Design and Research of Dynamic Stiffness Test System for Rubber Shock Absorber Based on LabVIEW

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Abstract. Rubber shock absorbers are an indispensable component in the fields of ships, automobiles, trains, airplanes and construction engineering. The dynamic stiffness value is an important indicator to measure the performance of rubber shock absorbers. Some existing dynamic stiffness testing methods are often difficult to meet the production enterprises and testing requirements of the testing unit. According to the testing requirements of rubber dynamic characteristics and the development of dynamic stiffness testing technology for rubber shock absorber at home and abroad, designing and developing a new type of rubber vibration damper dynamic stiffness testing technology. Through the USB6008 data acquisition card establishing the connection between the collected data and the data analysis platform based on LabVIEW software, realizing the real-time, accurate and efficient measurement of the rubber shock absorber.

1. Introduction

When a rubber material is used as the elastic member, the stiffness coefficient varies depending on the operating frequency, so the rubber shock absorber has static stiffness and dynamic stiffness [1]. At present, the electro-hydraulic servo fatigue test bench, the electric power test bench, and the mechanical fatigue test bench can measure the dynamic stiffness of rubber shock absorbers. However, for the electro-hydraulic servo fatigue test bench, the technical requirements for the shock absorption and isolation components of the vehicle are that the frequency is close to the upper limit of the available frequency range of the electro-hydraulic servo fatigue test bench, and the vibration displacement is small, resulting in low measurement accuracy, and the price is very high. Generally, the electro-dynamic vibration table has less excitation force and cannot meet the test requirements of large alternating force. Mechanical fatigue test bench cannot adjust the amplitude online. There are single test waveforms, large test displacement and velocity error, small test speed range, poor test results, and difficult to achieve multi-case rapid test cannot fully meet the test specification requirements. Hydraulic servo control method can obtain higher force and displacement, but the friction and high motion quality of the sealing system limit its small vibration [2]. In addition, most of the electro-hydraulic servo test benches and mechanical fatigue test benches used in China are imported from abroad, and the price is relatively expensive, thus limiting domestic use.

In view of the shortcomings of current dynamic stiffness measurement of rubber parts, according to the development of dynamic stiffness testing technology of rubber parts at home and abroad and the actual requirements of productive enterprises, a new type of rubber dynamic stiffness testing machine is designed. By changing the working frequency of the vibration table, a fast and accurate
measurement of the dynamic stiffness value of the rubber member is achieved. The actual experiment and use of a rubber test specimen shows that the technical scheme is correct and the test effect is good. Provide a basis for the design of the damper, and at the same time provide reference for the development of similar products.

2. Dynamic Stiffness Test Principle
Dynamic stiffness refers to the ability to resist deformation under dynamic load, that is, the dynamic force required to cause unit amplitude. Due to the different loads on the structure or material, it may be subjected to static or dynamic loads. Therefore, the stiffness is divided into static stiffness and dynamic stiffness. When subjected to dynamic loads, the ability to resist deformation under dynamic loads is called dynamic stiffness, dynamic stiffness is a measure of the ability of a structure to resist a predetermined dynamic disturbance. In particular, for a viscoelastic vibration-damping element, such as rubber, its dynamic stiffness is a key indicator for describing vibration damping performance. Since the rubber material is not a simple elastomer, but a viscoelastic material, the stiffness of the rubber member should be expressed in plural form [3-4].

In this study, the complex stiffness model is used in the modeling and analysis of rubber parts. When the vibration frequency is small in the actual test, the imaginary part of the complex stiffness has little effect on the overall stiffness value. The complex stiffness can be used to replace the whole complex stiffness value.

Figure 1. Dynamic stiffness test schematic

Figure 1 is a theoretical test method for dynamic stiffness. During the test, when the vibrating table vibrates at a given frequency, the relative vibration speed of the two ends of the rubber member at the vibration frequency can be measured, that is:

\[ v(t) = V_m \cos(wt + \varphi) \] (1)

Where:
- \( w \): angular frequency, (rad/s);
- \( \varphi \): phase difference between the velocity and force signal cross components, (rad);

By integral transformation, the relative vibration displacement is obtained:

\[ y(t) = \int v(t) + y_0 \]
\[ = y_{\text{max}} \sin(wt + \phi) \] (2)

Where:
- \( \phi \): phase difference between vibration displacement and dynamic alternating force, (rad);
- \( y_{\text{max}} \): peak value of vibration displacement, (mm);

Therefore, the dynamic stiffness of the rubber shock absorber to be tested is:
\[ K_d = \frac{F_{\text{max}}}{y_{\text{max}}} \]  

Where:
\( F_{\text{max}} \): peak load on rubber shock absorber, (N);
\( K_d \): dynamic stiffness, (N/mm);

3. System Overall Design

3.1. Tester Design

The rubber dynamic stiffness tester consists of an adaptive frequency stabilization shaker, detection components and computer measurement and control system. Among them, the computer measurement and control system mainly completes data acquisition, load control and dynamic stiffness test data processing. The schematic diagram of the main structure of the test machine is shown in Figure 2. The hardware consists of a piezoelectric accelerometer, a mass block, vibration table, and a magneto-electric speed sensor. Usually, it is difficult to install a force sensor on the rubber specimens to be tested. If the force sensor is mounted on a metal block, the inertial load of the metal member also acts, thus affecting the measurement accuracy. The system installs a piezoelectric accelerometer on the mass block, measures the peak value of the vibration acceleration of the mass block, and multiplies the mass of the mass block to obtain the peak load \( F_{\text{max}} \) acting on the rubber specimen to be tested. The measurement of dynamic deformation at both ends of the rubber specimen uses a magneto-electric speed sensor. The coil of the sensor is fixed on the mass block. Permanent magnet steel is fixed on the table of the vibrating table. When the vibrating table vibrates at a given frequency, the relative vibration speed of the two ends of the rubber specimen at the vibration frequency can be measured. Relative vibration displacement peaks \( y_{\text{max}} \) can be obtained by integrating circuit and peak circuit, which satisfies the dynamic stiffness theoretical test requirements. [5].

![Figure 2. Rubber dynamics tester’s structure diagram](image)

**Figure 2. Rubber dynamics tester’s structure diagram**

3.2. Design of Measurement and Control System

The rubber stiffness measurement and control system uses the LabVIEW virtual instrument platform to complete the collection, analysis and processing of the loading force and the displacement signal of the rubber parts. The software design is developed under the LabVIEW platform, with its efficient development environment, combined with the USB6008 data acquisition card, mainly to complete the
initial configuration of the system resources, set the vibration frequency, amplitude of the vibration table and other test specifications. Analyze and process the acquired signals (acceleration, speed), calculate the dynamic stiffness value and damping angle of the test piece, draw the relationship between dynamic stiffness and frequency.

3.2.1. Data Acquisition Module
During the test, it is necessary to obtain the force value signal and the displacement value signal of the rubber piece sample. Therefore, the data acquisition module of the test system selects the acceleration sensor and the speed sensor, and the force value and the displacement value can be obtained by integral transformation. With the USB6008 data acquisition card, the NI-DAQ Assistant library function in LabVIEW to complete the sampling channel, sampling rate, sampling points, and sampling mode can be called directly. The system is connected to the analog voltage double-ended input mode, which can effectively suppress the common mode interference signal and improve the acquisition accuracy. Channel 0 and channel 7 are used to separately collect the acceleration signal and the speed signal, and select the sampling channels that are far apart to eliminate the possibility of interference between adjacent sampling channels [6].

3.2.2. Data Processing Module
In the actual test process, it will be subject to various signal interferences such as mechanical vibration, electromagnetic field changes and system component noise. Therefore, the test system software must filter out the interference signal, and then perform various calculations on the data. Selecting a suitable filter can filter out the noise well and maximize the original signal. The test system uses the Inverse Chebyshev Filter in the LabVIEW software Filters sub-template for filtering, filter type set to low pass filter. The cutoff frequency is appropriately adjusted according to the frequency of the test excitation device. After filtering the signal, the spectrum characteristics of the vibration signal can be analyzed [7]. By selecting the single-frequency measurement in the waveform measurement function module, the amplitude, frequency and phase of the force and displacement signals can be obtained, and the curve value of the dynamic stiffness as a function of frequency can be calculated.

4. Application and Testing System
The device can load 5 000N pre-stress and 1 999N alternating load on the test piece. The frequency range is divided into 10 to 100 Hz and 40 to 400 Hz. The amplitude range is 0.1 to 0.5 mm. These parameters can meet the test specifications of most rubber shock absorbers. In this paper, the rubber shock absorber test piece on the car is used for dynamic testing, and the vibration table is used to apply different vibration frequencies to the test piece.

It can be seen from Table 1 that the corresponding \( F_{\text{max}} \) and \( y_{\text{max}} \) values are obtained on the measurement and control system. The dynamic stiffness \( K_d \) of the theoretical rubber shock absorber specimen can be calculated by Equation 3. Test system gets test results \( K_d' \), the absolute value of error between the two is \( \delta \). The traditional measurement method detects the comprehensive error as \( \pm 20\% \). The curve of Figure 3 can be obtained from the front panel of LabVIEW by data fitting algorithm. It can be seen from Figure 3 that the dynamic stiffness characteristic curve obtained in this test is consistent with the industry standard rubber characteristic curve, indicating that the test results obtained by the test analysis system designed in this paper are reliable.
Table 1. Rubber specimen test piece dynamic stiffness measurement results

| w / Hz | $F_{\text{max}} / N$ | $y_{\text{max}} / \text{mm}$ | $K_d / N \cdot \text{mm}^{-1}$ | $K'_d / N \cdot \text{mm}^{-1}$ | $| \delta |$
|-------|---------------------|------------------|-----------------|-----------------|-----|
| 38    | 105.23              | 0.21             | 501.10          | 480.11          | 4.19%|
| 40    | 101.14              | 0.24             | 421.42          | 412.13          | 2.20%|
| 45    | 88.68               | 0.28             | 316.71          | 290.62          | 8.24%|
| 50    | 90.89               | 0.30             | 302.97          | 284.47          | 6.11%|
| 60    | 172.21              | 0.33             | 521.85          | 574.25          | 10.04%|
| 75    | 194.62              | 0.12             | 1621.83         | 1493.28         | 7.93%|

Figure 3. Rubber shock absorber dynamics with frequency

5. Conclusions
The dynamic stiffness test system of rubber parts developed based on LabVIEW virtual instrument platform realizes fast and accurate measurement of dynamic stiffness parameters. The LabVIEW powerful function module is used to analyze and process the collected test data. The test results prove that the test results of the tester are accurate and reliable within the allowable range of error requirements, and the cost is low and easy to use. It is fully applicable to the test of the dynamic stiffness of most rubber shock absorbers. It provides new and effective methods and ideas for efficient and accurate testing of rubber shock absorbers.

6. References
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