A combine calibration method for total weighing-in-motion systems based on load-meter according to OIML R76-1 and R134-1

Lin Shuo, Guo Guiyong, Yao Jinhui
Department of intelligent measurement, Fujian Metrology Institute, No.9 Pingdong Road, Fuzhou City, Fujian Province, PRC
E-mail: linshuo1001@126.com

Abstract. This paper describes a combine calibration method for Total Weighing-in-motion Systems which are widely used in toll-by-weight and dispelling of overload on express way in China. Calibration with full-range and whole performances is able to carry out conveniently and with high-efficiency using the optimized method based on Load-meter according to OIML R76-1 and R134-1. The investigations of weighing data model and test results under different methods are presented. The uncertainty models for the method are analysed, and the applicability of the method is proved by the adaptability, stability and reliability tests results. Over 310 successful applications are performed, and the new method helps TWIM systems to meet the accuracy of class 1 in Fujian province.

1. Introduction
Total Weighing-in-motion Systems (TWIM) have advantages in high accuracy ($\pm 0.5\%$), high efficiency, reliability and long-life compared to other kinds of Weighing-in-motion System. They have been widely applied for weighing total vehicle mass in many provinces in China, and the application number is over 18,000 sets by now [1-2]. There are both static mode and dynamic mode on the TWIM which can be used as a control instrument, and the capacity is usually up to 100 tons, while the length may over 20 metres. According to OIML R134-1, the control instruments must meet the requirements of medium accuracy in OIML R76-1[3-4].

To confirm the metrological characteristics of TWIM, different verification standards may be used. Previously, only dead weights or substitution of weights were used as verification standards, so the verification of whole performances is impossible. At the same time, for the maxim vehicle mass is not allow to larger than 49 tons by Chinese traffic law, it is hard to cover the weighing range by reference vehicles. In fact, only in-motion tests using specific reference vehicles are performed in daily verification, so the accuracy of instrument can hardly meet the requirement of Class 1 when the load is larger the verification load. Therefore, a suitable calibration method that follows OIML R76-1 and R134-1 for TWIM is needed urgently.

At present, the Load-meter (LM) device which can be applied to verify the non-automatic instruments conveniently has been invented by Fujian Metrology Institute of China, and it is a kind of legally auxiliary verification device of R76-1[5]. As an effective complement for international recommendation, a method that combine static test with in-motion test based on Load Meter method for TWIM is presented in this paper. The necessity, procedures, uncertainty model, adaptability, and the applications of this method are illustrated.
2. TWIM data model and calibration test

2.1. Weighing data model

A TWIM system includes weighing bridges, several load cells, an indicator and the weighing-in-motion data processing device. The indication weighing data \( W_i \) can be expressed as

\[
W_i(t) = W_0 + A_i \sin(W_0 t + \vartheta_i) + \sum A_i \sin(W_0 t + \vartheta_i)
\]

In which \( A_0, W_0, \vartheta_0 \) are the amplitude, frequency and phase of first order low frequency interference signal, while \( A_i, W_i, \vartheta_i \) are the ones of high frequency signal. They are the inherent characteristics of instrument and they cannot be changed in calibration. \( W \) is the original weighing data which is the basis of the TWIM weighing data model. The model of \( W \) is presented as

\[
W = k_m \cdot W_i = k_m \cdot \left( \sum_{i=1}^{N} \omega_i m_i \right)
\]

The static load on every load cell \( m_i \) and weighting coefficient \( \omega_i \) make up the weighing data on each load cell, and the product with static-motion conversion coefficient \( k_m \) under the specific speed gives the weighing-in-motion data. Therefore, to ensure the accuracy of static weighing data \( W_s \) is the key point of calibration.

2.2. Calibration test

Comparison tests in different calibration states are performed. In the tests, 4 different TWIM instruments with the max capacity 100 t from two different manufactures A and B are chosen. In state I, the TWIMs are calibrated with full range and whole performances according to R76-1, and the errors within MPEs of medium accuracy. In calibration state II, the instruments are only calibrated by reference vehicles. The deviations of vehicle mass on the calibration points and the repeatability errors meet the requirement, but the errors at other weighing points and eccentric errors cannot be ensured. Three types of reference vehicle are used in test with the velocity of 10 km / h, including a two-axle rigid reference vehicle \( m = 5 \text{ t} \), a three-axle rigid vehicle \( m = 20 \text{ t} \) and a four-axle draw-bar trailer \( m = 48 \text{ t} \). The results are shown in table 1.

| TWIM No. | Calibration State | Max error in static | Max error in motion |
|----------|------------------|---------------------|---------------------|
|          | Eccentric | Vehicle | Repeatability | Two-axle rigid | Three-axle rigid | Four-axle draw-bar |
|          | Vehicle | mass | | reference vehicle | vehicle | trailer |
| A1       | I       | +15kg | +20kg | +8kg | +0.4% | +0.1% | +0.2% |
|          | II      | +38kg | +52kg | +13kg | +0.8% | +1.5% | +0.3% |
| A2       | I       | +12kg | +16kg | +5kg | +0.4% | +0.2% | +0.2% |
|          | II      | -42kg | -50kg | -14kg | -1.1% | -1.7% | -0.8% |
| B1       | I       | -12kg | -18kg | +8kg | +0.4% | +0.1% | +0.2% |
|          | II      | -45kg | -66kg | -10kg | -1.1% | -0.6% | -0.4% |
| B2       | I       | -12kg | -18kg | -5kg | -0.4% | -0.2% | -0.2% |
|          | II      | -42kg | -69kg | -16kg | -1.8% | -1.2% | -0.6% |

Table 1 shows the very good results under State I in both manufactures. Even though the repeatability errors lower than MPEs, the errors in motion are over ±0.5% when the static test errors of TWIM are not meet the requirements of medium accuracy. The static-motion conversion factor \( k_m \) and the gains amplify the static error, and the dynamic interference signal makes error randomly. Furthermore, the conventional true value of the reference vehicle mass will change after long distance driving in the open air. Calibration with only reference vehicles is not sufficient to ensure the accuracy of TWIM.
3. Test procedure and uncertainties

3.1. The principle of calibration
The key verification standard of the method combine static test with in-motion test is Load Meter (LM). A set of LM device includes several standard load units, which are driven by a high-precision hydraulic power system. The standard load is measured by transducers of class 0.5 according to ISO376-2011. They can be loaded not only simultaneously for static weighing test and repeatability test, but also independently for the eccentric tests. The reaction beams and the basements are removable after verification [6]. All these components can be installed on a van for transportation.

3.2. Test procedure
The static test using LM device is performed on the TWIM according to OIML R76-1 to ensure that the instrument meet the requirement of medium accuracy. For a typical 100 t TWIM with 12 load cells, the calibration items including 3 times of pre-load up to 90 t, 12 eccentric tests of 9 t, the weighing test up to 100 t, and the repeatability tests to 100 t. All these tests will be finished in 2 hours. Then the accurate vehicle mass of reference vehicles can be confirmed immediately. The in-motion tests under different operation speed are carried out next. The realistic scene of verification is shown in Figure 1.

![Figure 1. Scene of verification using combine method with LM device and reference vehicles.](image)

3.3. Uncertainties
The indication deviation $E$ in static test can be calculated by indication weight $I$ and the standard load $L$ according to:

$$E = I + 0.5e - L$$

The uncertainty $u(E)$ of the indication deviation $E$ in static test can be calculated from:

$$u^2(E) = u^2(I) + u^2(L)$$

The uncertainty component $u(I)$ comes from the indicator, and $u(L)$ is from LM device. The deviation of LM $\delta$ which meets the requirement of R76-1 in point 3.5.1 obeys uniform distribution [7]. Considering the range in the measurement series $I_j$, and the effects of repeatability, resolution, eccentric load, and temperature, the relative uncertainty can be calculated from:

$$u(E) = \max \left( \left\{ \frac{I_{j_{\text{max}}} - I_{j_{\text{min}}}}{1.69}, \frac{0.5e}{10\sqrt{3}}, \left[ \frac{0.25e}{\sqrt{3}(N-1)} \right]^2 + \left( \frac{0.05e}{\sqrt{3}} \right)^2 + \frac{\delta^2}{3} \right\} \right)^{1/2}$$

The uncertainty of in-motion test $u(TMV)$ includes 3 components: the mean values of tests $\overline{TMV}$, the resolution of TWIM $\delta_x$, the resolution and MPE of control instrument [8]. The relative uncertainty can be calculated from:

$$u(TMV) = \max \left( \left\{ \left( \frac{\sum TMV_i - \overline{TMV}}{n(n-1)} \right)^2 + 0.29\delta_x, \left( \frac{0.5e}{10\sqrt{3}} \right)^2 + \left( \frac{\text{MPE}}{\sqrt{3}} \right)^2 \right\} \right)^{1/2}$$
4. Adaptability of the method

4.1. Loading state
Compared with calibration using dead-weight as test standard, the loading state on the weighing bridge with LM method is different. As which shown in Fig.1, the bearing area of each load unit is a circle with the diameter of 300 mm. It is very similar to the contact area between truck tires and the weighing bridge. Though the verification results of two methods are mostly the same, LM method is closer to the real situation. The special build-up structure of transducer make LM device keep high accuracy under eccentric and tilt load [9-10].

4.2. Environment factors
With the help of a real-time feedback compensation system on the LM device, the deviations are within the scope of ±0.02% under the temperature range of (-10 ~ +40) °C. There is a location-acceleration of gravity transfer module in the control system of LM, so it will offer local standard load when the latitude and the altitude of the TWIM are input. At the same time, the results of long term stability test and the reliability test after over 10000 km transportation show that the long-term error is lower than 0.02% in 1 year. The environment test results are shown in Figure 2.

![Figure 2. The results of temperature tests and long-term stability tests.](image)

5. Conclusions
Using the combine calibration method based on Load-meter device, full weighing range and whole performances can be covered in the tests. In the year of 2017, over 310 TWIM systems were calibrated in Fujian Province, and all of them meet the accuracy Class 1. It helped the income of road toll increased by 3.04% in the year 2017. In addition, the weighing values are unified in the province and the disputes in toll-by-weight and dispelling of overload decreased sharply.

6. References
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