Experimental Study and Dynamic Modeling of Metal Rubber Isolating Bearing

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Abstract. In this paper, dynamic shear mechanical properties of a new metal rubber isolating bearing is tested and studied. The mixed damping model is provided for theoretical modeling of MR isolating bearing, the shear stiffness and damping characteristics of the MR bearing can be analyzed separately and easily discussed, and the mixed damping model is proved to be an rather effective approach. The test results indicate that loading frequency bears little impact over shear property of metal rubber isolating bearing, the total energy consumption of metal rubber isolating bearing increases with the increase in loading amplitude. With the increase in loading amplitude, the stiffness of the isolating bearing will reduce showing its “soft property”; and the type of damping force gradually changes to be close to dry friction. The features of “soft property” and dry friction energy consumption of metal rubber isolating bearing are very useful in practical engineering application.

1. Introduction

Metal rubber material is a kind of new functional structural material featuring net structure by staggered connection of metal wires at its inside. In macroscopic aspect, it has rubber-like macromolecular structure and elasticity; in microcosmic aspect, it is characteristic of mutual dry friction effect of its internal metal wires. With the excellent mechanical properties of vibration damping, the metal-wire spring rolls inside the metal rubber material and structure will rub, slip, extrude and deform under the action of external load to consume much energy, which leads to playing the role of damping. As a full-metal product, the metal rubber features strong adaptability to the environment, resistance to high or low temperature, resistance to corrosion; thus it is the optimal substitute of traditional rubber material. Due to the excellent vibration damping and isolation of metal rubber material under special conditions such as high or low temperature and corrosive environment, vibration isolators made of metal rubber have extensive application value in industries of machinery, military, aerospace, ocean ships[1-8].

The isolating bearing made of laminated rubber is generally used for current building vibration isolation and requires some improvement due to the endurance issues such as ageing, corrosion, fatigue. However, the metal rubber vibration isolator is applying metal rubber material to replace the traditional rubber, which is a kind of new material isolating bearing. In addition, as a nonlinear hysteresis characteristic material with variable stiffness and damping, the dynamic model of metal rubber material is an important research issue. In this paper, a new vibration isolator is developed and manufactured with stainless steel metal rubber, then its dynamic shear performance is tested and studied, followed by dynamic modeling and theoretical analysis, which can be referenced by the application of metal rubber material in practical engineering design[9-12].

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2. Experimental details and results
In this paper, 1Cr18Ni9Ti austenitic stainless steel wire with the wire diameter of 0.2mm is employed to make a spiral roll for workblank preparation, and then a cylindrical metal rubber isolating bearing is made after the process of cold press moulding within a round model, as shown in Fig. 1. The test specimen features external diameter of 30mm and internal diameter of 20mm with moulding density of 0.23.

![Figure 1. MR isolating bearing.](image1)

![Figure 2. Test specimen and machine.](image2)

In the test, the shear performance of the manufactured isolating bearing is tested on Hongda HT9711 electronic dynamic material tester, with the loading form of displacement control, as shown in Fig.2. The hysteresis curves of the metal rubber isolating bearing with different loading frequencies and loading amplitudes are tested, and to make sure that the deformation of the test specimen is within the restorable deformation scope, the loading strain amplitudes are 5%, 10%, 15% and 20% respectively, and the loading frequencies are 0.1Hz, 0.5Hz, 1.0Hz and 3.0 Hz respectively.

The shear stress-strain hysteresis curves of the test specimen with the strain amplitude of 10% and 15% at loading frequencies of 0.1Hz, 0.5Hz, 1.0Hz and 3.0Hz are presented in Fig.3 and Fig.4, from which it can be seen that the testing hysteresis curves with the same strain amplitude almost coincide despite of the different loading frequencies, which shows that the shear property of metal rubber isolating bearing vary little with variation of loading frequency. It means that the MR isolating bearing can exhibit some good performances when used in the engineering design within a wide range of loading frequency or seismic loading frequency. Therefore, as a typical test, one of the loading frequency (i.e. 1.0Hz) is selected for the following loading tests.

![Figure 3. Hysteresis curves of test specimen with strain amplitude of 10%.](image3)
Figure 4. Hysteresis curves of test specimen with strain amplitude of 15%.

Figure 5. Hysteresis curves of test specimen with strain amplitudes of 10%, 15% and 20%.

For the influence of the strain amplitude on the hysteresis behavior of MR bearing, the shear stress-strain hysteresis curves of the test specimen with loading strain amplitudes of 10%, 15% and 20% respectively are illustrated in Fig.5, from which it can be seen that with the increase of the loading amplitude, the shear stiffness seems decreasing, and the area enveloped by the curve seems growing, which means the total energy consumption of metal rubber isolating bearing increases accordingly.

The internal mechanism is that the relative slippage between metal wires is very small when the amplitude is small, and the mutual friction is not yet fully produced; however, with the increase of the loading amplitude, the obvious slippage appears between metal wires, and the total energy consumption increases accordingly. These properties will be very useful for the isolating bearing in practical engineering.
By the curve in Fig. 5, it can be basically understood the general characteristics of MR bearings and its mechanism, however, the above characteristics is not clearly shown from the experimental curve with just basic data processing.

For a better understanding and comparison of the behavior of different MR bearing, the following theoretical modeling approach will be applied, and the overall resilience force will be decomposed into two parts, then the shear stiffness and damping characteristics of the MR bearing were discussed and analyzed separately.

### 3. Theoretical modeling and analysis

The metal rubber material is featuring nonlinear hysteresis property of variable stiffness and variable damping, and it is very complicated in the constitutive relation, it is hardly described by any available mathematic model. Fortunately, some advisable theoretical modeling approaches are provided in reference [13,14]. In this study, the mixed damping model will be adopted for its theoretical modeling. Dynamic modeling and theoretical analysis for shear property of the isolating bearing are presented according to the experimental results, and the damping mechanism of the isolating bearing is discussed after the reconstruction of the displacement resilience force curve.

The following mathematic expression of resilience will be used and for identification of specific model parameters:

$$F_f = F_k + F_c = k_1x + k_3x^3 + k_5x^5 \pm c\sqrt{(A^2 - x^2)^\alpha}$$

(1)

Where, $F_f$ is the resilience force, $F_k$ is the nonlinear spring force, $F_c$ is the nonlinear damping force. $A$ is the amplitude of vibration, $x$ is the vibration displacement, $k_1, k_3, k_5$ is the coefficient of spring force, $c$ is called the damping coefficient, $\alpha$ is called the damping composition coefficient, which shows the sensitivity of damping force with the velocity.

The above model has clear physical significance, where the first three items are spring forces and the last item is damping force. There are five undetermined parameters to be identified with the following parameter separation and identification algorithm. The identification process features distinct physical significance and is not difficult to identify all the parameters with high precision, which are detailed as the following four steps: 1) Data Processing: classify the measured experimental data to obtain displacement-resilience hysteresis curve; 2) Decomposition: break the resilience force into two parts of spring force and damping force for separate parameter identification; 3) Curve fitting: apply the least square method to nonlinear spring force for parameter identification; 4) Curve fitting: apply the least square method to nonlinear damping force for parameter identification.

To test the effectiveness of the above mentioned identification algorithm, take the hysteresis curves in Fig. 3 as an example. Parameters of the hysteresis loop with frequency of 1.0Hz and strain amplitude of 15% (shown in Fig. 3) are identified and the hysteresis curves are reconstructed, which are shown in Fig. 6 and Fig. 7. From Fig. 6 it can be seen that the decomposed spring force and the decomposed damping force is clearly shown, and from Fig. 7 it can be seen that the theoretical curves coincides with experimental curves satisfiedly, indicating the adopted method here has good accuracy and clear physical significance.
Figure 6. Decomposition of hysteresis resilience force into spring force and damping force.

Figure 7. Curve fitting of the spring force and damping force.

According to the above theoretical modeling methods, the parameter identification and the reconstruction of hysteresis loop curves with the frequency of 1.0Hz and the strain amplitude of 10%, 15% and 20% respectively are presented in Fig.8 and Fig.9. It shows that the theoretical results can better simulate the experimental results, indicating that this approach is rather effective in all cases. Then the behavior of MR bearing can be understood and comparatively analyzed clearly.
Figure 8. Reconstruction of hysteresis curve with frequency of 1.0hz and strain amplitude of 10%, 15% and 20% respectively.

Figure 9. Reconstruction of spring force and damping force curves with frequency of 1.0Hz and strain amplitude of 10%, 15% and 20% respectively.

From the results of parameter identification in Fig.9, it can be easily concluded that the identification method features distinct physical significance, the nonlinear spring force parameters vary regularly, for a specific loading frequency, the shear stiffness decreases with the increase in amplitude, which indicates the shear stiffness of MR isolating bearing reduces with the increasing loading amplitude. This property can be expressed by so-called “soft property”.

From the results of identification of nonlinear damping force, it also can be seen easily that the process of damping force identification features distinct physical significance, the enveloped damping area increases much with the increase in loading amplitude, indicating that the damping energy consumption of the system increases greatly with the increase in loading amplitude.

In addition, as can be seen from the decomposition of the hysteresis curve, with the increase in loading...
amplitude, the damping force curve changes gradually from an ellipse to a rectangle close to that of dry friction damping. The reason can also be explained that the relative slippage and the mutual friction between metal wires will be more obvious with the increase of the loading amplitude, and the type of damping mechanism will be transformed into dry friction damping.

The features of “soft property” and dry friction energy consumption of metal rubber isolating bearing with increase in loading amplitude are very useful in practical engineering application.

4. Conclusions

A new kind of isolating bearing is developed and manufactured with stainless steel metal rubber, of which shear mechanical properties are tested and studied. The test result indicates that loading frequency bears little impact over shear property of metal rubber isolating bearing, i.e. its shear property hardly vary with variation of loading frequency.

Dynamic modeling and theoretical analysis of isolating bearing shear property are presented based on the test results, which indicates that the mixed damping model can satisfactorily describe the shear hysteresis dynamic property of metal rubber isolating bearing, with good accuracy and clear physical significance.

The results of modeling and analysis show that the shear stiffness of MR isolating bearing reduces with the increasing loading amplitude, expressed as “soft property”; with the increase in loading amplitude, the type of damping force changes gradually close to that of dry friction, which is very useful in practical structural engineering designing.

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