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UNIVERSAL METHOD TO MEASURE DYNAMIC PERFORMANCE OF VIBRATION ISOLATORS UNDER STATIC LOAD

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A two-mass method is proposed to determine the four-pole parameters of a uni-directional asymmetrical vibration isolator. It may be regarded as a universal testing procedure applicable to uni-directional or bi-directional, and asymmetrical or symmetrical vibration isolators under static load. Generally, vibration isolators incorporating some form of active control are examples of uni-directional asymmetrical vibration isolators. Experimental data are presented that validate the two-mass method.

1. INTRODUCTION

The effectiveness of a vibration isolator is determined by its dynamic properties and the dynamic properties of the structure above and below. To be able to design effective vibration isolators, it is necessary to dynamically characterize and test them. The dynamic properties of a vibration isolator depend primarily on the static load of the supported machinery, temperature and frequency and amplitude of vibration.

A vibration isolator may be dynamically described in terms of the four-pole parameters, which relate the force and velocity at the input of the vibration isolator to the force and velocity at its output. Molloy [1] introduced the four-pole parameter concept to mechanical systems based on four-pole or two-port networks in electrical theory, in which the variables are voltage and current. The concept has also been applied to acoustical systems, with the variables being acoustical pressure and volume velocity. For mechanical vibrations the variables are force and velocity. The four-pole parameters are expressed in terms of masses, springs and dashpots, which are analogous to resistances, capacitances and inductances in electrical networks.

In this study, there are three main advantages for using the four-pole parameters to dynamically characterize a vibration isolator. Firstly, the characterization is independent of the testing method. The traditionally used description of transmissibility is usually measured by supporting a mass on the vibration isolator, which is in turn supported on a rigid foundation, to form a single-degree-of-freedom system. The mass is excited by a shaker, while the output of the isolator is considered to be blocked. The transmissibility may then be measured as the ratio of the output force from the vibration isolator, to the input force to the mass. It depends on the supported mass, and is not independent of the test arrangement.

Secondly, mass effects of the vibration isolator evident at high frequencies are included. The traditional descriptions treat a vibration isolator as a massless spring, whereas in

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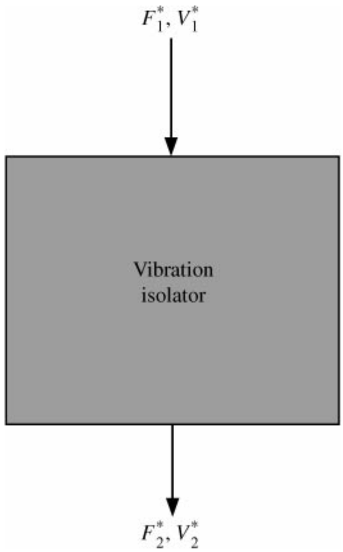

Figure 1. Block representation of a vibration isolator.

reality it has distributed mass and stiffness. The model of a massless spring fails to predict the existence of the longitudinal standing waves found in real vibration isolators.

Thirdly, the four-pole parameters of a mechanical system may be derived mathematically from the four-pole parameters of its constituent series and parallel parts. Thus, a complicated system comprising a number of masses, springs and dashpots may be analyzed from the characterizations of a mass, spring and dashpot in terms of the four-pole parameters.

A vibration isolator may be dynamically represented as a pseudo-linear system, Figure 1, where the dynamic force and velocity at its input are denoted by F_1^* and V_1^* respectively, and the dynamic force and velocity at its output by F_2^* and V_2^* respectively. Complex numbers are represented with the superscript*, and real numbers are not superscripted. Let α_{11}^*, α_{12}^*, α_{21}^* and α_{22}^* denote the four-pole parameters, which are complex, time-invariant functions of the circular frequency ω. The four-pole parameters relate the input and output forces of the vibration isolator and are defined by

$$\begin{bmatrix} F_1^* \\ V_1^* \end{bmatrix} = \begin{bmatrix} \alpha_{11}^* & \alpha_{12}^* \\ \alpha_{21}^* & \alpha_{22}^* \end{bmatrix} \begin{bmatrix} F_2^* \\ V_2^* \end{bmatrix}. \tag{1}$$

Assuming that Rayleigh's reciprocity theorem in the form of Maxwell's reciprocal deflections theorem applies to the system, it may be shown that [1]

$$\alpha_{11}^*\alpha_{22}^* - \alpha_{12}^*\alpha_{21}^* = 1. \tag{2}$$

Symmetrical vibration isolators are defined as those that behave in the same way if their inputs and outputs are interchanged. For these vibration isolators it may be shown that [2]

$$\alpha_{11}^* = \alpha_{22}^*. \tag{3}$$

Generally, vibration isolators incorporating some form of active control are examples of unit-directional asymmetrical vibration isolators. The development and application of active vibration isolators are becoming more prevalent, and so it is important to develop a method for their characterization. The derivation of the mathematical expressions for the four-pole parameters of active control feedback system is considered outside the main theme of this paper. Descriptions of active control systems may be found in references [3–8].

A search of the literature indicates that there is no method currently available for measuring the four-pole parameters of uni-directional asymmetrical vibration isolators under static load.

In this study a two-mass measurement method is proposed as a universally applicable procedure for determining the four-pole parameters of a uni-directional asymmetrical vibration isolator under static load. The term "universal" is used here to denote those systems which are linear in nature. The test method is described and the application to an asymmetric vibration isolator is shown experimentally.

2. USUAL METHODS FOR FOUR-POLE PARAMETERS

The usual method for measuring the four-pole parameters of a vibration isolator under static load relies on a blocked output arrangement that measures F_1^*, V_1^* and F_2^* with $V_2^* = 0$ [9]. The forces may be measured either directly [10] or indirectly [11]. The cases of symmetrical and asymmetrical vibration isolators are addressed in sections 2.1 and 2.2 respectively.

2.1. SYMMETRICAL VIBRATION ISOLATORS

Equations (2) and (3) imply that there are only two independent four-pole parameters needed to be measured for a symmetrical vibration isolator in order to completely characterize it.

Consider the two following special cases of the output being blocked or free. In the first case the output side is blocked, i.e., $V_2^* = 0$, which yields [9]

$$\alpha_{11}^* = \left.\frac{F_1^*}{F_2^*}\right|_{V_2^* = 0} \tag{4}$$

and

$$\alpha_{21}^* = \left.\frac{V_1^*}{F_2^*}\right|_{V_2^* = 0}. \tag{5}$$

In the second case the output side is unrestrained and is free to vibrate, i.e, $F_2^* = 0$, which yields [9]

$$\alpha_{12}^* = \left.\frac{F_1^*}{V_2^*}\right|_{F_2^* = 0} \tag{6}$$

and

$$\alpha_{22}^* = \left.\frac{V_1^*}{V_2^*}\right|_{F_2^* = 0} \tag{7}$$

For either case the remaining two four-pole parameters may be calculated from equations (2) and (3) for symmetrical vibration isolators. While the second case is experimentally convenient it does not allow the determination of the vibration isolator properties under static load, and therefore the properties measured in this way will not be representative of those for the installed vibration isolator.

Thus, the usual method is to measure the four-pole parameters of a symmetrical vibration isolator under static load and with a blocked output. Under these conditions the four-pole parameters are given by equations (3)–(5) and

$$\alpha_{12}^* = \frac{\alpha_{11}^* \alpha_{22}^* - 1}{\alpha_{21}^*}. \tag{8}$$

2.2. ASYMMETRICAL VIBRATION ISOLATORS

Asymmetrical vibration isolators are those vibration isolators that do not behave in the same way if their inputs and outputs are interchanged. For asymmetrical vibration isolators, equation (3) is no longer valid and so additional information must be obtained. This has normally been done by reversing the vibration isolator in the test rig so that its input and output sides are interchanged [9]. Consider this reversed configuration and denote the input force and velocity by F_{1R}^* and V_{1R}^*, respectively, and the output force and velocity by F_{2R}^* and V_{2R}^* respectively. Equation (1) then becomes

$$\begin{bmatrix} F_{1R}^* \\ V_{1R}^* \end{bmatrix} = \begin{bmatrix} \alpha_{22}^* & \alpha_{12}^* \\ \alpha_{21}^* & \alpha_{11}^* \end{bmatrix} \begin{bmatrix} F_{2R}^* \\ V_{2R}^* \end{bmatrix}. \tag{9}$$

For the blocked situation, $V_{2R}^* = 0$ and so from equation (9),

$$\alpha_{22}^* = \left. \frac{F_{1R}^*}{F_{2R}^*} \right|_{V_{2R}^* = 0} \tag{10}$$

and

$$\alpha_{21}^* = \left. \frac{F_{1R}^*}{F_{2R}^*} \right|_{V_{2R}^* = 0}. \tag{11}$$

Equation (10) provides the additional relationship to determine α_{22}^*, and equation (11) may be used to experimentally check the value of α_{21}^*. For the unblocked situation, equations (1), (2) and (9) may be combined to give [10]

$$\alpha_{12}^* = \frac{F_1^* F_{1R}^* - F_2^* F_{2R}^*}{V_1^* F_{2R}^* + V_{2R}^* F_1^*}, \tag{12}$$

$$\alpha_{11}^* = \frac{F_1^* - \alpha_{12}^* V_2^*}{F_2^*}, \tag{13}$$

$$\alpha_{22}^* = \frac{F_2^* - \alpha_{12}^* V_1^*}{F_1^*}, \tag{14}$$

and

$$\alpha_{21}^* = \frac{V_1^* - \alpha_{22}^* V_2^*}{F_2^*}. \tag{15}$$

This approach of reversing the vibration isolator in the test rig assumes that the vibration isolator is bi-directional and it may be operated with its input and output interchanged. It cannot be used if the vibration isolator is uni-directional, i.e., if it operates in only one direction and interchanging its input and output is inadmissible.

3. FLOATING MASS METHOD

One indirect method of measuring the output force of a blocked vibration isolator uses a blocking mass supported on soft springs as the output termination [11]. It assumes that the mass is blocked, which introduces a lower frequency limit to the measurements. To remove this limit, Dickens and Norwood [12] proposed the floating mass method as an alternate measurement technique. This method removes the blocked assumption by treating the mass as floating and correcting for its velocity. The floating and blocking mass methods differ only at low frequencies, because both may be considered to be blocked at high frequencies.

The blocking mass can therefore be replaced with a smaller floating mass to provide higher acceleration levels on the output side of the vibration isolator. The floating mass should be sufficiently small so that its acceleration levels are large enough to be measured with confidence at low frequencies.

As a further improvement, Dickens and Norwood [13] proposed that the forces be measured directly instead of indirectly. This eliminates the measurement inaccuracies of the indirect method.

3.1. SYMMETRICAL VIBRATION ISOLATORS

For a symmetrical vibration isolator, equations (1) and (2) yield the four-pole parameters in terms of the input and output forces and velocities as

$$\alpha_{11}^* = \frac{F_1^* V_1^* + F_2^* V_2^*}{F_1^* V_2^* + F_2^* V_1^*}, \tag{16}$$

$$\alpha_{12}^* = \frac{(F_1^*)^2 - (F_2^*)^2}{F_1^* F_2^* + F_2^* V_1^*}, \tag{17}$$

$$\alpha_{21}^* = \frac{(V_1^*)^2 - (V_2^*)^2}{F_1^* V_2^* + F_2^* V_1^*}. \tag{18}$$

and equation (3).

3.2. ASYMMETRICAL VIBRATION ISOLATORS

For an asymmetrical vibration isolator, additional information is required and may be obtained using the reversal technique of section 2.2. In this case equations (12)–(15) are applicable.

4. TWO-MASS METHOD FOR MEASURING FOUR-POLE PARAMETERS

The four-pole parameters of a bi-directional asymmetrical vibration isolator may be determined using the reversal technique explained in section 2.2. If the vibration isolator cannot be turned upside down because of gravitational effects, then this method may only be used if the test rig can be modified, or a second rig constructed, to interchange the driving and blocking ends. An example of this type of vibration isolator is the self-levelling passive vibration isolator using oil to adjust its operating height [14]. Furthermore, the reversal technique cannot be used if the vibration isolator is asymmetrical and uni-directional.

The problem is to measure the four-pole parameters of a uni-directional asymmetrical vibration isolator under static load. It is assumed that the vibration isolator has pseudo-linear dynamic operation at and near its operating point, i.e., equation (1) may be considered to be valid. Equation (2) is derived from Maxwell's reciprocal deflections theorem, which applies for passive element. It therefore cannot be assumed to be true for an active vibration isolator. Equation (3) is only true for symmetrical vibration isolators. Therefore, the constraining equations (2) and (3) cannot be applied in this situation.

Following the floating mass concept of section 3, it is proposed that by using two different floating masses and direct force measurements the four-pole parameters for a uni-directional asymmetrical vibration isolator under static load may be determined [15]. This is termed the two mass method, and is described in the following.

Consider a uni-directional asymmetrical vibration isolator being tested under static load and terminated with a floating mass. Let its four-pole parameters be α^*_{11}, α^*_{12}, α^*_{21} and α^*_{22}, and suppose that it is tested with two floating masses of different mass. The test configurations are identical except for the floating mass, and produce two sets of data. Let the two floating masses be denoted as m_{21} and m_{22}, and let the corresponding forces and velocities be, respectively, denoted by the second subscripts 1 and 2. The four-pole parameters are assumed to be the same for both sets of data, and therefore the two matrix equations corresponding to equation (1) are

$$\begin{bmatrix} F^*_{11} \\ V^*_{11} \end{bmatrix} = \begin{bmatrix} \alpha^*_{11} & \alpha^*_{12} \\ \alpha^*_{21} & \alpha^*_{22} \end{bmatrix} \begin{bmatrix} F^*_{21} \\ V^*_{21} \end{bmatrix} \tag{19}$$

and

$$\begin{bmatrix} F^*_{12} \\ V^*_{12} \end{bmatrix} = \begin{bmatrix} \alpha^*_{11} & \alpha^*_{12} \\ \alpha^*_{21} & \alpha^*_{22} \end{bmatrix} \begin{bmatrix} F^*_{22} \\ V^*_{22} \end{bmatrix}. \tag{20}$$

Combining equations (19) and (11) yields

$$\begin{bmatrix} F^*_{11} \\ V^*_{11} \\ F^*_{12} \\ V^*_{12} \end{bmatrix} = \begin{bmatrix} F^*_{21} & V^*_{21} & 0 & 0 \\ 0 & 0 & F^*_{21} & V^*_{21} \\ F^*_{22} & V^*_{22} & 0 & 0 \\ 0 & 0 & F^*_{22} & V^*_{22} \end{bmatrix} \begin{bmatrix} \alpha^*_{11} \\ \alpha^*_{12} \\ \alpha^*_{21} \\ \alpha^*_{22} \end{bmatrix}. \tag{21}$$

Solving equation (12) for the four-pole parameters gives

$$\begin{bmatrix} \alpha^*_{11} \\ \alpha^*_{12} \\ \alpha^*_{21} \\ \alpha^*_{22} \end{bmatrix} = \frac{1}{F^*_{22}V^*_{21} - F^*_{21}V^*_{22}} \begin{bmatrix} -V^*_{22} & 0 & V^*_{21} & 0 \\ F^*_{22} & 0 & -F^*_{21} & 0 \\ 0 & -V^*_{22} & 0 & V^*_{21} \\ 0 & F^*_{22} & 0 & -F^*_{21} \end{bmatrix} \begin{bmatrix} F^*_{11} \\ V^*_{12} \\ F^*_{21} \\ V^*_{22} \end{bmatrix}. \tag{22}$$

Inspection of equation (13) shows that it is only valid if

$$F^*_{22}V^*_{21} \neq F^*_{21}V^*_{22}. \tag{23}$$

Note that the output of the vibration isolator cannot be blocked, since it would imply that $V^*_{21} = V^*_{32} = 0$ and equation (23) would not be true. However, one of the sets of data may be obtained under blocked conditions. The fundamental requirement is that the two sets of data be obtained under conditions of different output mobilities so that equation (23) is valid.

Dickens [15] has shown that for high frequencies the effective load at the output of the vibration isolator is the floating mass, and assumes that the instrumentation does not significantly affect the modal behaviour of the system over the frequency range of interest. Let the excitation and motion be sinusoidal. Consequently, for high frequencies,

$$F_{21}^{*} = \mathrm{j}\omega m_{21} V_{21}^{*} \tag{24}$$

and

$$V_{22}^{*} = \mathrm{j}\omega m_{22} V_{22}^{*}. \tag{25}$$

Equations (23)–(25) yield

$$m_{21} \neq m_{22} \tag{26}$$

Equation (26) is the necessary non-trival condition for the validity of equation (22). Using equations (22), (24) and (25) it may be shown that

$$\alpha_{11}^{*} = \frac{1}{m_{21} - m_{22}} \left(\frac{m_{21} V_{11}^{*}}{F_{21}^{*}} - \frac{m_{22} F_{12}^{*}}{F_{22}^{*}} \right), \tag{27}$$

$$\alpha_{12}^{*} = \frac{\mathrm{j}\omega m_{21} m_{22}}{m_{21} - m_{22}} \left(\frac{F_{12}^{*}}{F_{22}^{*}} - \frac{F_{11}^{*}}{F_{21}^{*}} \right), \tag{28}$$

$$\alpha_{21}^{*} = \frac{1}{m_{21} - m_{22}} \left(\frac{m_{21} V_{11}^{*}}{F_{21}^{*}} - \frac{m_{22} V_{12}^{*}}{F_{22}^{*}} \right) \tag{29}$$

and

$$\alpha_{22}^{*} = \frac{\mathrm{j}\omega m_{21} m_{22}}{m_{21} - m_{22}} \left(\frac{V_{12}^{*}}{F_{22}^{*}} - \frac{V_{11}^{*}}{F_{21}^{*}} \right). \tag{30}$$

From an experimental point of view, inspection of equations (27)–(30) shows that the absolute difference $|m_{21} - m_{22}|$ should be as large as possible. Also, it must be possible to measure the output velocities with confidence, which means that the masses m_{21} and m_{22} cannot be too large.

The importance of this proposed two-mass method is that the data may be obtained with the active vibration isolator operating in its normal arrangement and not reversed. All that is required are two floating masses of sufficiently different mass to produce different sets of data for substitution into equation (22). The only assumption made is that the four-pole parameters remain unchanged for the two floating masses. Consequently, equation (2) and (3) are not assumed.

The two-mass method is not limited to uni-directional asymmetrical vibration isolators. It may also be applied to uni-directional symmetrical, bi-directional symmetrical and bi-directional asymmetrical vibration isolators. Consequently, it may be regarded as a universal testing procedure applicable to uni-directional or bi-directional, and asymmetrical or symmetrical vibration isolators under static load. For example, commonly employed passive vibration isolators are normally symmetrical and bi-directional asymmetrical vibration isolators. From a strict point of view, the symmetrical concept cannot be applied to a uni-directional vibration isolator because its input and output cannot be interchanged.

Note that for passive vibration isolators, equation (2) is valid, and equation (3) is valid for uni-directional and bi-directional symmetrical vibration isolators. The two-mass method provides additional information that may be used as a check on the quality of the four-pole parameters obtained.

5. VIBRATION ISOLATOR TEST FACILITY

A vibration isolator test facility was developed and tested [15, 16], and includes a test rig schematically depicted in Figure 2. It employs the floating mass method and direct force measurements of section 3, and may apply the two-mass method of section 4.

Vibration isolators are commonly operated in the compression mode, and this is the configuration primarily tested by the vibration isolator test facility. Vibration isolators operated in other configurations involving lateral and transverse orientations may also be tested by the vibration isolator test facility using two vibration isolators of the same type. These include inclined orientations employing axial and shear modes of the rubber elements.

The test rig is designed to test the axial i.e., vertical direction, which is normally the primary direction of interest. The vibration isolator under test is mounted between two large masses, and static load is applied by air-bags positioned above and beneath the two masses. The dynamic load is applied by an electro-dynamic shaker via the excitation mass, and the floating mass provides a reaction force to the output force of the vibration isolator. The rig has two supporting frames, an upper frame that supports the shaker and a lower frame that provides the reaction forces for the upper static loading

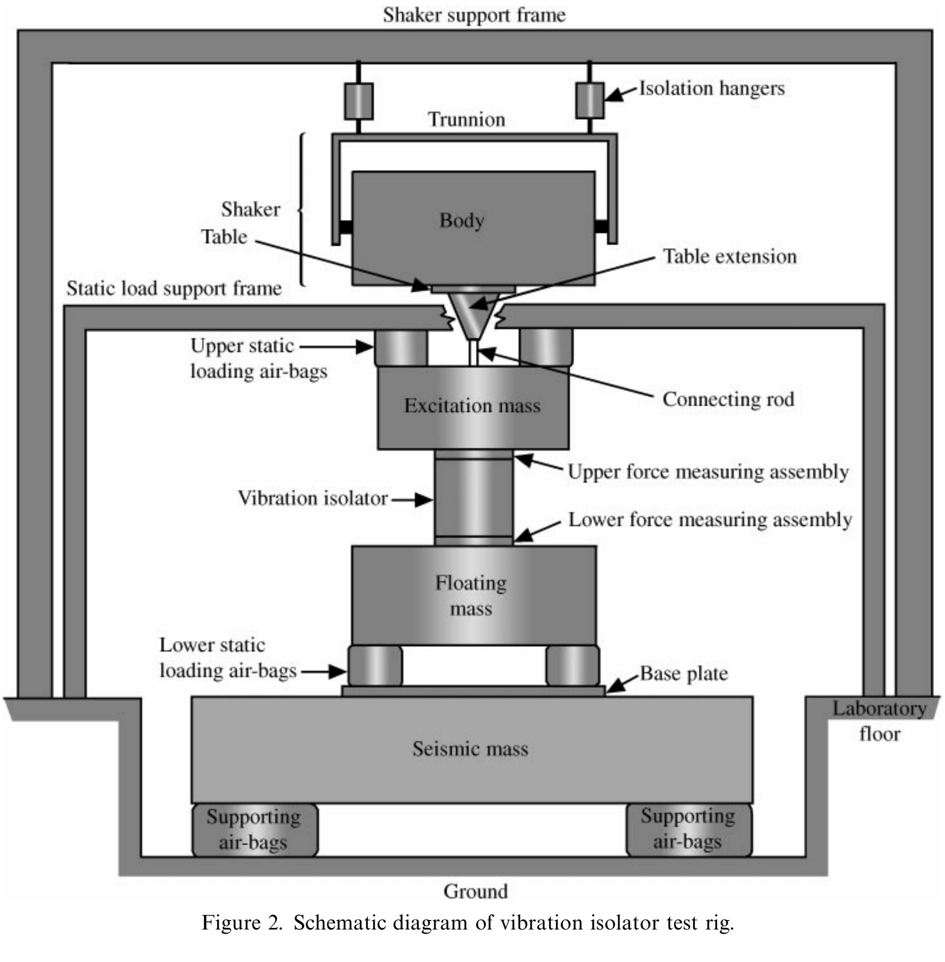

Figure 2. Schematic diagram of vibration isolator test rig.

air-bags. Air-bags are used to provide the static load as the static force can be easily adjusted, while at the same time giving a degree of isolation between the mass and the supporting structures.

The excitation mass is laterally constrained by chains attached to the lower frame. The upper and lower frames are, respectively, termed the shaker support frame and the static load support frame. The lower static loading air-bags sit on a base plate mounted on top of a seismic mass.

Two frames are used to reduce coupling between the static loading structure and the shaker. The shaker is decoupled from its supporting frame by four isolation hangers and drives the excitation mass through a single centrally located connecting rod. The seismic mass is a block of reinforced concrete of mass 22 t supported on air-bags, and decouples the floating mass from the laboratory floor.

The input and output velocities of the vibration isolator are measured using accelerometers attached to the excitation and floating masses.

The input force to the vibration isolator is the dynamic force applied by the excitation mass to the vibration isolator and is measured directly by a force-measuring assembly. The output force is the dynamic force applied by the vibration isolator to the floating mass and is determined directly by a force-measuring assembly. Each force-measuring assembly consists of a parallel arrangement of eight force transducers.

6. EXPERIMENTS AND DISCUSSION

The two-mass method was employed to determine the four-pole parameters of a simulated uni-directional asymmetrical vibration isolator. The results obtained were compared with the calculated four-pole parameters. The experiments were conducted in the vibration isolator test facility.

The vibration isolator had a homogeneous rubber element and two end plates of equal mass with an additional plate attached to one end. Thus, the vibration isolator may be treated as a rubber element and two unequal end masses, and hence was asymmetrical. Although it was passive and bi-directional, it simulated a uni-axial type by restricting it to operate in any one direction.

The vibration isolator was tested using two floating masses. The same test method and configuration was implemented in both situations except for the floating mass. Prior to testing, the vibration isolator was conditioned at $20 \pm 1^{\circ}$C for at least 18 h and the tests were conducted at the same temperature. Prior to temperature conditioning, the vibration isolator was mechanically conditioned by loading and unloading it six times up to the maximum testing static plus dynamic strain, plus 10%.

The static force applied to the vibration isolator yielded a compression ratio of 0·90. A linear swept sine test was conducted from 20 to 400 Hz with 0·5 Hz steps. The maximum longitudinal strain amplitude in the rubber element was 1×10^{-3}, and consequently the complex normal modulus of the rubber element should remain approximately constant during the testing [17, 18].

The tests using the two floating masses produced two data sets of the input and output forces and velocities. Subsequently, the application of equation (22) yielded the four-pole parameters of the vibration isolator. These are termed the measured four-pole parameters.

The four-pole parameters of the vibration isolator were also calculated using the following procedure, and are called the calculated four-pole parameters. The vibration isolator comprised a symmetrical vibration isolator and a plate. The plate did not have any modal behaviour within or near the frequency range of interest, and so may be treated as a rigid mass. Consequently, the four-pole parameters of the asymmetrical vibration isolator were calculated from the four-pole parameters of the symmetrical vibration isolator and the rigid mass. The four-pole parameters of the symmetrical vibration isolator were measured using the floating mass method [14]. The four-pole parameters of the rigid mass were calculated from the measured mass [1].

The measured and calculated four-pole parameters for the vibration isolator are compared in Figures 3–6. The measured and calculated four-pole parameters show good agreement, particularly for the four-pole parameters α^*_{11} and α^*_{21}. As expected for an asymmetrical vibration isolator, the four-pole parameters α^*_{11} and α^*_{22} are not identical. The key difference occurs at the first anti-resonance, which is associated with the resonance of the end plates on the rubber element. The frequency of this anti-resonance occurs at

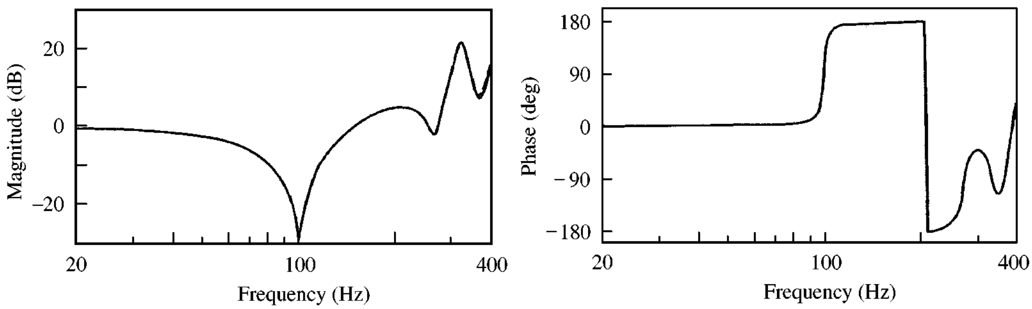

Figure 3. Four-pole parameter α^*_{11} for uni-directional asymmetrical vibration isolator. ——, two-mass method; – – –, calculated.

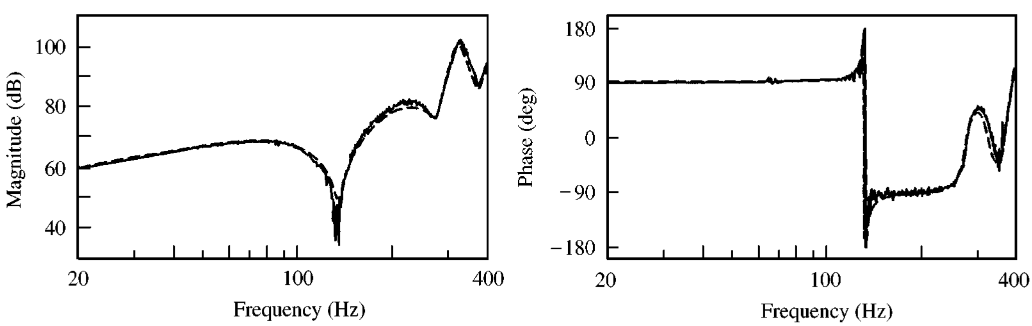

Figure 4. Four-pole parameter α^*_{12} for uni-directional asymmetrical vibration isolator. ——, two-mass method; – – –, calculated.

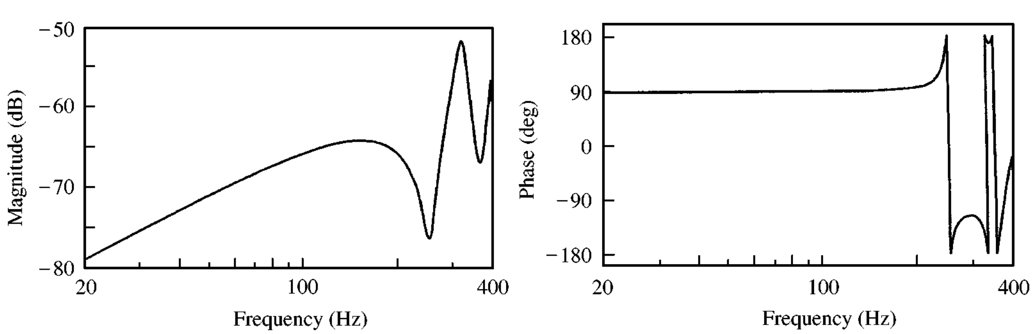

Figure 5. Four-pole parameter α^*_{21} for uni-directional asymmetrical vibration isolator. ——, two-mass method; – – –, calculated.

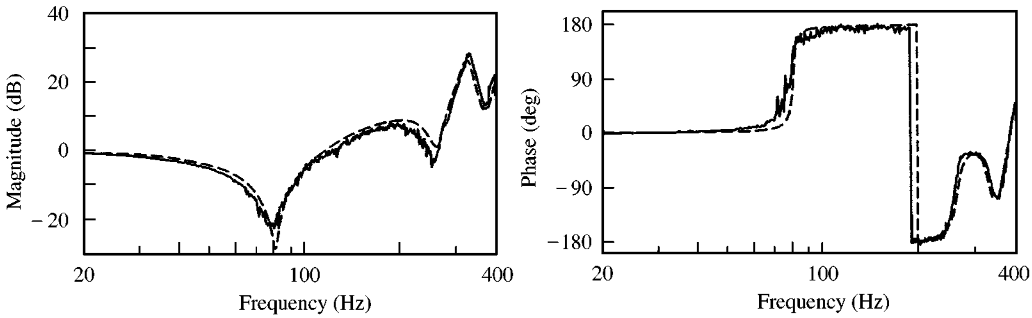

Figure 6. Four-pole parameter α^*_{22} for uni-directional asymmetrical vibration isolator. ——, two-mass method; – – –, calculated.

approximately 100 and 80 Hz for the four-pole parameters α^*_{11} and α^*_{22} respectively. Another difference is the increased magnitude of the four-pole parameter α^*_{22} compared to α^*_{11} for frequencies above the anti-resonance. These differences are as expected from a theoretical analysis.

7. CONCLUSION

The usual methods for measuring the four-pole parameters of a vibration isolator under static load rely on a blocked arrangement. Asymmetrical vibration isolators require additional information which is normally obtained by reversing the vibration isolator in the test rig so that its input and output sides are interchanged. This approach is inapplicable if the vibration isolator is also uni-directional, and generally vibration isolators incorporating some from of active control are example of uni-directional vibration isolators.

The two-mass method has been proposed to measure the four-pole parameters of a uni-directional asymmetrical vibration isolator under static load, by using two different floating masses. The only assumptions made are that the system is linear and that the four-pole parameters remain unchanged for the two floating masses. Consequently, equations (2) and (3) are not assumed, and the method may be regarded as a universal testing procedure.

The two-mass method was satisfactorily employed to determine the four-pole parameters of a simulated uni-directional asymmetrical vibration isolator. This demonstrated the validity of the method.

It may be regarded as a universal testing procedure applicable to uni-directional or bi-directional, and asymmetrical or symmetrical vibration isolators under static load.

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