METHODS TO MEASURE THE FOUR-POLE PARAMETERS OF VIBRATION ISOLATORS

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ABSTRACT: This paper describes the background to the development of a test facility and associated methods for measuring the four-pole parameters of vibration isolators under service conditions. The experimental methods of measuring the four-pole parameters of passive and active vibration isolators are discussed. Improvements to the measurement techniques are outlined, and implemented in a test rig capable of testing passive, semi-passive and active vibration isolators with feedback control.

1. INTRODUCTION

Vibration isolators are important vibration control elements used in industrial, maritime and military applications. For example, the control of vibration and structure borne noise transmission is of paramount importance in naval surface ships and submarines to decrease the probability of detection by unfriendly sonar receivers. The acoustic signature management of naval vessels at frequencies up to about 2 kHz is crucial, and of particular concern are the longitudinal standing waves that occur in the rubber elements of vibration isolators. These standing waves significantly reduce the effectiveness of the vibration isolators and may cause an unwanted increase in the radiated underwater noise.

The dynamic properties of a vibration isolator primarily depend upon its exciting frequency and amplitude, static load and temperature. Thus its properties should be measured over an appropriate frequency range and under its service load and temperature.

2. METHODS OF MEASURING THE FOUR-POLE PARAMETERS

The four-pole parameters may be used to describe the dynamic performance of a vibration isolator [1]. A vibration isolator may be dynamically represented as a pseudo-linear system, where the dynamic force and velocity at its input are denoted by $F_1^\bullet$ and $V_1^\bullet$ respectively, and the dynamic force and velocity at its output by $F_2^\bullet$ and $V_2^\bullet$ respectively. Complex numbers are represented with the superscript $^\bullet$, and real numbers are not superscripted. Let $\alpha_{11}^\bullet$, $\alpha_{12}^\bullet$, $\alpha_{21}^\bullet$ and $\alpha_{22}^\bullet$ denote the four-pole parameters, which are complex, time invariant functions of the frequency. The four-pole parameters are defined by

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

Vibration isolators may be passive, semi-active or active. Passive vibration isolators have only passive elements, semi-active vibration isolators have passive and active elements, and active vibration isolators have only active elements. A passive element includes a resilient material such as a rubber, metal spring, cork, felt or air-bag. An active element incorporates an actuator designed to supply a dynamic force in response to the signal from a controller, which may operate on the feedback or feedforward principle. Hansen and Snyder [2] describe various actuators, including pneumatic, proof mass, electrodynamic, electromagnetic, magnetostrictive, shape memory alloy, piezoelectric (electrostrictive) and electrorheological fluid types.

2.1. Passive vibration isolators

Passive vibration isolators are bi-directional in nature. Assuming that Rayleigh's reciprocity theorem in the form of Maxwell's reciprocal deflections theorem applies to the resilient element of a passive vibration isolator, it may be shown that [1]

$$\alpha_{11}^\bullet\alpha_{21}^\bullet - \alpha_{12}^\bullet\alpha_{21}^\bullet = 1 \tag{2}$$

An experimentally convenient arrangement has the vibration isolator with a blocked output. This yields

$$\alpha_{11}^\bullet = \left.\frac{F_1^\bullet}{F_2^\bullet}\right|_{V_2^\bullet=0} \tag{3}$$

and

$$\alpha_{21}^\bullet = \left.\frac{V_1^\bullet}{F_2^\bullet}\right|_{V_2^\bullet=0} \tag{4}$$

Equation (2) yields

$$\alpha_{12}^\bullet = \frac{\alpha_{11}^\bullet\alpha_{22}^\bullet - 1}{\alpha_{21}^\bullet} \tag{5}$$

2.1.1. Symmetrical vibration isolators

Symmetrical vibration isolators are defined as those that behave the same if their input and output ends are interchanged. For such a vibration isolator it may be shown that [3]

$$\alpha_{11}^\bullet = \alpha_{22}^\bullet \tag{6}$$

Therefore the four-pole parameters of a symmetrical vibration isolator may be determined by measuring the input force, input velocity and output force of the blocked vibration isolator, and applying equations (3) to (6) [3].

2.1.2. Asymmetrical vibration isolators

Asymmetrical vibration isolators are those vibration isolators that do not behave the same if the input and output ends are interchanged. For asymmetrical vibration isolators, equation (6) is no longer valid and so additional information must be obtained. This is normally been done by reversing the vibration isolator in the test rig so that its input and output ends are interchanged [4]. Consider this reversed configuration and denote the input force and velocity by F_{1R}^* and V_{1R}^* respectively, and the output force and velocity F_{2R}^* and V_{2R}^* respectively. Equation (1) then becomes

$$\begin{bmatrix} F_{1R}^* \\ V_{1R}^* \end{bmatrix} = \begin{bmatrix} \alpha_{22}^* & \alpha_{12}^* \\ \alpha_{21}^* & \alpha_{11}^* \end{bmatrix} \begin{bmatrix} F_{2R}^* \\ V_{2R}^* \end{bmatrix} \tag{7}$$

For the blocked situation, $V_{2R}^* = 0$ and so from equation (7),

$$\alpha_{22}^* = \left. \frac{F_{1R}^*}{F_{2R}^*} \right|_{V_{2R}^*=0} \tag{8}$$

and

$$\alpha_{22}^* = \left. \frac{F_{1R}^*}{F_{2R}^*} \right|_{V_{2R}^*=0} \tag{9}$$

Equation (8) provides the additional relationship to determine α_{22}^*, and equation (9) may be used to experimentally check the value of α_{21}^*. This technique is called the blocked reversal method, and requires the measurement of the input force, input velocity and output force of the blocked vibration isolator in its normal and reversed configurations.

The reversal technique may also be applied to the unblocked situation, where $V_2^* \neq 0$ and $V_{2R}^* \neq 0$. For this unblocked situation, equations (1), (2) and (7) may be combined to give [5],

$$\alpha_{12}^* = \frac{F_1^* F_{1R}^* - F_2^* F_{2R}^*}{V_1^* F_{2R}^* + V_{2R}^* F_1^*}, \tag{10}$$

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

$$\alpha_{22}^* = \frac{F_2^* + \alpha_{12}^* V_1^*}{F_1^*} \tag{12}$$

and

$$\alpha_{21}^* = \frac{V_1^* - \alpha_{22}^* V_2^*}{F_2^*} \tag{13}$$

This technique is called the unblocked reversal method, and requires the measurement of the input force and velocity, and output force and velocity of the unblocked vibration isolator in its normal and reversed configurations.

The blocked reversal method is experimentally simpler than the unblocked reversal method, because it does not require the measurement of the output velocity. These methods of reversing the vibration isolator in the test rig assume that the vibration isolator is bi-directional and may be operated with its input and output ends interchanged.

2.2. Active vibration isolators

Generally vibration isolators incorporating some form of active feedback control are examples of uni-directional vibration isolators. A vibration isolator is defined to be uni-directional if it operates in only one direction and interchanging its input and output ends is inadmissible. The methods described in Sections 2.1.1 and 2.1.2 cannot be used if the vibration isolator is uni-directional.

Feedback systems may be described in terms of the four-pole parameters, provided that the feedback signal may be expressed as a linear function of the input or output forces or velocities of the active vibration isolator. Feedforward systems do not have such linear relationships, and consequently are not amenable to four-pole parameter characterisation.

The requirement is to measure the four-pole parameters of a uni-directional vibration isolator that may be symmetrical or asymmetrical, 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 and applies for passive elements. It therefore cannot be assumed to be true for an active vibration isolator. Equation (6) is only true for symmetrical vibration isolators. Therefore the constraining equations (2) and (6) cannot be applied in this situation.

Dickens and Norwood proposed the two mass method for measuring the four-pole parameters of uni-directional vibration isolators [6]. They showed that the method may be regarded as a universal testing method, and applicable to symmetrical, asymmetrical, uni-directional and bi-directional vibration isolators. Dickens presented experimental data for a uni-directional asymmetrical vibration isolator [7].

The two mass method measures the input and output forces and velocities of the unblocked vibration isolator with its output terminated by two different mobilities. The test configurations are identical except for the output terminations, and produce two sets of data. The data is then used to determine the four-pole parameters of the vibration isolator. Let the two output terminations have mobilities of H_{21} and H_{22}, and let the corresponding forces and velocities be respectively denoted by the second subscripts 1 and 2. It may be shown that the four-pole parameters are given by [6]

$$\begin{bmatrix} \alpha_{11}^* \\ \alpha_{12}^* \\ \alpha_{21}^* \\ \alpha_{22}^* \end{bmatrix} = \frac{1}{F_{22}^* V_{21}^* - F_{21}^* V_{22}^*} \begin{bmatrix} -V_{22}^* & 0 & V_{21}^* & 0 \\ F_{22}^* & 0 & -F_{21}^* & 0 \\ 0 & -V_{22}^* & 0 & V_{21}^* \\ 0 & F_{22}^* & 0 & -F_{21}^* \end{bmatrix} \begin{bmatrix} F_{11}^* \\ V_{11}^* \\ F_{12}^* \\ V_{12}^* \end{bmatrix} \tag{14}$$

By definition, the mobility equations are

$$V_{21}^* = H_{21}^* F_{21}^* \tag{15}$$

and

$$V_{22}^* = H_{22}^* F_{22}^* \tag{16}$$

Substituting equations (15) and (16) into equation (14) gives

$$\begin{bmatrix} \alpha_{11}^* \\ \alpha_{12}^* \\ \alpha_{21}^* \\ \alpha_{22}^* \end{bmatrix} = \frac{1}{\Delta^*} \begin{bmatrix} -H_{22}^* F_{22}^* & 0 & H_{21}^* F_{21}^* & 0 \\ F_{22}^* & 0 & -F_{21}^* & 0 \\ 0 & -H_{22}^* F_{22}^* & 0 & H_{21}^* F_{21}^* \\ 0 & F_{22}^* & 0 & -F_{21}^* \end{bmatrix} \begin{bmatrix} F_{11}^* \\ V_{11}^* \\ F_{12}^* \\ V_{12}^* \end{bmatrix} \quad (17)$$

where

$$\Delta^* = F_{21}^* F_{22}^* \left(H_{21}^* - H_{22}^* \right) \quad (18)$$

Clearly for equation (14) to be valid $\Delta^* \neq 0$, which implies that the outputs cannot be free and the two output terminations cannot be equal. Dickens and Norwood implemented the method by using two different blocking masses in the vibration isolator test rig [6].

3. PREVIOUS WORK

This Section reviews the work undertaken previous to the AMRL studies, which are covered in Section 4.

After their introduction to the analysis of dynamic mechanical systems by Molloy [1], the four-pole parameters have been applied to vibration isolation by other researchers, Snowdon [3, 8, 4], Veit [9], Klyukin [10] termed transfer matrix, Meltzer and Melzig-Thiel [5], Vakakis [11], Jacobsen and Ohlrich [12], Norwood [13], Hixson [14], Ha et al [15], Easwaran et al [16] and Ha and Kim [17]. Of these researchers, Molloy, Snowdon, Vakakis, Hixson and Easwaran et al gave theoretical studies with no experimental work. Ha and Kim presented a theoretical investigation with experimental results for a beam structure. Snowdon [4] referred to experimental work by Schloss [18]. The remaining researchers and Schloss [18] gave results of experiments that were all conducted at the ambient temperatures, and are discussed in the following paragraphs.

Veit [9] investigated the sound transmission attenuation through the liquid and walls of compensators, which are rubber bellows for coupling together pipes. He showed experimental plots of the magnitudes of the four-pole parameters over the approximate frequency range from 100 Hz to 3 kHz.

Klyukin [10] presented experimental data of the force transmissibilities of vibration isolators over the frequency range from 60 Hz to 5.44 kHz, in the form of octave bands.

Snowdon [4] proposed that the testing apparatus of Schloss [18] be utilised to measure the four-pole parameters of vibration isolators, and is discussed in Section 4.

Meltzer and Melzig-Thiel [5] used a test rig that could measure the four-pole parameters of a small vibration isolator at static loads up to 1 kN. Their frequency range of interest was up to 1 kHz and they presented data for a vibration isolator over the approximate frequency range from 70 Hz to 1.25 kHz.

Jacobsen and Ohlrich [12] tested a small vibration isolator by assuming that its dynamic properties were negligibly affected by static load, and consequently used the experimentally attractive method of a free output [3]. They presented plots of the four-pole parameters α_{11}^*, α_{12}^* and α_{21}^* in third octave bands from 40 Hz to 12.5 kHz, and stated that the data were not reliable at high frequencies.

Norwood [13] measured the characteristics of a small, unloaded vibration isolator over the frequency range from 4 Hz to 3 kHz, and presented them in narrow-band plots of the magnitudes of the four-pole parameters.

Ha et al [15] investigated the vibration transmission from the engine through the body to the steering wheel of a car. They presented plots of the magnitude of the four-pole parameter α_{21}^* over the frequency range from 0 to 50 Hz.

In summary, only Meltzer and Melzig-Thiel [5] have presented results of the four-pole parameters for statically loaded vibration isolators. They presented data for a small vibration isolator of rubber mass 56 g over the approximate frequency range from 70 Hz to 1.25 kHz.

4. AMRL STUDIES

To investigate vibration isolators used for naval applications, it was necessary for AMRL to develop a vibration isolator test facility that was capable of measuring the four-pole parameters of statically loaded large vibration isolators over the frequency range from 5 Hz to 2 kHz, and temperature range from 10 to 60°C. The required static loads were from 1 to 30 kN.

The literature search of Section 3 indicated that consideration should be given to the methods used by Meltzer and Melzig-Thiel [5], and proposed by Snowdon [4] using the testing apparatus of Schloss [18]. Meltzer and Melzig-Thiel were the only researchers to measure the four-pole parameters of a statically loaded vibration isolator.

Meltzer and Melzig-Thiel [5] used the test rig shown in Figure 1. Their test rig transmitted the static load to the vibration isolator via the moving element of the shaker, and the maximum static load was 1 kN. Consequently their test rig was only suitable for small vibration isolators. However, AMRL wished to test large vibration isolators, and so the test rig of Meltzer and Melzig-Thiel was not suitable for the current study.

Schloss [18] used the test rig shown in Figure 2 to measure the blocked transfer impedance and blocked driving point impedance of vibration isolators under static load. Results were presented over the approximate frequency range from 20 Hz to 2 kHz for a vibration isolator under a static load of 3.6 kN. Schloss claimed to have measured frequencies up to 5 kHz

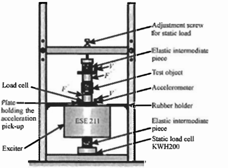

Figure 1: Test rig of Meltzer and Melzig-Thiel, after Meltzer and Melzig-Thiel (1980)

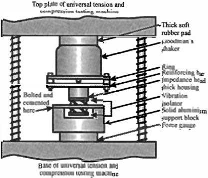

Figure 2: Proposed test rig of Snowdon, after Schloss (1965)

and static loads up to 44 kN. His test rig assumed a blocked output and measured the input and output forces, and input acceleration. Snowdon [4] proposed using the test rig of Schloss to measure the four-pole parameters, by also assuming a blocked output and measuring the input and output forces, and input acceleration. This method of using a blocked output was experimentally convenient, and consequently the investigation of measurement methods in this study began with a developmental test rig that utilised a blocked output and measured the input and output forces, and input acceleration.

4.1. Developmental test rig

To study techniques for measuring the four-pole parameters, a developmental test rig was initially required. It was required to measure dynamic forces, either indirectly or directly. The measurement of the direct forces of large vibration isolators at high frequencies is experimentally difficult, because of the large vibration isolator masses and forces involved. The indirect method infers the forces from other measurements, and it is experimentally convenient to determine the forces by considering inertial forces calculated from acceleration measurements. Hence the indirect method was initially incorporated.

Thus a developmental test rig was required that provided a blocked output and measured the indirect input and output forces, and input acceleration. Verheij [19-20] described a method for measuring the indirect blocked output force. He developed a method for determining the blocked apparent mass of a statically loaded vibration isolator. The Institute of Applied Physics (TPD) test facility is based on Verheij's work and is capable of characterising vibration isolators over the approximate frequency range from 20 Hz to 2 kHz with static loads applied hydraulically up to 1 MN [21]. However, the characterisation is in terms of the apparent mass and dynamic stiffness, and not the four-pole parameters. The results are presented as third-octave band plots. Notwithstanding, the current study was commenced using Verheij's method of indirectly measuring the blocked output force.

A test rig that could be made suitable by modification, was the test rig developed by Farquharson [22]. Farquharson developed a test rig based on the measurement method of Verheij, and designed to measure the blocked apparent mass and blocked transfer mobility, i.e. blocked four-pole parameter α_{21}^{*}, of a vibration isolator under static load. It measured the indirect output force and input acceleration. No experimental results were presented because the commissioning results were unsatisfactory due to structural resonances and flanking vibration transmissions.

The type of test rig used by Schloss shown in Figure 2 is prone to the same measurement problems as Farquharson's test rig emanating from structural resonances and flanking vibration transmissions. The parameter of concern for Schloss's test rig is the output force. The output is assumed to be blocked and the output force is measured directly. The machine used by Schloss was the screw type designed for quasi-static tests, and would have numerous lightly damped modes throughout and near the frequency range of interest. The reaction forces transmitted by the shaker to the frame of the test rig would excite some frame modes in the frequency range of interest, which may affect the measurement of the output force. Also the reaction forces transmitted from the shaker may generate a flanking vibration path via the frame to the output force gauge. Additionally, Schloss does not specify the method of supporting the test rig, and the effect of ground borne vibrations on the measurement was not mentioned.

In the measurement of the output force, the test rig of Farquharson had one stage of vibration isolation via air-bags located between the output force measuring mass and the frame of the test rig, which the test rig of Schloss did not have. Even so, it was found necessary to modify the test rig of Farquharson to reduce the effect of the structural resonances of the frame of the test rig, flanking vibration transmissions and the ground borne vibrations. The modification to reduce the effect of the structural resonances and flanking transmissions was realised by supporting the shakers with soft vibration isolators supported from a separate frame to the frame enclosing the test vibration isolator. The modification to reduce the effect of the ground borne vibrations was brought about by mounting the test rig on a large seismic mass supported on air-bags, instead of the laboratory floor.

The modified and improved test rig is termed the developmental test rig, and could measure the four-pole parameters of a vibration isolator under static load [23-25]. It measured the indirect input and output forces, and input acceleration, Figure 3. It could measure up to a frequency of 1 kHz, and was excited by a pair of shakers with a combined

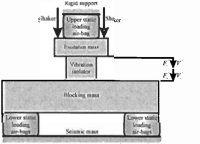

Figure 3: Schematic diagram of develpmental test rig.

force capability of 200 N [25]. Improvements to the measurement technique were investigated using the developmental test rig, and are discussed in Sections 4.2 to 4.5.

4.2. Blocking and Floating Masses

The developmental test rig used Verheij's method to measure the output force. The blocking mass was supported on soft mounts, and was assumed to be effectively blocked above a lower frequency limit. However, the blocking mass still had a small but measurable acceleration that could be used to determine the blocked output force on the vibration isolator, termed the indirect output force measurement.

The limitations of the blocked mass method were the imposition of a lower frequency limit dependent on the modal behaviour of the masses, and a limit on the upper frequency caused by the requirement to measure a small acceleration of a large mass. Dickens and Norwood [6] proposed an alternate measurement method, called the floating mass method, in order to overcome these deficiencies. This method does not assume that the blocking mass in Figure 3 is blocked, but rather considers it to be floating and corrects for its velocity. The floating mass method reduces the lower frequency limit of measurements. It is therefore possible to use a lighter blocking mass, since the lower frequency limit is not determined by the blocking mass.

4.3. Force Measurement

The input and output forces to the vibration isolator may be measured by the indirect or direct methods. The indirect input force is calculated by measuring the input force to the excitation mass and its acceleration, and then subtracting the inertial force of the excitation mass from its input force. The indirect output force is determined by measuring the acceleration of the blocking mass and calculating its inertial force.

The direct force method measures the forces directly by transmitting the input and output forces using force transducers mounted in force measuring assemblies [7]. The inertial effects of associated masses, such as mounting end plates, are accounted for by measuring their accelerations.

Dickens and Norwood [24] studied the direct and indirect force measurements. They found that the error magnitude of the input force measured indirectly was significant for high frequencies, and that conversely the error magnitude for the indirect measurement of the output force was significant for low frequencies. Use of the indirect measurement imposed a lower frequency limit on the input and output force measurement, which was primarily determined by the modal behaviour of the blocking mass at low frequencies. In general, the method of using indirect input and output force measurements was inaccurate, and generated significant errors in the measured four-pole parameters. The accuracy of the direct force measurement was predominantly determined by the intrinsic precision of the force transducers, and was fundamentally more accurate than the indirect method. Consequently, Dickens and Norwood proposed the direct measurement of the input and output forces. If the direct input and output forces were measured, then there was no lower frequency limit of measurements imposed by the modal behaviour of the masses.

Verheij [20] was primarily concerned with measuring the blocked apparent mass of the vibration isolator defined as the output force divided by the input acceleration, and related to the four-pole parameter . The results derived in this way were not significantly affected by the error in the input force, and were mainly affected by the errors in the blocked mass assumption as explained by Dickens and Norwood [6]. At lower frequencies it was sufficient to use this to describe the vibration isolator performance, but as the frequency increases the other four-pole parameters become important in the determination of the vibration isolator effectiveness.

4.4. Correction for Velocity Errors Introduced by Force Measuring Assemblies

To measure the input and output direct forces, force measuring assemblies were introduced serially into the system and so their effect on the modal behaviour of the system needed to be considered [7]. Their effect was to produce inaccuracies in the measurement of the velocities at high frequencies, since the measuring accelerometers were attached to the excitation and blocking masses and not the ends of the vibration isolator, Figure 4. This also introduced errors into the inertial force corrections to the direct forces, to account for the associated masses such as the end plates of the force measuring assemblies.

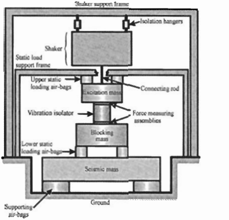

Figure 4: Schematic diagram of vibration isolator test rig.

To be able to measure with confidence up to 2 kHz, a method was required to account for these inaccuracies introduced into the measurement of the velocities. If the velocities were correctly measured, then so also were the direct forces. One technique was to actually measure the accelerations of the ends of the vibration isolator. However, this was practically difficult because of space restrictions and the necessity to have large sensitive accelerometers to measure the small output motions.

Another approach was to separately characterise the force measuring assemblies, and then correct for their influence on the measured velocity data. This latter approach was proposed and practically demonstrated by Dickens [7]. It was termed the method of correcting direct force measurements. This method removed the modal limitations of the force measuring assemblies used for the direct force measurement, and extended the upper frequency limit of measurements. The upper frequency limit was then governed by the ability of the instrumentation to measure forces and accelerations with confidence, which in turn was practically dictated by the force capability of the shaker or shakers.

4.5. Universal Testing Method

As discussed in Section 2.2, the two mass method is a universal test method suitable for passive, semi-active and active vibration isolators with feedback control.

4.6. Vibration isolator test facility

A vibration isolator test rig was developed that incorporated the floating mass method, measured the direct forces and implemented the method of correcting direct force measurements [7, 26, 27]. The static load was applied to the vibration isolator by the upper and lower static loading air-bags, Figure 4. The test rig had two frames with constrained layer damping, air-bags, isolation hangers and a 22 t seismic mass to minimise modal and coupling influences, and flanking and ground borne vibration transmissions. The test rig formed part of the vibration isolator test facility and was capable of applying the two mass method. The vibration isolator was enclosed within a temperature enclosure that maintained a constant temperature. The facility was demonstrated to be capable of measuring the four-pole parameters of small and large vibration isolators over the frequency range from 5 Hz to 2 kHz, with static loads over the range from 1 to 30 kN and over the temperature range from 6 to 60°C. Details of the facility [7] are to be published elsewhere.

The facility is capable of implementing the unblocked reversal method and the two mass method, Sections 2.1.2 and 2.2. Vibration isolators in vertical and inclined orientations can be tested. By using two vibration isolators of the same type, the facility can also be used to measure their lateral four-pole parameters. It is capable of testing symmetrical, asymmetrical and uni-directional asymmetrical vibration isolators.

5. CONCLUSIONS

A passive vibration isolator is bi-directional, and its four-pole parameters may be conveniently measured experimentally with its output end blocked. If it is symmetrical, then it is sufficient to measure its input force, input velocity and output force. If the vibration isolator is asymmetrical then it is necessary to use the blocked or unblocked reversal methods. The blocked reversal method requires the measurement of the input force, input velocity and output force of the blocked vibration isolator in its normal and reversed configurations, whereas the unblocked reversal method also requires the measurement of the output velocity.

The methods of measuring the four-pole parameters of passive vibration isolators are not applicable to active vibration isolators. A suitable technique for measuring the four-pole parameters of active vibration isolators with feedback control is the two mass method, which may be regarded as a universal method and is suitable for symmetrical, asymmetrical, uni-directional and bi-directional vibration isolators.

A vibration isolator test facility has been developed at AMRL that incorporated the floating mass method, measured the direct forces and implemented the method of correcting direct force measurements. It was demonstrated to be capable of measuring the axial and lateral four-pole parameters of small and large vibration isolators under static loads and controlled temperatures, in vertical and inclined orientations. The facility is capable of implementing the unblocked reversal method and the two mass method. It is capable of testing symmetrical, asymmetrical and uni-directional asymmetrical vibration isolators, including passive, semi-active and active elements with feedback control.

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