49g$, $0.5g$, $0.51g$, $0.52g$, $0.53g$, $0.54g$, $0.55g$, $0.56g$, $0.57g$, $0.58g$, $0.59g$, $0.6g$, $0.61g$, $0.62g$, $0.63g$, $0.64g$, $0.65g$, $0.66g$, $0.67g$, $0.68g$, $0.69g$, $0.7g$, $0.71g$, $0.72g$, $0.73g$, $0.74g$, $0.75g$, $0.76g$, $0.77g$, $0.78g$, $0.79g$, $0.8g$, $0.81g$, $0.82g$, $0.83g$, $0.84g$, $0.85g$, $0.86g$, $0.87g$, $0.88g$, $0.89g$, $0.9g$, $0.91g$, $0.92g$, $0.93g$, $0.94g$, $0.95g$, $0.96g$, $0.97g$, $0.98g$, $0.99g$, $1g$</td>
<td>large</td>
</tr>
<tr>
<td>3</td>
<td>$5g \leq e \leq 2g$</td>
<td>$500 \leq n \leq 10,000$</td>
<td>$0g$, $2g$, $4g$, $6g$, $8g$, $10g$, $12g$, $14g$, $16g$, $18g$, $20g$, $22g$, $24g$, $26g$, $28g$, $30g$, $32g$, $34g$, $36g$, $38g$, $40g$, $42g$, $44g$, $46g$, $48g$, $50g$, $52g$, $54g$, $56g$, $58g$, $60g$, $62g$, $64g$, $66g$, $68g$, $70g$, $72g$, $74g$, $76g$, $78g$, $80g$, $82g$, $84g$, $86g$, $88g$, $90g$, $92g$, $94g$, $96g$, $98g$, $100g$</td>
<td>large</td>
</tr>
<tr>
<td>4</td>
<td>$5g \leq e \leq 2g$</td>
<td>$100 \leq n \leq 1,000$</td>
<td>$0g$, $10g$, $20g$, $30g$, $40g$, $50g$, $60g$, $70g$, $80g$, $90g$, $100g$, $110g$, $120g$, $130g$, $140g$, $150g$, $160g$, $170g$, $180g$, $190g$, $200g$, $210g$, $220g$, $230g$, $240g$, $250g$, $260g$, $270g$, $280g$, $290g$, $300g$, $310g$, $320g$, $330g$, $340g$, $350g$, $360g$, $370g$, $380g$, $390g$, $400g$, $410g$, $420g$, $430g$, $440g$, $450g$, $460g$, $470g$, $480g$, $490g$, $500g$, $510g$, $520g$, $530g$, $540g$, $550g$, $560g$, $570g$, $580g$, $590g$, $600g$, $610g$, $620g$, $630g$, $640g$, $650g$, $660g$, $670g$, $680g$, $690g$, $700g$, $710g$, $720g$, $730g$, $740g$, $750g$, $760g$, $770g$, $780g$, $790g$, $800g$, $810g$, $820g$, $830g$, $840g$, $850g$, $860g$, $870g$, $880g$, $890g$, $900g$, $910g$, $920g$, $930g$, $940g$, $950g$, $960g$, $970g$, $980g$, $990g$, $1000g$</td>
<td>small</td>
</tr>
</tbody>
</table>

Figure 2. a domestic NAWI of class 2: relationship between measurement results, measurement uncertainty and MPE(1) (maximum capacity 220g, scale interval 0.01g, complementary scale interval 0.001g)

Figure 3. a domestic NAWI of class 2: relationship between measurement results, measurement uncertainty and MPE(2) (maximum capacity 310g, scale interval 0.01g, complementary scale interval 0.001g)

Figure 4. a domestic NAWI of class 1: relationship between measurement results, measurement uncertainty and MPE(1) (maximum capacity 620g, scale interval 0.01g, complementary scale interval 0.001g)

Figure 5. a domestic NAWI of class 1: relationship between measurement results, measurement uncertainty and MPE(2) (maximum capacity 620g, scale interval 0.01g, complementary scale interval 0.001g)

Figure 6. a NAWI of class 1 in some of EU countries: relationship of measurement results, measurement uncertainty and MPE(1) (maximum capacity 220 g, scale interval 0.001 g, complementary scale interval 0.0001 g)

Figure 7. a NAWI of class 1 in some of EU countries: relationship between measurement results, measurement uncertainty and MPE (2) (maximum capacity 220g, scale interval 0.001g, complementary scale interval 0.0001g)
3.2 Criteria for deciding conformity of the specified measuring instruments other than NAWIs in type approval tests

For NAWIs, even if CASE 1 became the only case that would be accepted in type approval tests, no problem would occur. But this is not applicable to other categories of specified measuring instruments.

3.2.1 Uncertainty > MPE

Some categories of specified measuring instruments have the measurement uncertainty larger than the MPE. No result could pass type approval tests if CASE 1 became the only case of conforming. Type approval tests have no meaning for them. In this case, the measurement uncertainty should not be considered in conformity decision. First of all, the measurement uncertainty should be reduced.

3.2.2 Uncertainty \leq MPE

Other categories of specified measuring instruments have the measurement uncertainty smaller than the MPE. If the proportion of the uncertainty to MPE is large, requirements would be much severer by making CASE 1 as the only case of conforming compared to the current legislation in which the measurement uncertainty is not considered. For example, if the proportion of the measurement uncertainty rises up to 90 % of the MPE, the MPE will virtually become one-tenth compared with that of the current legislation. This means a high probability of being decided as nonconforming. Accordingly, this report proposes that the measurement uncertainty should not be considered in conformity decision if the proportion of the measurement uncertainty to the MPE exceeds one-third. For these categories of specified measuring instrument as well, the measurement uncertainty should be reduced first.

This report proposes that the measurement uncertainty should be considered in conformity decision if the proportion of the measurement uncertainty to the MPE is less than one-third. This value of one-third is based on the long experiences in the industry and this would be accepted by manufacturers. In any case, the consensus among manufacturers is indispensable to avoid confusion.

4. Conclusion and Summary

The following are the conclusions obtained from the investigation:
(1) The measurement uncertainty in the type approval tests is different from the measurement uncertainty in performance of non-automatic weighing instruments (NAWIs). The factors of the measurement uncertainty in type approval tests are the dispersion of rounding error and the dispersion of the mass of weights.
(2) If conformity decision in type approval tests is based on the average or standard deviation of the measurement values, the dispersion of repeatability should also be evaluated as one of the factors of the measurement uncertainty.
(3) In type approval tests, if the measurement uncertainty is equal to or less than one-third of the MPE, the measurement uncertainty should be considered in conformity decision. In this case, if the measurement results including the measurement uncertainty lie within the MPE, it should be decided as conforming, and the rest, nonconforming. Before applying these criteria, the consensus among the manufacturers of each instrument shall be achieved.
(4) In type approval tests, if the measurement uncertainty exceeds one-third of the MPE, the measurement uncertainty should not be considered in conformity decision. Efforts should be made to reduce the measurement uncertainty.
(5) As to the measurement uncertainty in verification, there are several ways of approaching such as the way applied to type approval tests, or the way in which the measurement uncertainty is not considered at all, etc.

Acknowledgement

The author is indebted to Shinko Denshi co., Ltd., Sartorius K.K. and Mettler-Toledo K.K. for their substantial contribution to the completion of this paper. The author wish to thank Dr. M. Koike, Dr. K. Ebara, Dr. H. Tanaka, Mr. T. Nakamura, Mr. M. Horita, Mr. T. Kojima, the staffs of Mass and Force Standards Section of Mechanical Metrology Division, and the staffs of Legal Metrology Division of National Metrology Institute of Japan (NMIJ), AIST for helpful suggestions and useful discussions.

Reference


