Acoustic design for noise reduction

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1. Introduction

One of the main challenges that mechanical engineers will have to take up in the next years will be to design lighter but quieter structures. Actually, engineers have essentially three main types of approaches for tackling noise problems:

(i) Classical control tools such as muffler, barriers, absorbing materials, enclosures which are still useful but not very convenient in terms of added weight and cost and very often not feasible in regards of the production constraints.

(ii) Control by an appropriate structural acoustic and vibration design which consist essentially in modifying mechanical parameters of the structure: change the dimensions, the material characteristics, add stiffeners, add local masses, add damping internally et externally, or modify the fixations conditions, decrease the energy transmission between coupled structures or systems [1].

(iii) Active noise control which may be divided in two main categories. Active noise control through anti-noise which consist essentially in finding the appropriate signal to feed to speakers to cancel the noise in specific positions where control microphones have been placed. It is actually the preferred approach for controlling the noise in internal volumes such as cavities and ducts. The other way, is to actively control the "bad" vibration which means the vibration which causes the noise. This is a more challenging problem which implies that you must know in great details the link between the acoustic and the vibratory energy [2]. This method uses essentially piezos sensors and actuators for sensing and acting on the structure.

In this paper, we will concentrate on the second approach the one dealing with modifying or creating an appropriate design which minimizes the radiated noise.

2. Theoretical predictions

Structural acoustic and vibration design cannot be made by trial and error methods. It has been demonstrated many times in the past that it is too complex to be handled by chance. The most classical example is addition of stiffeners. Doing so, is beneficent for the vibration level, however often times the radiated noise in not reduced but may even increase.

To predict the acoustical power radiated by a structure one has to solve a mechanical integro-differential system which governs the equation of movement of the structure as well as the wave equation for the surrounding fluid.

These fundamental equations can be solved (i) either by discretizing the displacement in terms of a modal basis or any convenient functional, (ii) or by discretizing the structure itself and/or the volume which involve the use of finite element or boundary element approaches. This is not a simple task. More details on these methods can be found in the following references [3,4].

To fix approximately the ideas these two methods have some advantages (+) and drawbacks (–) which are described in the following tables.

Table 1

Analytical approach
The + • This method which is more physical, authorizes a physical insight of how and why structures radiate noise. • This method increases the difficulties in terms of analytical calculations but reduces the computation time (about 10 to 100 times quicker than a numerical approach). • This method allows for the study of low and even medium frequencies. • The programs based on analytical methods are easy to use and are especially efficient for parametric studies.
The – • This method is limited to simply shaped structures and volumes (plate, cylinder). • This method looses its advantages when the structures become complex (holes, variable boundary conditions) • The method becomes heavy when dealing with coupled substructures.

Table 2

Numerical approach
The + • In principal, the method is valid for structures or volume of any shape, with weak or strong fluid coupling. • The method benefits regularly from the increasing capacity of computers (computer time and memory). • Once validated, this method can be used instead of experiments when measures become too costly. • Commercial codes are available. • The method allows inter connection with other fields, such as fluids mechanics and heat transfer, using also numerical approaches. • It is undoubtedly the method of the future.
The – • the method is limited to low frequencies for the moment. • The method tends to be used as a black box with the risks its implies. The user of commercial codes based on numerical approaches is better to be quite knowledgeable in structural acoustic and vibration. • The method necessitates access to efficient computers and cannot be performed decently on a P.C.

3. Acoustic design

In order to find design ways of controlling the noise, the authors have been deeply involved in developing the previous approaches for various mechanical configurations going from simple to more complex structures. These models have been developed to solve real problems submitted by several industries. It must be mentioned, here, that noise control at the source by design modification is a VERY COMPLEX and TEDIOUS task. There are absolutely no simple solutions, and research and development involve years and not weeks or months. There are no general rules neither. Each industrial problem is a particular one, with its own type of excitation, geometry (so its own model response and its own radiation factor), and type of coupling between its subsystems. However, in order to help clarify the situation, we have tried to summarize in Table 3 the great tendencies that engineers have to keep in mind when they want to deal with noise control by design at the source.

4. Conclusions

To face noise control at the source in the future, engineers will have to work closely with researchers to profit from the new knowledge and the new tools available. Analytical and numerical tools can be used in conjunction to get a better understing of the phenomena and to help find a better design.

The general tendencies given here and obtained from parametric studies have to be confronted with practical cases to get more confidence in their value. The challenge is huge since, although general tendencies are now well mastered, each industrial products reveals a very particular case with a very high degree of complexity, not handled at present by the different prediction models.

5. Bibliography

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Table 3

Mechanical modifications	Vibratory response	Radiation efficiency	Sound power
Increase of stiffness (measures, stiffeners)	↘ especially in low frequencies	↗ especially in low frequencies	• ↘ in low frequencies • even or ↗ in medium frequencies NOTA: always better to increase the added stiffness than the number of stiffness
Increase mass (local point mass)	↘ especially in high frequencies	⟶	↘ for high frequencies
Increase mechanical impedance mismatch at the junction between excitation and structure	↘ broad band effect	⟶	↘ broad band effect
Increase damping	↘ at the resonances	⟶	↘ only at resonance frequencies and above the critical frequency
Dimension: tend towards square surface	↘ less modal density	↘	↘