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THREE-COMPONENT PRIMARY VIBRATION CALIBRATION SYSTEM AT NIM

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Abstract: A three-component primary vibration calibration system had been set up in National Institute of Metrology, which consists of an air bearing three-component shaker, a sinusoidal three-component control system and a primary three-component vibration measuring system. A motion coupling device based on air bearing force transferring and motion guiding has been developed to simultaneously generate three-component vibration in the three orthogonal coordinates. The rectilinear, circular, and elliptical space motions have been realized by the sinusoidal three-component control algorithm. The three-component measuring system can simultaneously measure the three orthogonal motion quantities based on sine-approximation method.

Keywords: three-component shaker, primary vibration calibration, sensitivity, interferometry.

1. INTRODUCTION

PTB had set up the multi-component acceleration standard measuring device, which had been used to calibrate the sensitivities and transverse sensitivities of vibration transducers under multi-axial excitation [1, 2]. Akira Umeda had researched sensitivity matrix calibration method of accelerometers using a three-dimensional vibration generator and three laser interferometers [3]. The three-component vibration calibration system provides possibility to calibration all of the sensitivities of a tri-axis accelerometer.

At National Institute of Metrology, China, the three-component primary vibration calibration system has been researched for several years. This three-component primary vibration calibration system consists of an air bearing three-component shaker, a sinusoidal three-component control system and a primary three-component vibration measuring system. In order to reduce the cost and improve the performance, some new technologies have been used in the system.

Normally the air bearing technology is used in high frequency shakers, which can provide precise guiding of vibration direction. For three-component shakers, normally oil film is used to transfer force and guide direction, which need more auxiliary equipment and may heat the device under test. So the motion coupling device based on air bearing force transferring and motion guiding was developed, which is cheaper, easy to maintain, and not thermic.

Commercial multi-axis vibration control system can provide sinusoidal and random control functions, but it is expensive. It is not designed for calibration purpose, cannot efficiently generate specific orbits according to calibration procedure. In order to generate rectilinear, circular, and elliptical space motions for calibration purpose, the sinusoidal three-component vibration control system based on PXI acquisition system was developed in NIM, which is cheaper, easy to be operated synergistically with three-component measuring system.

ISO 16063-11 presents clear and detailed single-axis primary measuring method and procedure [4]. According to ISO 16063-11, three synchronized primary vibration measuring channels can be used to constitute a primary three-component measuring system. Because high sample rate acquisition card need be used and high volume data need be processed, it is hard to realize three-component primary vibration measurement. So a band pass sampling method is used to reduce the sample rate and data volume.

2. AIR BEARING THREE-COMPONENT SHAKER

The air bearing three-component shaker with linear power amplifiers is illustrated in figure 1, which consists of a mounting base, three electrodynamics shakers and an air-bearing cross coupling unit. The mounting base is used to support the whole structure and fix the three orthogonal electrodynamics shakers. The three electrodynamics shakers are used to excite the air-bearing cross coupling unit orthogonally. The air-bearing cross coupling unit is used to compound space motion under orthogonal exciting. The detailed construction of the air-bearing cross coupling unit is illustrated in figure 2, which consists of five sets of air bearing. X axis force transferring air bearing is used to couple the excitation produced by X direction shaker. Y axis force transferring air bearing is used to couple the excitation produced by Y direction shaker. X axis motion guiding air bearing is used to provide X direction guiding. Y axis motion guiding air bearing is used to provide Y direction guiding. Z axis force transferring is used to couple the excitation produced by Z direction shaker. Because the transducer under test need be mounted on the top of coupling unit, there is no space to install Z axis motion guiding air bearing.

Fig.1 The air bearing three-component shaker

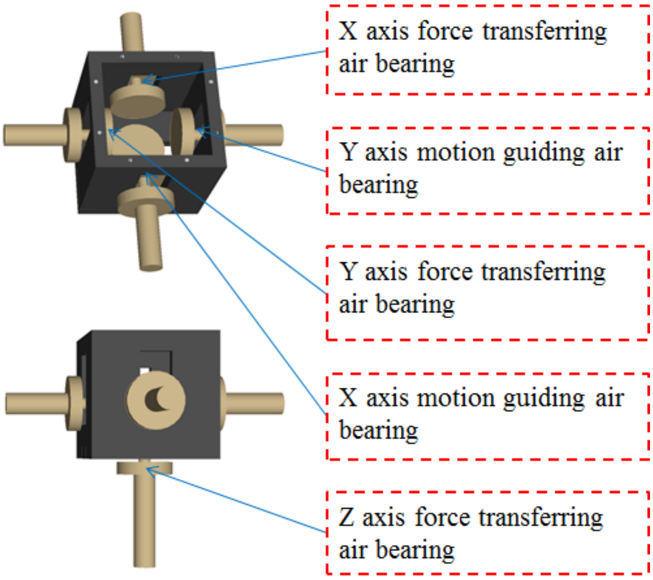

Fig.2 The air-bearing cross coupling unit

The restrictions of the air bearing three-component shaker are shown in table 1.

Table 1. The restrictions of three-component shaker

Max. peak force	1000 N
Max. pay load	10 kg
Max. peak acceleration	20 m/s^2
Frequency range	5 Hz – 1.6 kHz
Air pressure required	4 – 8 bar
Cross motion under control$^{1)}$	< 1%

1) The cross motion of each direction can be suppressed by the sinusoidal three-component vibration control system.

3. THREE-COMPONENT CONTROL SYSTEM

The sinusoidal three-component control system is illustrated in figure 3. A PXI acquisition system with three NI PXI-4461 acquisition cards is used to acquire the three-axis acceleration feedback signal and to excite the three-axis shaker vibration. Endevco Model 133 signal conditioner is used to amplify the output of the feedback accelerometer.

Fig.3 The sinusoidal three-component control system

By adjusting the amplitudes and phases of the three axis controlling signals, the rectilinear, circular, and elliptical space motions can be realized by the sinusoidal three-component control algorithm. When only one axis is excited, the cross motion of the other two axes can be supressed very well. When Z axis is excited, the cross motions without control and with control are shown in table 2. When X axis is excited, the cross motions without control and with control are shown in table 3. When Y axis is excited, the cross motions without control and with control are shown in table 4.

Table 2. Cross motions when Z axis is excited

Frequency (Hz)	Cross (%)			
	X-axis		Y-axis	
	Without control	With control	Without control	With control
5.0	0.514	0.089	1.799	0.235
8.0	0.480	0.056	1.860	0.137
10.0	0.299	0.042	2.096	0.271
16.0	0.613	0.026	1.665	0.023
20.0	0.420	0.055	1.705	0.027
25.0	0.852	0.134	1.655	0.025
31.5	1.169	0.114	1.941	0.094
40.0	1.094	0.237	1.428	0.049
50.0	1.881	0.100	1.980	0.074
63.0	1.688	0.186	1.971	0.094
80.0	3.771	0.089	6.101	0.080
160.0	11.20	0.092	6.098	0.053
315.0	14.51	0.038	13.21	0.057
630.0	19.79	0.032	9.201	0.025
1000.0	11.95	0.152	2.999	0.211
1250.0	15.30	0.024	7.710	0.024
1600.0	12.92	0.052	3.152	0.057

Table 3. Cross motions when X axis is excited

Frequency (Hz)	Cross (%)			
	Y-axis		Z-axis	
	Without control	With control	Without control	With control
5.0	7.339	0.177	1.917	0.121
8.0	7.562	0.146	1.837	0.049
10.0	9.051	0.036	1.646	0.041
16.0	7.614	0.027	2.097	0.015
20.0	8.543	0.027	2.038	0.014
25.0	6.854	0.015	1.711	0.017
31.5	6.944	0.036	1.816	0.013
40.0	6.999	0.011	2.028	0.011
50.0	6.706	0.136	1.540	0.059
63.0	7.097	0.084	1.660	0.028
80.0	7.905	0.049	2.361	0.016
160.0	1.117	0.039	2.184	0.021
315.0	9.047	0.033	0.629	0.009
630.0	6.518	0.015	0.792	0.011
1000.0	3.830	0.012	4.481	0.013
1250.0	8.126	0.031	7.488	0.020
1600.0	19.70	0.135	13.24	0.054

Table.4. Cross motions when X axis is excited

Frequency (Hz)	Cross (%)			
	X-axis		Z-axis	
	Without control	With control	Without control	With control
5.0	5.466	0.246	0.129	0.121
8.0	3.220	0.044	0.051	0.057
10.0	4.576	0.033	0.224	0.057
16.0	5.640	0.061	0.211	0.092
20.0	4.630	0.018	0.352	0.014
25.0	6.372	0.031	0.214	0.022
31.5	6.074	0.033	0.181	0.046
40.0	5.547	0.013	0.605	0.014
50.0	5.935	0.115	0.486	0.015
63.0	5.902	0.138	0.230	0.022
80.0	5.687	0.071	0.262	0.027
160.0	11.16	0.063	0.800	0.022
315.0	4.035	0.021	1.076	0.042
630.0	6.464	0.020	2.732	0.016
1000.0	8.273	0.036	5.766	0.019
1250.0	9.442	0.032	9.867	0.028
1600.0	4.084	0.124	14.43	0.084

4. THREE-COMPONENT MEASURING SYSTEM

The primary three-component vibration measuring system is illustrated in figure 4. Three heterodyne interferometers are used to measure the vibration signals of three orthogonal directions.

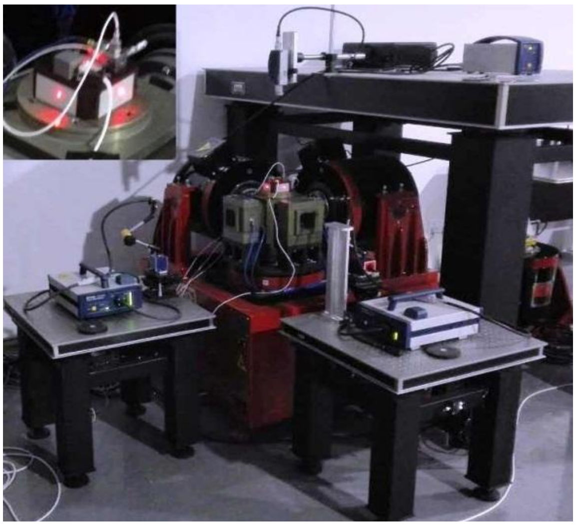

Fig.4 The three-component vibration measuring system

The RF interference signals of the three interferometers and outputs of the transducer under test are sampled by a six-channel data acquisition system. The central frequency of the RF signal is about 40 MHz, normally there are two sampling method. One is using high-speed acquisition card to fulfil Nyquist’s theorem, but the data volume will be too large to sample and process. The other is using analogue mixer and low-pass filter to reduce the signal frequency, but the phase shift and inconsistency of the analog devices will influence measuring result. Because the frequency band of RF signal of the interferometer in this application is fewer than 2 MHz, the band-pass sampling method is used to directly sample the RF signals of the three interferometers with fewer than 10 MHz sampling rate without analog devices. According to ISO 16063-11, three synchronized interference signals are demodulated to realize primary three-component measuring.

5. EXPERIMENTAL RESULTS

A tri-axis accelerometer (model: Kistler 8766A50, SN: 2118860) was selected to be calibrated using the three-component primary vibration calibration system. The magnitude of sensitivities measured are shown in table 5, the phase shift of sensitivities measured are shown in table 6.

Table 5. The magnitude of sensitivities measured

Frequency (Hz)	Magnitude of sensitivities (mV/m/s^2)		
	X-axis	Y-axis	Z-axis
5.0	9.60	9.82	10.04
8.0	9.62	10.01	10.11
10.0	9.66	10.09	10.11
16.0	9.67	9.45	10.14
20.0	9.68	9.83	10.09
25.0	9.66	9.83	10.14
31.5	9.68	9.72	10.16
40.0	9.72	9.39	10.19
50.0	9.72	9.81	10.16
63.0	9.73	9.77	10.14
80.0	9.90	9.66	10.09
160.0	9.72	9.80	10.13
315.0	9.82	9.88	10.12
630.0	9.83	10.16	10.16
1000.0	9.68	9.75	10.14
1250.0	9.67	9.82	10.12
1600.0	9.50	9.76	10.11

Table 6. The phase shift of sensitivities measured

Frequency (Hz)	Phase shift of sensitivities (°)		
	X-axis	Y-axis	Z-axis
5.0	0.38	-0.73	0.07
8.0	-0.15	0.52	1.40
10.0	-0.29	-0.54	-0.67
16.0	-1.14	-0.72	-1.13
20.0	0.11	-1.59	-0.27
25.0	-1.61	0.43	0.59
31.5	0.11	-0.45	0.73
40.0	1.19	-0.13	0.41
50.0	0.03	0.34	0.53
63.0	-0.53	-0.67	0.45
80.0	0.80	-0.09	-0.07
160.0	0.06	-0.29	-0.62
315.0	0.76	0.49	0.56
630.0	-0.93	-0.63	1.28
1000.0	0.26	-0.04	-0.04
1250.0	0.49	0.42	-0.09
1600.0	0.26	0.10	-0.03

6. CONCLUTIN

At National Institute of Metrology, China, the three-component primary vibration calibration system has been set up, which consists of an air bearing three-component shaker, a sinusoidal three-component control system and a primary three-component vibration measuring system.

In the three-component shaker, the force transferring and motion guiding structure based on air bearing is used to realize the space motion coupling device, which is cheaper, easy to maintain, and athermic.

Based on a PXI acquisition system, the sinusoidal three-component vibration control system is developed to generate rectilinear, circular, and elliptical space motions for calibration purpose.

Following the primary measurement method in ISO 16063-11, the three-component synchronized primary vibration measuring based on down-sampling method is developed to realize three-component primary vibration calibration.

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