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The Design of a Low Frequency Calibration Shaking Table

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Abstract

The design of a low frequency calibration shaking table is introduced in this paper. First, we confirm the design specification of low frequency calibration environment of vibration specification, we choose shaking sensor. Then, the design of the relative velocity feedback analyzes this method in detail and carry out the simulation table according to the national standard and the deployment a vibration exciter is introduced. According to the design method as the control method of the shaking table. We did simulation and calculation. Finally, we test the amplitude versus frequency response characteristics and distortion under the situation of open loop and closed loop. The results show that the low frequency movement signal of low frequency shaking table is improved and it can meet the requirement of the calibration of low frequency vibration sensor.

Keywords*: Low Frequency Shaking Table; Low Frequency Calibration; Relative Velocity Feedback*

1. Introduction

Vibration is a kind of common physical phenomenon, existing in many engineering fields widely. We need to use the vibration equipment measuring vibration in order to research the vibration problem. And for purpose of guaranteeing the accuracy of the vibration measurement results, we need to calibrate the instrument. Vibration calibration is aimed to obtain accurate measurement results by using these sensors, within the scope of the amplitude and frequency to determine its calibration coefficient (sensitivity).

Vibration calibration is accomplished in the vibration calibration instrument, vibration calibration instrument usually consists of two parts: calibration shaking table and measuring system. The function of calibration shaking table is to provide the calibration excitation signal. This paper introduces the design of a low frequency calibration shaking table.

2. The Design Requirements of Low Frequency Calibration Shaking Table

Low frequency calibration shaking table is the source of vibration calibration and the key instrument for it. According to different occasions and requirements, low frequency calibration shaking table is diverse obviously .For example, exciting force ranges from more than 10 N to more than100 N, and the range is from a few millimeters to hundreds of mm.

In the view of the current shaking sensor's calibration requirements, large vibration forces and ranges of low frequency calibration shaking table has technical advantages could obtain low frequency motion signal with higher SNR, but this kind of vibration table is complex in technology, expensive in manufacture, cost-higher in maintenance. So state-level or larger industries usually have demand on this kind of equipment.

On the contrary, small size low frequency calibration shaking table can meet the need of general department for calibrating that is moderate in cost and technology and relatively simple in maintenance, and also satisfies the calibration need. Ultimately the purpose of scientific research to serve the application. In this paper, the actual design of small scale low frequency shaking table that has many advantages in addition to the scientific research, tries to make the vibration meet the general measuring mechanism and vibration equipment manufacturers' requirements.

Design specifications as shown in table 1.

Table 1. Technical Specification of Small Scale Low Frequency Shaking Table

Technical specification		Horizontal vibration table	Vertical vibration table
Trip(p-p)		20mm	
Exciting force		100N	
Table size		250mm×230mm	230mm×150mm
Maximum load		4kg	
maximum bare table acceleration		20 m/s2	10m/s2
Total harmonic distortion	Acceleration	≤5%（0.5Hz-100Hz）	
	speed	≤5%（0.1Hz-100Hz）	
The transverse acceleration, bending and rocking		f≤10Hz时：≤1% 10Hz-100Hz：≤10%	f≤10Hz时：≤3% 10Hz-100Hz：≤10%
Table noise	f＜10Hz	≥40dB	
	f≥10	≥60dB	
Acceleration amplitude stability		≤0.1%	

Vibration table `s vibration forces and ranges are the two important indicators. Vibration forces influences the maximum acceleration of the vibrating table, and structural vibration under the excitation of the natural environment is not more than 10 to 3 g generally. In a strong earthquake acceleration amplitude is bigger, but it is generally not more than 2 g. For example, 8.0 earthquake in Wenchuan, about 21 kilometers from the epicenter of the Wolongtai to obtain the maximum acceleration peak value is 0.976 g on strong earthquake records [1, 2]. So low frequency calibration vibration table is designed according to the maximum of 1.0 to 2.0 g no-load acceleration, retaining a certain margin in the design. The actual maximum no-load acceleration may be better than design value. When Low-frequency vibration is calibrated, the motion signal SNR is a big problem. The range of the vibrating table is always limited, under the condition of the vibration table range, with the reduction of frequency,vibration table`s acceleration will be smaller, and the noise of the vibration table is a certain value. So the low-frequency acceleration motion signal of vibration table is with often worse the SNR. There are three ways to improve the SNR: increasing range, reducing noise and filtering. 《The vibration and shock sensor calibration`s method section 21: comparison calibration 》：in this paper requirements noise of vibration excitation equipment acuity in 20 db (f < 10 Hz), if the noise excitation equipment is 10-4 m/s2.According to the requirements of 20 db, the need for the movement of the acceleration amplitude:

$$a = 10^{-4}\, m/s^2 \times 10^{\frac{20(\mathrm{dB})}{20}} = 10^{-3}\, m/s^2$$

The acceleration amplitude at 0.5 Hz amplitude for the corresponding movement

$$x = \omega^2 \times a = 9.86mm$$

Amplitude of shaking table movement displacement is designed to 10 mm, peak to peak value of 20 mm.

3. The Design of Control System

Low frequency shaking table needs reasonable control to get an accurate signal, In this paper the shaking table is designed by choosing relative-velocity feedback control technology. Relative speed feedback control is to increase the system damping, to expand the scope of speed flat section, to improve the distortion degree of low frequency signal. In order to extract the feedback, a relative velocity meter is designed.

The designed range low frequency calibration shaking table is 20 mm, the movement of relative speedometer is 20 mm at least. Practically, in order to debug and to use easily, the movement of relative speedometer that should retain certain remainder follows 25 mm to design. Relative velocity meter obeying magnetoelectric principle, relies on coil that is installed in a magnetic fieldcutting lines of magnetic force to produce inductive electromotive force to measure movement signal on the table.

Relative velocity feedback principle as shown in figure 1.

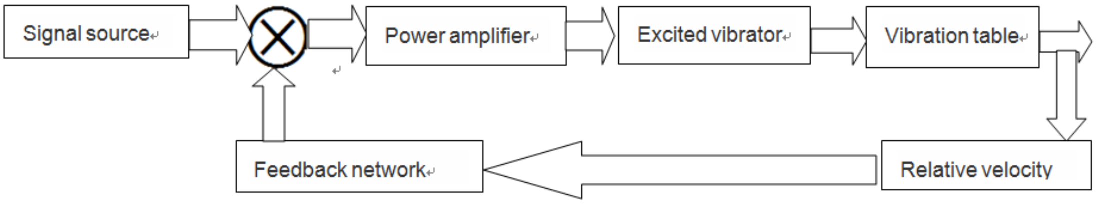

Figure 1. Relative Velocity Feedback Principle Diagram

If the signal source voltage is u, Magnification of power amplifier is KA, magnification of feedback network is Ks, electromechanical coupling coefficient of relative velocity meter is G2, vibration table`s movement displacement is x, vibrator coil of excitation voltage is e.

$$e = \left(u - K_s G_2 s x\right) K_A \tag{1}$$

The transfer function of the vibration table is [3]:

$$\frac{x}{e} = \frac{G_1}{mLs^3 + \left(bL + mR\right)s^2 + \left(kL + bR + G_1^2\right)s + kR} \tag{2}$$

In this formula, the quality of the vibration table about moving parts (including table, the excitation coil, table loading) is m, the viscous damping coefficient is b, stiffness of support spring is k, the part of movement relative to the based displacement is x, coupling coefficient of vibrator electromechanical is G1, resistance of coil is R, coil inductance is L. So we have:

$$\frac{x}{u} = \frac{G_1 K_A}{mLs^3 + \left(bL + mR\right)s^2 + \left(kL + bR + G_1^2 + K_s K_A G_1 G_2\right)s + kR} \tag{3}$$

——x : movement displacement of table;
——u : vibrator coil`s resistance
——G_1 : coupling coefficient of vibrator electromechanical

——K_A : magnification of power amplifier
——m : the quality of the vibration table about moving parts
——L : coil inductance
——b : the viscous damping coefficient
——R : resistance of coil
——k : stiffness of support spring
——K_B : magnification of feedback network
——G_2 : electromechanical coupling coefficient of relative velocity meter

Type (3) as the relative velocity feedback, the vibration table mathematical relationships. Assume that vibrator coil inductance is 0.25 H, transfer function is:

$$\frac{x}{u} = \frac{146.2}{1.4s^3 + 6.71s^2 + 17982.6s + 3442.8} \qquad (4)$$

Acceleration amplitude-frequency characteristic curve of horizontal shaking table under open loop situation as shown in figure 2.

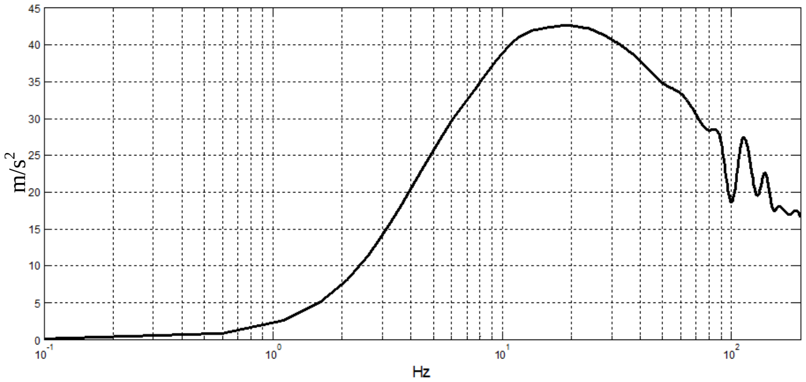

Figure 2. Acceleration Amplitude-Frequency Characteristic Curve of Horizontal Shaking Table under Open Loop Situation

According to the figure 2, vibration table there is a resonance peak, the causes of the formant is feedback after feedback circuit and coil inductance coupling. The coil inductance is bigger, the corresponding frequency of resonant point is lower; Coil inductance is smaller, the frequency corresponding to the resonance peak point is bigger, resonant peak is lower .In the actual feedback circuit is designed by increasing the first-order low-pass filter circuit. That can eliminate the resonant peak.

4. Frequency Response Function Test

Amplitude frequency characteristics is one of the important indicators, using Jacqueline Nottingham - 06 type quartz flexible accelerometer in acceleration signals of shaking table , using the relative velocity meter measurement of shaking table in velocity signal of shaking table , Amplitude-frequency response characteristic of horizontal shaking table under open loop situations as shown in table 2.

Table 2. Amplitude-Frequency Response Characteristic of Horizontal Shaking Table under Open Loop Situation

Frequency (Hz)	Input voltage (Vo-p)	Acceleration output voltage (V)	Speed output voltage (A)
0.5	0.1	0.0077	1.87
0.8	0.1	0.0175	2.98
1	0.1	0.0270	3.68
2	0.1	0.0937	6.82
3	0.1	0.1895	9.28
5	0.05	0.162	5.02
8	0.05	0.230	4.37
10	0.05	0.245	3.85
15	0.1	0.532	5.510
20	0.1	0.535	4.168
30	0.1	0.513	2.623
40	0.1	0.476	1.813
50	0.1	1.427	1.313
60	0.1	1.358	1.095
70	0.1	1.242	0.833
80	0.2	2.312	1.376
90	0.2	2.171	1.148
100	0.2	1.513	0.664
110	0.2	2.164	0.781
120	0.2	1.986	0.712
130	0.2	1.591	0.515
140	0.2	1.841	0.358
150	0.2	1.471	0.399
160	0.2	1.467	0.419
170	0.2	1.426	0.307
180	0.2	1.381	0.264
190	0.2	1.425	0.273
200	0.2	1.342	0.295

Notes: for measuring acceleration, using piezoelectric accelerometer above 50Hz (including it), the sensitivity of 0.407 V/m/s2, 40Hz (below) using quartz flexible accelerometer, the sensitivity of 0.126 V/m/s2. For measuring velocity, the use of vibration velocity meter is with the sensitivity of 123 v/m/s.

According to table 3, under the same excitation, horizontal direction of the shaking table with open-loop condition is under 1 vp - p input voltage equivalent acceleration and equivalent velocity.

It is shown in table 3.

So we can get the acceleration amplitude-frequency characteristic curve as shown in Figure 5.

After using the closed-loop feedback control, it tests the amplitude-frequency characteristics of shaking table horizontally.

It is shown in table 4.

And we can get table 5. According to table 5, by interpolation, can horizontal direction of the shaking table of acceleration amplitude frequency characteristic curve of closed-loop conditions, as shown in figure 3.

Table 3. Equivalent Output with 1Vp-P Exciter of Horizontal Shaking Table under Open Loop Situation

Frequency(Hz)	Acceleration(m/s2)	Speed(m/s)
0.5	0.6032	0.15285
0.8	1.4682	0.24147
1	2.2222	0.29836
2	7.4444	0.55367
3	14.246	0.75366
5	25.713	0.81463
8	34.921	0.71220
10	38.889	0.62602
15	42.222	0.44797
20	42.530	0.33887
30	40.713	0.21325
40	37.778	0.14732
50	34.816	0.10683
60	33.366	0.08911
70	30.516	0.06772
80	28.403	0.05594
90	26.793	0.04671
100	18.587	0.02698
110	26.572	0.03171
120	24.423	0.02894
130	19.558	0.02094
140	22.629	0.01455
150	18.084	0.01622
160	18.033	0.01699
170	17.531	0.01244
180	16.978	0.01077
190	17.518	0.01106
200	16.473	0.01198

Table 4 .Amplitude Versus Frequency Characteristic of Horizontal Shaking Table under Closed Loop Situation

Frequency(Hz)	Input signal(Vp-p)	Acceleration(m/s2)	Speed(m/s)
0.1	0.5	/	0.0034
0.2	1.0	/	0.0077
0.3	1.0	/	0.0082
0.5	1.5	0.041	0.0130
0.8	2	0.093	0.0184
1	2	0.123	0.0197
2	2	0.350	0.0280
3	2	0.712	0.0380
5	2	1.907	0.0613
8	0.5	1.273	0.0253
10	0.5	2.117	0.0338
15	0.1	1.271	0.0134
20	0.1	4.494	0.0356
30	0.1	4.813	0.0255
40	0.2	5.335	0.0202
50	0.2	4.155	0.0123
60	0.2	3.694	0.0093
70	0.2	3.302	0.0074
80	0.2	3.075	0.0058

90	0.2	3.052	0.0051
100	0.2	2.826	0.0042
110	0.2	2.644	0.0036
120	0.2	2.534	0.0035

Table 5. Equivalent Output with the Same Exciter of Horizontal Shaking Table under Closed Loop Situation

Frequency(Hz)	Acceleration(m/s2)	Speed(m/s)
0.1	/	0.0068
0.2	/	0.0077
0.3	/	0.0082
0.5	0.027	0.0088
0.8	0.046	0.0093
1	0.062	0.0098
2	0.175	0.0140
3	0.356	0.0190
5	0.954	0.0306
8	2.546	0.0509
10	4.235	0.0677
15	12.70	0.1346
20	44.94	0.3563
30	48.13	0.2546
40	26.66	0.1010
50	20.77	0.0621
60	18.48	0.0464
70	16.52	0.0372
80	15.38	0.0294
90	15.26	0.0258
100	14.13	0.0212
110	13.22	0.0179
120	12.68	0.0173

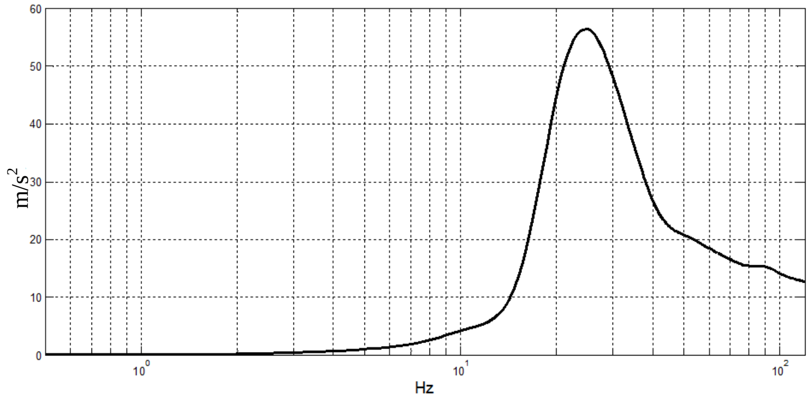

Figure 3. Acceleration-Amplitude versus Frequency Characteristic Curve of Horizontal Shaking Table under Closed Loop Situation

5. Distortion Measurement

According to the harmonic analysis method [4, 5], the results are shown in table 6:

Table 6. Distortion Test Result of Horizontal Shaking Table

Frequency (Hz)		0.1	0.2	0.3	0.5	0.8	1	2	3	5	8	16
Distortion (%)	Open loop acceleration	/	/	/	89.0	52.7	41.2	18.8	6.88	0.90	0.48	0.45
	Open loop speed	/	/	/	46.9	21.9	13.8	6.48	2.32	0.14	0.32	0.24
	Closed loop acceleration	/	/	/	6.71	5.39	4.84	3.70	3.33	2.18	/	/
	Closed loop speed	6.68	4.73	3.76	2.66	2.25	2.06	1.42	0.96	0.43	/	/
Frequency (Hz)		20	30	40	50	60	70	80	90	100	110	120
Distortion (%)	Open loop acceleration	0.36	0.30	0.39	0.51	0.46	0.90	0.72	0.95	0.69	0.77	2.29
	Open loop speed	0.23	0.61	0.49	0.31	0.53	1.62	1.47	1.66	1.80	0.68	20.5
	Closed loop acceleration	/	/	/	/	/	/	/	/	/	/	/
	Closed loop speed	/	/	/	/	/	/	/	/	/	/	/

According to the test results, after adding feedback, vibration distortion decreased significantly, The motion signal quality is improved, This method can meet the general needs of low frequency vibration sensor calibration.

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Because of my limited academic standards, there are some shortcomings unavoidable, welcome to point it out.

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