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STIFFENERS EFFECTS CONSIDERATION IN THE VIBROACOUSTIC BEHAVIOUR OF COMPLEX MECHANICAL STRUCTURES

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ABSTRACT
Many complex structures, like gearboxes or engine blocks, contain a lot of ribs on their radiating surface. Those ribs are generally designed for mechanical and vibrating reasons. Their effects on the acoustic radiation are rarely taken into account. However, these are not systematically negligible. The influence of stiffeners on the acoustic radiation can be divided in three physical effects: the "vibrating effect", the "source effect", the "obstacle effect". In this paper we propose a study of these different effects, with theoretical considerations, and with the help of some applications (gearbox, automotive engine block). The aim of our work is to understand the physical phenomenon, and to evaluate the different effects in order to take them into account in the design and boundary element modelling phases.

1 - INTRODUCTION

Boundary element methods (BEM) are among the numerical methods currently used in industry for the low frequency domain. Many complex automotive structures contain a lot of ribs on the radiating surface. Indeed, additional ribs are often designed in order to decrease the vibrating power. This addition leads to different questions:

- is this addition benefic in term of acoustic radiation?
- is the modelling of the ribs necessary in the boundary element mesh?

The study presented in this paper tries to answer to these questions.
In order to know if a rib must be modelled or not in the acoustic mesh, engineers need criteria. Until nowadays, only one criterion was used: ribs of height under $\lambda/6$ are not modelled. In fact, this criterion is an extension of a current criterion for the maximum element size of a BEM mesh, and is not satisfactory regarding to the different physical phenomena. In the present paper, we propose some more accurate evaluation parameters for the ribs influence.

2 - THEORY

In the sound radiation of stiffened structures, we can divide the influence of ribs into three physical categories: the "vibrating effect", the "obstacle effect" and the "source effect" [1].
The "vibrating effect" is the best known vibroacoustic effect of ribs. By stiffening the structure, the ribs modify the vibrating behaviour, and then the acoustic radiation. Designers generally add stiffeners in order to decrease the vibrating power and to modify the eigenfrequencies. This "vibrating effect" of ribs has been already studied on plates [2,3]. J. Nicolas [2] has in particular shown that, for the frequency domain below the plate critical frequency, stiffening decreases the vibrating power but increases the radiation efficiency, witch consequently does not systematically decreases the radiated power. In this paper (3.1), we show that this phenomenon is also verified for more complex structures.

In boundary element methods, the vibrating behaviour of the radiated surface of the structure is used as boundary condition. This vibrating behaviour is generally calculated with a structural finite element method. That means that, even if ribs are not modelled in the acoustic mesh, the "vibrating effect" is taken into account if ribs are modelled in the structural finite element model.
That is not the case for the two other effects of ribs (source and obstacle).
The ribs represent an obstacle to the sound field, and then can modify it. That is the "obstacle effect". The theoretical influent parameters of this effect are the following: the surface and size of the rib regarding the acoustic wavelength, its position regarding the vibrating behaviour of the structure, the symmetry of the deformation regarding the rib plane [1]. It is then clear that the current evaluation criterion $\lambda/6$ does not take into account the entire phenomenon.
In the vibrating behaviour of a structure, ribs have also a normal vibrating behaviour, witch is not always neglecting, and they can so be considered as acoustic sources. As the criterion $\lambda/6$ does not consider the vibrating parameters of the ribs, it is not accurate for the "source effect" evaluation. A new parameter has then been proposed for this evaluation [4]:

$$E_r = \left(S\left\langle V_n^2\right\rangle\right)_{ribs} / \left(S\left\langle V_n^2\right\rangle\right)_{structure} \tag{1}$$

where S is the radiating surface and $\left\langle V_n^2\right\rangle$ is the quadratic normal velocity of the radiating surface.
This energetic parameter compares the vibrating energy of the ribs with the one of the rest of the structure.

3 - APPLICATIONS

We present, in this paper, two objects of application: an automotive gearbox and an automotive cylinder block.

3.1 - Vibrating effect

The vibrating effect of ribs have been studied for the cylinder block. The vibrating behaviour was calculated with finite elements for the engine block composed of the cylinder block, the oil pan and the cylinder head (figure 1). The acoustic radiation was calculated for the cylinder block alone. Two version of the cylinder block have been used: the first prototype contains a low number of ribs (figure 2), the second prototype contains some additional ribs (figure 3).

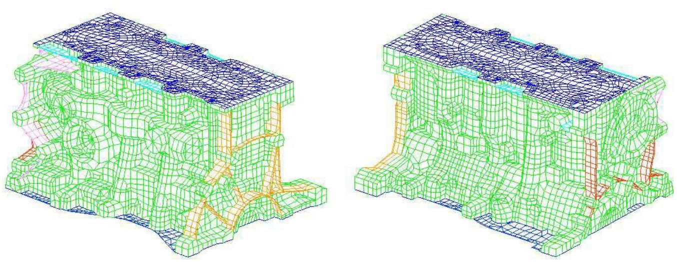

Figure 1: Engine block finite element model.

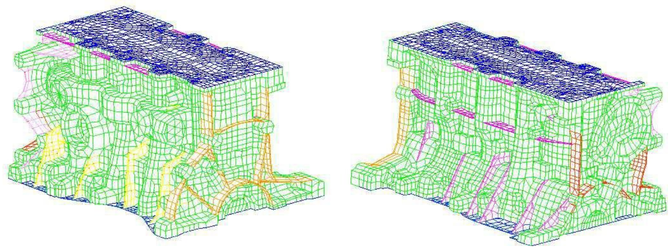

Figure 2: Prototype 1 of the cylinder block.

The vibrating behaviour of the engine block have been calculated for both configurations of the cylinder block. The vibrating behaviours have been used as boundary conditions for the calculation of the acoustic radiation of the cylinder block. In order to isolate the "vibrating effect" of the additional ribs, a boundary element mesh without ribs has been used.

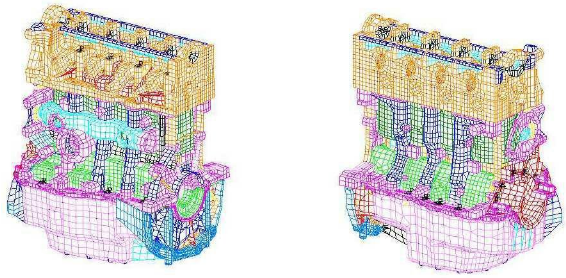

Figure 3: Prototype 2 of the cylinder block.

Figure 3 presents the comparison of the vibrating power, the acoustic power and the radiating efficiency for both configurations. Those results confirm J. Nicolas work [2]: stiffeners increase the radiation efficiency in low frequencies (below critical frequency). That means that the only evaluation of the vibrating power gain is not sufficient for the prevision of the gain in term of acoustic power.

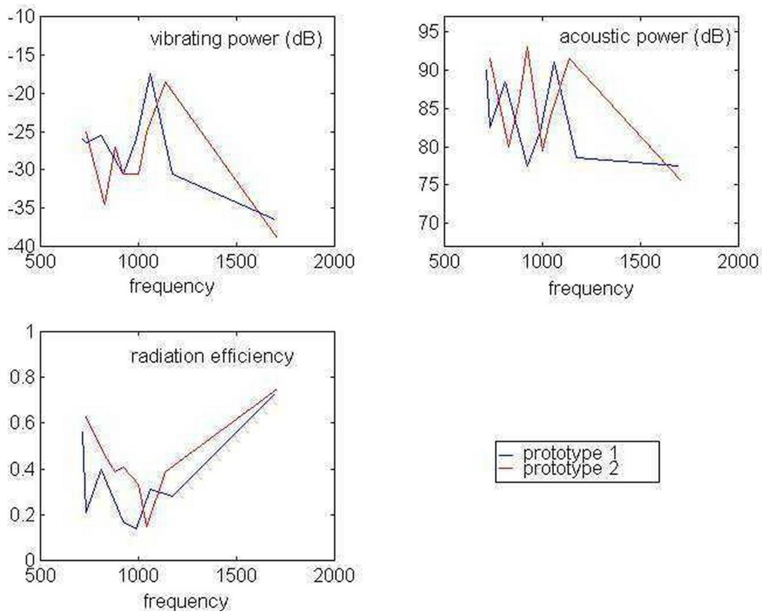

Figure 4: Vibrating power, acoustic power and radiation efficiency of the two cylinder blocks.

3.2 - Obstacle effect

The obstacle effect has been studied for both gearbox [5] and cylinder block. The finite element model of the gearbox is presented on figure 5.

For both structures, the same process has been used: the ribs have been divided in several groups, the acoustic radiation was calculated with meshes with different groups of ribs and compared to the result obtain with a mesh without ribs. In order to isolate the obstacle effect from the source effect, ribs were set motionless, with a null velocity condition. With this process we identified the influent ribs in term of obstacle effect. Results then obtained showed that:

- - the criterion $\lambda/6$ is not effective to identify the influent ribs
- - in case of local deformations of the structure, the more influent ribs are those close to the deformation.

3.3 - Source effect

The source effect of ribs was also studied for both application cases and for some stiffened plates [1], [4]. The new criterion proposed was calculated for each group of ribs.

For all cases, the source effect was negligible for frequencies below the critical frequency, even when the criterion E_r was important. That means that, at low frequencies, the radiation efficiency of ribs is low compared to the one of the rest of the structure.

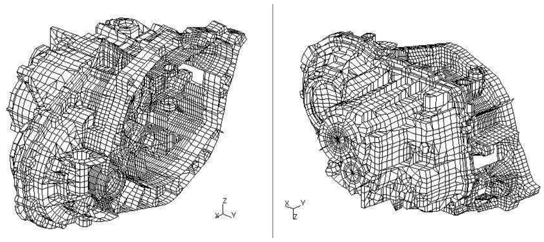

Figure 5: Finite element model of the gearbox.

For frequencies up to the critical frequency, two cases can been encountered:

- when the deformation is global, the new criterion E_r is accurate to evaluate the source effect of ribs
- when the deformation is local, the accurate parameter is $\left\langle V_n^2 \right\rangle_{ribs} / \left\langle V_n^2 \right\rangle_{structures}$.

4 - CONCLUSION

This study shows the importance of ribs in stiffened structures, and the importance of the acoustic calculation. The ribs influence has been separated in three different physical phenomena, and evaluation parameters have been proposed for each of them.

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