BEM Methods For acoustic and vibroacoustic problems in LSDYNA

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Abstract

*The present work concerns the new capability of LS-DYNA® in solving acoustic and vibroacoustic problems using a new keyword *FREQUENCY_DOMAIN_ACOUSTIC_BEM*
In vibroacoustic problems, which are assumed to be weak acoustic-structure interactions, the transient structural response is computed first. By applying the FFT, it is transformed into a frequency response. The obtained result is taken as boundary condition for the acoustic part of the vibro acoustic problem. Consequently, the radiated noise at any point into space can be calculated. The new developed LS-DYNA keyword is based on boundary element method (BEM) in which only the surface of the acoustic domain needs to be discretized. Besides BEM that solves the Helmholtz equation as a linear system, the new card allows, also, to use two other approximate Rayleigh and Kirchhoff methods. Both methods do not require a system of equations to be assembled and solved. Consequently, they are faster than BEM. Rayleigh method assumes that the radiating structure is a plane surface clamped into an infinite rigid plane. In Kirchhoff method, BEM is coupled to FEM used for acoustics in LS-DYNA by prescribing non reflecting boundary condition. In this case, at least one fluid layer needs to be merged to the vibrating structure.

INTRODUCTION

In the last years, several numerical methods have been used to simulate acoustic and vibroacoustic problems. The finite element method (FEM) is the most popular and used one. However, it needs the discretization of the whole acoustic domain. Consequently, when the observation point is situated far from the acoustic source, the mesh becomes very large. In addition, in order to simulate the acoustic radiation in an infinite medium, absorbing boundary conditions are to be applied.
Recently, the boundary element method (BEM) solving the Helmholtz equation became widely used namely in electromagnetism [1], acoustics [2]. Its development is now well documented in literature [3]. Compared to FEM, the chief advantage of the BEM is that only the boundary of acoustic domain needs to be meshed. In addition, the radiation in an infinite medium given by Sommerfeld condition is automatically satisfied so that the external domain doesn't need to be bounded.
Besides *MAT_ACOUSTIC keyword [4] usually used to solve acoustic problems in the LS-DYNA®, users can actually use another new acoustic card (**FREQUENCY_DOMAIN_ACOUSTIC_BEM**) based on BEM. It allows the simulation of acoustic as well as vibroacoustic problems. It is to be emphasis that in a vibroacoustic case, this

method is only used for weak coupling when the structure is not affected by the acoustic propagating waves (Air acoustics). Otherwise, the use of *MAT_ACOUSTIC card is necessary. Another feature of this coupling is that the acoustic calculations are done in the frequency however, the structural response is computed using LSDYNA® temporal analysis. The temporal response of the structure is stored into a binary file and is transformed, therefore, into frequency domain by using FFT in order to be applied as boundary condition for the BEM.
Besides the BEM which gives exact results, this new module allows to use two other approximate methods. The most simpler is Rayleigh method in which each element is assimilated to a plane surface mounted in an infinite rigid plane and vibrating independently from other elements. In the second one, called Kirchhoff method, at least one fluid layer is merged to the structure. This fluid layer is treated by using the already existing acoustic module of LS-DYNA®. Non reflecting boundary conditions are to be applied on the fluid layer to model the propagation into an infinite medium. Finally, the obtained results from this strong coupling analysis could permit to calculate the pressure at any point of the fluid medium using boundary integral discretization.

MATHEMATICAL BACKGROUND

In frequency domain, the acoustic wave propagation in an ideal fluid in absence of any volume acoustic source is governed by Helmholtz equation given as follows:

$$\Delta p + k^2 p = 0 \qquad \text{(eq. 1)}$$

where $k = \omega / c$ denotes the wave number, c is the sound velocity, $\omega = 2\pi f$ is the pulsation, p(r) is the pressure at any field point.
Equation 1 can be transformed into an integral equation form by using Green's theorem. In this case, the pressure at any point in the fluid medium can be expressed as an integral, of both pressure and velocity, over a surface as given by the following equation:

$$C(r)p(r) = \int_{S_y} \left(G(r, r_y) \frac{\partial p(r)}{\partial n_y} - p \frac{\partial G(r, r_y)}{\partial n_y} \right) dS_y \qquad \text{(eq.2)}$$

where $G(r, r_y) = \dfrac{e^{-ik|r-r_y|}}{4\pi|r - r_y|}$ is the Green's function, n is the normal on the surface S and C is the jump term resulting from the treatment of the singular integral involving Green's function. The normal derivative of the pressure is related to the normal velocity by $\dfrac{\partial p}{\partial n} = -i\omega\rho v_n$.

The knowledge of pressure and velocity on the surface allows to calculate the pressure of any field point. This constitutes the main idea of the integral equation theory. In practical cases, the problems are either Neumann, Dirichlet or Robin ones. In Neumann problem, the velocity is prescribed on the boundary while in Dirichlet case the pressure.
is imposed on the surface. Finally, for Robin problems the acoustic impedance, which is a combination of velocity and pressure, is given on the boundary.

To deduce the other acoustic variables on the surface, BEM can be used to discretize the integral equation. The most simple one is that called collocation method. In this technique, the integral equation is written for each node of the boundary. Assembling the produced elementary vectors yields to a linear system for which the solution allows to deduce the other half of the acoustic variables. Although this method uses simple integrals, it involves non symmetric complex and fully populated system. In the variational BEM, the equation is multiplied by a test function and integrated over the surface. As for the FEM, the variational BEM provides a symmetric linear system. However, it stills complex and fully populated. Another feature compared to the collocation is that the variational approach involves double integrals. It is to be emphasis that in BEM the linear system depends on the frequency via Green's function. For each frequency, the system has to be solved. For this reason, we have used an iterative solver which is more efficient for this kind of problems than the direct solver.

DESCRIPTION OF BEM CARD OF LSDYNA®

Computing acoustic pressure, in a non meshed infinite medium, due to a mechanical response is possible now in LS-DYNA® using the keyword:
***FREQUENCY_DOMAIN_ACOUSTIC_BEM.**
In order to use it, a unique name must be specified on the execution line by adding bem = bfile where bfile is the name of the binary file. Depending on which method is to be applied, velocity or both velocity and pressure are stored in this file at a time increment given by the user in the keyword.
In this keyword, fluid density and sound speed are to be given. Another input variables are minimal and maximal frequencies as well as the total required number of output frequencies for which the acoustic pressure will be calculated. The user can impose his own velocity profile for each node in frequency domain by using *DEFINE_CURVE card. In this case, LS-DYNA® analysis is not taken into account. However, in case the user prefers applying LS-DYNA® analysis, the temporal calculated mechanical response is considered as boundary conditions for the acoustic part of the problem. Consequently, FFT is applied in order to transform the temporal response into the frequency domain. Hence, if required the minimal and/or maximal input frequencies can be shifted, respectively, to minimal and/or maximal FFT frequencies. Due to the use of FFT, the user can choose among several windows in order to overcome the problem of leakage [5].
The geometry of the vibrating structure, forming the surface for which integral equation is considered, can be specified by *SET_SEGMENT, SET_PART or PART. In the same manner, the field points constituting the observation points can be given by *SET_SEGMENT or SET_NODE. If the user is interested by the pressure in dB, he has to enter a reference pressure as an input variable. Otherwise, the pressure will be calculated only in the problem units.
Several acoustic methods are proposed in LS-DYNA®. The first one is the BEM as described above. In this case, the keyword can be used for Neumann and Robin closed interior or exterior problems. For open domains, only Neumann problems can be considered. If LS-DYNA® analysis is used before, the binary file contains only velocities. To solve the linear system, the user can choose direct or iterative solver. Besides this exact method, the user can choose between two other approximate methods. Both methods do not require a system of equations to be assembled and solved. They are faster than BEM but they are used only for external problems.

In Rayleigh method, only the velocity of the surface is needed in the integral equation and therefore stored in the binary file. In Kirchhoff method, BEM is coupled to FEM for acoustics of LS-DYNA® (*MAT_ACOUSTIC) with Non Reflecting Boundary condition. In this case, at least one fluid layer, having the same acoustical characteristics as in the BEM card, with non reflecting boundary condition, is to be merged to the vibrating structure. Consequently, the saved pressure and the velocity at the surface are transformed into frequency domain in order to use them for the calculation of the pressure at any point of the fluid.

NUMERICAL APPLICATIONS

Vibrating Plate Problem

For the validation of the new method, we consider an elastic plate with a local force loading. The vibrating plate is assumed to be elastic and clumped at its edges. The plate mesh is described in figure 1, as well at the location of the external node (node 1001) where the acoustic pressure is evaluated. The plate is loaded using a nodal force excitation.

Contrary to the sphere case, Rayleigh method can be applied to the plate problem since the surface is planar. Consequently, we can use for this problem Kirchhoff, Rayleigh and Boundary Element methods. In order to use Kirchhoff method we have to consider a 3D meshes connected and merged to the plate, as described in figure 2. A classical LSDYNA acoustic material MAT_ACOUSTIC is used for the 3D mesh, to output pressure values that will be used for the BEM without solving a linear system, which reduces CPU time.

In figure 3 we plot the pressure comparing the BEM method used as reference solution and the Rayleigh method an approximate solution.

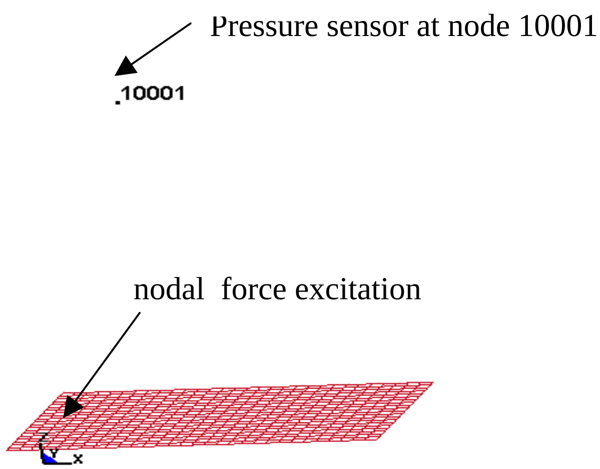

Figure 1: Vibrating plate mesh and location of pressure sensor

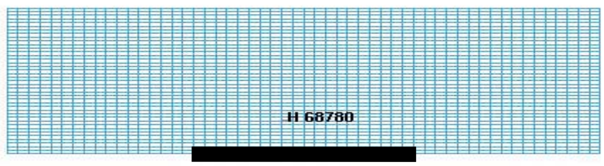

Figure 2: Vibrating plate model used in Kirchhoff method

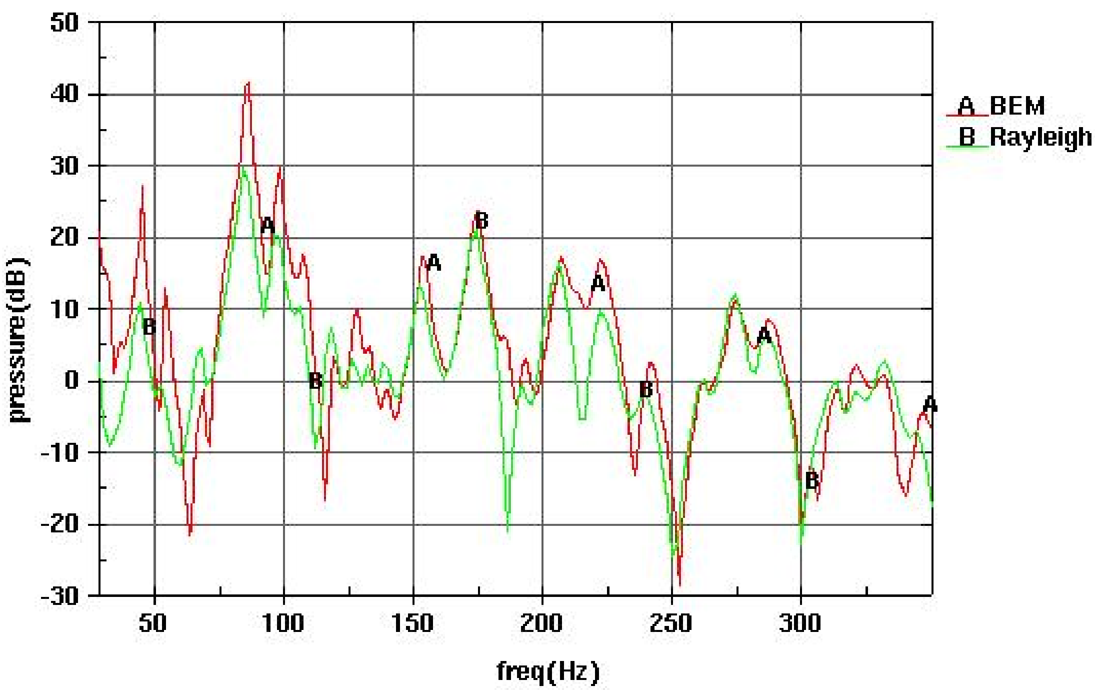

Figure 3: Comparison between BEM and Rayleigh method

Conclusion

In this paper we have presented a new card of LS-DYNA® based on boundary element method for acoustics. We have validated it for simple cases. In this card, the user can choose between BEM and two other approximate methods: Rayleigh and Kirchhoff which can be only used for some particular cases. Despite the good obtained results for the studied problems, this new card needs more validations for complex geometries.

References

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