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Plate Sound Radiation Prediction in Machines Using Multiple Input Techniques

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In systems with various types of noise sources, the characterization and ranking of each source may require a different approach. Also, one of the main challenges in such investigations, consists of isolating each source from the influence of the others. Often in machines, the constituting plates are efficient radiators whose specific contributions need to be properly determined. In this presentation, we describe a method of plate radiation characterization using multiple input techniques. These techniques have frequently been used in case of discrete sources such as, for instance, vehicle engine cylinders where the pressure variations are modelled as the inputs. This application differs from the traditional ones by the fact that the inputs are now, the elements of a continuous medium. Here the surface of a plate is meshed, each element is taken as a sub-source and consequently, the plate is modelled as an assembly of sub-sources. The plate contributions at the operational modes, are then obtained through vibration measurements and therefore, are not affected by the noise from the other sources. Investigations on structures of various geometries and materials have so far, demonstrated the efficiency of this type of application.

1 Introduction

This research has been motivated by the need to identify and characterize noise sources in small portable machines. In such equipments, several noise generating mechanisms may be present and each mechanism may require a different approach to evaluate its role in the overall radiated noise.

In a grinder for instance, the wheel guard as well as the grinding disc are two radiating sources that must be isolated with regard to each other and the rest of the sources (body radiation, air release, grinder-object friction noise, wheel guard and grinding disc radiation, etc.) in order to evaluate their contribution.

This paper describes a multiple input method application for separating the noise contribution by a grinder wheel guard, at operating modes. This kind of method is generally used in case of "lumped" sources. But in this case a continuous medium, i.e. a plate, is modeled as a multiple source system where sub-surfaces are regarded as separate but interdependent sources.

2 Theoretical background [1]

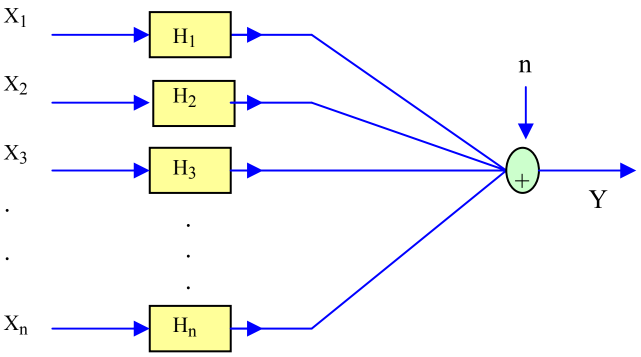

Figure 1: A multiple input single output model

Consider a systems such as in Figure 1, where the sources X_1, X_2..., X_n are mutually partially coherent, i.e. there exists an exchange of energy among them. In this case, the contribution of the sources can not be predicted through ordinary transfer functions associated with single input/output systems, because such formulation overestimates each input's contribution. The real transfer functions H_1, $H_{2, \ldots,}$ H_n in such systems are obtained by solving the following equations:

$$[G_{iy}] = [G_{ij}][H_i] \qquad (1)$$

$[G_{ij}]$ is a cross spectral matrix where signals i and j represent the inputs and the matrix $[G_{iy}]$ contains the cross spectra between the inputs i and the output y. The solution requires the inversion of the matrix $[G_{ij}]$:

$$[H_i] = [G_{ij}]^{-1} [G_{iy}] \qquad (2)$$

The system's output auto spectrum is then obtained throgh:

$$G_{yy} = \sum_{i=1}^{n} \sum_{j=1}^{n} H_i^* H_j G_{ij} + G_{nn} \qquad (3)$$

where G_{nn} represents the uncorrelated noise.

3 Application to the radiation problems

A plate like structure can be meshed into sub-surfaces and each sub-surface can be modeled as an independent source. When the structure is subject to an excitation, strong coherency exists among these sources. Therefore to characterize them through transfer functions, one can not but resort to multi-input model discussed above (one must however, be aware that coherences equal to unity will result in singularities in calculated transfer functions). Consequently, the vibrations at sub-surfaces can be modeled as inputs to the system and the radiated noise as the output.

If the plate like structure is a part of a machine, first the multi-input transfer functions $[H_i]$ in (2) are obtained through an artificial excitation, e.g. through impacts. It will then suffice to acquire vibration data while the machine is running. Using these data the in the relation (3), will yield the operating radiated noise.

4 Test procedures and results

Accelerometers were placed on the surface of the investigated structures to provide the input signals and a microphone overhung, at a small distance, to yield the output signal. 2 or 4 microphones were used and the system was therefore modeled as a set of (2 or 4) independent multi input- single output systems.

The test procedure consisted of: **(a)** exciting the structure by a number of impacts and computing the transfer functions between the accelerations and the sound(s) signals, using the relation (2); **(b)** comparison of the measured and calculated radiations through relation (3), as a test of the computation process; **(c)** excitation by shaker (128 spectral averages): Computation and measurement of the radiated noise and their comparison to test the method; **(d)** in case of the grinder: radiated noise computation, using the transfer functions obtained in **(a)** and the accelerations at operating mode. In all the data acquisitions a "Response" time window was used.

4.1 Simple steel plate

Before tackling the radiation from the grinder wheel guard, some simple plates were first examined among which we only consider here, a 245mm x 300mm x 3mm steel plate fixed on 4 legs. A 110mm T-section is diagonally attached beneath this plate excited in the middle, by a shaker. Seven light weight accelerometers are glued to the upper surface in an arbitrary disposition. 4 microphones positioned at various distances from and in the near field of the plate (Figure 2) provided the outputs of 4 multiple input- single output models .

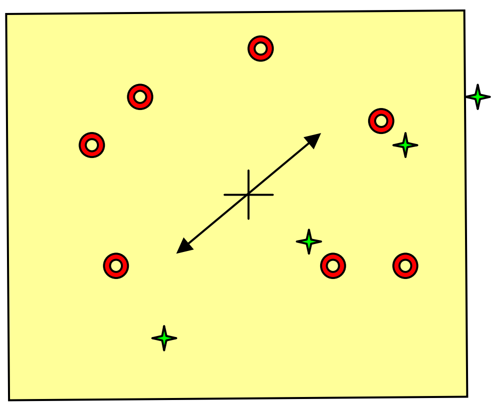

Figure 2. Rectangular steel plate (upper view) with accelerometers & microphones

Figure 3 shows the measured and calculated radiated sound, at 2 microphone positions, when the plate is excited with a hammer with a rigid plastic head. The hammer hit 64 times on the upper surface, along the T-section represented by the short diagonal arrowed line in Figure 2.

Theoretically the measured and calculated data should perfectly superpose. This is not exactly the case here because of the small number of transducers. However, the computation procedure can be considered as valid.

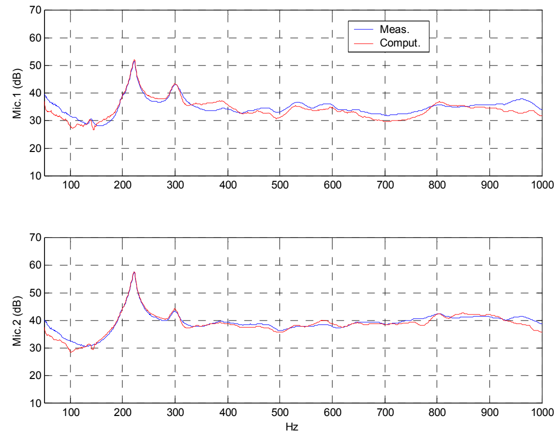

Figure 3. Radiation from steel rectangular plate caused by impacts.

When the plate is excited by the shaker, the results seem quite acceptable, especially considering the inadequate number of the accelerometers (Figure 4.)

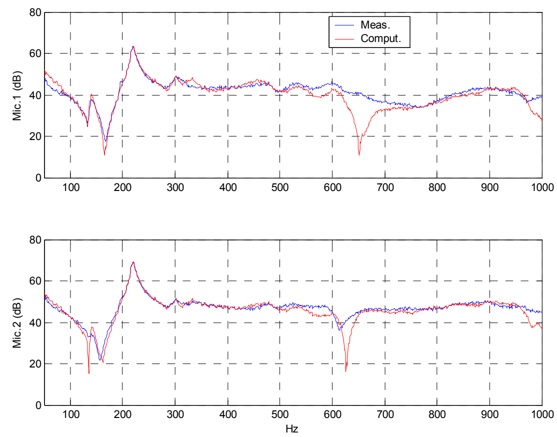

Figure 4. Radiation from steel rectangular plate caused by shaker, transfer functions from line impacts.

It is important to note that, in the radiation calculations, one may use the transfer functions obtained in a different way than above, e.g. through repeatedly impacting on one single point (as shown by X in the Figure 2). The results in such cases are generally less accurate, as seen in Figure 5.

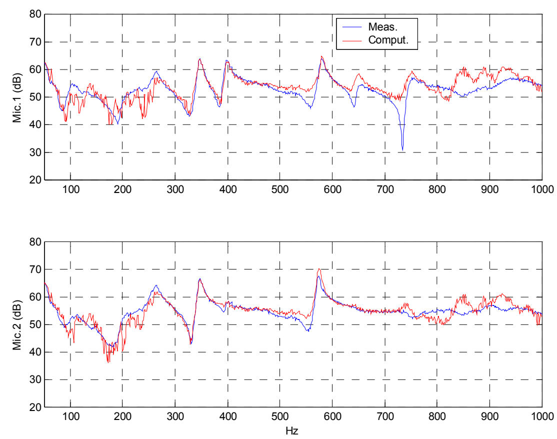

Figure 5. Radiation from steel rectangular plate caused by shaker, transfer functions from point impacts.

This suggests that the impact points must form a pattern as similar as that of the real excitation interface.

4.2 Grinder wheel guard

For the next example, the radiation from a (2mm thick steel) grinder wheel guard has been investigated. The surface was meshed in 8 sub-areas and consequently, 8 accelerometers were used. This number was adequate to study the plate behaviour within the range of the analysis (1kHz.) Two microphones, on a support made of a PVC tube, at 35-40mm of the middle of the plate provided the output signals.

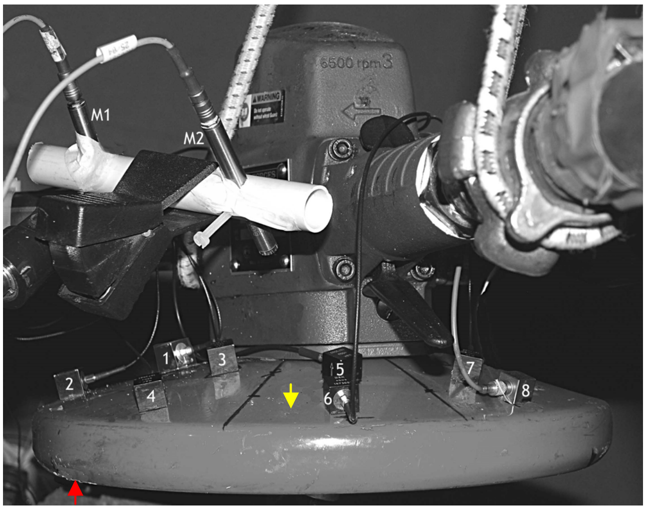

Figure 6: Grinder wheel guard instrumented wit 2 microphones & 8 accelerometers. The red arrow shows the shaker excitation position and the yellow arrow represents one of the impact points around the periphery .

To obtain the transfer functions, 40 evenly distributed impacts around the external edge were carried out (roving impacts). A typical impact point is represented by the red arrow in the figure 6.

A perfect match was achieved between the measured and calculated radiation caused by the impacts, implying the validity of the computation process (Figure 7.)

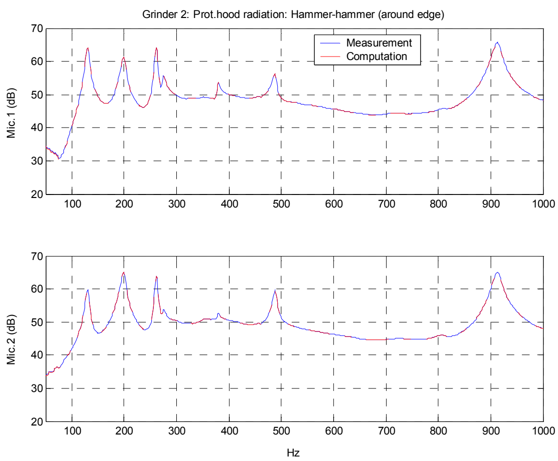

Figure 7. Wheel guard radiation caused by impacts.

Next, the structure was excited through a shaker. The excitation was positioned below the guard's bend (red arrow in Figure 6). Measured and calculated shaker induced radiations are illustrated in the Figure 8. Again, one observes a good match between the measurement and computation results.

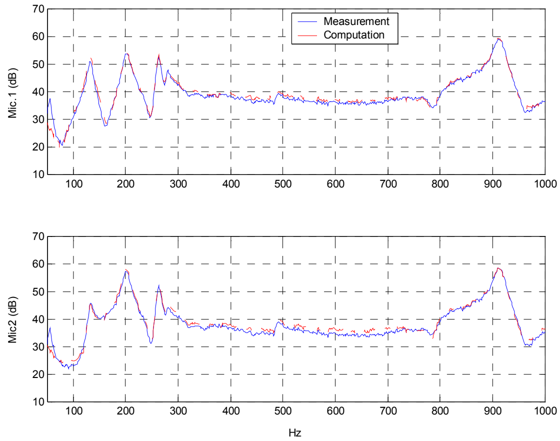

Figure 8. Wheel guard radiation caused by shaker.

When the grinder is running unloaded, the calculated wheel guard radiation at the specified points, yield the results presented in red in Figure 9. The measured noise at the same positions are illustrated in blue colour.

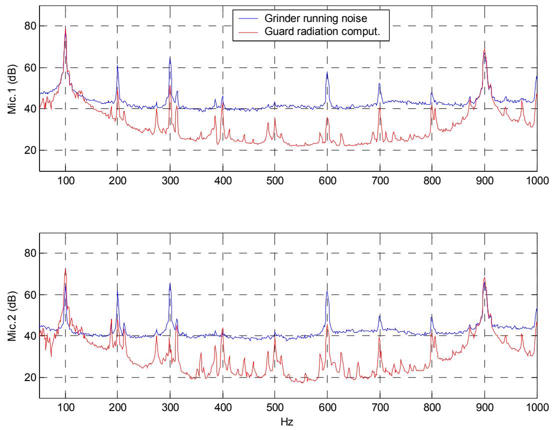

Figure 9. Calculated wheel guard radiation and noise at same positions while the grinder is running.

5 Discussion

The application of multiple input technique to a sub-structure (a grinder wheel guard, in this case) involves two main steps: 1) calculation of noise/accelerations transfer functions and 2) calculation of the radiated sound at operating modes. In the transfer function step, the excitation is provided by impacts. A careful selection of the impact points appears to be the most sensitive issue in the application of the method. The investigations carried out by the author suggest that the geometrical location of the impact points should follow as closely as possible, the excitation - structure interface or a pattern symmetrical to this interface.

Also, the precision of the calculated radiation depends on the number of the model's inputs (vibration measurement points). Obviously, one will have to make a compromise on this number, when it comes to large structures.

When the calculated wheel guard radiation is compared to the unloaded grinder signal (composed, mainly, of harmonics of the rotation speed of about 100 Hz, in this case), as shown in Figure 9, one can observe the insignificance of the former in the overall noise, except at about 900Hz where the guard appears to go through a highly radiating mode. The high level of noise calculated at 100Hz may however, be an over-estimation caused by the high coherence values (unity) among the inputs, at this frequency (Figure 8.) It is therefore advisable that the analysis of the results from this method, be carried out along with that of the ordinary coherences among inputs.

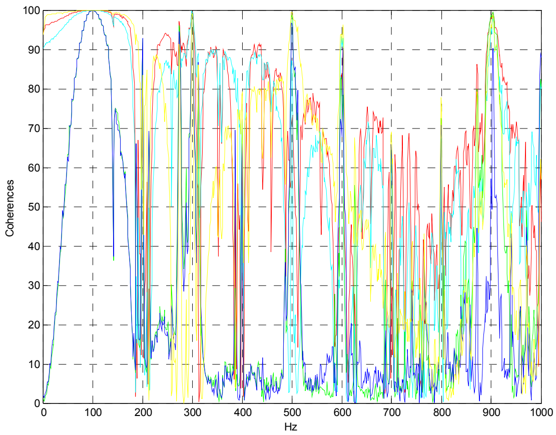

Figure 8. Typical coherences between the inputs

6 Conclusion

Multi-input technique has been implemented and analyzed in case of continuous media such as plates. It is shown that, although devised to characterize lumped sources, this method is also able to predict quite accurately in a machine, the noise radiated by plate like elements. The complexity of this application resides however, in the choice of the impact point pattern to calculate the transfer functions. The analysis of the results should be carried out with an eye on the coherences between the inputs.

Reference

J.S. Bendat, A.G. Piersol "Engineering application of correlation and spectral analysis", *John Wiley & Sons* (1980.)