VIBRATION ISOLATION – EXPLORING THE FOUNDATIONS

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Introduction

Effective vibration isolation of machinery is important in many applications. Springs or rubber like materials are often used as mounts for vibrating machinery in order to reduce the transmission of vibrations to the supporting structure. These isolators are normally selected by ensuring that the natural frequency of the mounted system is well below the frequencies of the exciting forces which arise when the machinery is operating. This design method is based on a simple model[1] which approximates the machine as a lumped mass supported on a rigid foundation by an idealised linear spring and damper, Figure 1.

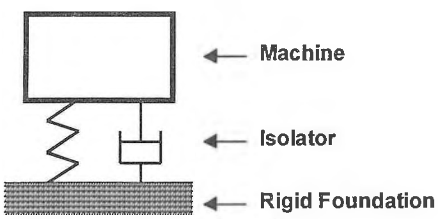

Figure 1 Simple Model of Vibraion Isolation

While this simple approach to the design machinery isolation works well in many instances, there are applications where a more sophisticated approach is needed in order to achieve desired levels of isolation. Some factors which limit the application of the above simple model are given below.

- Foundations are often far from being perfectly rigid. For example a rooftop air conditioning unit is often placed on a relatively light and flexible roof leading to poor isolation.
- The behaviour of the isolator may not be well described by the simple spring and damper. At higher frequencies, the mass of the isolator becomes important and can lead to wave effects and internal resonances within the isolator.
- The machine itself may be far from rigid. The attachment points of the isolators may have significant flexibility, especially at higher frequencies.
- It may not be appropriate to approximate a machine as a point-like mass. Any machine is three-dimensional and may have unevenly distributed mass. It can be vibrating in several directions at once and may have rotational modes of vibration as well. This aspect of isolation design can sometimes be treated by considering each independent mode of linear or rotational vibration separately with repeated applications of the basic theory.

This paper describes research work which explores the first of the above factors, the flexibility of the foundation. In particular, the importance of the size of the contact area between an isolator and its foundation is examined.

The measure of flexibility used here is mobility, M, defined as the ratio of the complex amplitudes of the time varying velocity, V, to the time varying force, F, at the point of application of the force on

$$M = \frac{V}{F}$$

a body. All terms are expressed as functions of frequency so that in general the mobility of a structure or foundation varies in both amplitude and phase with the frequency of the applied excitation. When a foundation is near rigid then the mobility approaches zero, that is, the velocity induced by any force is very small. The relationships between foundation mobility, isolator characteristics and isolator effectiveness are described elsewhere[2]. In general the effectiveness of isolation decreases if the mobility of the supporting structure is too high.

Size Effects on the Mobility of a Foundation

The mobility of a structure or foundation at a point can be measured. For example one can apply a time varying force with a shaker or an instrumented impact hammer and measure the resulting velocity at the point of application. Mobility at a point can also be theoretically calculated for simple structures.

However, actual connections between a machine and a supporting structure may cover a significant area. For example in ships, engine mounts may be quite large so that force is applied to the supporting structure over a large area (say 300 mm by 150 mm), and not at a point. The aim of the research described here is to explore the significance of area contact as opposed to point contact in determining foundation mobility.

Theoretical Models of Area Contact

A theoretical model[3] was developed where mobility was predicted for a circular region of contact on an infinite plate, Figure 2. Although this is far from a practical situation of a machinery mount in contact with a supporting structure, the model allows one to understand some fundamental characteristics of area contact. The above definition of for mobility under point contact was modified to take into account contact over a surface area[3], and is termed surface mobility.

Figure 3 shows the resulting predictions of surface mobility in non-dimensional terms for the case of a uniform, con-phase force distribution over the circular contact area. On the vertical axis, surface mobility is normalised by dividing by the mobility for point contact on an infinite plate. The horizontal axis is Helmholtz

Number which physically represents π times the ratio of the diameter of the contact region to the governing wavelength of the bending waves in the plate.

Helmholtz Number = $ka = \pi (2a)/\lambda$

where $\lambda = 2 \pi / k$ = wavelength

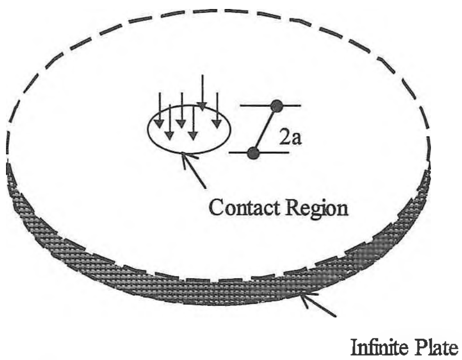

Figure 2 Model of circular surface contact on an infinite plate

The wavelength of bending waves in a plate varies linearly with frequency, long wavelengths at low frequencies and shorter wavelengths at higher frequencies. Hence Figure 3 shows that for this case, mobility depends on the ratio of the size (diameter) of the contact region to the wavelength of the bending waves in the plate. This case also shows a series of minima occurring whenever the diameter of the contact region is approximately equal to an integral number of wavelengths. These minima did not occur when a case of uniform con-phase velocity excitation was studied, however the general downward trend in normalised mobility with Helmholtz number remained.

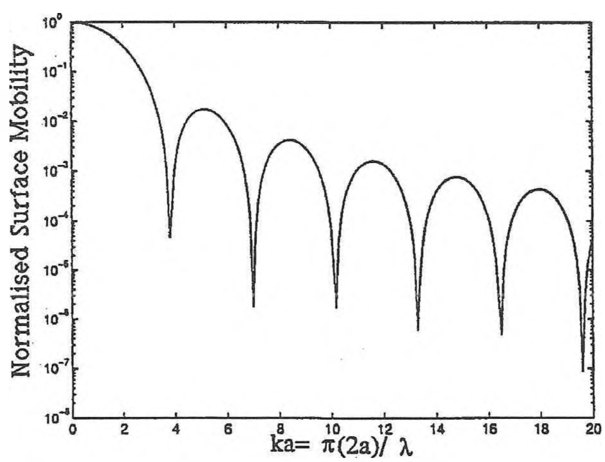

Figure 3 Normalised surface mobility for a circular contact region on an infinite plate subject to a uniform con-phase force distribution

Similar theoretical studies[4] were also carried out for the case of a rectangular contact region on an infinite plate. The results are more involved due to the increased complexity of the geometry, however the general characteristics are quite similar to the circular contact case, that is mobility is strongly affected by the dimensions of the contact area relative to the wavelength of the bending waves in the plate.

Experimental work[3] has verified the theoretical model for circular contact and experimental work is in progress for the verification of cases of rectangular contact. Experimentally, the infinite plate was approximated by a large plate with its edges well damped (buried in sand).

Some work has also been carried out on using finite element techniques to model surface contact. This could lead to a method of predicting surface mobility for more practical support structures.

Discussion

The above theoretical work on surface contact has not yet been developed to the point where it can be quantitatively applied to practical vibration isolation problems. It does however bring out some important points on the nature of the interaction between a large isolator and a supporting structure.

(1) It can be seen that large area contact can result in a mobility which is significantly different to measured or predicted point mobility. In the idealised cases studied, area mobility was less than point mobility, but this need not always be the case. It may be worthwhile developing methods to directly measure surface mobility for critical isolation applications. Such measurements could help to avoid situations where poor isolation occurs in important frequency ranges due to high surface mobility in the foundation.

(2) The research also helps to answer the question, 'How large is large?' In the above models, surface mobility was approximately equal to point mobility when the dimensions of the contact region were small compared to the governing wavelength in the supporting structure. Mobility changed significantly once the contact dimensions were of the order of, or larger than, the governing wavelength in the supporting structure.

Acknowledgements

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