Application of LS-DYNA® for Auto NVH Problems

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Abstract

NVH (Noise, Vibration and Harshness) is an important topic for the design and research of automotives. Increasing demands for improved NVH performance in automotives have motivated the development of frequency domain vibration and acoustic solvers in LS-DYNA.

This paper presents a brief introduction of the recently developed frequency domain vibration and acoustic solvers in LS-DYNA, and the application of these solvers in auto NVH problems. Some examples are given to illustrate the applications.

Introduction

Originally LS-DYNA is a nonlinear, transient dynamic finite element analysis software, and is mainly used in crashworthiness, impact analysis. With many new features added to LS-DYNA in recent years, the application of LS-DYNA has been extended to many new areas. One of such areas is automotive NVH analysis.

NVH stands for noise, vibration and harshness. They are important properties of automotives. To improve customers' comfort and make the new vehicles more competitive, all the auto makers are doing intensive research and testing to improve the NVH performance of their new vehicles. The lab testing, which is the traditional way to perform NVH study, is usually expensive and time consuming. Thus the numerical simulation with CAE models, which is relatively cheaper and faster, gain more and more attention. Due to the fact that vibration and noise are essentially related to driving frequencies, the NVH problems are usually studies in frequency domain. To perform NVH analysis with CAE models, the capabilities to run modal analysis, vibration analysis and acoustic computation are needed for a software. Besides, a massive parallel computing capability is a must since the auto models are usually very complicated and they may involve millions of nodes and elements sometimes.

In LS-DYNA, the modal analysis capability has been made available, by the keywords *CONTROL_IMPLICIT_GENERAL, and *CONTROL_IMPLICIT_EIGENVALUE, and some other optional keywords, for example, *CONTROL_IMPLICIT_SOLUTION, *CONTROL_IMPLICIT_STABILIZATION, etc.

Recently a series of frequency domain features were introduced to LS-DYNA, in addition to the existing implicit eigenvalue analysis keywords. They aimed to solve a variety of vibration and acoustic problems. The corresponding keywords are listed below:

- FREQUENCY_DOMAIN_ACOUSTIC_BEM_{OPTION}
- FREQUENCY_DOMAIN_ACOUSTIC_FEM
- FREQUENCY_DOMAIN_FRF
- FREQUENCY_DOMAIN_RANDOM_VIBRATION_{OPTION}

- FREQUENCY_DOMAIN_RESPONSE_SPECTRUM
- FREQUENCY_DOMAIN_SSD

These keywords are used to activate the acoustic simulation (by FEM or FEM), or FRF (Frequency response function) analysis, or random vibration analysis, or response spectrum analysis, or steady state dynamic analysis.

The acoustic solvers include indirect and direct BEM, approximate Rayleigh method and Kirchhoff method, as well as FEM. More detailed introduction of the BEM and FEM acoustic methods in LS-DYNA can be found in references [1] and [2]. The results of acoustic computation are given in the form of ASCII files Press_Pa and Press_dB, which are accessible to LS-PrePost®, and binary plot databases d3atv and d3acs. D3atv shows the acoustic transfer vector, which is the acoustic pressure due to unit normal nodal velocity for each surface node. D3acs is generated by FEM acoustic computation and it shows the contour plot of acoustic pressure for an internal problem. The Finite element mesh is used to model the acoustic domain inside the cabin or compartment.

The vibration analysis solvers include FRF (frequency response function), SSD (steady state dynamics) and random vibration.

FRF provides a transfer function between excitations and response, and it can be used to locate the energy transfer path, or some important dynamic properties of structures [3]. The result of FRF analysis is written in ASCII files frf_amplitude and frf_angle. Frf_amplitude / frf_angle shows the amplitude / phase angle of FRF analysis respectively. They can be accessed by LS-PrePost, as xyplot files. For auto NVH analysis, FRF can be given in many different forms, as given in Table 1.

Input	Output	FRF
Force	Acceleration	Accelerance, Inertance
Acceleration	Force	Effective mass
Force	Velocity	Mobility
Velocity	Force	Impedance
Force	Displacement	Dynamic compliance
Displacement	Force	Dynamic stiffness

Table 1: FRF formulations

SSD provides the steady state dynamic response of structures, subject to harmonic excitation [3]. The result of SSD analysis is given in binary plot database d3ssd, which is accessible to LS-PrePost.

Random vibration provides PSD response of structures under random PSD loading and it gives the distribution of energy in a range of vibration frequencies [4,5]. RMS value of the nodal and elemental variables can also be provided. The RMS plot can be used to identify the hot-spot of auto bodies in all kinds of operation conditions. The results of random vibration analysis are given in binary plot database d3psd and d3rms, which are accessible to LS-PrePost.

It is worthy to note that the vibration analysis solvers are all based on the results of modal analysis. In other words, the computation of FRF, SSD and random vibration relies on the eigen-modes (natural frequencies and modal shape vectors, provided in binary plot database d3eigv). So the modal analysis is the basis for these new frequency domain vibration solvers.

With both the vibration and the acoustic solvers ready, and with the implicit eigenvalue analysis capability, LS-DYNA is well prepared to perform NVH analysis for automotives.

Several other assistant keywords are also provided in LS-DYNA, such as *FREQUENCY_DOMAIN_MODE, *FREQUENCY_DOMAIN_PATH, etc. These keywords can be used to set up simulation environment for frequency domain analysis.

In this paper, a few examples are given to illustrate the application of LS-DYNA in auto NVH problems. They include a FRF example for a car model, a random vibration example for the same car model, and internal acoustic evaluation by finite element and boundary element methods in LS-DYNA.

FRF analysis on a BIW model

A BIW model is employed to demonstrate the FRF analysis procedure with LS-DYNA. The keyword *FREQUENCY_DOMAIN_FRF is used for this example, as well as *CONTROL_IMPLICIT_GENERAL and *CONTROL_IMPLICIT_EIGENVALUE for modal analysis. The model has 137 parts, including 176598 nodes and 165573 elements. For frf analysis, unit nodal force is applied at point A (user node ID 1), and response in form of acceleration is calculated at point B (user node ID 928300). The load is given in z direction and the response is also computed in z-direction.

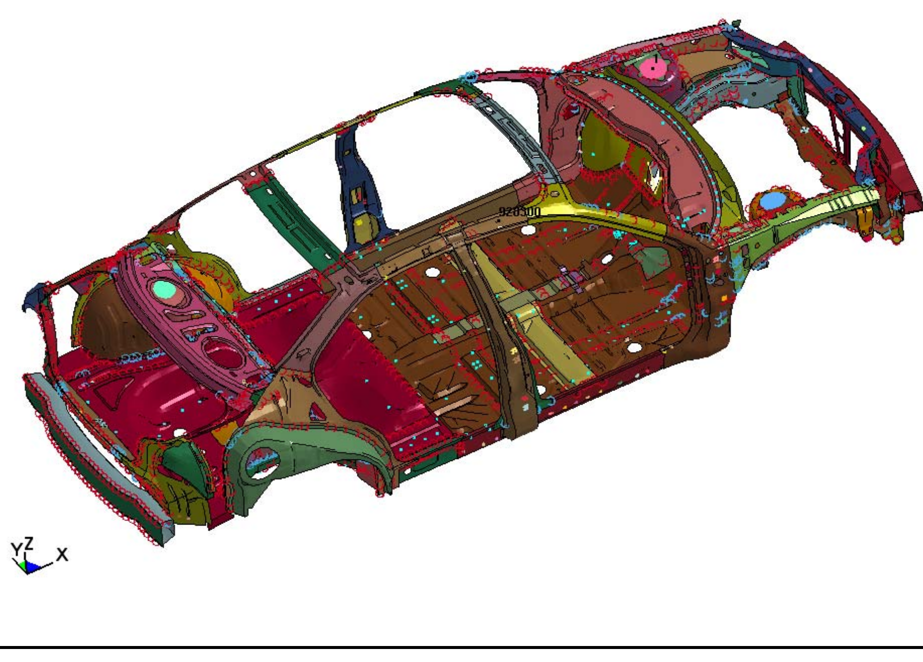

Figure 1: BIW model for FRF analysis (model provided by JSOL Corporation)

The accelerance result at point B (user node ID 928300) for the range of 1-200 Hz is plotted in Figure 2. Only amplitude of the FRF result is given.

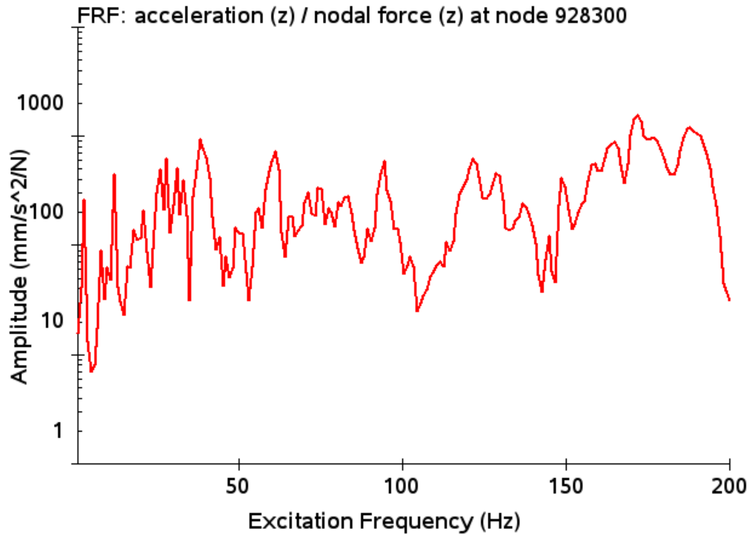

Figure 2: FRF result (amplitude) at point B

SSD analysis on a side frame model

In this example, a side frame model is subjected to harmonic vibration. It is constrained to shaker table via three holes. The model is depicted in Figure 3. The model has only 1 part, with 18551 nodes and 18082 shell elements. Keyword *FREQUENCY_DOMAIN_SSD and *DATABASE_FREQUENCY_BINARY_D3SSD are used in this example.

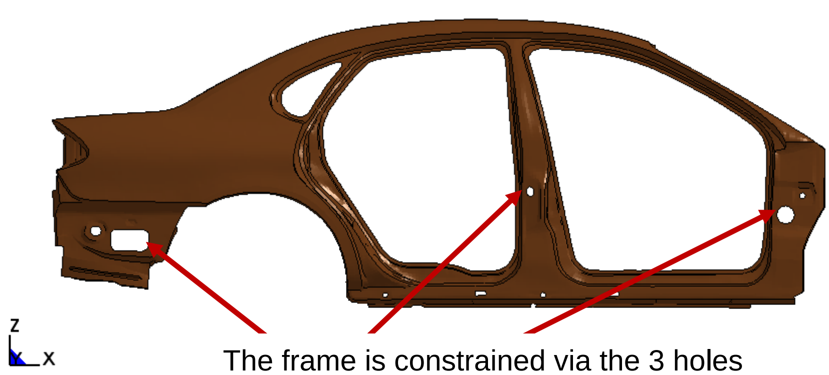

Figure 3: Side frame model of an automotive (model from NCAC)

The excitation is given in the range of 10-140 Hz, in the form of unit nodal force in y direction (vertical to the frame). The results are given in binary plot database d3ssd. For 4 excitation frequencies, the distribution of the acceleration is given in Figure 4.

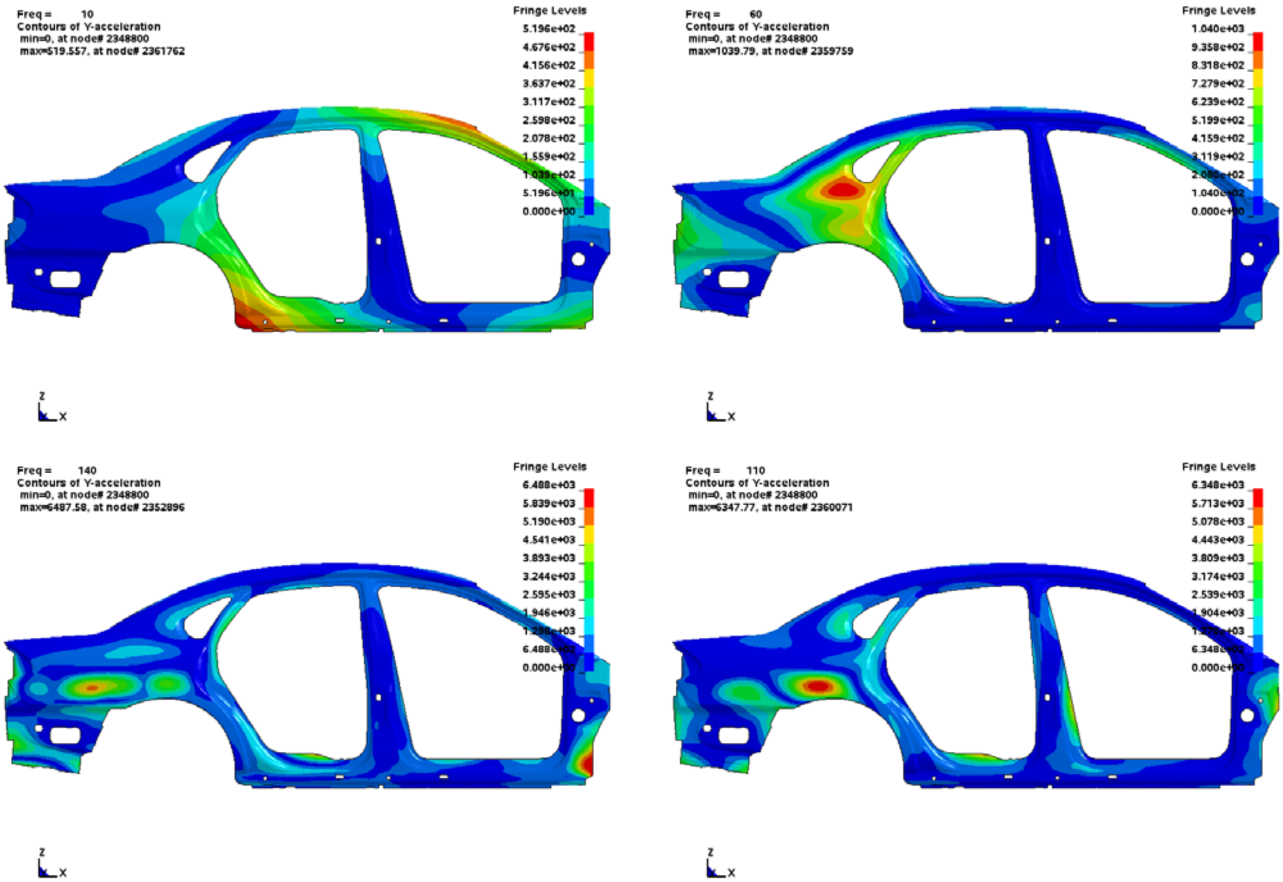

Figure 4: Acceleration SSD for auto frame

Random vibration analysis on a BIW model

Random vibration analysis for the same model in Figure 1 is also performed, to study the dynamic behavior of the BIW under base acceleration PSD excitation. The acceleration is specified in x-direction (see Figure 1). The PSD curve is given as white noise (1*g*^2/Hz) for the range of 1-200 Hz as follows.

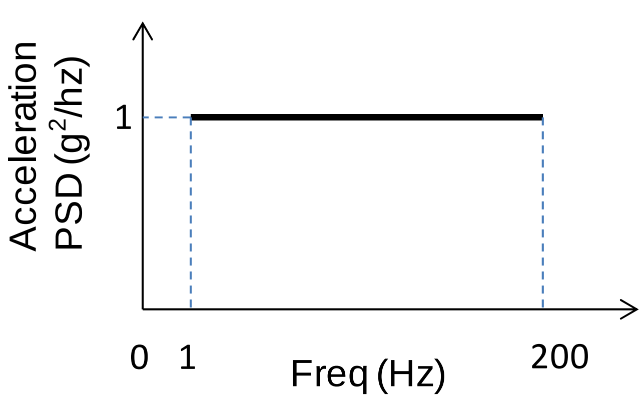

Figure 5: Acceleration PSD for random vibration analysis

The keywords

*FREQUENCY_DOMAIN_RANDOM_VIBRATION, and
*DATABASE_FREQUENCY_BINARY_D3PSD, and
*DATABASE_FREQUENCY_BINARY_D3RMS are used in this example.

The whole structure is constrained to a shaker table through a set of nodes. For response, binary plot database d3psd, and d3rms are provided. D3psd provides the PSD (power spectral density) values of nodal and elemental results, such as displacement, velocity and acceleration and stress components as well as Von-Mises stress. D3rms provides the RMS (root mean square) values of the same variables.

In Figure 6, the RMS value of the x-displacement is provided.

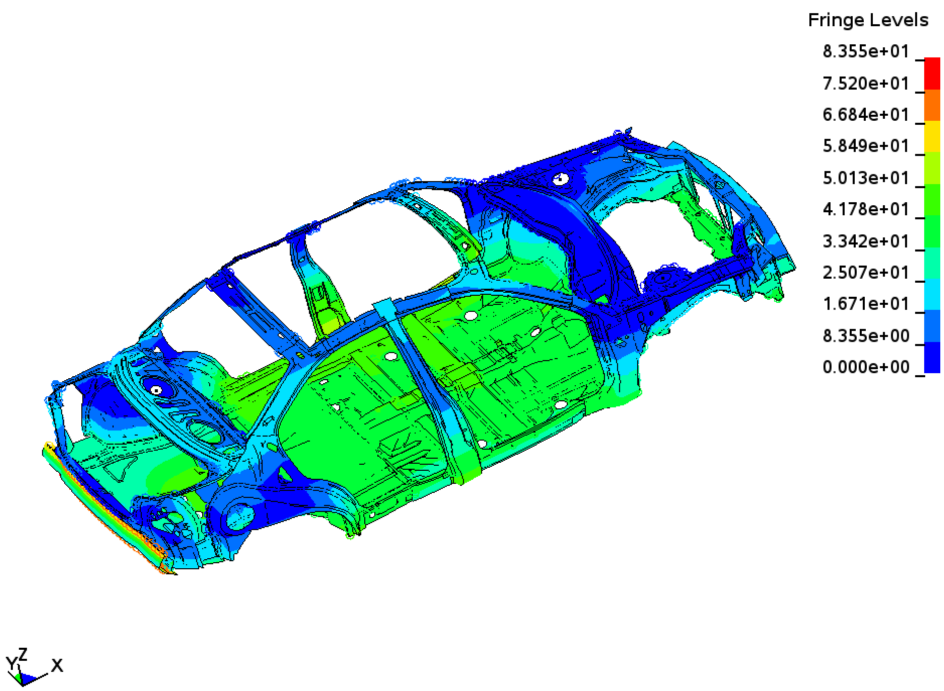

Figure 6: The RMS of x-displacement (unit: mm)

In Figure 7, the RMS value of Von-Mises stress is provided. This figure can help to locate the zones with high stress.

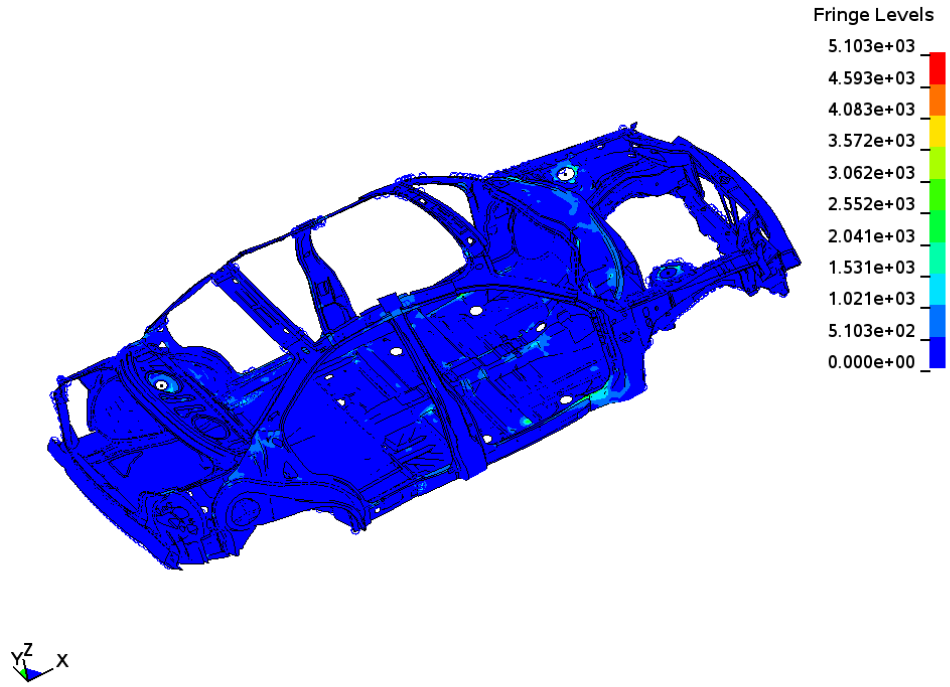

Figure 7: The RMS of Von-Mises stress (unit: MPa)

Compartment acoustic analysis

In this example, a series of numerical methods are adopted to study the acoustic behavior of a simplified cabin model. The interior noise of the cabin is computed in this example. The methods employed include finite element method (*FREQUENCY_DOMAIN_ACOUSTIC_FEM), and boundary element method (*FREQUENCY_DOMAIN_ACOUSTIC_BEM).

The model can be found in Figure 8.

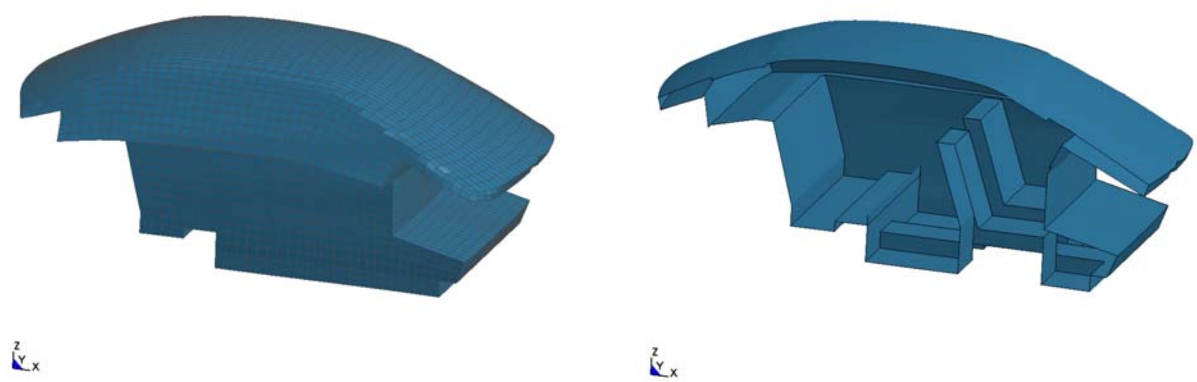

Figure 8: A simplified cabin model (mesh and profile)

The model is excited by unit normal velocity (1mm/s) given at the base panel, the excitation is given in the frequency range of 10-300 Hz. The other surfaces of the model are assumed to be rigid.

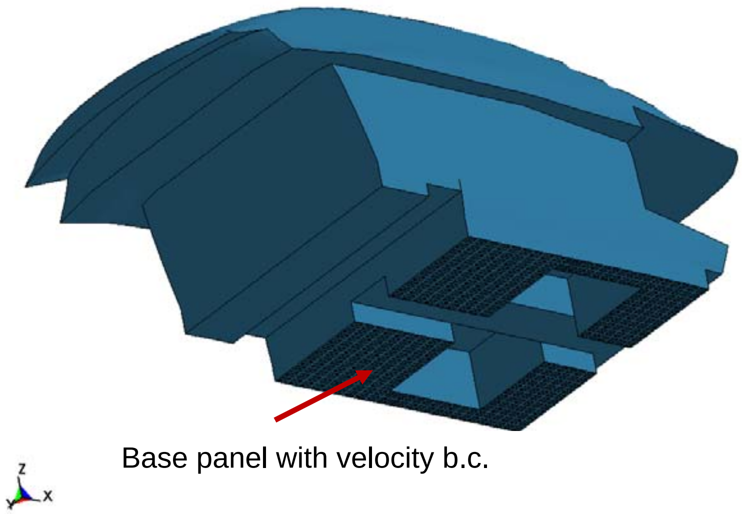

Figure 9: base panel subjected to uniform normal velocity

Results given by LS-DYNA (BEM and FEM) and Nastran results are plotted together in Figure 10. As one can see that the results given by NASTRAN and LS-DYNA (FEM) have better match. This is because that NASTRAN also uses FEM for its acoustic computation.

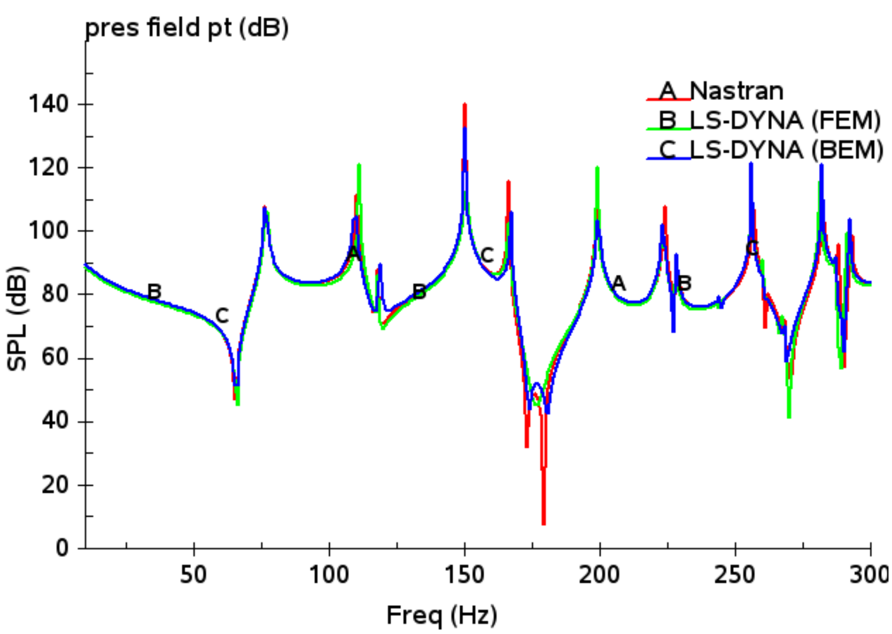

Figure 10: SPL at field point

Conclusion

A family of new keywords have been introduced in LS-DYNA to perform frequency domain analysis. They can be used to perform vibration and acoustic computation and have important applications in auto NVH analysis. A series of binary databases are also implemented to facilitate post-processing the computational results. These new frequency domain features, combined with the existing implicit eigenvalue analysis capability, and time domain dynamic analysis capability, establish LS-DYNA as an attractive tool for auto NVH analysis problems.

References

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