Discussion on NVH Analysis with Various Eigensolvers in LS-DYNA®

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Abstract

NVH (Noise, Vibration and Harshness) analysis is a new area of application of LS-DYNA in automotive industry, in addition to the existing applications of crashworthiness and occupant safety analysis.

NVH analysis heavily relies on the eigenmode solutions of the structures. Due to the increasing size of the finite element models of automotives and parts, a fast and efficient eigensolver is strongly preferred. During the past two years, a new eigensolver technology, MCMS (Multi-level Component Mode Synthesis), was implemented to LS-DYNA. This method reduces the large scale finite element model to a smaller model, using a recursive application of the Craig-Bampton substructuring approach. Thus less computational resources are required in MCMS.

With some large scale examples, this paper discusses the performance of NVH analysis based on the different eigensolvers (Lanczos and MCMS methods) in LS-DYNA.

Introduction

For the most basic problem involving a linear elastic material which obeys Hooke's Law, the matrix equations take the form of a dynamic three-dimensional spring mass system. The generalized equation of motion is given as (1)

$$[M][\ddot{u}] + [C][\dot{u}] + [K][u] = [F] \tag{1}$$

where $[M]$, $[C]$, and $[K]$ are mass, damping, and stiffness matrices, respectively. $[F]$ is the force vector. For general vibration modal analysis, equation (1) reduces to (2)

$$[K][\Phi] = [M][\Phi][\Lambda] \tag{2}$$

The matrix $[\Lambda]$ is the diagonal matrix of eigenvalues, $[\Phi]$ contains the corresponding eigenvectors and $[\Phi]^T [M][\Phi] = [I]$, where $[I]$ is an identity matrix. The Block Shift and Invert Lanczos has been used to solve the standard vibration analysis problem from (2) in LS-DYNA for many years. Lanczos assumes that $[K]$ and $[M]$ are symmetric positive semi-definite.

In the late 1960s, Component Mode Synthesis (CMS) was introduced for reducing the size of a finite element model, particularly where many subsystems are connected. This method re-characterizes large finite element models into a set of relatively small matrices containing mass, stiffness and mode shape information that captures the fundamental low frequency modes of the structure. The Craig-Bampton method, which has been most popularly used, combines the motion of boundary points with modes of the subsystem assuming that the boundary points are held fixed.

The MCMS method reduces the full scale model using a recursive application of the Craig-Bampton approach to a smaller model. The recursion is based on the elimination tree for the sparse factorization of the stiffness matrix. Since the eigensolution is computed for each smaller substructure model, it requires far less computing resources than Lanczos on the full scale model.

In the MCMS method, based on the transformation process explained above, multi-level transformation is processed as follows. A FE model of plate shown in Figure 1 illustrates a partitioning of the plate into substructures in a two level. The substructure 1 consists of interior and boundary degrees of freedom. At the next level, substructure 3 consists of the interface degrees of freedom between substructure 1 and substructure 2. The substructure 7 consists of the interface degrees of freedom that separate substructure 1, 2, 3 and substructure 4, 5, 6. The partitioning can be shown in a tree topology in Figure 1.

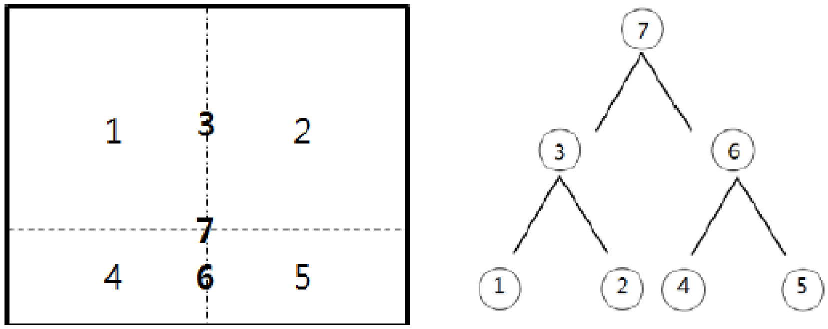

Figure 1. A plate FE model partitioned with two level and the substructure tree topology

The new option EIGMTH of 101 in the keyword *CONTROL_IMPLICIT_EIGENVALUE is used to implement the MCMS method in LS_DYNA. The MCMS method is available as of LS-DYNA R11. The target application is automotive NVH models where thousands of approximate eigenmodes are computed for frequency domain and fatigue analysis.

Modal analysis on a BIW model

In this paper, a 2012 TOYOTA Camry model from The National Crash Analysis Center (NCAC) is used for investigation. Figure 2 shows the finite element model of the Camry BIW model. There are totally 981,184 nodes and 959,064 elements.

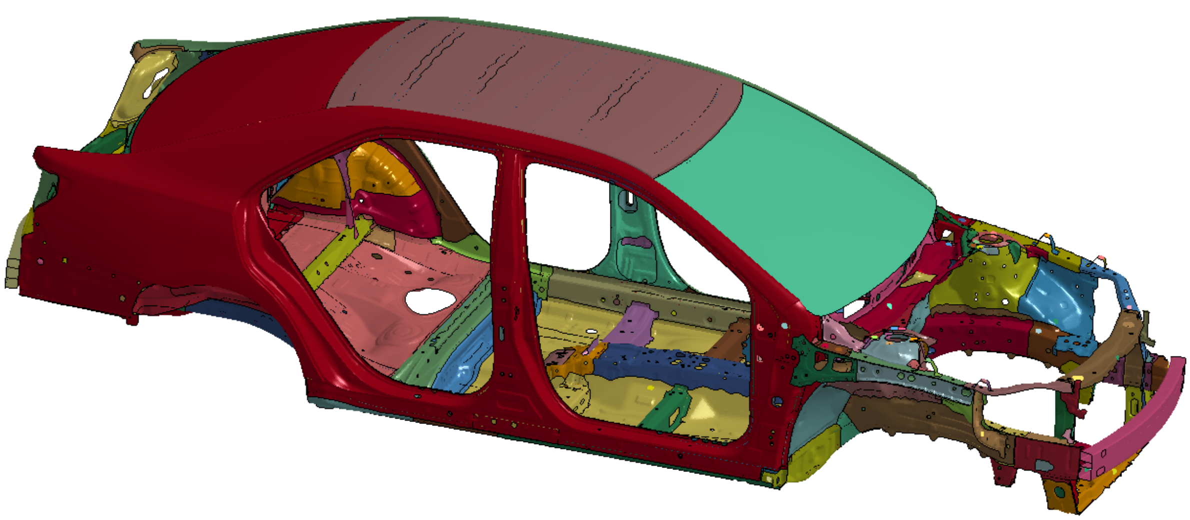

Figure 2. The finite element model of 2012 TOYOTA Camry (NCAC)

First, different number of modes from 1000 to 6000 are calculated, and the CPU time by Lanczos and MCMS methods are compared. Figure 3 shows the CPU time of the two methods. One can see that the CPU time increases significantly with the number of the modes increasing. Comparing to the Lanczos method, the MCMS method has a mild increase rate for the CPU time. The CPU time saving becomes more and more significant as the number of modes extracted increases. For example, to extract 6000 modes, the MCMS method takes around only 1/3 of the CPU time the Lanczos method would take.

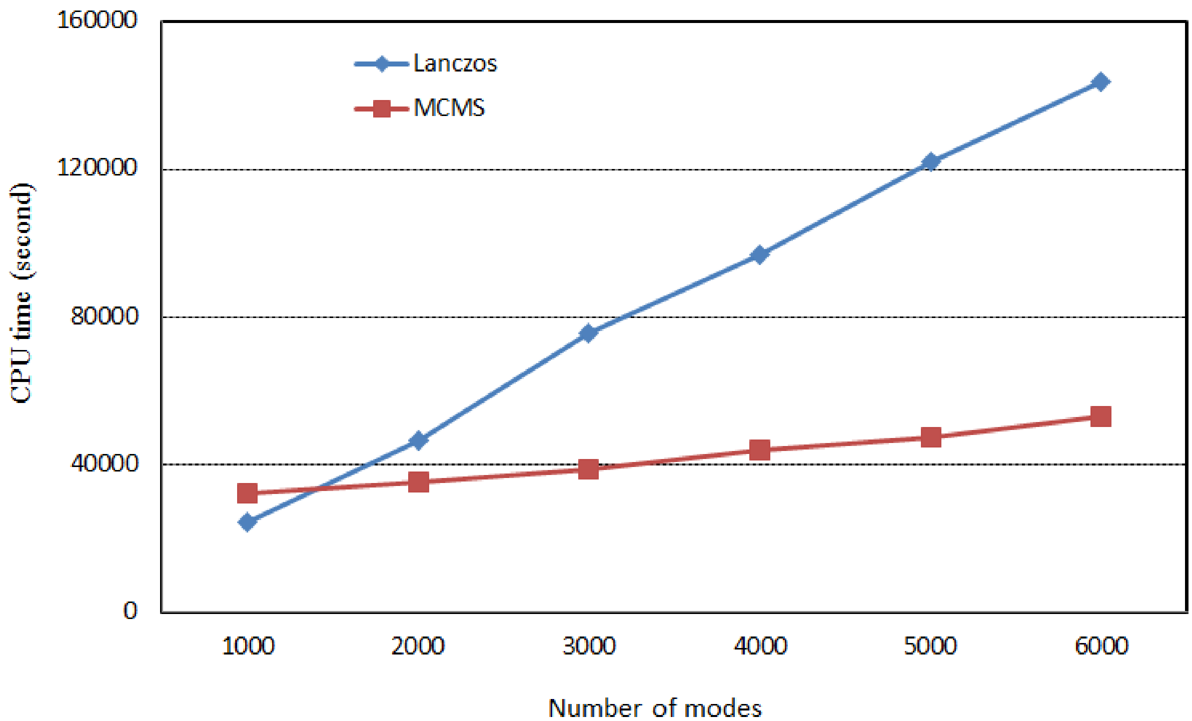

Figure 3. Comparison of CPU time between Lanczos and MCMS

Then, the accuracy of MCMS method is investigated. Figure 4 shows the relative error of the first 1000 modes from modal analysis of MCMS and Lanczos methods. One can see that the relative error increases with the mode number increasing.

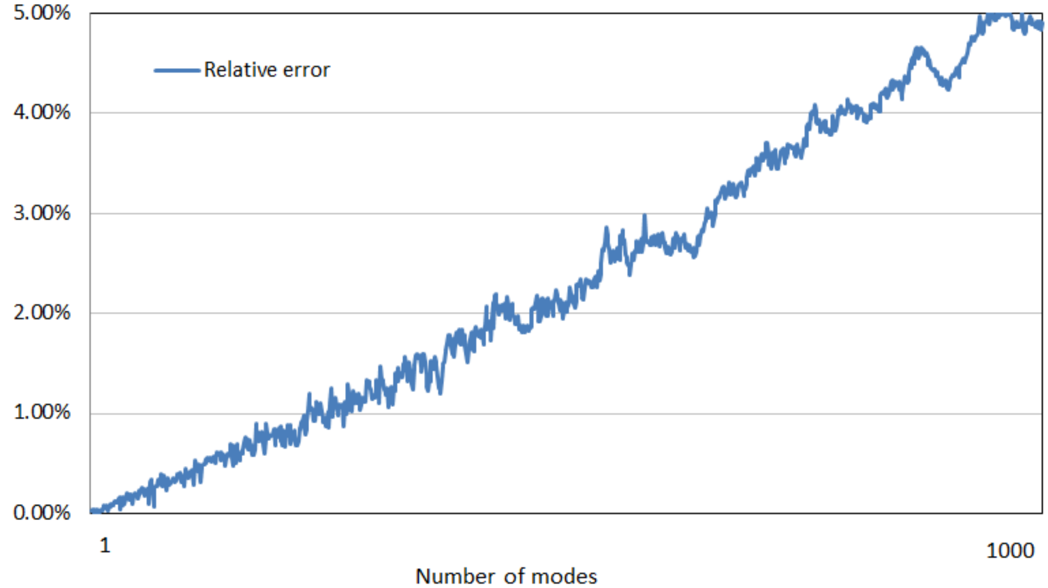

Figure 4. Relative error of eigenvalues computed using MCMS compared to Lanczos

Table 1 shows the first 20 eigenfrequency results by MCMS and Lanczos methods. One can see that the MCMS results have a very good match with the results by Lanczos method especially for the lower order modes. As is known to all, the lower order modes are more important than the higher order modes in dynamic analysis generally.

Table 1 Comparison of the first 20 modes between MCMS and Lanczos methods

Mode# (Hz)	Lanczos	MCMS	Relative error (%)
1	6.3987	6.4007	0.031
2	6.9753	6.9774	0.031
3	10.5841	10.5881	0.038
4	12.2648	12.2652	0.003
5	13.7231	13.7276	0.033
6	15.3923	15.3941	0.012
7	17.5771	17.5831	0.034
8	23.6371	23.6389	0.007
9	25.3125	25.3138	0.005
10	27.1840	27.1890	0.018
11	29.8688	29.8800	0.037
12	30.4541	30.4654	0.037
13	31.6618	31.6702	0.026
14	33.5736	33.5934	0.059
15	34.8371	34.8638	0.077
16	36.7754	36.7970	0.059
17	37.3751	37.4032	0.075
18	39.8271	39.8518	0.062
19	41.9039	41.9143	0.025
20	42.1791	42.2082	0.069

SSD analysis on a BIW model

The same model is used to for steady state dynamics(SSD) analysis. A nodal force is applied via node 407670 at Z direction as shown in Figure 5.

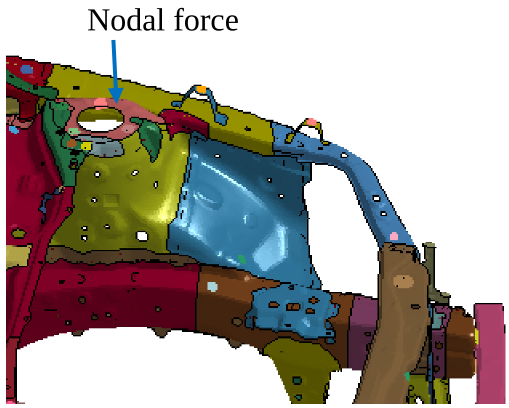

Figure 5. A nodal force applied to the BIW model

Figures 6 and 7 are the results of Z acceleration from D3SSD at frequency 1 Hz. The maximum of Z acceleration for Lanczos method is 0.078038 mm/s^2 and the MCMS method result is 0.0779201 mm/s^2. There is a very good match between MCMS and Lanczos results --- not only for the maximum acceleration value, but also for the contour map of the whole structure.

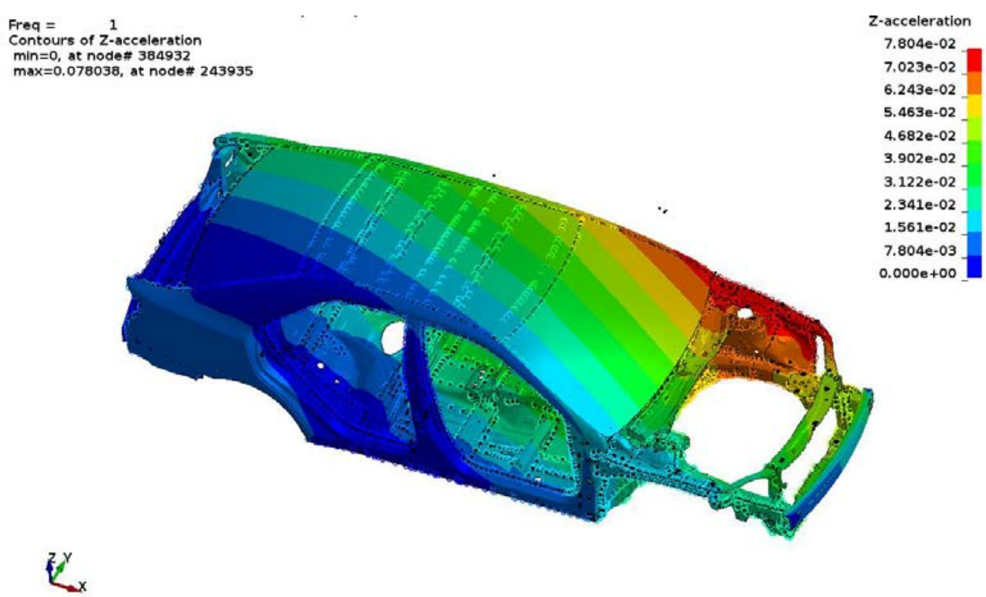

Figure 6. Z acceleration at 1 Hz by Lanczos method

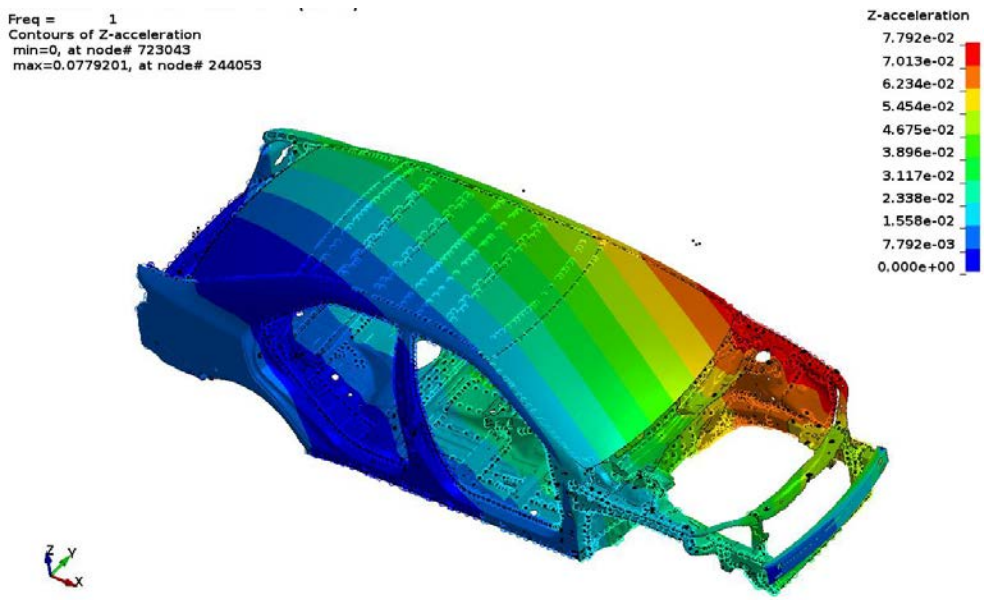

Figure 7. Z acceleration at 1 Hz by MCMS method

Figures 8 and 9 are the results of Z acceleration from D3SSD at frequency 50 Hz. The maximum of Z acceleration for Lanczos method is 142.029 mm/s^2 and the MCMS method result is 135.864 mm/s^2. There is some difference between the results by MCMS and Lanczos methods, as the relative error of modal analysis by the MCMS will increase with the increasing of the number of computed modes. It can still be seen that there is a good match of the contour map for the whole structure.

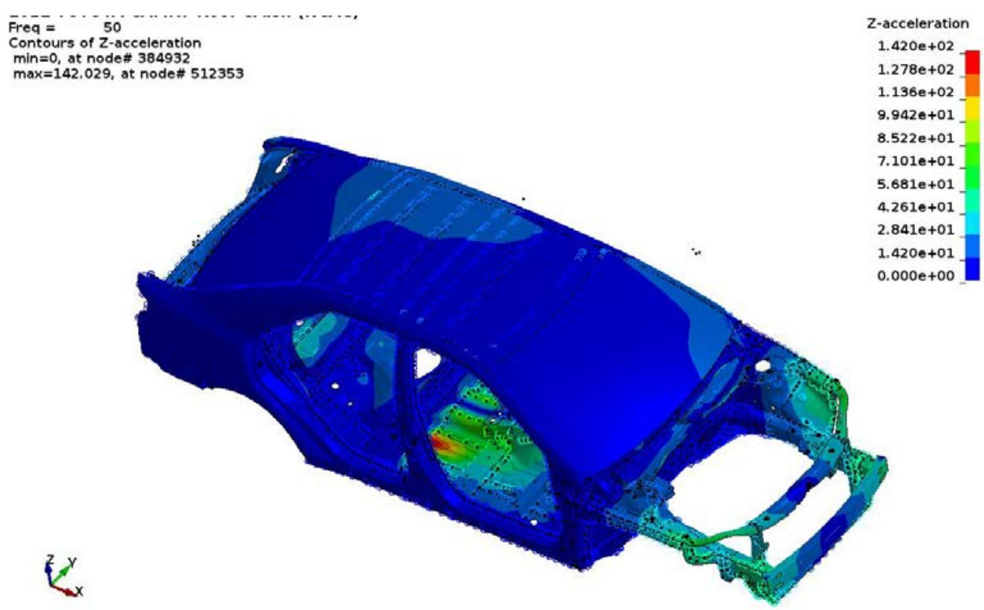

Figure 8. Z acceleration at 50 Hz by Lanczos method

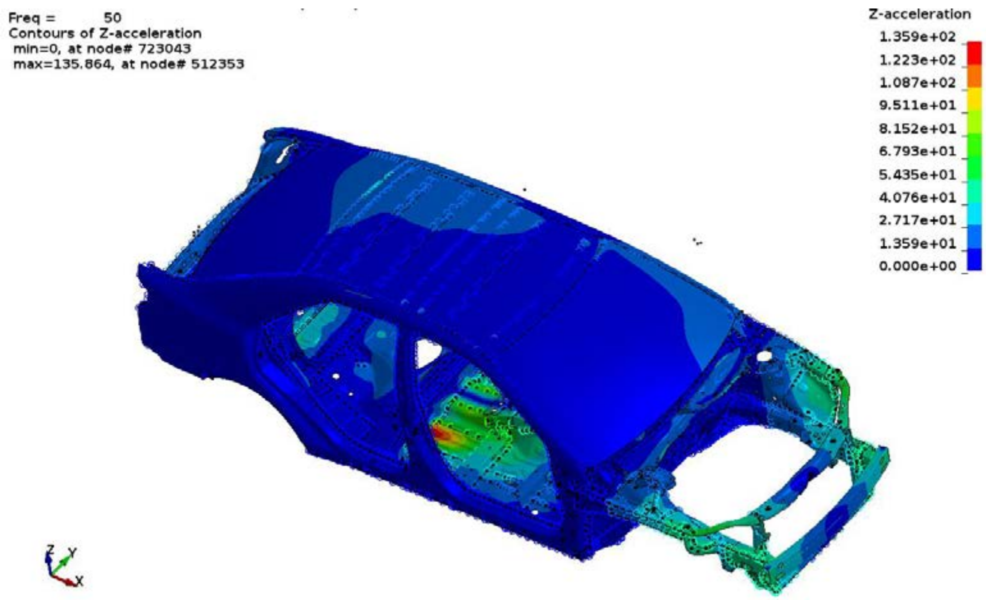

Figure 9. Z acceleration at 50 Hz by MCMS method

Figure 10 shows the frequency response curve of Z acceleration of node 672925 by both Lanczos and MCMS methods. There is a good match at lower frequency and a little difference at higher frequency, as expected.

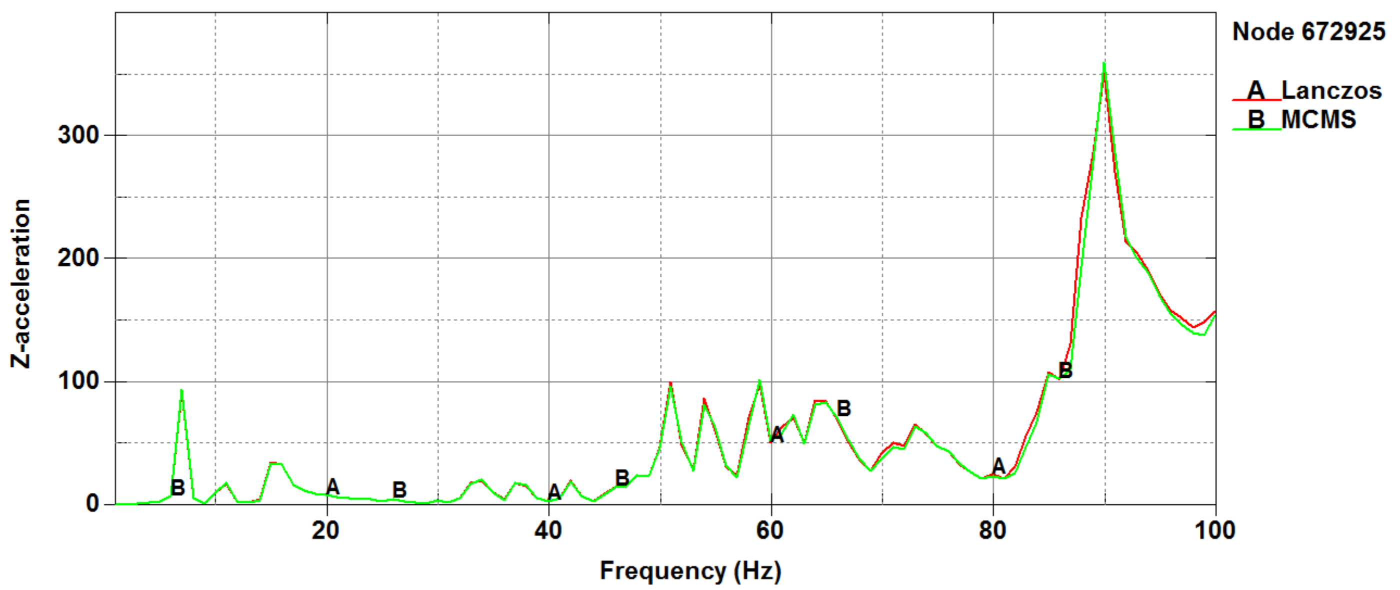

Figure 10. Z acceleration of node 672925

Summary

In this paper, a new eigensolver, MCMS (Multi-level Component Mode Synthesis) method for computing approximate eigenmodes is introduced. This method uses a recursive application of the Craig-Bampton substructuring approach. The MCMS method is less accurate, but it requires far less computer resources than the Lanczos method.

The target application of this new eigensolver is automotive NVH models where thousands of approximate eigenmodes are computed for frequency domain and fatigue analysis.

For illustration purpose, a full size car model is adopted to run modal analysis, and SSD analysis, based on the Lanczos and MCMS eigensolvers. The results by the two methods are compared. The performances of the two eigensolvers are discussed. It is shown that the MCMS method can provide reasonably accurate results for eigenmodes and frequency response, with much less CPU cost.

For the next step, further testing of the MCMS eigensolvers, on random vibration analysis problems, and response spectrum analysis problems, will be pursued.

References

[1] K. Chang-Wan, R. Grimes, A New Eigensolver for High Performance NVH Analysis: MCMS (Multi-Level Component Mode Synthesis), 11th European LS-DYNA Conference 2017, Salzburg, Austria.

[2] LS-DYNA Keyword User's Manual, Livermore Software Technology Corporation, 2017.