The Digital Upgraded Reconstruction of Ultra-low Frequency Vibration Calibration Standard Apparatus

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ABSTRACT :

The technical indexes of the ultra-low frequency vibration calibration standard apparatus of IEM (Institute of Engineering Mechanics, China Earthquake Administration) are advanced internationally. The apparatus has run for over twenty years and is undergoing the digital upgraded reconstruction now. The paper introduces the working principle and control type of the apparatus, also discusses laser interference technique, multiple feedback technique and digital control technology involved by digital upgraded reconstruction. Furthermore, the paper analyses the parameters calibration method of amplitude-frequency characteristic and phase-frequency characteristic etc on the low frequency vibration sensors, achieves to the object of transferring the vibration value of quantity accurately.

KEYWORDS: vibration calibration, standard apparatus, digital control, calibration method

1. SUMMARY

Vibration calibration apparatus is the criteria of vibration value transmission and the quality of vibration measuring instrument, also acts as the technology basis and supporting platform for the vibration and impact researching field and the practice of the vibration technology application in measurement, adjustment and scientific experiment. Vibration calibration system is a branch of the national mechanical measurement standard system. The state seismological bureau plans to set several thousand of three-component earthquake observation instruments, gradually establish the city earthquake safety and major structure monitoring alarm system, dispose simple rapid report system of the quake magnitude in large scale. What calls for attention are the instruments applied to the earthquake forecast, strong quake observation, rapid report of the magnitude and early-warning of earthquake and tsunami should be equipped with sound ultra-low frequency feature, excellent amplitude frequency and phase frequency characteristics as well we the sophisticated measurement precision. The precise measurement, accurate earthquake and nuclear explosion location as well as the successful forecast and early warning of the above-mentioned instruments depend on the standard apparatus of the ultra-low frequency amplitude-phase characteristics measurement.

At present, there are few institutions that have the low frequency vibration calibration standard apparatus, while only the state seismological bureau engineering mechanical research institute has the ultra-low frequency vibration calibration standard apparatus (frequency scope: 0.01～100Hz,calibration uncertainty: ±0.5%～±1%) . The equipment was a major task item of the state seismological bureau's seventh and eighth-five year plans, which was assessed and recognized by the state bureau of technical supervision when successfully developed in 1988, then granted as the top level of state seismological bureau and in charge of the vibration value transmission of northeast area at the meantime. Besides the task of ordinary checking of the state seismological bureau system, it assumes a great deal of the measurement of national low (ultra-low) frequency vibration apparatus as well as the inspection of special use sensors of the national defense system. The equipment withstands more than 20 years' test and its technical index has been in the leading position both at home and abroad. By combining the upgrading and regeneration of the equipment, the dissertation aims at exploring the technical and parameter problems like body design, multiple feedback, digital control, laser measurement and measuring software, etc.

2. THE COMPONENTS of VIBRATION CALIBRATION STANDARD APPARATUS SYSTEM

Ultra-low frequency vibration calibration standard apparatus is a complicated comprehensive system relating to the technologies of mechanism, electron, laser, control and software, etc, and mainly used in the calibration of low frequency, ultra-low frequency vibration sensors and vibration equipment. It is mainly composed of controlling system, laser measuring system, collecting and analyzing system as well as the assistant instruments and meters. The sine signal generated by the precise signal generator pushes the vibration table through servo controller and power amplifier. The vibration table amplitude is measured by laser interferometer, and the parameters of control signal, laser signal and calibrated senor signal are measured by the precision instruments like frequency counter and digital voltmeter, then sent to the digital system for the completion of digital control and precise measurement. Please refer to figure 1,the system block diagram.

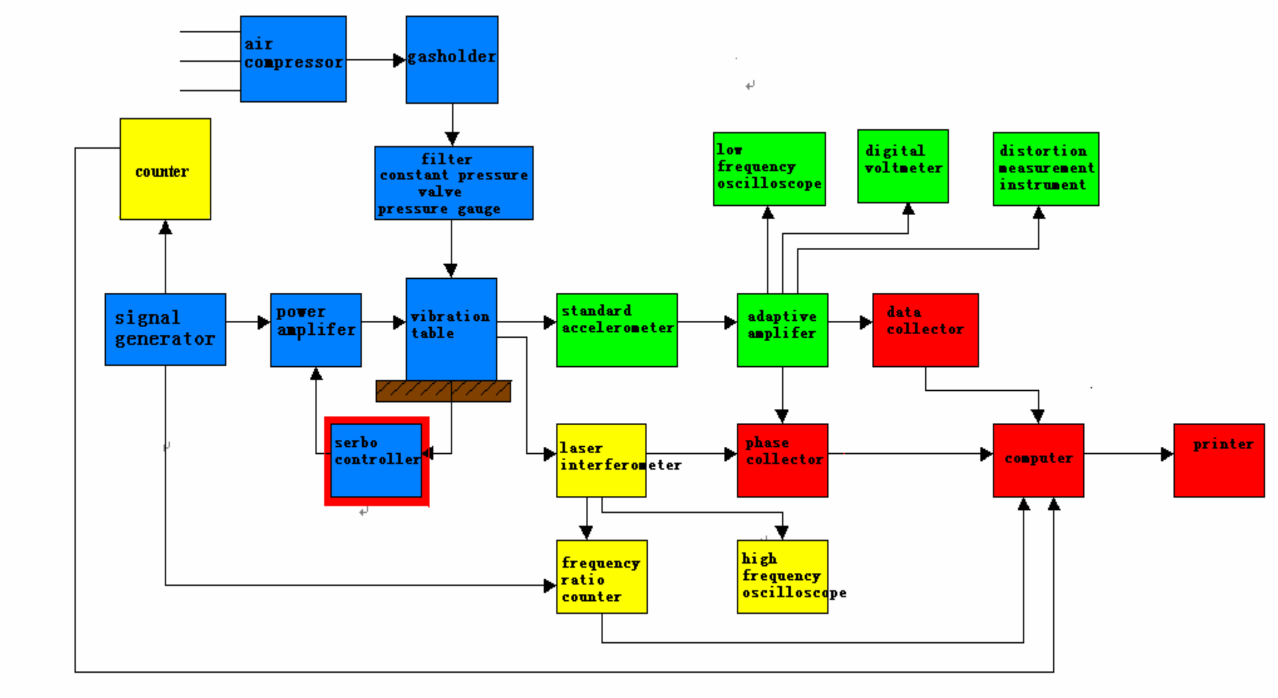

Figure 1 The system block diagram

Technical index:

The upgrading of the present standard apparatus:

Stoke： horizontal：150mm（p-p）
vertical：80mm（p-p）

Frequency scope： 0.01-500Hz

Maximum loading： 10kg

Maximum non-load acceleration： horizontal：$30 m/s^2$
vertical：$40 m/s^2$

Acceleration distortion： <1%

Velocity distortion： <1% （0.01-0.1Hz）

The minimum background noise of the mesa： $1\times10^{-4} m/s^2$ (frequency below 10Hz)

Mesa vibration grade： <0.1%

New horizontal large stroke standard apparatus：

Stoke: 500mm（p-p）

Frequency scope： 0.01-500Hz

Mesa size： 240×200mm

Maximum loading： 5kg

Maximum non-load acceleration：	20m/s^2
Acceleration distortion：	<1%（0.1-20Hz）
Velocity distortion：	<1%（0.01-0.1Hz）
Transverse vibration component：	<1%

3. VIBRATION TABLE

Low frequency vibration table is the major part in the system of low frequency vibration calibration apparatus. Standard vibration table includes horizontal vibration table, vertical vibration table and the power amplifier.

Figure 2 is the simple structure diagram of vertical vibration table. It consists of seat, vibration exciter, moving coil, aerostatic slideway interior displacement and interior accelerometer. There is no mechanical spring in the table, and the location as well as support is completed by “automatic controlling electromagnetic spring”. The interaction between the ac current sent to the moving coil by the power amplifier and the air gap magnetic field of the vibration exciter generates vibrating movement.

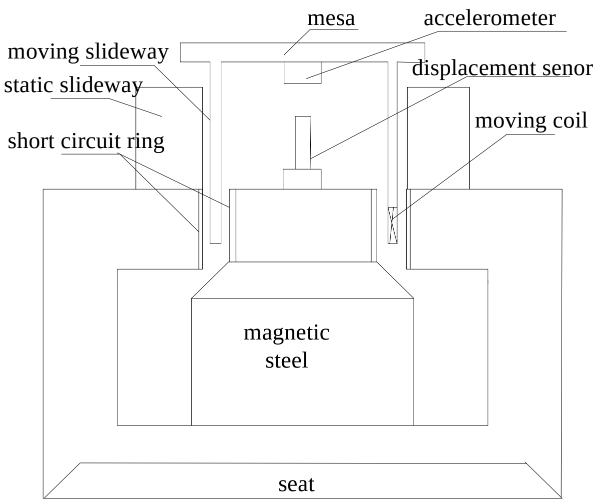

Figure 2 Horizontal table

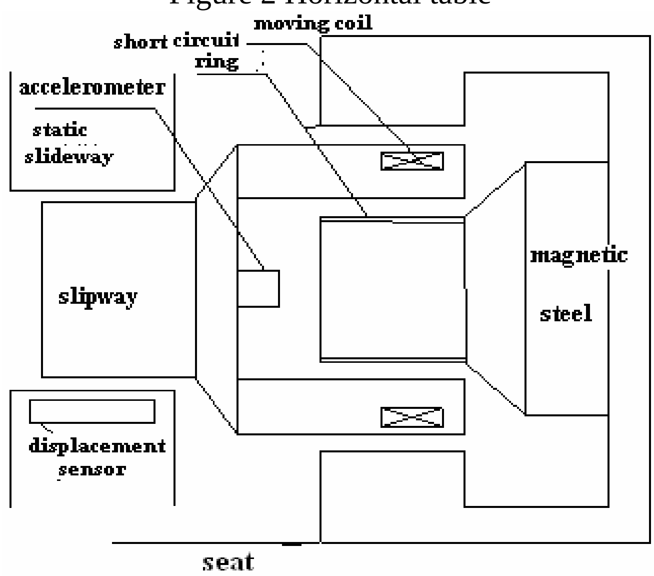

Figure 3 Horizontal table

Figure 2 and Figure 3 is the simple structure diagram of horizontal vibration table. It is composed of seat, vibration exciter, slip table, moving coil, aerostatic slideway interior displacement and interior accelerometer. Table support is also completed by "automatic controlling electromagnetic spring".

Vibration table mechanics model can be simplified as single degree of freedom mass, damping and stiffness system. And the vibration mechanics equation of the moving parts is:

$$m\ddot{x} + C_f\dot{x} + k_f x = F(t) \tag{3-1}$$

in the formula： m ——The general mass of the moving parts

C_f —— Movement damping coefficient of the moving parts

K_f ——Suspending support system spring stiffness of the moving parts

When the gas gap magnetic field passed by the moving coil is uniform constant, and the sinusoidal excitation current frequency is ω, the $F(t)$ can be expressed as:

$$F(t) = Bli(t) = BlI\sin(\omega t) = F\sin(\omega t) \tag{3-2}$$

The vibration mechanics equation solution is:

$$x(t) = x_h(t) + x_s(t) = Ae^{-\xi\omega_n t}\sin(\omega_d t - \phi) + \frac{F}{\sqrt{(K_f - m\omega^2)^2 + \omega^2 C_f{}^2}}\sin(\omega t - \varphi) \tag{3-3}$$

The damping ratio is：

$$\xi = \frac{C_f}{2\sqrt{mK_f}} \tag{3-4}$$

Undamped natural frequency：

$$\omega_n = \sqrt{\frac{K_f}{m}} \tag{3-5}$$

Damped natural frequency：

$$\omega_d = \omega_n\sqrt{1-\xi^2} \tag{3-6}$$

From the equation solution, the free vibration term $x_h(t)$ would disappear with the time goes by, due to the existence of damping. When one vibration part is under the harmonic excitation, it can reach the steady statement $x_s(t)$. Here, the moving part would generate a harmonic vibration with constant amplitude, the same frequency as the excitation frequency, and the phase difference is ω. The calibrated senor installed on the table would also make the harmonic vibration along with the working table, so as to achieve the calibration.

4. CONTROL

Original analog control is an open loop system. In order to further improve low and high-frequency performance of vibration table, improve the control precision calibrated by displacement、speed、acceleration, it not only adopted relative velocity and absolute velocity、acceleration feedback technique, but also added displacement feedback technique, achieve the multiple feedback closed loop control of vibration table. So that the control precision of these factors like harmonic distortion, stability of vibration level、 horizontal vibration ratio、low-frequency background noise and other technical indexes of vibration table is greatly advanced. See in Figure 4.

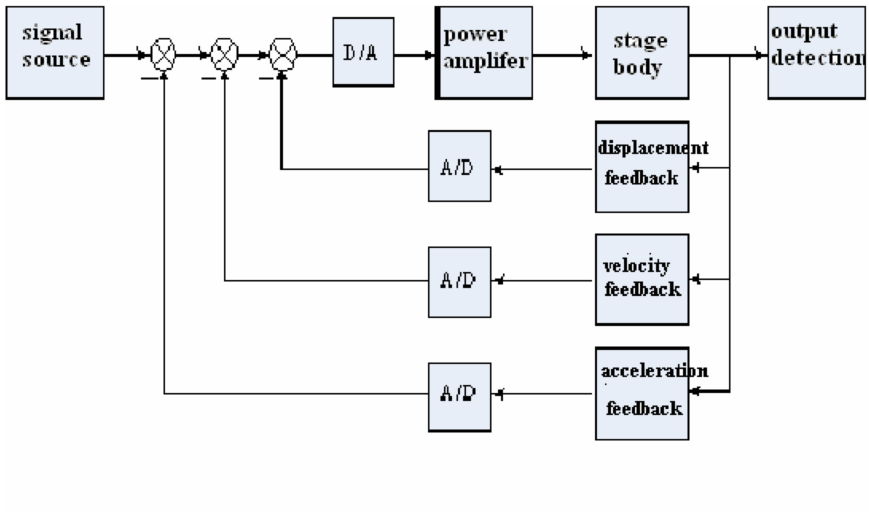

Figure 4 Multiple feedback system diagram

In order to enhance the system stability and control precision, digital upgrade is carried out, and digital control card with the function of analog/digital、 digital/analog is developed, realize the digital closed-loop control of displacement、velocity and acceleration parameters of (ultra) low-frequency vibration calibration table. Multiple I/O interface control realizes test conversion of analog/digital、 vertical/horizontal, accurate and high-speed acquisition control of laser signal. Any digital wave generator achieves vibration waveform input (fixed-frequency wave、sweep-frequency wave、random wave, etc.) and real-time display、distortion、amplitude and phase-frequency characteristics and other automatic analysis processing function. See in Figure5.

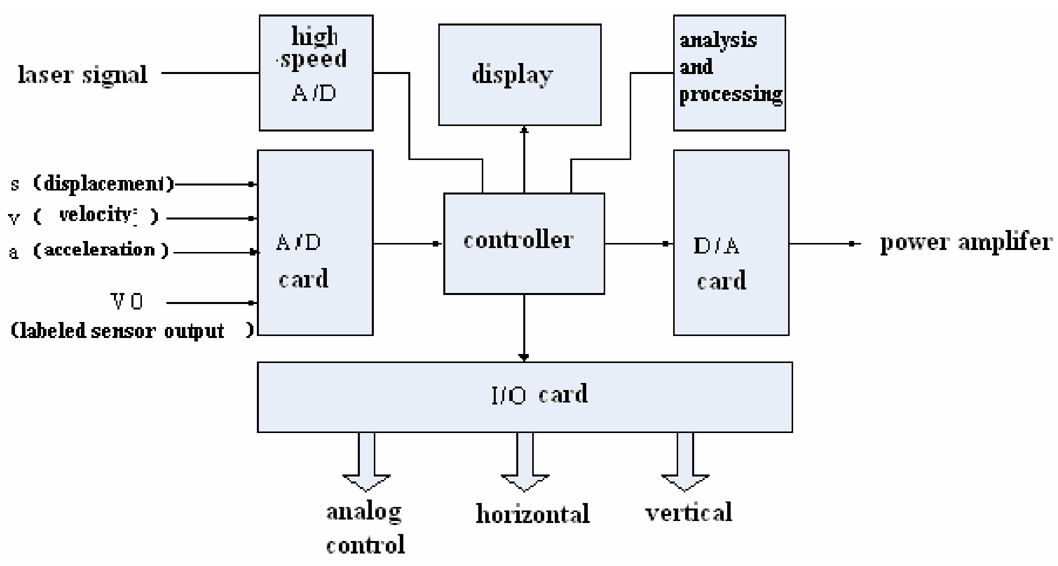

Figure 5 Digital control structure diagram

5. LASER CALIBRATION and PARAMETER MEASUREMENT

With the rapid development of national economy and high technology, it has put forward that while we test the amplitude-frequency characteristics of sensors , to test phase-frequency characteristics is also needed in the engineering survey of. mechanical electric power、bridge architecture、water conservancy construction、geological exploration、aero-space、 defence and military, as well as in the area of mechanical fault diagnosis and monitoring、modal analysis technique、earthquake、geophysical measurement，etc. At present, only Sine Approximation Method calibration technique recommended by ISO16063-11 "laser interferometer vibration of absolute calibration" can actualize the absolute measuring of sensors phase-frequency characteristics within the range of broadband.

5.1 Orthogonal Michelson Laser Interferometer

Sine Approximation Method adopted (orthogonal) perpendicular Michelson laser interferometer, see in Figure 6. Light source is a He-Ne laser of 0.63282μm wavelength. The A laser sends a beam which goes through a after polarizer and then forms 45°linearly polarized light beam to spectroscope axis, it equals to the vector sum of two mutual perpendicular、same size and same light intensity laser beams. 1/4 wave plate converts incident polarized light into two measuring beams of mutual perpendicular and 90°phase displacement. Because of the parallel between 1/4 wave plate optical axis and vertical beam, and the vertical hysteresis of optical lenses, when vertical beam pass the 1/4 wave plate, it will increase 1/4 wavelength on optical path, that is, lag behind 1/4 cycle of horizontal beam in time domain. After interference between two measuring beams and linearly polarized reference beam was happened, Wollaston prism or polarizing beam splitter will separate two-component beam in space, two photodetectors of horizontal and vertical will accomplish the receiving and detection of interference signals. Due to 90°phase difference, two-way photoelectric signals respectively change according to cosine and sine function.

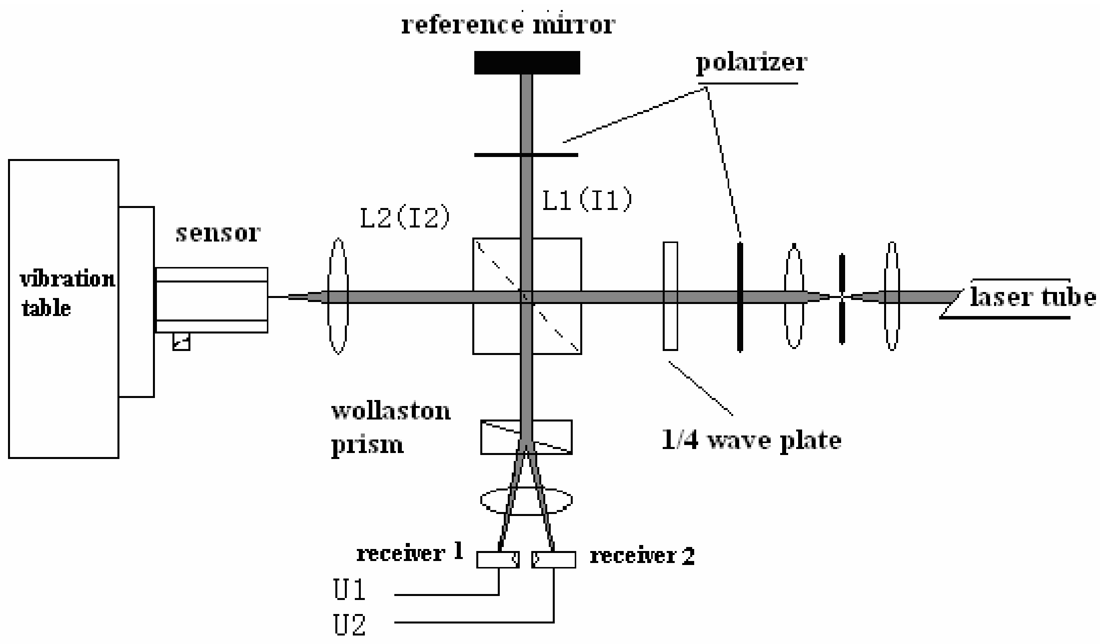

Figure 6 Sine approximation method laser interferometer diagram

In Figure7, cosine curve connected by circular points is photoelectric signal output by photodetectors of horizontal. Sine curve connected by triangular shaped dots is photoelectric signal output by photodetectors of vertical. Cosine curve connected by square points is displacement signal of vibration table. As shown in the Fig, vertical photoelectric signals lag behind horizontal photoelectric signal 90° in phase. Movement of vibration table and photoelectric signal of photodetector have these relations: variation period of interference fringes is not constant; when vibration stroke is close to the maximum displacement (peak and wave trough), fringe number decrease, and phase displacement overturn.

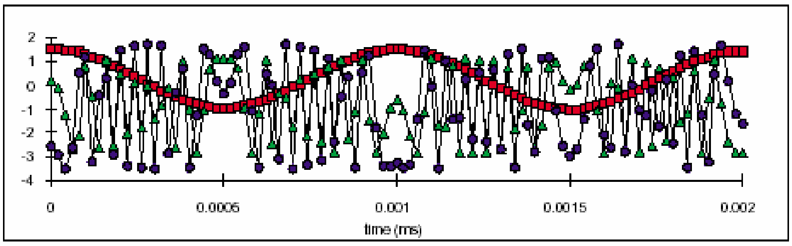

Figure7 Oscillogram of photoelectric signal and vibration signal

5.2 Parameter Measurement

Sine Approximation Method recommended by international standard ISO16063-11 "laser interferometer vibration of absolute calibration" is appeared based on the development of modern computer technology and digital signal processing technology. With the great increasing of acquisition speed、resolution and memory capacitance of data acquisition card, it will be possible to actualize the acquisition and storage of photoelectric signals of frequency change over several MHz. Furthermore, the improving of computer operation speed and powerful function of application software also can achieve data analysis processing and complicated mathematical solution easily.

Figure8 is the amplitude and phase characteristics measuring structural diagram of laser vibration sensor. It composed chiefly of incentive system、vibration table、orthogonal Michelson laser interferometer、optical measuring system and data acquisition processing system. In this virtual apparatus system: photoelectric receiver、acceleration sensor change physical signal to be electric signal; various amplifier conduct signal adjustment; data acquisition to signal acquisition、A/D conversion; finally application software accomplish mathematical calculation、signal analysis、display and other functions.

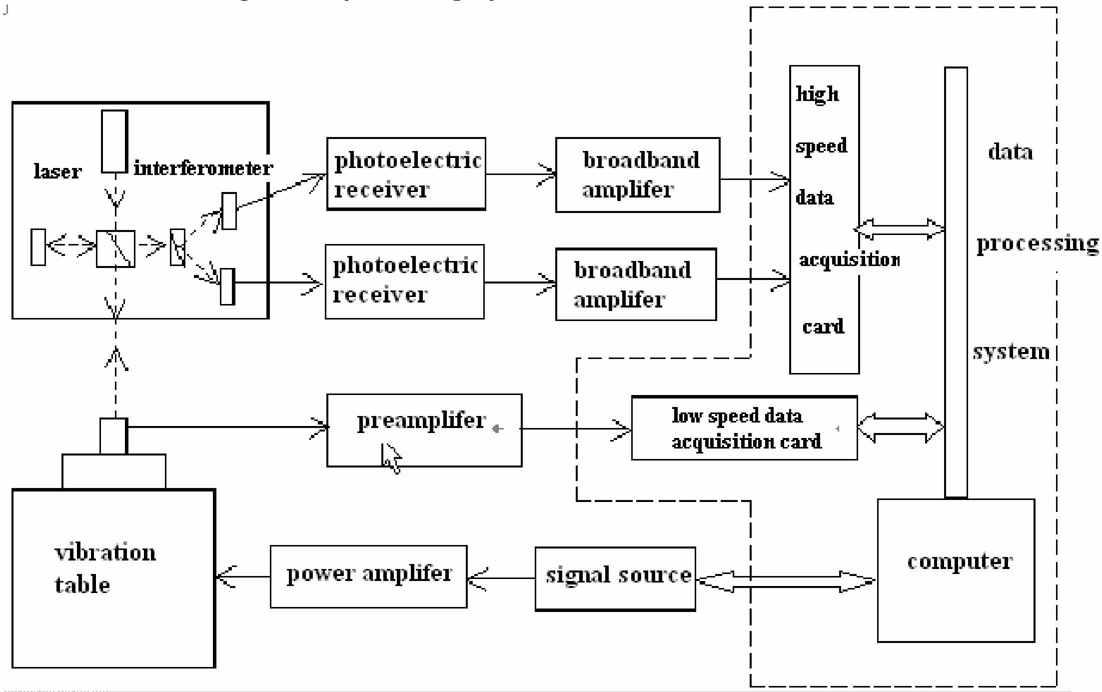

Figure 8 Structural diagram of amplitude and phase characteristics measuring system

By using virtual apparatus system and method3: Sine Approximation Method recommended by ISO16063-11, and through Lab View graphical programming software of NI company, combining data collection communication and necessary apparatus and other hardware with computer, to actualize high-precision calibration of amplitude and phase characteristics of ultra-low frequency vibration sensor.

6. CONCLUDING REMARKS

The upgrading and transforming of the vibration calibration standard apparatus developed by state seismological bureau engineering mechanics institution has been in proceeding. The design and processing of vertical, horizontal vibration table and laser interferometer has been completed and entered the debugging phase. The design of 0.5m horizontal large excursion vibration table has already started. Through upgrading and technology development, the standard apparatus will form a set of full numerical controlled ultra-low frequency vibration calibration standard, which is in the leading position both at home and abroad, and the infrastructure as well as the corollary instruments and equipments are in accordance with our present national economic and technological development. The goal of achieving the vibration value transmission of the earthquake instruments and equipments and the source identification measuring method and technology is to achieve the unification and accuracy of the major parameters source identification and value transmission.

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