Brief Introduction of the Close Loop Feedback Methods of the Low Frequency Vibration Tables

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SUMMARY
In calibration system of vibration sensors, standard vibration tables play an important role. According to the negative feedback theory, the close loop feedback method is often used to decrease nonlinear distortion of a vibration table. At first, three kinds of common feedback methods are introduced. And then a combination feedback method is showed based on afore mentioned methods. The experimental result can show that the close loop feedback method can effectively reduce the degree of distortion of low frequency vibration tables.

Keywords: low frequency vibration table, close loop feedback, DSP

1. GENERAL INSTRUCTIONS

In recent decades, the demands for low frequency vibration measurement are increasing, such as aerospace, engineering structure, earthquake prediction, sea wave early warning and precision machining. Measuring a low frequency vibration signal, a vibration table is required low THD (Total Harmonic Distortion) of output for its measurement accuracy.

To get low THD of a vibration table, there are many technologies, such as negative feedback with displacement or acceleration signals. But for some reasons, the results of feedback are not satisfactory. In 1985, Institute of Engineering Mechanics, China Earthquake Administration, studied the vibration control based on analogical electronics technology and classical control theory, and applied for National Patent No.10371. Due to its complexity of design and weak adaptability, the device was difficult to use modern control theory to realize advanced control, and would gradually disappear in favour of the digital control system with computers.

According to the negative feedback theory, the close loop feedback method is often used to reduce the output THD of a low frequency vibration table. A DSP (Digital Signal Processor) system was designed to improve its dynamic characteristics, and has strong capability of restraining interference.

2. THE CHARACTERISTICS OF A LOW FREQUENCY VIBRATION TABLE

Because of a better assembling between moving-coil construction and the operation board of a vibration table, its first-order resonant frequency is above several hundred Hz. As a result, the moving parts of a vibration table are regarded as a rigid body in low frequency band. The vibration table was simplified to a single degree of freedom mechanical model (Figure 2.1).

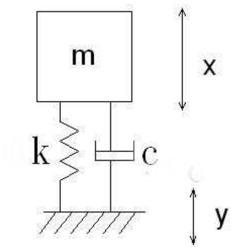

Figure2.1 Simplified mechanical model of a low frequency vibration table

Its mechanical equation and electrical equation were got (Equation 2.1).

$$\begin{cases} m\ddot{x}+c\dot{x}+kx=F=Bli \\ L\dfrac{di}{dt}+Ri+Bl\dot{x}=e \end{cases} \tag{2.1}$$

And we could reduce the transfer function of a low frequency vibration table in the zero initial conditions (Equation 2.2).

$$\frac{X(s)}{E(s)}=\frac{\dfrac{Bl}{mL}}{s^3+\dfrac{mR+cL}{mL}s^2+\dfrac{Rc+kL+(Bl)^2}{mL}s+\dfrac{Rk}{mL}} \tag{2.2}$$

In Equation 2.2, m is the mass of a vibration table, k is its spring stiffness, c is the viscous damping coefficient of the spring, B is the magnetic intensity of its air gap, l is the length of its moving-coil winding, L is the inductance of its moving-coil winding, R is the resistance of its moving-coil winding, E is the voltage of the power amplifier.

Then we got an amplitude-frequency characteristic curve of the low frequency vibration table (Figure 2.2). For the sake of analysis, we ignored its short-circuiting ring and the influence of its eddy current. They did not influence the curve shape. So we got three corner frequency points.

(1) displacement-velocity corner frequency: $\omega_{Dv}=\dfrac{RK}{(Bl)^2}$;

(2) velocity-acceleration corner frequency: $\omega_{vA}=\dfrac{(Bl)^2}{Rm}$;

(3) acceleration- acceleration differential corner frequency: $\omega_{AA}=\dfrac{R}{L}$。

The system had a low SNR (Signal to Noise Ratio) in the frequency below ω_{VA} because of its high THD, weak instability and vibration influence of the ground. As a result, the low frequency vibration table could not work in this band.

The close loop negative feedback theory is often used to expand its low frequency band of a vibration table (Figure 2.3). According to the feedback control theory, the proper design of feedback controller can have strong capability of restraining interference and tracking the input signal. That is to say, the output of a low vibration table depends on the input and the measurement unit, instead of its interference signals and the characters of the system. Despite the nonlinear factors, a vibration table can decrease its output THD based on the negative feedback theory.

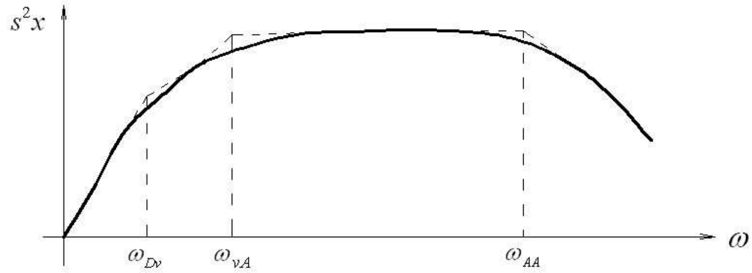

Figure 2.2 Amplitude-frequency characteristic curve of the vibration table

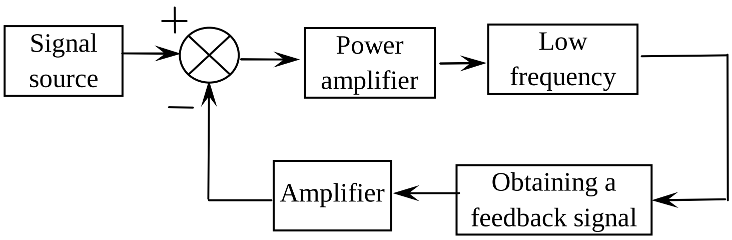

Figure 2.3 Principle block diagram of the close loop negative feedback theory

3. CHOICE AND COMPARISON WITH THE FEEDBACK PARAMETERS

The feedback system can improve the low frequency performance of a vibration table. According to the characters of a low frequency vibration table, it is a key technology to choose proper motion parameters for the feedback control system.

3.1 Acceleration parameter feedback method

With acceleration feedback method, the nonlinear distortion of a vibration table can be obviously improved in $\omega_{vA} < \omega < \omega_{AA}$. In this frequency band, the signal phases of feedback and excitation signal are easily controlled. Because of its narrow band above dozens Hz, a vibration table can not reduce the THD below 1Hz. Also, the band is close to resonance zone. It leads to less deep feedback. Simple acceleration feedback can not compensate the highest distortion band. Because of much larger signal phase difference between feedback and excitation signal, the system can not reduce the THD and can easily lead to instability of the system. As a result the drifting of the board is larger; even bring about low frequency oscillation.

3.2 Displacement parameter feedback method

With displacement feedback method, the system has satisfactory feedback effect in $\omega < \omega_{Dv}$ band. In $\omega \geq \omega_{Dv}$ band, the fundamental wave phase lag of the displacement parameter is 45° at least, even the more that of second and third harmonic. This condition can not reduce the THD. When the harmonic phase shift is larger than 90°, the feedback system can not improve the performance index of a low frequency vibration table, even increase the THD. Furthermore, the high THD of a displacement meter can bring about the high THD of the vibration table with displacement feedback method.

3.3 Velocity parameter feedback method

To a low frequency vibration table, velocity characteristics band is the widest frequency band. In this band, the system can apply to velocity feedback. It can reduce the THD of $\omega_{Dv} < \omega < \omega_{vA}$ band and $\omega < \omega_{Dv}$ band. So it is reasonable to apply to velocity feedback.

In the wide band of $\omega_{Dv} < \omega < \omega_{vA}$, the velocity signal is in phase with that of the excitation signal. The system has excellent feedback effect. In $\omega < \omega_{Dv}$ band, maximal phase difference of feedback signal (velocity) and excitation signal is 90°, and the phase differences of the harmonics are less than 90°. So applying to negative feedback of velocity parameter can reduce the THD and improve the stability of the vibration level.

Thus, velocity feedback can apply to a low frequency vibration table. This feedback is negative feedback in displacement and velocity band. And it can not lead to low frequency oscillation in low frequency band. So the deeper feedback can greatly improve the performance of a low frequency vibration table.

4. COMBINATION FEEDBACK METHOD

The analysis above show that velocity feedback can effectively reduce the THD of a low frequency vibration table. Velocity feedback is divided into two kinds: relative velocity feedback method and absolute velocity feedback method.

4.1 Relative velocity feedback method

Relative velocity refers to the board velocity relative to the base of a vibration table. Relative velocimeter was fixed between the board and the base. Through a relative velocimeter, relative velocity signal was obtained and connected with the input. That was the close loop feedback. Applied to close loop feedback of relative velocity, the system got a transfer function (Equation 4.1).

$$\frac{X(s)}{U(s)} = \frac{\dfrac{\omega_{vA} \cdot \omega_{AA}}{Bl}}{s^3 + \omega_{AA} s^2 + \omega_{vA} \cdot \omega_{AA} \cdot (1 + K_1) s + \omega_{Dv} \cdot \omega_{vA} \cdot \omega_{AA}} \tag{4.1}$$

In Equation 4.1, U was the output voltage of signal source. K_1 was the feedback quantity of relative velocity. K_1 reflected the feedback level of relative velocity. So after relative velocity, ω_{Dv} and ω_{vA} were ω'_{Dv} and ω'_{vA}. With relative velocity feedback method, the system had much more damping, wider low frequency character and the increasing stability of the system (Equation 4.2 and Equation 4.3).

$$\omega'_{Dv} \approx \frac{\omega_{Dv}}{1 + K_1} \tag{4.2}$$

$$\omega'_{vA} \approx (1 + K_1)\, \omega_{vA} \tag{4.3}$$

4.2 Absolute velocity method

Absolute velocity refers to the board velocity relative to the ground. The absolute velocity negative feedback could reduce the THD and the degree of the instability in velocity characteristic band. The output acceleration signal of a vibration table was obtained through a servo accelerometer. With an integrator, the acceleration signal was converted to an absolute velocity signal. Because of an accelerometer could have lower nonlinearity, the absolute velocity feedback could effectively reduce the THD of the system.

Applied to close loop feedback of absolute velocity, the system got a transfer function (Equation 4.4).

$$\frac{X(s)}{U(s)}=\frac{\frac{\omega_{vA}\cdot\omega_{Dv}}{Bl}}{s^3+\omega_{AA}s^2+\omega_{vA}\cdot\omega_{AA}\cdot(1+K_2)s+\omega_{Dv}\cdot\omega_{vA}\cdot\omega_{AA}} \tag{4.4}$$

In Equation 4.4, K_2 was the feedback quantity of absolute velocity. And after absolute velocity feedback, there was a equation in velocity characteristics band (Equation 4.5).

$$\frac{X(s)}{Y(s)}\approx\frac{1}{1+K_2} \tag{4.5}$$

With absolute velocity feedback and proper parameters, the ground interference to the board of the vibration table was $\frac{1}{1+K_2}$ times less than none of feedback. Thus the absolute velocity feedback of the system led to vibration isolation in velocity characteristics band.

4.3 Combination feedback method based on DSP unit

For practical application, the adequate relative velocity negative feedback was applied to the absolute velocity negative feedback, so that the system had much more damping in low frequency band and could increase stability of the system. This was the combination feedback method (Figure 4.1). The system with combination feedback method could have a stable, much deeper close loop negative feedback. At the same time, the system also had an advantage of servo-controlled vibration isolation.

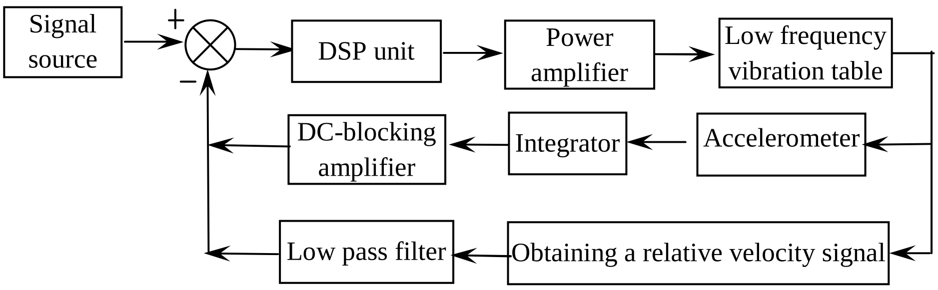

Figure 4.1 Principle block diagram of the combination feedback method

Electronic components often have drift because of the effect of temperature and environment. DSP digital controller unit was used to realize combination feedback method of the low frequency vibration table to reduce the drift. The DSP unit was designed to implement complicated algorithm to control the system.

DSP controller unit mainly consisted of DSP chip, A/D converter chip and D/A converter chip (Figure 4.2). The control chip was TMS320F2812. It is one of C2000 series high-performance DSP chip, which is produced by Texas Instrument.

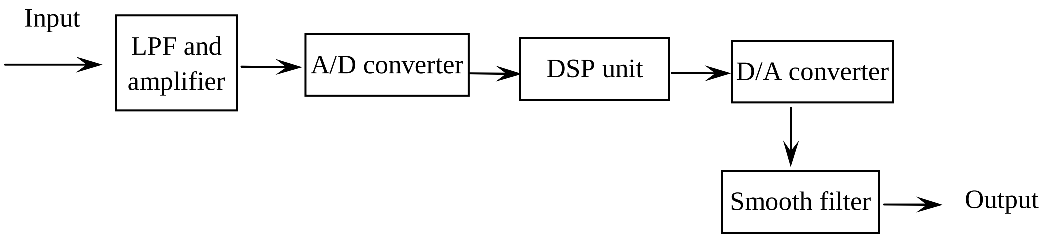

Figure 4.2 Principle block diagram of the DSP unit

5. EXPERIMENT RESULTS

We implemented the combination feedback based on DSP unit above to prove it valid on a low frequency vibration table. Experiments on the system at several frequency points below 1Hz before and after combination feedback. Then we got the THD of different frequency points. The THD of the low frequency vibration table varied with frequencies (Figure 5.1).

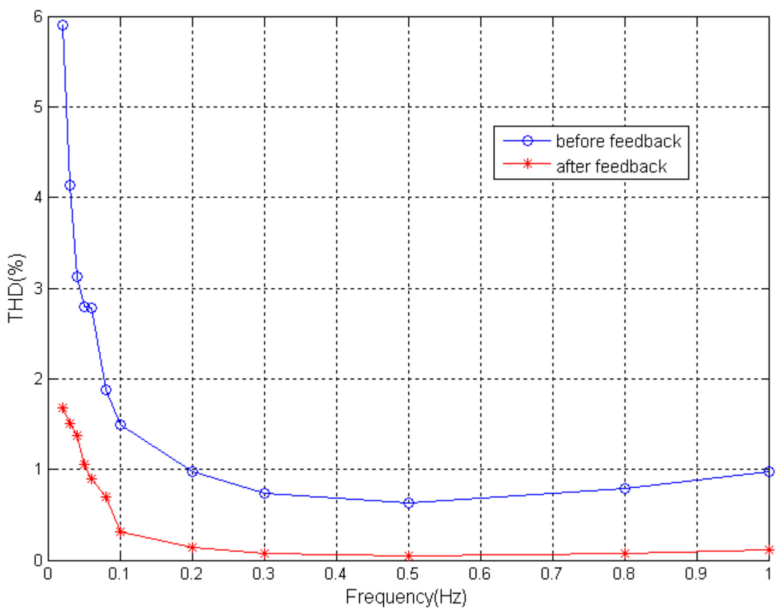

Figure 5.1 THD comparison of before and after combination feedback

6. CONCLUSION

The system can implement combination feedback method based on DSP unit. With the DSP controller, the THD of the system is reduced. The THD of the system based on combination feedback method is 5-10 times lower than none of feedback (Figure 5.1).

Theoretically any kind of feedback methods can reduce the output THD of a vibration table. Actually, the proper feedback method can have satisfactory effect in corresponding frequency band because of the characteristic of vibration sensors. Combination relative velocity feedback method with absolute velocity feedback, the THD is more effectively reduced of a low frequency vibration table. The DSP unit can implement complicated algorithm. Also it has high reliability and less influence by environment.

AKCNOWLEDGEMENT

This work has been sponsored by the Earthquake Research Funds (Grant No.201108007), China. I am deeply grateful to Prof. Yang, Institute of Engineering Mechanics, China Earthquake Administration, China, for his intellectual support throughout the course of this study. Also I am grateful to Ms.Qiao-yu Yang, associate Professor, Institute of Engineering Mechanics, China Earthquake Administration, China, for her invaluable assistance and counsel. At the same time, I express my thanks to my colleagues in the project group for their cooperation.

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