ELIMINATION OF STRUCTURE-BORNE NOISE USING AN ELASTOMERIC INSULATING MATERIAL

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1.0 Introduction

New buildings are increasingly being constructed on sites subject to vibration. Often, the source of the noise is railway lines or industrial installations that are close by. In the building, the vibrations can cause excessive amplitudes or an increase in airborne noise level due to reflection from vibrating components, for example floors or ceilings. An acoustical consultant or engineer is faced with the task of constructing the building in such a way that the specifications of the client are maintained, but the permissible values are not exceeded.

Whether the vibrations in the foundation cause excessive disturbances in the finished building depends on the excitation strength and frequency, the foundation and the structure of the building. For an evaluation, the excitation must be measured as a function of the frequency whilst the connection of the building to the foundation as well as the structure of the building must be know. A computer model calculation of the vibration system can provide information about the expected vibrations in the building. An acoustical consultant must be present to measure the vibrations at several points near the site to maintain an accurate model. Where the vibration and consequently the secondary airborne noise exceed the specified limits, the excitation or transmission into the building must be reduced. For disturbances emanating from rail traffic and for the isolation of machine vibrations, there is a wide range of procedures available to reduce the emission. Even so, and in many cases, isolation at the source may not be possible for a variety of reasons. The designer must then reduce the vibration and ground-borne noise within the planned building. By means of bedding the building on an elastomeric material such as REGUPOL® or REGUFOAM®, this transmission can be effectively reduced.

2.0 Technical Information

2.1 Natural Frequency

There are only two parameters that effect the ***natural frequency*** of a system. There are mass (weight) and stiffness (spring rate).

Increasing the mass (weight) or reducing the spring rate will produce a lower natural frequency and conversely reducing the weight or increasing the spring weight will result in a higher natural frequency. With a REGUPOL® or REGUFOAM® material the above relates as follows: An increase or decrease in weight produces a corresponding stress change in the material, and an increase or decrease in thickness results in a spring rate change. That is a thinner material increases the spring rate while a thicker material decreases the spring rate.

The metric formula for natural frequency is [1]:

$$Nf = 0.159\sqrt{\frac{k}{m}}$$

where :

$Nf = \text{Hertz},\ k = \text{SpringRate(N/m)},\ m = \text{mass(kg)}$

If the weight referred to represented a machine, it would definitely have a natural frequency on its mounting. Furthermore it may generate disturbing vibrations of its own while in operation. These latter vibrations are caused by either unbalanced moving parts within the machine or an unbalanced condition arising from the work being performed. These vibrations are referred to as forcing vibrations, and their frequencies are called ***forcing frequencies***. The major forcing (disturbing) frequency is generally the operating speed of the heaviest parts of the machine. However, higher secondary frequencies can sometimes create more of a disturbance than those created by the operating speed itself, thus requiring that these secondary frequencies also be isolated. Instrumentation used by an acoustical consultant is usually required to determine the disturbing secondary frequencies.

2.2 Frequency Ratio

The forcing frequency divided by the natural frequency is the ratio that indicates the effectiveness of a vibration insulation material [1].

$$\text{Frequency Ratio} = \frac{Ff}{Nf}$$

Where :
Ff = Forcing Frequency in Hertz; Nf = Natural Frequency in Hertz

2.3 Transmissibility

Transmissibility is the percentage of disturbance being transmitted through the insulation material. It is expressed by the ratio of the vibration amplitudes or forces. For example, if the purpose of an insulation material is to reduce the force transmitted to the support, then [1]:

$$T = \frac{Ft}{Fd};$$

Where : T = Transmissibility; Ft = Force Transmitted;
Fd = Disturbing Force

Transmissibility can also be expressed as an insulation factor. An insulation factor is essentially (1-T) expressed as a percentage. Most insulation materials are designed so that the force transmitted to the foundation is only a small fraction of the unbalanced force or disturbing vibration being generated and acting on the system. As can be seen, the larger the difference between the disturbing frequency and the natural frequency of the insulating material, the more insulation is present. A transmissibility of zero is necessary for theoretically perfect insulation. However, for this to happen the frequency ratio would have to be infinitely large and thus is impossible to achieve. Realistically, insulation factors above 80% are usually adequate for the intended application, be it architectural or industrial.

3.0 Case Studies

Two case studies will be presented in brief, the first being an industrial application and the second an architectural one. These two examples show the extremes of loads that can be involved in a vibration problem and how to best find a solution to structure-borne noise and vibration problems using different insulation materials.

3.1 Industrial

In this case, a generator test cell at Siemens AG headquarters in Erfurt, Germany was insulated. This division of Siemens is a global manufacturer of generators, turbines and auxiliary equipment for the power generation industry. The problem involved a generator test pad where generators were being moved into place for quality control and other testing. These generators are quite heavy, weighing in at 627 kN. It was decided to isolate the generator on an inertia block or plinth. Siemens was looking for a solution to insulate this isolating inertia block against the transmission of vibration to other parts of the building, in order to reduce structure-borne noise in the nearby offices and protect surrounding equipment from damage due to vibration. The isolating plinth weighed in at an additional 863kN. The dimensions of the isolating plinth were a width of 4.3m and a length of 16.5m. The height of the plinth was 2.3m. The plinth was reinforced with steel rebar to bear the extreme weight of the generator.

The generators that were being tested were of two rotating speeds, 3000 rpm and 3600 rpm. This is equivalent to 50 and 60 Hz respectively. From this information a calculation can be done to determine the optimal dimensions of the insulating material supplied.

3.1.1 Calculations

Calculation of the Load :

$$\text{Load} = \frac{\text{Weight(N)}}{\text{Area}(\text{mm}^2)} := \frac{627\text{kN} + 863\text{kN}}{4.3\text{m} \times 16.5\text{m}} = 0.021\text{N/mm}^2$$

The design was done with the lower frequency in mind since the lower frequencies are usually the more difficult to attenuate. Using A natural frequency versus load chart for the Regupol 6010SH supplied by DRI, it was found that at a load of 0.021 N/mm^2 would give a material natural frequency of 24Hz at 30 mm thickness [1]. This relates to a transmissibility or insulation factor of about 0.50, which was deemed to be sufficient for their application. Had a larger insulation factor have been required, a more compressible insulation material could have been chosen with a lower natural frequency down to 7Hz, or additional layers could have been added.

3.2 Architectural

In this case, a condominium/townhouse complex was being constructed in Toronto, Canada, situated between a freight railway line and a subway line. The subway passes about 20m west of the building and the rail line is about 40m to the south. No vibration reducing measures had been applied to the subway track, and the rails were directly connected to a slab. The rail line featured rail on tie configuration, with gravel ballast, but no insulation for the ballast. A quantitative forecast of vibration was required by an acoustical consultant before it could be determined if a form of vibration insulation was required and to what extent. The structure-borne sound from the railways is determined by the condition of the rails, wheels, soil composition, etc. making it difficult to forecast. Measurements were taken of the vibration of the ground surface at the planned site and of the vibration of the ground surface and structures along the subway line. It is not possible to go into detail of the forecasting of vibration and any sound pressure levels at this point, however it was revealed that for both sites the vibration of the ground surface has a peak at 63Hz. There is almost no difference in the level between the two sites between the 63Hz and 125Hz bands, where structure-borne noise from the railway lines is generally a problem. [2]

The acoustical consultant specified a design frequency of 10Hz. For the porches facing the street, which were the last items to be insulated against vibration, different loads were calculated based on regular and snow loads. Short-term loads such as snow loads do not have to be taken into account with the REGUFOAM® material since brief peak loads of up to 4 times of the static constant loads can be absorbed. To insulate the porches, an area of 200mm x 200mm was specified. Forces were specified at 17N. The other constraint was on material thickness which could be no greater than 50mm.

3.2.1 Calculations

$$\text{Area} = \frac{\text{Force}}{\text{Load}} = \frac{17\text{N}}{0.012\text{N/mm}^2} = 1417\,\text{mm}^2 = 38\text{mm} \times 38\text{mm}$$

Using a load versus frequency chart for 50mm Regufoam 150, it was determined that the required static load was 0.012 N/mm^2 for insulation down to 9 Hz [1]. The dimensions of the insulating material required was calculated to be:
At these parameters, the deflection of the material is 7mm, and the building has an insulation factor of 85%. Unfortunately, no follow up readings have yet been taken on site.

References

[1] Regupol Vibration Insulation Handbook – Dodge-Regupol Inc., Lancaster, PA (2000).

[2] A. Minemura and T. Koga, "Measures to Insulate an Underground Lecture Hall from Structure-Borne Sound Caused by a Subway", Internoise '99 (1999).