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Effect of Beading on Radiated Noise

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ABSTRACT

In the automotive industry, the use of beading is widely spread. Beads are primarily used to stiffen the floor and dash panels. The aim is to reduce vibration levels and hopefully at the same time reduce radiated noise. Beading has a positive effect close to the first panel mode's natural frequency however it can have a negative effect at all other frequencies. Typically, engineers assume a radiation efficiency of "1" (one) over the whole frequency range for simplicity or lack of available implemented formulation in their simulation tools. This assumption directs the investigation at reducing the vibration levels only. This approach can be misleading because even though radiation efficiency tends to "1" (one) above coincident frequency it is not the case below coincidence. While increasing stiffness reduces vibration levels, it also increases radiation efficiency. This can yield to higher levels of radiated noise.

This paper presents a comparison between panels with uniform cross-section and beaded panels in two different configurations: i) Academic frame and plate case and ii) Automotive floor. Vibration levels, radiation efficiency and sound radiated power are presented for all cases. Different types of beadings are compared and conclusions are drawn as to whether these beadings really reduce radiated noise.

INTRODUCTION

It is a common practice in the industry to consider only vibration response (acceleration or velocity) when designing automotive panels, railway wheels and other complex manufactured components. Unfortunately, reducing only vibration levels and hoping that this will have a beneficial effect on noise radiated often prove to be disappointing.

In fact, if the noise radiated was solely depending on velocity levels, this type of approach would be very effective especially in computation cost. As this paper will show, noise radiation does not only depend on velocity levels but also depends on radiation efficiency, a quantity describing the ability of a panel to radiate noise for a given level of vibration. This quantity will be described in a further section.

This paper will focus on showing the importance of acoustics consideration in the optimization of beaded panels. It will also describe in detail and with example how radiation efficiency can play a significant role in the radiated noise from a beaded panel compared to a uniform cross-section plate.

NOISE RADIATION DRIVING PARAMETERS

BENDING STIFFNESS

Adding beads to a panel increases its bending stiffness by increasing its cross-section moment of inertia and moving the centre of gravity away from the middle plane (see figure 1).

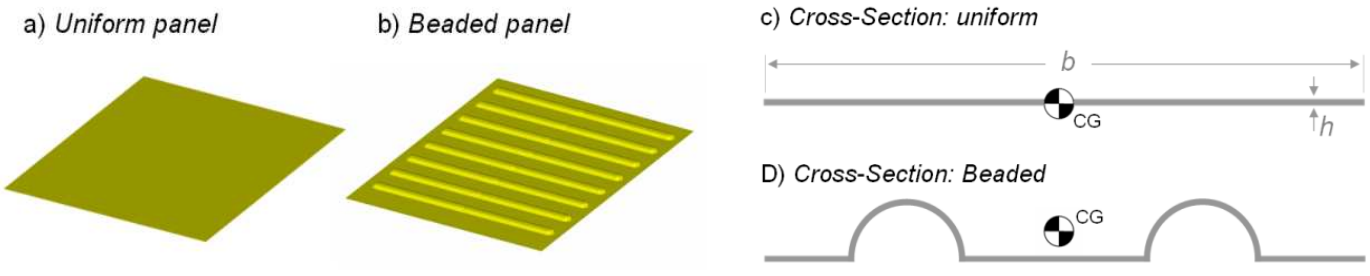

Figure 1: Cross-section for uniform and beaded panels

Bending stiffness is proportional to the moment of area of panel cross-section as expressed in equation 1. Finally, in addition to breaking the first few modes of a panel, the use of beads increases the bending stiffness significantly. This in return is likely to reduce vibration levels and potentially increase radiation efficiency of the panel resulting in the potential increase in radiated noise.

$$B = \frac{I\ E}{(1-\nu^2)} \qquad 1)$$

Where B is the bending stiffness, I is the moment of area of the cross section (I = bh^3/12 for uniform X-section) and ν is the Poisson's ratio.

RADIATION EFFICIENCY

Radiation efficiency is defined as "the acoustic power radiated by the plate into a half space, divided by the acoustic power that an infinite piston (all parts vibrating in phase) would radiate into the same half space if it were vibrating with the same RMS velocity as the plate" [1]. The radiation efficiency can be viewed as the ability of a panel to radiate noise (see equation 2).

$$\prod_{rad} = \sigma A \rho_0 C v_{rms}^2 \qquad 2)$$

where σ is radiation efficiency, Πrad is the power radiated by the panel, A is the radiating area of the panel, ρC is the characteristic impedance of air and V^2rms is the average rms velocity of the panel.

Many commercial software use a radiation efficiency equal to one for the whole frequency range of interest. In reality, radiation efficiency equals one only at a very high frequency, most of the time outside the frequency domain where design decisions are taken. Equation 2 indicates that the power radiated by a plate is proportional to its average velocity times its radiation efficiency. Therefore, considering radiation efficiency in predicting sound power radiated is essential. Several papers have been written on the computation of radiating efficiency.

To illustrate the radiation efficiency concepts in this section, the Leppington, Broadbant and Heron formulation implement in VA One is used [2,3]. The coincidence frequency (also called critical frequency) is defined as the frequency where the acoustical wavelength exactly matches the bending wavelength in the plate. This is where radiation efficiency is the highest and can be higher than one. Typically, radiation efficiency tends towards one at frequencies above coincidence frequency. Below coincidence, radiation efficiency can be orders of magnitude lower and depends on the panel construction and shape. Curvature and presence of ribs can significantly affect the radiation efficiency below coincidence (see figure 2). Note in this case that for a 1mm steel panel, the coincidence frequency is around 12 500Hz. If the plate is curved or ribbed, the lower part of the frequency domain of the radiation efficiency is increased by several orders of magnitude.

When beads are added to a panel, it increases the bending stiffness of the panel and therefore shifts the radiation efficiency curve to the left bringing the coincidence frequency lower. Therefore, for a given frequency, the radiation efficiency can be significantly increased. In figure 3, at 1000 Hz, the radiation efficiency is increased by a factor of close to 10 for an increase in bending stiffness of 10. In this case, the coincidence frequency went from 12 500Hz to 4 000Hz.

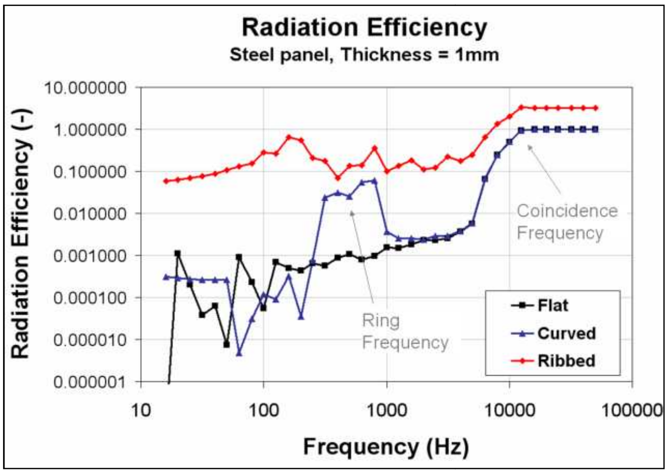

Figure 2: Radiation efficiency of 1mm steel panel for flat, curved and ribbed panel construction

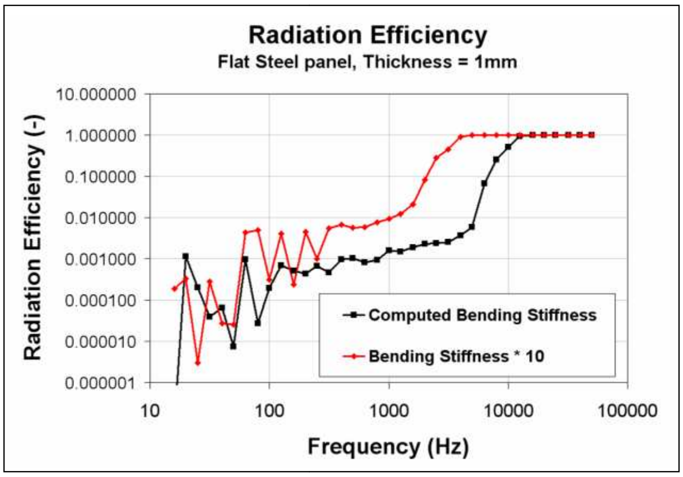

Figure 3: Effect of increasing bending stiffness on radiation efficiency

This indicates that considering strictly the velocity levels of a panel to derive its radiated sound power by considering a radiation efficiency equal to one over the full frequency domain will yield the wrong predictions. The following section provides examples to illustrate this concept.

APPLICATION EXAMPLES:

CASE 1: ACADEMIC FRAME AND PLATE

In this paper 4 different beading configurations were studied. The plate size is 0.74m by 0.585m and is surrounded by a stiff frame to maintain same amount of power getting into the structure.

Panel and frame are modeled in Finite Elements (FE) and the panel is connected to a Boundary Element Method (BEM) fluid. Only the panel is radiating noise in the acoustic fluid. The boundary conditions used for the structure are free-free. The large central panel and the frame have a thickness of 1mm and are made of steel. The structural FE model was built using 6 elements per wavelength and is valid up to 800 Hz. Normal modes are computed to 1040Hz to avoid truncation of modes. The frame is excited by a point force of 1N (rms) in each 1 Hz bandwidth. The same model was used for each configuration, only the central plate was changed (figure 4Figure 4). The configurations studied are showed in Figure 5 5. The first configuration is the flat plate. It is shown in black in all graphs. The second configuration has three beads along the length of the plate. Configuration three has seven beads along the plate length and finally the fourth configuration has eight beads along the width of the plate. All beads were created from elliptical section 10mm high and 30mm across.

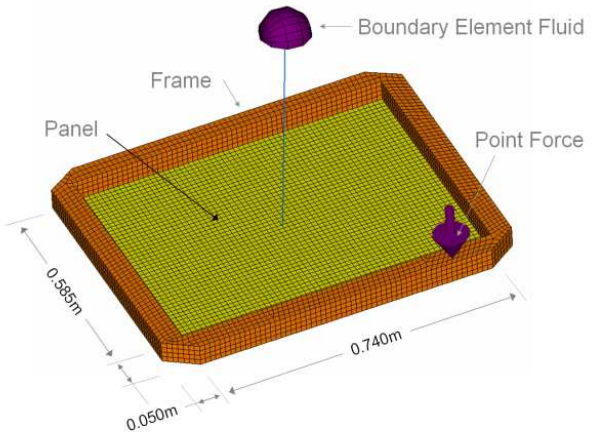

Figure 4: Description of the vibro-acoustic model

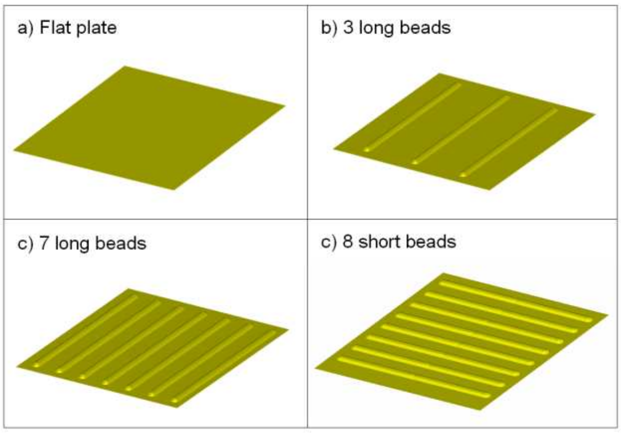

Figure 5: Configurations for the academic beam-plates study

The addition of beads on the central plate reduces the number of modes as shown in Figure 6. The non-beaded plate has more than one hundred modes below 800 Hz. The beaded panels on the contrary have between fifty and eighty modes below the same frequency.

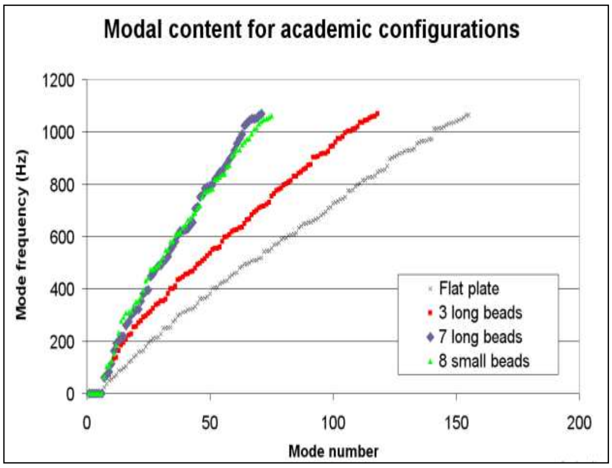

Figure 6: Modal content for all configurations

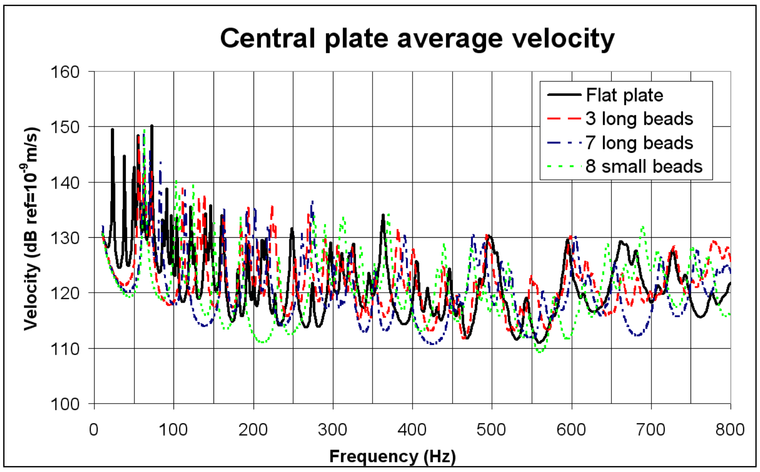

Figure 7: Average velocity of central plate study

As mentioned earlier, beads are used to break the first few modes of a plate and reduce average velocity hoping this will in turn reduce noise radiation. Figure 7 shows average velocity levels on the central panel for all configurations analyzed. The flat panel is in black and can be used as a reference to compare the other configuration levels. From 0 to 50 Hz, the effect of beading can clearly be seen. The velocity levels are significantly lower than for the flat plate case. At other frequencies, the benefit of beading is less clear, sometimes velocity levels are reduced sometimes they are increased.

The central plate radiation efficiency shows quite a different behavior. Figure 8 shows that for most of the frequency domain the radiation efficiency increased with the addition of beads. The overall levels of radiation efficiency provide further insight at the magnitude of the differences between the flat plate and the beaded ones (see figure 9).

As discussed in the previous section, this is not a surprise since bending stiffness is now increased significantly. From the previous section, it was also seen that the sound power radiated is proportional to the product of panel average velocity and radiation efficiency. Since velocity did not decrease significantly over the frequency range and radiation efficiency has significantly increased over the whole frequency range, it is reasonable to assume that sound radiation will increase for all the cases studied.

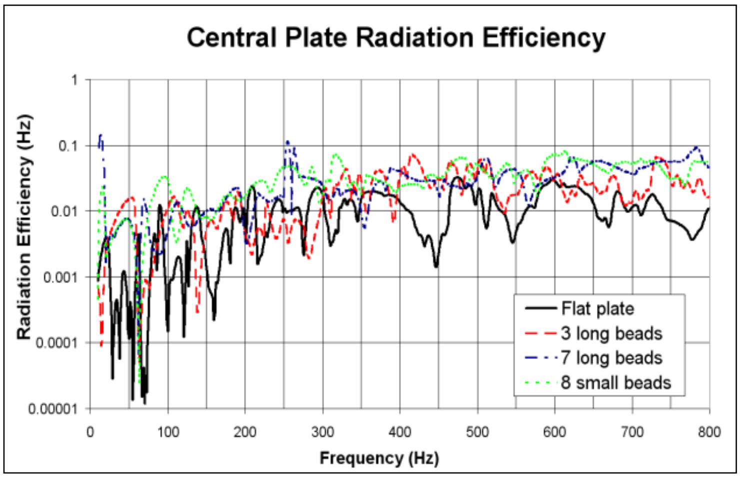

Figure 8: Radiation efficiency of the 4 configurations studied

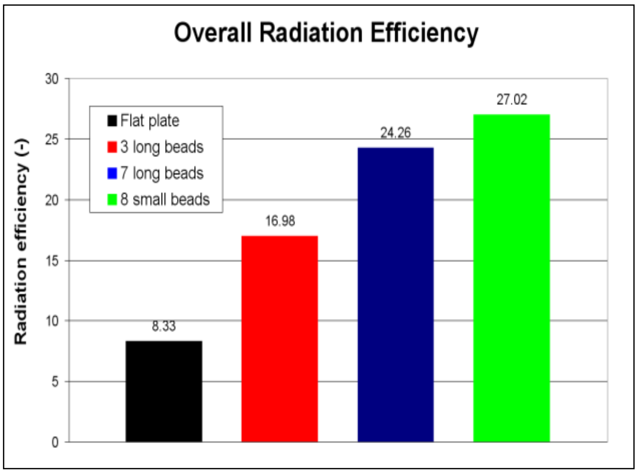

Figure 9: Radiation efficiency overall levels for different central plate beading configurations

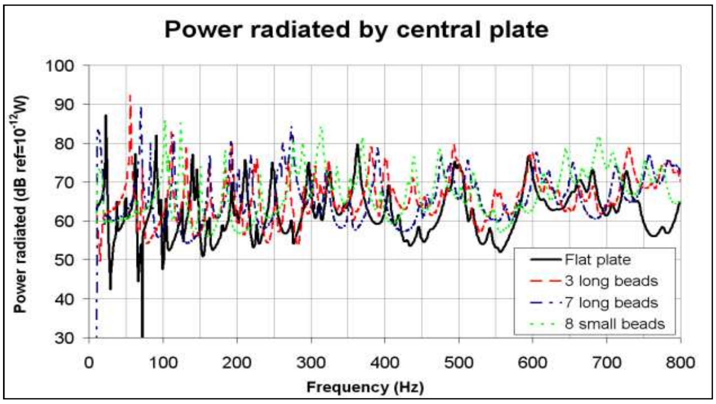

Figure 10: Sound power radiated for different central plate beading configurations

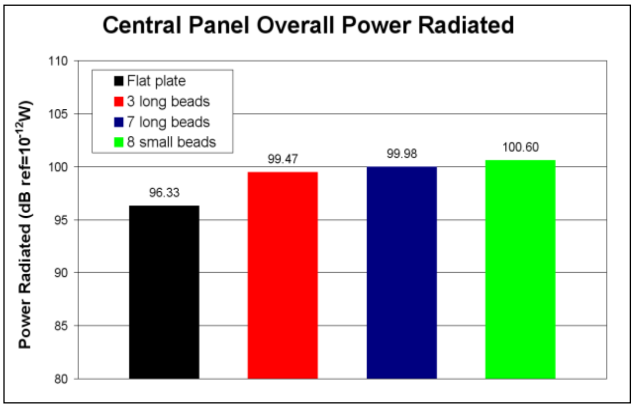

Figure 11: Overall sound power radiated for different central plate beading configurations

Figure 10 confirms this assumption; only the first peak has disappeared and for most of the configurations, the central plate radiates more noise than the flat plate case. It is easier to assess the difference in sound radiation levels when looking at the overall values. Figure 11 shows the overall levels of sound radiated power from 10 to 800 Hz. It is interesting to note that by adding just a little beading (three beads along the length) the sound power has increased by more than 3 dB and that adding eight beads along the width increases sound power radiated by more than 4 dB.

It is important to remind the reader that these differences are for the frequency range from 10 to 800Hz. Onsay and all have observed that: “Both low and high frequency behaviors of the panels are affected by the choice of bead configuration…” [4]. One can imagine that for a frequency domain where acoustic design is performed (approx. 10 to 5000 Hz) the increased radiated noise will be much larger. Therefore, adding beads in this case might force the noise control engineer to design a heavier or more expensive sound package (carpet, dash insulator…) to counteract the beads negative effect on radiated noise.

CASE 2: AUTOMOTIVE FLOOR

In this example a floor without beads is compared with a beaded floor panel (see figure 12). A heavily beaded panel is use to better illustrate the effect of beading on noise radiation. The models are similar to the previous example where the structure is modelled as FE and the fluid is modelled as BEM. The structure used is 0.85mm steel with 1% structural damping. To avoid having to build a frame around the structure, the large mass method is used to constraint acceleration on the nodes at the perimeter of the floor panel. A mass of one metric ton is excited by a force of 10N in each 1 Hz bandwidth. The mass is connected to the edge nodes using RBEs.

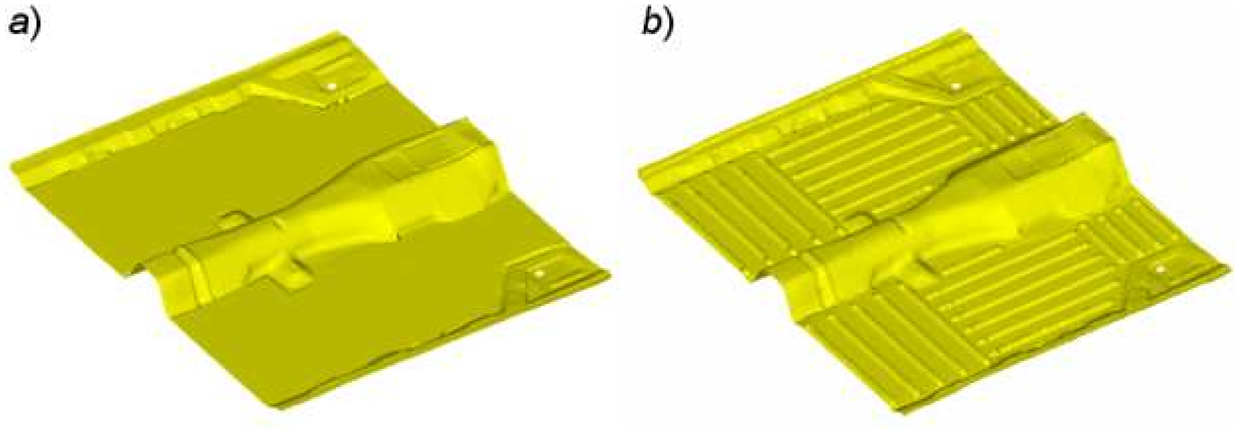

Figure 12: Automotive floor panels: a) non-beaded b) beaded

The results are shown in figure 13. The graphs have been placed on top of each other for better visualization of the results. On the average velocity graph, the benefits of the beads can be seen in the frequency range between 0 and 120 Hz except for a single peak at 58 Hz. In the rest of the frequency domain, the average velocity is slightly decreased except at some frequencies that have been circled in green. In the radiation efficiency graph, most of the beaded curves lie above the non-beaded panel. The increase in bending stiffness contributes to the increase in radiation efficiency. The green circles are located at the same frequencies as for the average velocity graph. These circles indicate where the increase in velocity matches an increase in radiation efficiency. At these frequencies, the sound power radiated should also increase for the beaded case. The sound power radiated graph confirms that for the beaded case, the sound radiated by the floor is higher at the frequencies where circles can be found. The beading reduces the sound radiated power mostly at low frequency around the first few panel modes. It is interesting to note that for the beaded floor the highest level of sound power is 68dB as opposed to only 61dB for the non-beaded case. Finally, the overall sound power levels for both non-beaded and beaded cases are presented in figure 14. The beaded floor radiates more than the non-beaded floor by more than 3 dB for the frequency range of 10 to 800 Hz. Larger effect are to be expected on a wider frequency domain.

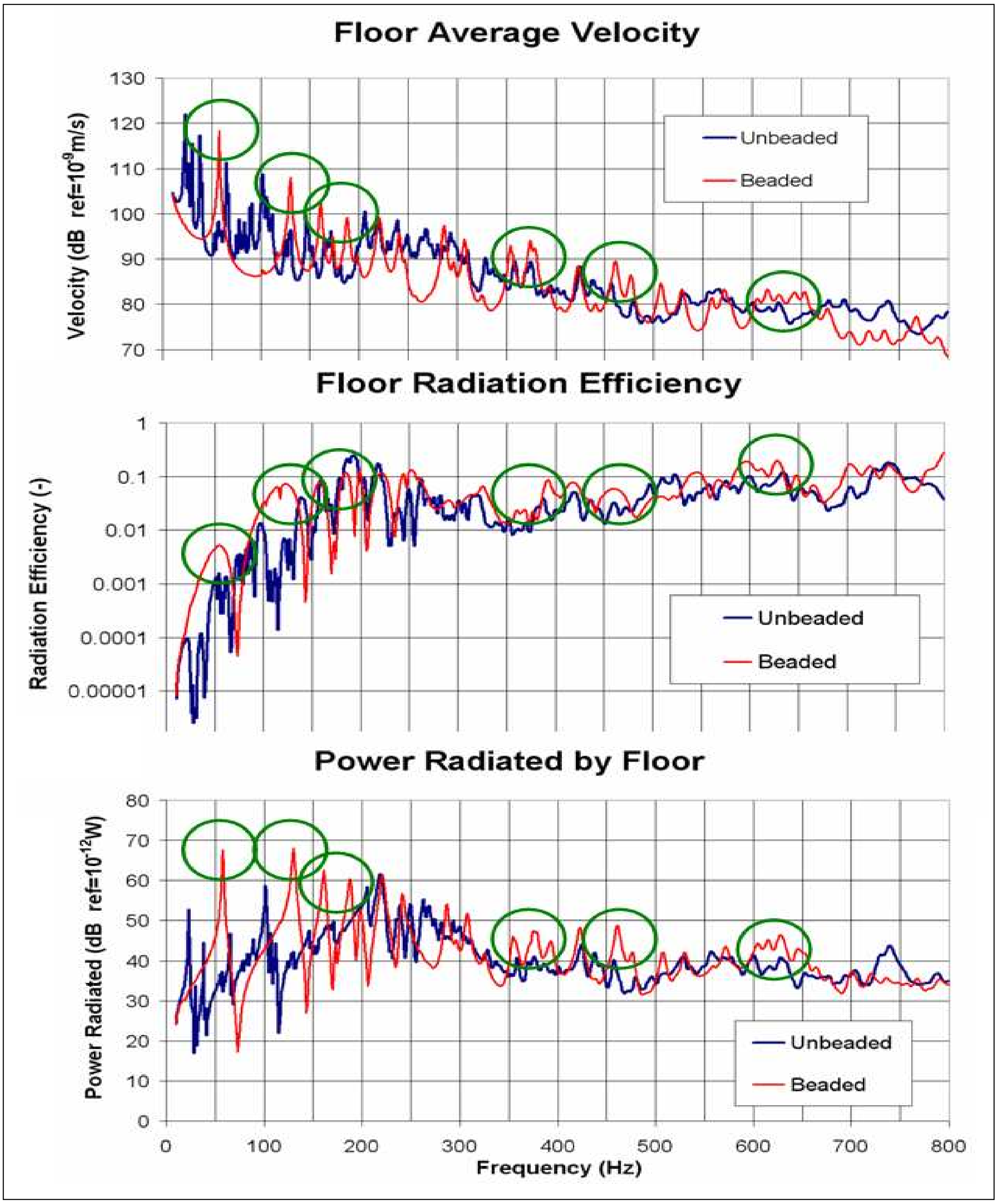

Figure 13: Floor vibro-acoustic results. Circles indicate where both velocity and radiation efficiency peaks coincide to generate higher sound power radiation

Please note that the beading used in this paper is quite heavy and is intended to indicate the trend of the beading effect. The effect of beading one would measure in a real vehicle might be different depending on quantity and size of the beading used. But the principle remains: adding beads does not necessarily reduce panel radiated noise.

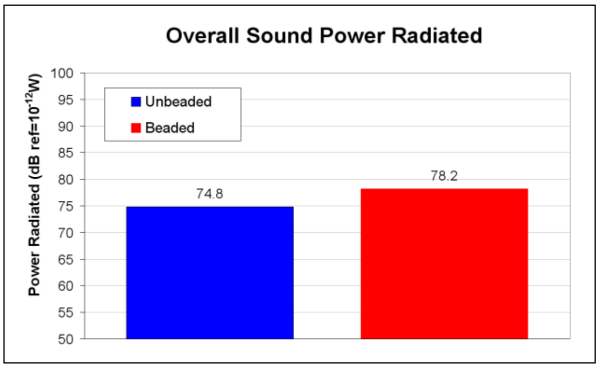

Figure 14: Overall sound power radiated by non-beaded and beaded floor

CONCLUSION

This paper has demonstrated the importance of taking into consideration not only the vibration response but also the acoustic aspect of a problem when designing beads in general. The assumption that the sound radiated power scales directly with vibration levels therefore considering the value of radiation efficiency to be equal to one is only valid above the coincidence frequency (around 12 500 Hz for non-beaded and 5 000Hz for beaded steel 1mm). Below coincidence, radiation efficiency can vary over several orders of magnitude. The sound power radiated is proportional to the product of radiation efficiency and velocity and therefore any match in peaks of these two quantities will yield a higher noise radiation. Finally, optimization of beads should always be done on sound radiated power if one wants to reduce noise radiated otherwise the acoustic engineers will have to design heavier or more expensive countermeasure to reduce the noise emitted by such beaded/stiffened panels.

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