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A NEW METHOD FOR DYNAMIC FORCE MEASUREMENT AT NIM

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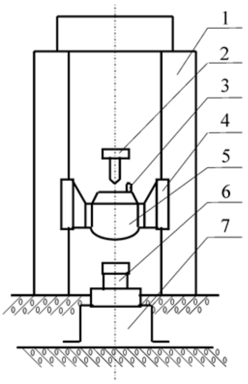
Abstract – The paper describes a new method for dynamic force measurement at NIM. National institute of Metrology has established fall hammer type1MN dynamic force standard equipment. According to Newton's law, the dynamic force acting on the force transducer is traceable to mass and acceleration by $F = ma$, where m is the mass of hammer and a is the impact acceleration of hammer. Original we measure the impact acceleration of drop hammer by a standard accelerometer. Now we measure the acceleration by a laser Interferometer. Traceability for force is realized via the measurement of acceleration with laser-Doppler-interferometers and the determination of the dropping masses. This paper introduces the structure and the working principle of the equipment, performance parameters and the uncertainty evaluation. This paper also compares the data between the accelerometer and laser-Doppler-interferometer.

Keywords: dynamic force calibration; laser-Doppler-interferometer; standard machine.

1. INTRODUCTION

Recently, the demand for dynamic force measurements has increased due to the rising number of dynamic applications and improved safety standards. The measurement of dynamic force develops rapidly and has made great progress. More and more people have convinced that the force transducer and used in dynamic force measurement should be carried out not only the static calibration but also the dynamic calibration. By the dynamic calibration we can get the dynamic characteristics of transducer or the measuring system. Dynamic force calibrating procedures have been developed many years before at PTB and NIM force lab[1] [2] [3]. National Institute of Metrology (NIM) has developed a kind of dynamic force calibration equipment (Figue1). This equipment is fall hammer type dynamic force calibration equipment, which can generate the bell shape force pulse (Gauss pulse). The specifications of the equipment are: force measuring range: 500N-1MN, force rising time: ⩾ 0.3ms, expanded uncertainty: 3 %(k=3).



1. Tracks 2.releasing mechanism 3. Standard accelerometer 4. Guiders 5.hammer 6.dynamic force transducer 7.anvil

Fig.1. Standard dynamic force equipment

The dynamic force acting on the force transducer is traceable to mass and acceleration by $F = ma$, where m is the mass of hammer and a is the impact acceleration of hammer. Original we measure the impact acceleration of drop hammer by a standard accelerometer. With the new method we measure the acceleration by a laser Interferometer. Traceability for force is realized via the measurement of acceleration with laser-Doppler-interferometers and the determination of the dropping masses. The specifications of new equipment are: force measuring range: 500N-200kN, force rising time: ⩾0.3ms, expanded uncertainty: 2 %(k=3) [2].

2. STRUCTURE AND WORKING PRINCIPLE

2.1 Structure and working principle of original method

The 1MN fall hammer type dynamic force calibration equipment (Fig.1) consists of anvil, frame, tracks, hammer, guiders, lifting and releasing mechanism, reference dynamic force transducer and standard accelerometer. The equipment has the feature of less separate parts and high structure internality to reduce the influence of the vibration of the separate parts upon the dynamic force wave during the impact process. The anvil and frame are mounted on the different basements to guarantee the high rigidity and higher frequency response of the whole equipment.

Calibration is conducted by using comparison method. The block diagram of the measuring system which consists of the standard accelerometer system (reference system) and the force transducer system to be calibrated is shown in figure 2[4].

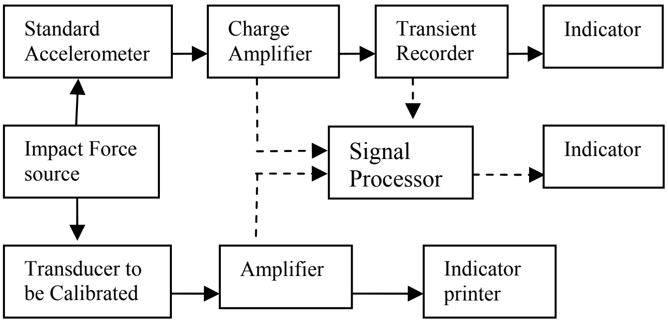
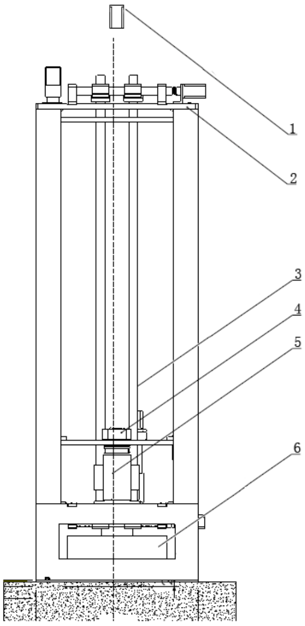


Fig.2. block diagram of the system

2.2 Structure and working principle of new method

2.2.1 Mechanical system setup

The new 200kN equipment is fall hammer type dynamic force calibration equipment also. It consists of anvil, frame, track, hammer, guiders, lifting and releasing mechanism, references dynamic force transducer and the laser-Doppler-interferometer. An LDI head (Polytec OFV550) mounted on top of the equipment, which can be adjusted easily. As shown in Fig.3.



1. Laser-Doppler-interferometer
2. Servo Motor 3. Tracks 4. Electromagnet
5. Hammer 6. Anvil

Fig.3. Standard dynamic force equipment

The new equipment has two hammers to adapt to different range. One is two kilogram, the other is twenty kilogram. The hammer can be upgraded by electromagnet automatic. In order to ensure the whereabouts of the hammer is ideal free-falling. We adjust the level of drop hammer and base level strictly. The gap of hammer and tracks is designed suitable.

2.2.2 Data Processing System

The data processing system is consisted of PXI-1042 and PXI-5122. The national instrument 5122 is high-resolution digitizers. It has two 100Ms/s simultaneously sampled input channels with 14-bit resolution.

2.2.3 The principle of acceleration measurement by laser-Doppler-interferometer

The working principle of the equipment is also to adopt Newtonian Second Law: $F = ma$. The dynamic force can be determined by multiplying the known mass of hammer by the impact acceleration. The differences of two equipments are the measure method of acceleration and the Level of automation. First we can measure the velocity of the hammer by laser-Doppler-interferometer directly. Laser-Doppler-interferometer operates on the Doppler principle, measuring the frequency or phase shift of back-scattered laser light from a vibrating structure, to determine its velocity[5] [6].

$$v = \lambda_{air}(\Delta f)/2\sin\frac{\theta}{2} \qquad (1)$$

Equation (1) is the relationship of v and Δf, where θ is the Angle of incident light and reflected light.

$$\Delta f = f_D - f \qquad (2)$$

Where f is the Laser light frequency, f_D is The frequency of the reflected light.

The time series of acceleration during time of impact is derived from the recorded LDI velocity signal by numerical differentiation, a process which runs offline.

3. FIRST TEST AND MEASUREMENT

We have done some preliminary tests. The following figures show the result of test. Figure 4 shows the velocity change process of impact process, recorded by the Laser-Doppler- interferometer. From the fig we can see the velocity change process of impact. Velocity gradually increases to reach maximum value, then decreases, crossing zero then the opposite direction began to increase, reaching a maximum, under the force of gravity began to slow down.

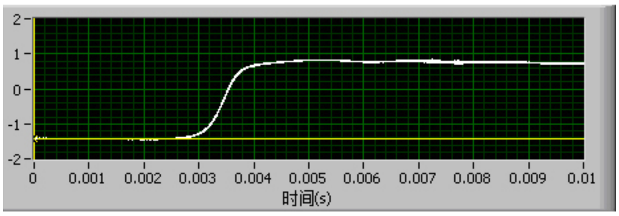
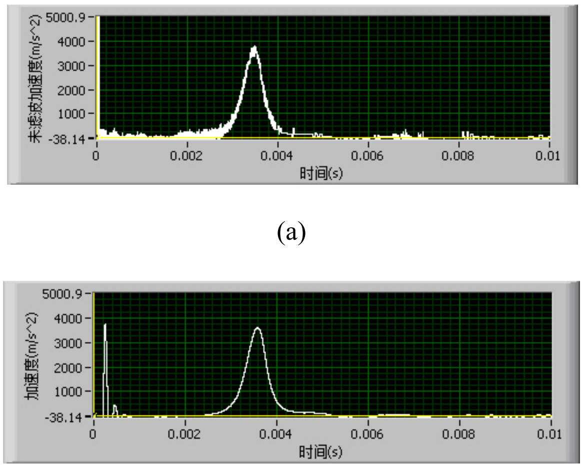


Fig.4. velocity change process

The acceleration recorded by the laser-Doppler-interferometer is shown in figure 5. Through the differential processing of velocity signals, we can get the acceleration change process of impact. Figure 5 (a) shows the acceleration signal, without filtering. Figure 5 (b) shows the acceleration signal by filtering.



(a)

(b)

Fig.5. acceleration recorded by laser-Doppler-interferometer

Because 5122 is a two channel digitizers, so we can record the laser signal and accelerometer signal simultaneously. Figure 6 shows the acceleration of impact recorded by accelerometer and laser-Doppler-interferometer. White curve is the velocity curve. Green curve is the acceleration curve of laser measurement. Yellow curve is the acceleration curve of accelerometer measurement. From the figure we can see, laser measurement and accelerometer measurements in a slightly different phase.

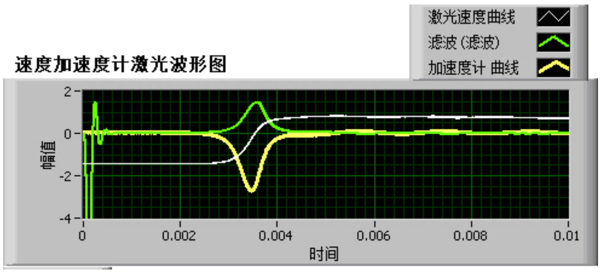


Fig.6. phase relationship of laser measurement and accelerometer measurements

4. COMPARISON TEST RESULTS

4.1 The experimental progress

In order to compare two different methods, we measure the same impact process of hammer by two methods at the same time. The experiment was shown in figure 6.The results are as follows.

4.2 The data of this experiment

Table1

Test No	Force measured by laser-Doppler-interferometer		Force measured by accelerometer		Relative Error (%)
	Force(kN)	Rising time(ms)	Force(kN)	Rising time(ms)	
1	2.69106	0.897	2.708	0.820	-0.63
2	2.45578	0.898	2.466	0.860	-0.41
3	2.76208	0.846	2.774	0.840	-0.43
4	2.67064	0.853	2.670	0.860	0.02
5	2.83829	0.821	2.838	0.802	0.01
6	3.25984	0.743	3.282	0.754	-0.68
7	3.00506	0.821	3.004	0.794	0.04
8	3.06224	0.769	3.090	0.784	-0.90
9	3.59279	0.692	3.596	0.704	-0.09
10	4.94202	0.579	4.954	0.580	-0.24
11	4.98126	0.564	4.996	0.570	-0.30
12	4.87118	0.589	4.898	0.578	-0.55
13	4.98117	0.590	5.000	0.564	-0.38
14	5.33842	0.501	5.364	0.540	-0.48
15	5.72315	0.521	5.745	0.508	-0.38
16	5.23175	0.573	5.250	0.520	-0.35
17	5.04459	0.573	5.050	0.500	-0.11
18	6.16695	0.469	6.190	0.478	-0.37
19	6.34854	0.495	6.365	0.480	-0.26
20	6.56036	0.495	6.570	0.480	-0.15
21	7.67463	0.416	7.750	0.420	-0.97
22	7.73894	0.390	7.795	0.420	-0.72
23	7.15251	0.442	7.200	0.440	-0.66
24	7.18320	0.443	7.190	0.448	-0.09
25	9.31046	0.374	9.400	0.362	-0.95
26	9.31288	0.364	9.406	0.362	-0.99
27	9.13346	0.374	9.145	0.380	-0.13

Data can be seen from the table, the two methods measure the consistency is better, the maximum deviation within 1%. We can directly see Figure 7.

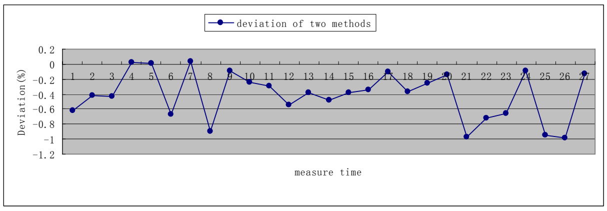


Fig.7.deviation of two methods

5. EVALUATION OF UNCERTAINTY

The evaluation of uncertainty of original method has been introduced in the reference [1].now we mainly discuss the sources of uncertainty of new method.

5.1 The uncertainty of the hammer mass

Because of the mass measurement error of hammer, it will bring some uncertainty to the impact force measurement. The relative standard uncertainty of hammer mass is $U_{r.m} = 3.33\times10^{-4}$ (k=3).

5.2 Uncertainty of the velocity measurement by laser-Doppler-interferometer

The uncertainty of velocity depends on many factors, namely LDI instrument and the internal or external demodulation method, data acquisition, speckle noise, beam angle and parasitic velocity components. Instrumental influences are laser wavelength, modulation frequency of the Bragg cell and the internal demodulation electronics for analogue output[7].

5.2.1 Parasitic velocity components

Because of the fact that the LDI beam is off-set and oblique with respect to the central axis of hammer, the interferometer is susceptible to possibly superposed transverse velocity components.

The relative standard uncertainty of parasitic velocity components is $U_{r.5.2.1} = 1\times10^{-3}$ (k=3).

5.2.2 Uncertainty of the VD-09 velocity decoder

Signal processing is a critical part of any laser-Doppler-interferometer system. The Digital Velocity Decoder VD-09 decreases the noise level significantly by an order of magnitude, compared to analog decoders. With VD-09 installed, the OFV-5000 Velocity Controller becomes a general purpose tool for a wide range of scientific and research vibration analysis issues.

The relative standard uncertainty of VD-09 velocity decoder is $U_{r.5.2.2} = 1.7\times10^{-3}$ (k=3).

5.3 Uncertainty of the data analyzing system PXI-5122

As the results of calibration, the relative amplitude error of 5122 is 0.3%, which follows from the rectangular distribution in half width of the confidence interval of 0.3%.

$$u_{r,5.3} = 0.25\%/\sqrt{3} = 1.44\times10^{-3}$$

5.4 The uncertainty due to the system frequency response error

The system frequency response error including the influence of the deficient lowest frequency is $\pm 0.69\%$ and follows from the rectangular distribution. Then the relative standard uncertainty of the system frequency response error is

$$u_{r,5.4} = 0.69\%/\sqrt{3} = 3.98\times10^{-3}$$

5.5 The hammer deflection upon impact acceleration

When the hammer acts on the calibrated transducer, the hammer and accelerometer may deflect in the tangential direction due to the clearance between the tracks and the guiders, which can cause an error of the impact acceleration up to $\pm 0.011\%$. Then the relative uncertainty is

$$u_{r,5.5} = 0.011\%/\sqrt{3} = 6.35\times10^{-5}$$

5.6 The relative combined standard uncertainty of the equipment is

$$u_{r,a.} = \sqrt{{U_{r.m}}^2 + {U_{r.2.1}}^2 + {U_{r.2.2}}^2 + {U_{r.5.3}}^2 + {U_{r.5.4}}^2 + {U_{r5.5}}^2} = 4.68\times10^{-3}$$

Therefore the relative expanded uncertainty of the equipment is 1.4 %(k=3)

6. CONCLUSION AND OUTLOOK

Through uncertainty analysis and experiment results show that the laser interferometer measurement of dynamic force and acceleration measuring dynamic forces with similar characteristics, the laser method has less uncertainty. And the new method can make the dynamic force calibration directly traceable to the mass and length.

Follow-up study, the acceleration distribution of the hammer in impact process, and study its effect on the dynamic force calibration. The other study is effect of hammer natural frequency. Because high-speed impact, the broadband dynamic force can stimulate the natural frequency of drop hammer, so that the distortion of dynamic forces waveform occurred.

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