Influence of Vibration on Metrological performance of Mobile Laboratory of Highway Metrology and Countermeasures

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Abstract: The vibration conditions affecting the metrological performance of the mobile laboratory of highway metrology were detailedly analyzed. The corresponding research strategies were formulated for different forms of vibration, and the technical measures to mitigate the vibration impact were further proposed, which is an important reference for the design of mobile laboratory of highway metrology.

1. Introduction
The development of mobile laboratory technology in the field of highway measurement is of great significance for promoting the development of highway measurement, but it also brings further problems. For example, in the environment of fixed laboratory, the impact of vibration is negligible, but the vibration conditions of the mobile laboratory are not ideal due to the on-site verification. The more important point is that the foundation is not stable enough which resulting in high natural frequencies. In addition, the bumping vibration of the carrier during transportation may cause collision and impact of the measuring instrument, and it also affects the metering performance of the measuring instrument.

The verification procedures such as "Geophysical instrument" clearly state that environmental vibration should not affect the measurement results, but the quantitative vibration requirements are not given. On the one hand, it shows that the research on the measurement performance affected by vibration is not deep, on the other hand, the influence of vibration must be taken into account. Only by clarifying the influence of vibration, we can grasp the law and take measures to reduce the negative impact of vibration on the measurement work, so as to accurately carry out the measurement work.

2. Vibration composition of mobile laboratory of highway metrology
The measuring instruments carried in the mobile laboratory of highway metrology are affected by various vibration modes. By analyzing the influence forms of their metering performance, they can be roughly divided into two categories, transport vibration and parking vibration.

2.1. Transport vibration
The transportation vibration of the mobile laboratory of highway metrology mainly comes from the random vibration based on the road and the cyclic vibration of the engine running[1]. The influence of the vibration transmission on the measuring instrument should also be considered. For a specific mobile laboratory carrier, comprehensive factors should be analyzed, such as road spectrum characteristics, vehicle speed, engine working state and aerodynamics factors, etc., due to the complex
and variable factors, the superposition results are ever-changing, if all factors are taken into account, the research will be extremely complicated, so the main influencing factors should be grasped and an approximate model should be established accordingly\cite{2}. For example, Gu Xiaohua ignores the vibration caused by aerodynamics when studying the fatigue life of vehicle-mounted equipment, and believes that the vibration level of the engine and transmission system coupled to the vehicle floor is not obvious, only considering the random excitation spectrum of the road to the wheel, and the vehicle model is simplified to a 1/4 vehicle model with single degree of freedom, and its dynamic response is studied.

It can be seen that in the theoretical study of the response problem of transportation vibration in the mobile laboratory of highway metrology, on the one hand, it is necessary to establish its vibration transmission model, on the other hand, it is necessary to establish a random excitation spectrum of the road to the wheel, Perform a real vehicle test to correct the results if possible\cite{3}.

2.2. Parking vibration

The research on parking vibration of mobile laboratory of highway metrology can be compared with fixed laboratory, considering the different measurement occasions, the latter should be further considered some aspects as follows:

1) The foundation of installed equipment in fixed laboratory is generally designed specially with high quality and low natural frequency. Through such design, the basic vibration reduction effect can be achieved, and mobile laboratories are generally subject to on-site measurement. Due to environmental constraints, ideal foundation conditions are difficult to achieve;

2) Constrained by the characteristics of on-site measurement, the equipment and the foundation generally adopt the simplest connection method to achieve the purpose of improving the measurement efficiency, and thus the possible consequence is that the environmental vibration or the vibration of the instrument amplified;

3) For relatively sophisticated instruments and equipment, in order to reduce the impact of environmental vibration, fixed laboratories generally use measures such as designing vibration damping ditch or vibration isolation platform to reduce the transmission of vibration. On-site measurement requires an alternative solution to achieve this purpose;

In addition, on-site measurement is more affected by traffic flow. To reduce this effect, the measurement work should be carried out at the night or when the traffic flow has less impact.

3. The effect of vibration on metering performance

Regarding the influence of vibration on the metering performance, the following will study in accordance with the classification of the vibration in the previous section.

3.1. Impact of transport vibration on metering performance

Mobile laboratory of highway metrology generally carry out metering work under parking conditions. However, due to their mobile characteristics, it is inevitable to experience transportation. Therefore, it is necessary to consider the impact of bumpy vibration during transportation on measuring instruments. The theoretical study of transport vibration is generally based on the approximate model\cite{4}. The pros and cons of the model hypothesis directly affect the accuracy of the vibration prediction results, while the real vehicle test can obtain the first-hand vibration data, so the real vehicle test is a relatively reliable way to study transport vibration.

To this end, we select the most commonly used measuring instruments for real vehicle transport test, measuring instruments shown in Figure 1-3 respectively: precision balance, dial indicator and vernier caliper, Select modified Ford Transit car as test carrier, which shown in Figure 4, the test pavement selects the standard road for the flatness rutting test of Research Institute of Highway Ministry of Transport.
3.1.1. Flatness rutting test introduction
The test section is cement concrete pavement with a length of not less than 500m. The international flatness index (IRI) of the pavement is not more than 2.0, and there are obvious wheel marking lines. Different thicknesses and different numbers of experiments are arranged along different locations of the test circuit on the platform road to achieve the purpose of changing the flatness of the test line. Generally, the change of the height of the road surface relative to the reference plane along the road strike length is called the road roughness function, which is referred to as road roughness.

During the test, the vehicle equipped with the laser flatness meter will cycle along the test section and collect the relative elevation data of the road surface for about 3 hours. Generally, each laser flatness meter will arrange a series of laser collection points along the width of the road. Since the vibration of the vehicle is directly affected by the relative elevation of the road surface at the wheel track, the data is specially collected and analyzed. The collected relative elevation data is averaged and graphically depicted in Figure 5.

3.1.2. Experiment procedure
The standard gauge block is used as the calibration object of length and mass, and the measurement results of the appliances before and after the actual vehicle test are compared.

1) Measure the standard gauge weight with precision balance. First, make sure that the measurements are carried out in a windless, vibration-free indoor environment and place the precision balance on a smooth work surface. In addition, in order to ensure the influence of the weighing position on the measurement results, the standard gauge blocks were placed at different positions on the precision balance platform to compare the weighing results. It was found that the displayed
weighing results were different when the standard gauge blocks were placed at the center and the edge of the platform, and there is a stable error of about 0.1g, which is supposed to be related to the structure of the balance. For this reason, the position where the gauge block is placed should be the same at each weighing. Place the gauge block in the center of the balance, read the number and record it after the number is stable, then take off the gauge block. When the count return to zero, put the gauge block on the center of the platform again, do this five times, and take the average, in comparison with the actual vehicle test.

2) Measure the standard gauge block size with the vernier caliper. Inspired by the precision balance measuring the weight of the standard gauge, the vernier caliper should ensure that the position of each gauge block is consistent when test. Use the vernier caliper to measure the height of the gauge block, read the measured value, then set the vernier caliper to zero, and measure the height of the gauge block again at the same position. Do this five times, recorded and averaged to compare with the measured value after the actual vehicle test.

3) Measures the standard gauge block size with the dial gauge. When using the dial gauge to measure the thickness of the gauge block, in order to ensure the measurement accuracy, the gauge block should be fixed, measured 5 times at the same position, and the measurement data should be recorded and averaged for comparison with the measured value after the actual vehicle test.

3.1.3. Test record and analysis
According to the measurement method of 3.1.2, the precision balance, the vernier caliper and the dial gauge are used to measure the gauge block. The measurement data before and after the test is recorded and averaged as shown in Tables 1-3.

| Table 1. Precision balance weighing block (unit: g) |
|-----------------------------------------------|
| test count | 1 | 2 | 3 | 4 | 5 | average |
| Value before test | 192.9 | 192.9 | 193.0 | 193.0 | 192.9 | 192.94 |
| Value after test | 192.9 | 193.0 | 192.9 | 192.9 | 192.9 | 192.92 |

| Table 2. vernier caliper measurement block height (unit: mm) |
|-------------------------------------------------------------|
| test count | 1 | 2 | 3 | 4 | 5 | average |
| Value before test | 80.00 | 80.00 | 80.00 | 80.00 | 80.00 | 80.00 |
| Value after test | 80.00 | 80.00 | 80.00 | 80.00 | 80.00 | 80.00 |

| Table 3. Dial gauge measurement block (unit: mm) |
|-----------------------------------------------|
| test count | 1 | 2 | 3 | 4 | 5 | average |
| Value before test | 2.425 | 2.425 | 2.425 | 2.426 | 2.425 | 2.425 |
| Value after test | 2.425 | 2.425 | 2.425 | 2.425 | 2.425 | 2.425 |

It can be seen from Tables 1~3 that during the length measurement, the mean value of the vernier caliper and the dial gauge does not change before and after the actual vehicle test. It can be considered that the performance has not changed after a short period of transport vibration; The relative measurement error before and after the precision balance test can be expressed as:

$$\Delta = \frac{|G_i - G_j|}{G_i} \times 100\% \leq \frac{|192.92 - 192.94|}{192.94} \times 100\% = 0.01\%$$

It can be seen that the relative measurement error is within the allowable range, and it can be considered that the measurement performance of the precision balance does not change after a short time of transportation vibration. However, for some precision instruments, such as precision horizontal arm three-coordinate measuring instruments, the vibration acceleration is required to be less than $5 \times 10^{-3}$m/s², the speed is less than $5 \times 10^{-3}$m/s, the displacement is less than $5 \times 10^{-6}$m; The laser interferometer with precision of 0.02 μm allows the vibration speed to be less than 0.03 mm/s, but the data of transport vibration test clearly exceeds the limit, so it is necessary to take measures to further reduce the transport vibration.
3.2. Influence of parking vibration on metering performance
The effect of parking vibration on metering performance can be compared to the impact of fixed laboratory. If the vibration impact of the fixed laboratory on the measurement performance is negligible, that is, if the reliability of the measurement results in the fixed laboratory is relatively high, the measurement results of parking can be compared with it. And the metering performance during parking is evaluated by this comparison. However, many equipments must be metered on site in reality testing, which makes the above research methods seem one-sided, so it is necessary to conduct vibration research on the measurement of all testing equipment.

The composition of the parking vibration mainly includes the vibration of nearby environmental and the vibration generated by the operation of the equipment itself, In most cases, the two have a coupling effect on the metering performance. Environmental vibrations include natural vibration sources nearby and artificial vibration sources (vehicles, etc.), which represent a stable and non-repetitive random fluctuation of the ground. Environmental vibration has a significant impact on the metering performance during parking, However, the impact of metering performance is ever-changing for different environment, we don’t discuss it here, but an example is given to illustrate the analysis. Generally, precision measuring equipment will require the threshold of environmental vibration, just avoid use them in an environment where the vibration exceeds this threshold.

1) Firstly, set the dynamics modeling of the testing equipment and the basic environment, and it can be simplified according to the actual situation within the error tolerance;
2) Secondly, the hypothesis of the basic environmental vibration should be set, which should combine with the vibration measuring equipment to make a feasibility demonstration;
3) Solving the vibration response of the detection equipment under the vibration of the basic environment;

The vibration response of the testing device is compared with the vibration value required by the manufacturer to determine whether the metering operation can be performed in the base environment.

3.3. Influence of human factors on measurement performance under vibration environment
In addition to the direct impact on the measurement and testing equipment, the vibration environment will also indirectly affect the measurement results through operator. For example, in a certain form of vibration, people's emotions, thinking, analysis and reaction ability will become negative, and the measurement results obtained in this case may deviate from the actual situation.

4. Vibration reduction measures
In order to reduce the impact of vibration from various sources on the metrological performance of mobile laboratory of highway metrology, we design schemes from some aspects, like vibration source, vibration propagation path, affected equipment and test personnel. Before determining the vibration reduction measures, you can consider segmenting the main influence frequency and performing corresponding vibration reduction processing for each frequency band.

4.1. Weakens vibration from source level
Considering the actual working conditions of the mobile laboratory of highway metrology, the vibration mainly comes from the natural vibration source and nearby vehicles. The natural vibration source generally has less impact and can be ignored. It is not practical to improve the structure of other vehicles to reduce the occurrence of vibration, but it can still be started from the following aspects:
1) The measurement work should be carried out on a flat road as much as possible to reduce the occurrence of random vibration based on the road surface spectrum;
2) Where there are vehicle passing, the vibration isolation pad is reasonably laid to cushion the impact of the vehicle on the road surface;
3) Set a vehicle deceleration prompt near the metering work area to reduce the vibration’s impact caused by excessive speed;
4) Reasonably select the measurement time, for example, choose a night with a relatively small traffic flow.

4.2. Reduces vibration transmission in Vibration propagation path level

The existing technical measures to reduce vibration transmission, such as the installation of vibration isolation trenches, will greatly reduce the measurement efficiency and increase the measurement cost. In order to achieve efficient and low-cost measurement, the following measures can be considered:

1) The measuring workbench should be placed on the basis of relatively large mass and size to reduce the natural frequency;

2) In order to reduce the impact of the transportation on the metering performance of the metering equipment, the design of the cabinet is very important. It should be noted that the cabinet should be rigidly designed, and the box should be anti-vibration;

3) The vibration isolator is arranged around the carrier cabinet, with large damping in the resonance area of the system, so that the system does not resonate, and there is less damping in the vibration isolation area, so that the system has good vibration isolation frequency, and is resistant to shock and good stability.

4) Reasonably select the vibration isolation table to isolate the equipment;

5) Referring to the installation of high-speed rail, the sand cushion is laid reasonably under the workbench.

4.3. Designed vibration isolation device for affected devices

As the final link to reduce the impact of vibration on the measurement work, do a good job of vibration prevention at the level of equipment affected by vibration, which is of great significance to the measurement work, and can be started from the following aspects:

1) Vibration-influencing equipment should consider anti-vibration design, such as rigidification of equipment containing liquid crystal screen, filling glue for equipment which including electronic components, eliminating the assembly gap of structural parts;

2) The equipment should be installed firmly to prevent resonance amplification caused by unstable installation.

4.4. Subjective initiative of Metering personnel

Metering personnel can exert subjective initiative to weaken the effects of vibration, such as reasonable data processing\[6\]. The vibration data is collected by setting the vibration sensor, and the measurement result is converted into a standard state, thereby judging the device performance and technical indicators.

5. Conclusion

The mobile laboratory of highway metrology has strict requirements on the measurement accuracy, and the vibration has a great influence on the accuracy of the measurement. In this paper, the vibration composition is analyzed, and the influence of transportation vibration on the measurement performance of the measuring instrument is studied by the actual vehicle test. It is found that the short-term transportation vibration has negligible influence on the measurement performance. To determine this conclusion, long-term transportation vibration tests on more measuring instruments should be carried out. In addition, this paper proposes technical measures to improve the measurement accuracy from many levels, which is of great significance for guiding the measurement work of mobile laboratory of highway metrology.

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