Random Vibration Fatigue Life Simulation of Bolt-on Metal Brackets using LS-DYNA®

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Abstract

Prediction of Vibration Fatigue Life is an important milestone during product design and development of Vehicle Brackets. Bracket in Vehicle is defined as a simple structure fastened to foundation structure or other brackets supporting mass of various modules. CAE simulation for Fatigue Life prediction gives useful information early in design cycle, and saves considerable time and cost compared with physical Shaker Table tests. LS-DYNA Implicit Simulation technology for Random Vibration Fatigue Life of Bolt-on Metal Bracket is developed. The simulation provides flexibility to evaluate multiple design options and accommodate design changes early in production development cycle. Bolt Fastening is included in the Simulation Process and the Fastening Stress is assumed to be maintained as the pre-stress for the assessment of Vibration Fatigue Life. This Fastening Stress is often very high and results in significant effect on Fatigue Life. Random loading is provided via the Power Spectral Density (PSD), which describes excitation acceleration levels in the frequency domain. System response to unit excitation is calculated using LS-DYNA's steady state dynamics analysis. This analytical stress FRF and random loadings are then combined to calculate the stress response PSD, which is cycle-counted and used for the calculation of Fatigue Life.

Introduction

In GM, Bracket design can be validated with CAE Simulation of the following typical Bracket Performances; (1) Resonant Frequency, (2) Mechanical Shock from Road Loads like Pot Hole, (3) Mechanical Shock from Minor Collision, and (4) Random Vibration Fatigue. GM Bracket Validation Specifications are documented in many public GM Documents including GMW3172 (General Specification for Electrical/Electronic Components – Environmental/Durability), GMW17010 (Mechanical Shock and Vibration Durability Test - Thermal Under Hood Procedure Specification), GMW16390 (General Specification for Analysis/ Development/ Validation (A/D/V) of Rechargeable Energy Storage Systems), and etc. Bolt-on Brackets are fastened by specification defined in GMW17000 (GM Global Fastening Catalogue). The nominal Standard Dynamic Torque of Torque Specifications Table in GMW17000 is used for the simulation. Bracket Suppliers can buy GM Documents on-line at HIS Markit Standards Store, and obtain specific requirements to validate their parts as specified in GM Documents. In this paper, only Random Vibration Fatigue (RVF) is the scope of work. In most cases of Vibration Fatigue of Vehicle, the loading is non-deterministic except few parts. In other words, many vibration environments are not related to a specific driving frequency, and have input from multiple sources such as Road Profiles and Powertrain Vibrations that requires RVF. For the prediction of RVF, component-level simulation is chosen in order to (1) utilize the existing GMW Validation Specification of physical Shaker Table test, and (2) efficiently apply to all Brackets independent from the parent Vehicle-level performances. In this paper, a VBM (Video Bypass Module) Bracket is chosen to demonstrate simulation of RVF using LS-DYNA Implicit.

Example of VBM Bracket

A 1.2mm Gage CR1 Steel Bracket holds a 200 Gram VBM (Video Bypass Module) through three clips, and undergoes two sets of loads; (1) Two M6 Bolt Torque 9NM as specified in GM Global Fastening Catalogue, and (2) PSD Input of Random Road and Powertrain Excitation specified in a GMW. The bracket is mounted to the vehicle by two Bolts as shown in the Figure 1. The VBM Bracket holds the VBM Module Assembly through the snap fits. The VBM Bracket Assembly is fastened to vehicle body structure sheet metal part. Fasteners are represented as pre-stress of Bolt Shank to simulate the Fastening effect. In this example, two M6 Bolts are used which is represented in hexa dominant mesh with Pretension section defined at mid span of bolt shank length. The VBM Polymer Holder is held by sheet metal with expansion clip. Expansion clip is modeled with design inference to simulate the clip expansion load. Shaker table was modeled to represent the vehicle fastening ideally representing the fixture scenario.

The LS-DYNA model is composed of 22408 elements and 30441 nodes as shown in Figure 2. The VBM Bracket is modelled as 1739 shell elements, while the other parts of VBM Module, Polymer Holder, and Bolt & Nuts are in solid elements. The average mesh size is 3mm with the minimum length of 0.73mm in a few areas to accommodate geometry detail. VBM Assembly Part data is shown in Table 1 in Units of Kg, MPa, & mm. Snap fit that holds the module and clip that clamps sheet metal to VBM polymer bracket has design interference. Design interferences are represented with contact interference - Shrink. Bolt Fastening Force is applied to bolt pretension section that fasten Sheet metal and Shaker Table. Shaker Table is constrained to represent the grounded fixture as the excitation zone. Input PSD from GMW16390 is shown in Figures 3 and 4 as graphs of the distribution of the acceleration levels over a range of frequencies in two different sets of measuring units.

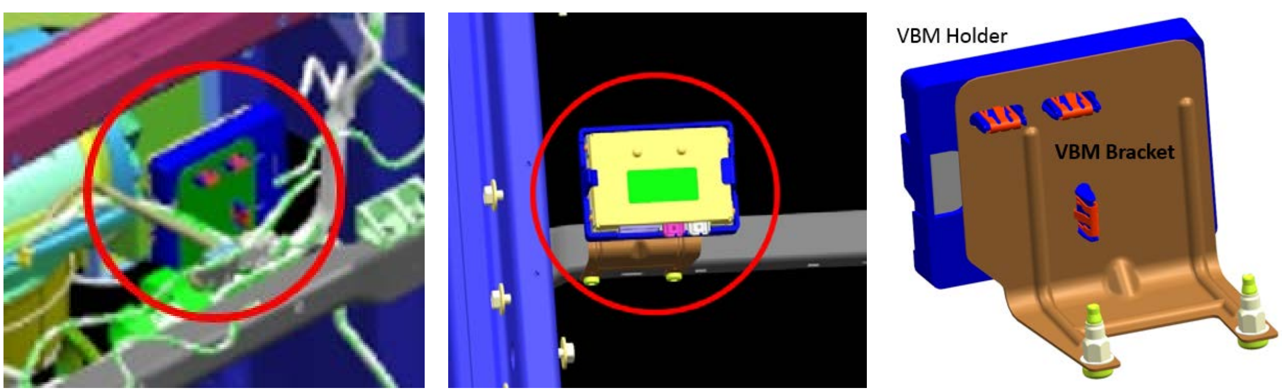


Figure 1: VBM Module Assembly in CAD Display

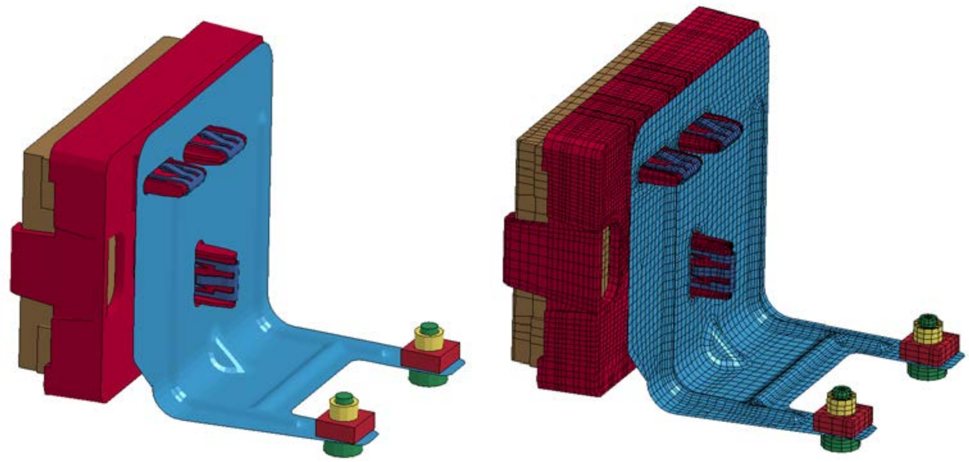
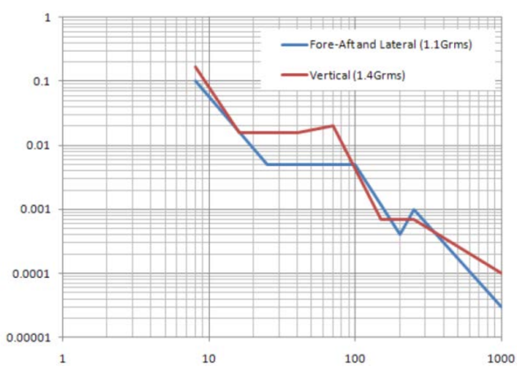


Figure 2: Geometry and Mesh of VBM Module Assembly in LSPP Window

Components	Material	Density (Kg/mm^3)	Young's Modulus (MPa)	Poisson's Ratio	Mass (Kgs)	YS (MPa)
Bolt-on Bracket (Subject)	GMW2M-ST-S-CR1(1.2mm)	7.924e-06	207000	0.29	0.12	210
Module Bracket	GMP-PP-004	1.05e-06	6288	0.40	0.05	15
VBM	GMW15665M-AL-E-6063-T1-60 Scaled Density 40%	1.00e-06	68300	0.33	0.2	83

Table 1: VBM Assembly Part data in Units of Kg, MPa, & mm



Generic Profile			
Fore-aft and Lateral (1.1G_{rms})		Vertical (1.4G_{rms})	
Hz	G^2/Hz	Hz	G^2/Hz
8	0.1	8	0.17
25	0.005	16	0.01574
100	0.005	40	0.01574
200	0.0004	70	0.02
250	0.001	150	0.0007
1000	0.00003	250	0.0007
		1000	0.0001

Figure 3: GMW16390 Input PSD Plot and Table in Units of Gravitation and Hz

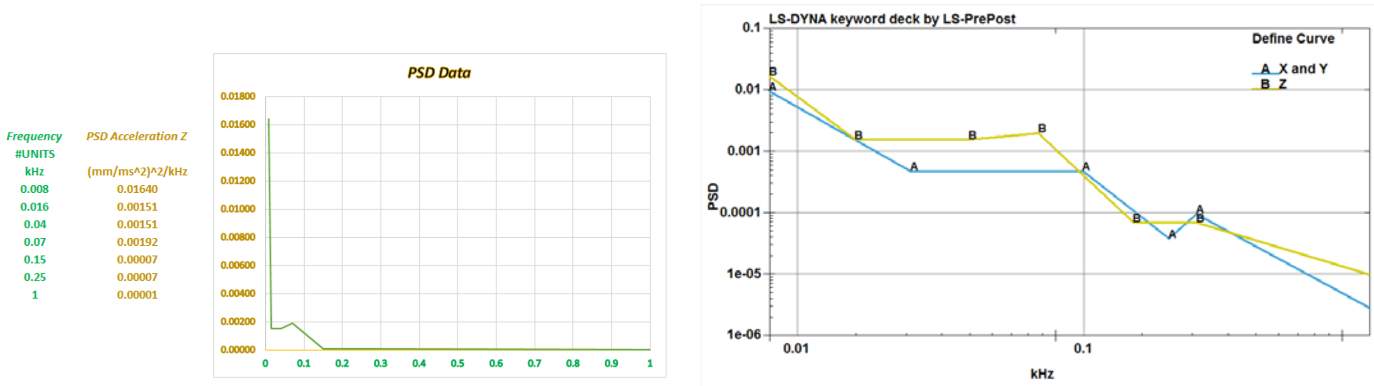


Figure 4: GMW16390 Input PSD Table and Plot in LS-DYNA Units in mm, msec, and KHz

LS-DYNA RVF Simulation Process

The process chart shown in Figure 5 is the LS-DYNA Functions with Keywords used for the simulation; Bolt Fastening, Modal, and Fatigue. These simulation procedures are seamless without being stopped and restarted, and run as one single job launch. Fastening Force is input to Bolt Fastening, and PSD Input data for each X, Y and Z-Direction are input to Fatigue. For Fatigue, individual directional simulations as well as a combined PSD Input of X, Y, and Z are run as separate load cases.

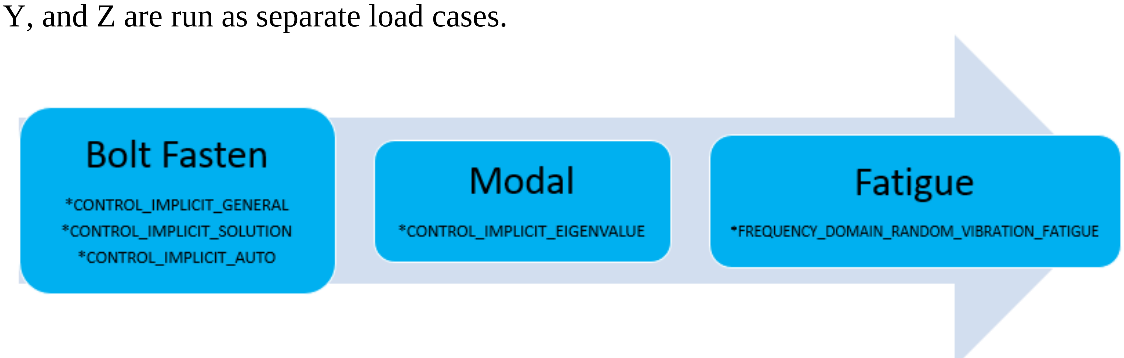


Figure 5: LS-DYNA RVF Process Flow

Bolt Fastening

The simulation is performed in Implicit LS-DYNA with nonlinear geometric and material effect considered for the entire loading. In Step-1 of Bolt Fastening, the design interference load is applied so that snap and clip area are subjected to strain movement until the interference between parts is removed. This transition fit is carried out using *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_MORTAR with flag IGNORE in Optional Card C set to 3 and MPAR1 set to a time to remove the transition fit. Figure 6 shows the keyword format.

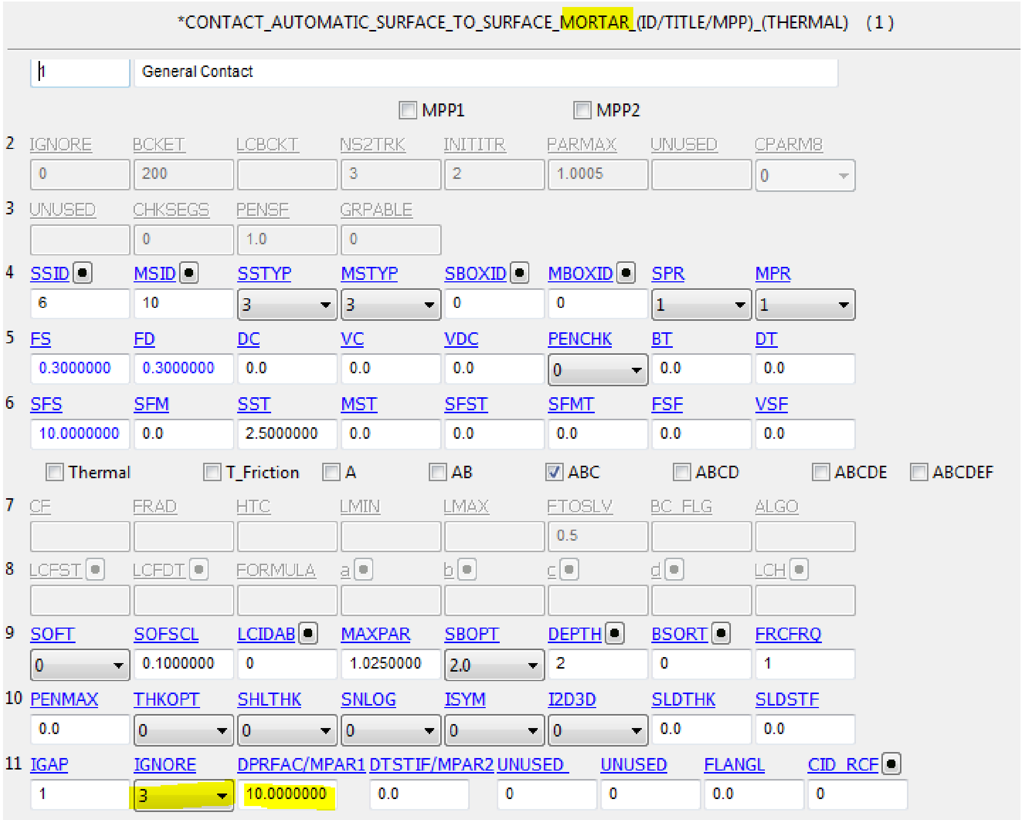


Figure 6: Contact card definition for Snap-Fit

In Step-2, Bolt Fastening Force of 8200N is applied to the sheet metal, which is fastened to the Shaker Table in addition to the Step-1 design interference effect. Fasteners are represented as pre-stress of Bolt Shank to simulate the Fastening effect. M6 Bolt is used and represented in hex dominant mesh with Pretension section defined at mid span of bolt shank length. The pre-stress is applied in LS-DYNA using the card of *INITIAL_STRESS_SECTION. Figure 7a shows pre-stress card with the 90 ms time-history of input stress with the max value of 0.373 GPa along with a *DATABASE_CROSS_SECTION that specifies the Bolt part id. A low of elements that cross the section plane are shrunk during the Step-2 to reach the applied stress. The nut is constrained to the shank using constrained nodal rigid body. The bolt fastens the bracket to the shaker table as shown in the image below. While tightening the Fasteners, tension load is developed in the fastener. The tensile load creates a compressive force in the joint. The stress that developed in the fastened part is called Fastening Stress, and shown in Fig.7b. The Fastening Stress observed in this case for the VBM Bracket is 149 Mpa. This stress is the input to RVF calculation of the metal bracket.

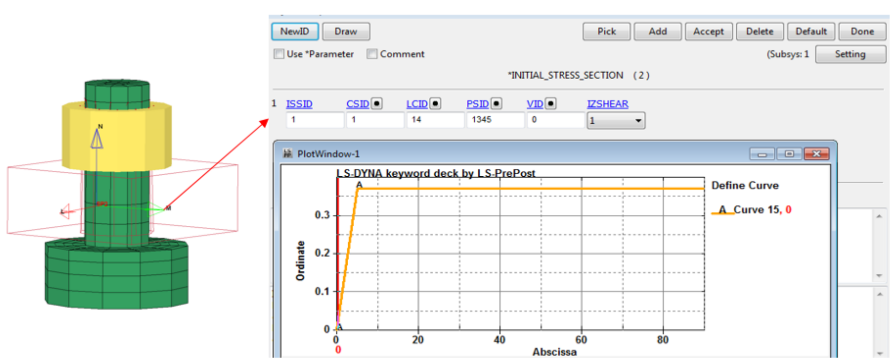


Figure 7a: Card and Modeling of Bolt Fastening

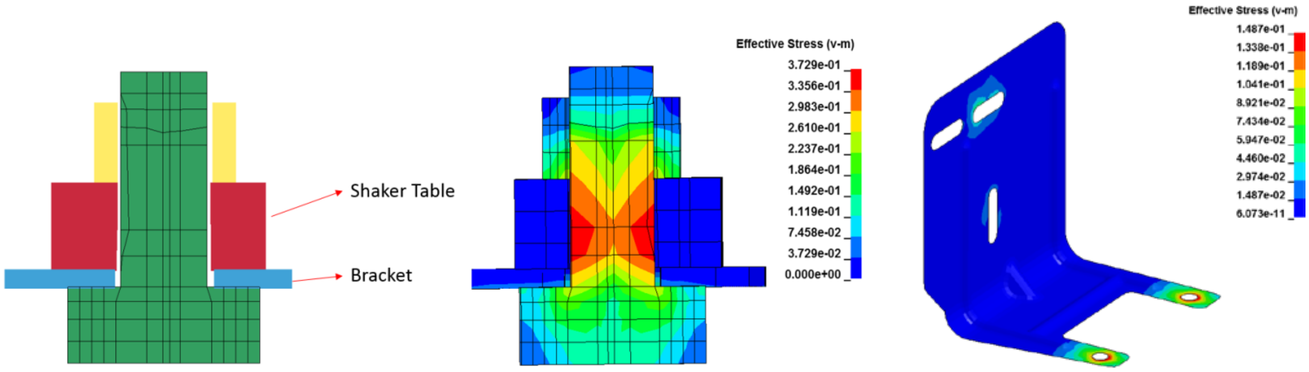


Figure 7b: Modeling and Stress Plot of Bolt Fastening

Modal Analysis

The modal analysis performed is a fixed normal mode analysis done by constraining the bolting location in six degrees of freedom. This modal analysis is carried out after the pre-stress is applied using the feature intermittent Eigen value analysis. The method can be used anytime the modal response of a structure is required during application of a load. It can be used on both static and transient analysis. A load curve input controls the output of required number of modes at specific time intervals. This *DEFINE_CURVE in the card *CONTROL_IMPLICIT_EIGENVALUE is input as a negative id defining time vs the number of Eigen modes required. Figures 8a, 8b and 8c show the three lowest modes and their frequencies for VBM bracket obtained from Modal Analysis.

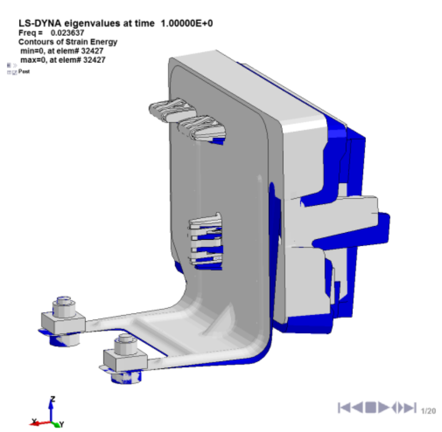


Figure 8a: 23Hz Bending Mode

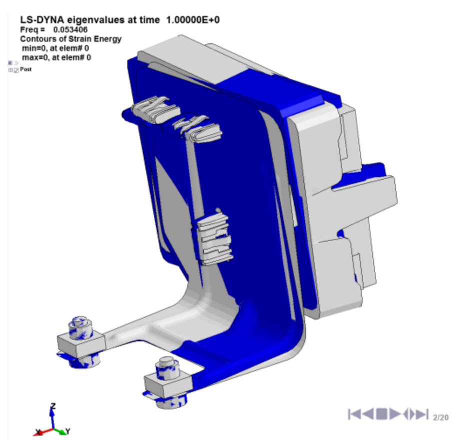


Figure8b: 53Hz Lateral Mode

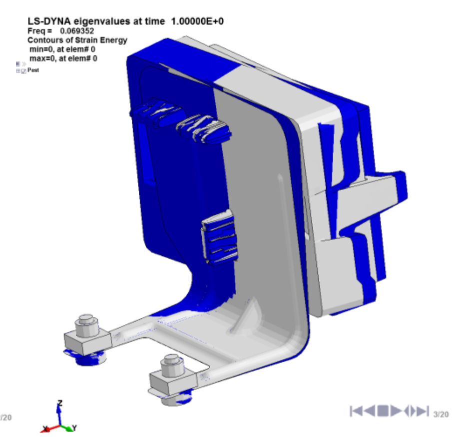


Figure 8c: 69Hz Torsional Mode

Fatigue Analysis

LS-DYNA can run SSD (steady state dynamics) to provide structural response under harmonic or steady state vibration condition. The results, which are dependent on frequencies, include magnitude and phase angle of nodal and elemental response. These results are given in D3SSD file, as well as NODOUT_SSD, and ELOUT_SSD files from LS-DYNA output. FRF provides a transfer function between load and dynamic response in frequency domain. It is a characteristic of systems under harmonic loading conditions. Unit Nodal force as a function of frequency is applied at points of Shaker Table Elements, and FRF response in form of Acceleration is calculated at Bracket Mesh Grids.

Fatigue is the progressive and localized structural damage that occurs when a material is subjected to cyclic loadings. Fatigue analysis can be carried out in time or frequency domain but in LS-DYNA the frequency domain approach is adopted. LS-DYNA can run fatigue analysis for structures under random vibration or sinusoidal vibration. It is based on material's SN fatigue curve. Upon analysis based on probability distribution and Palmgren-Miner's Rule of Cumulative Damage Ratio, we can predict the chance of fatigue failure.

$$E[D] = \sum_i \frac{n_i}{N_i}$$

Where $E[D]$ is the Expected Damage, n_i is the number of cycles and N_i is the number of cycles for the failure at the given stress level as specified by the Materials S-N data. Values of n_i are calculated with the specified Input PSD excitation in LS-DYNA. The Random Vibration Analysis provides PSD and RMS of nodal and elemental responses. The analysis methods available to further calculate E[D] are as follows; Steinbergs's Three Band Method, Dirlik Method, Narrow Band, Wirsching, Chaudhury and Dover, Tunna, Hancock, and Lalanne Method [3].

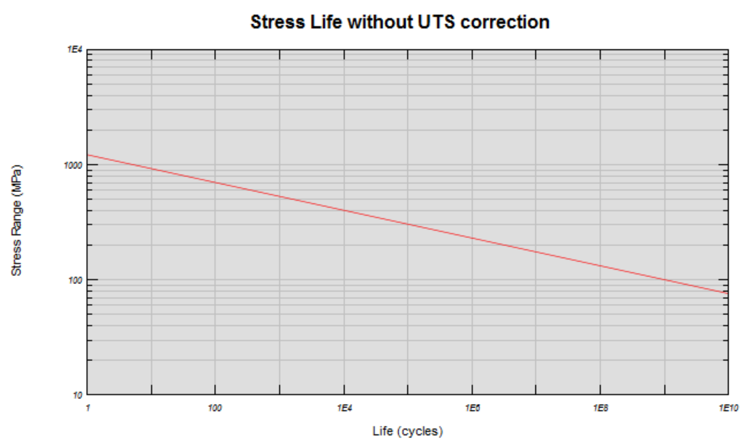


Figure 9: Material SN Fatigue Curve

For RVF analysis, a modal analysis is performed after completing the Fastening Load. Modal results are written out into D3EIGV file. This file is then used to apply the random vibration input. LS-DYNA outputs Stress PSD into a binary file call D3PSD, and Stress RMS output in D3RMS. Fatigue life results are calculated and output in D3FTG file. The units used in the model are Kg, mm, ms, KN, and therefore the LS-DYNA fatigue life results are output in ms. The ms lives are converted to life in hours manually. The keyword used for RVF is *FREQUENCY_DOMAIN_RANDOM_VIBRATION_ FATIGUE as shown in Figure 10 with the card definitions.

Figure 10: LS-DYNA Keyword for Frequency Domain Analysis

To run multiple load cases *CASE cards can be used so that the Fastening and Modal analyses are performed only once simultaneously. Results are processed using LS-Prepost® as it can read in all the binary files output by LS-DYNA and process them. D3Plot is read in and FCOMP is set to FRNX. This feature sets the value of any fringe component to the maximum value found during the entire simulation. Stress value to be displayed should be set to MAX of all the integration points for Von-Mises Stress. Stresses can be output for all the frequency values specified in the PSD data. This input in given as LCFREQ the keyword *DATABASE_BINARY_ D3PSD. As examples, the PSD Stresses at 8, 16, and 40Hz are shown in Figure 11, respectively.

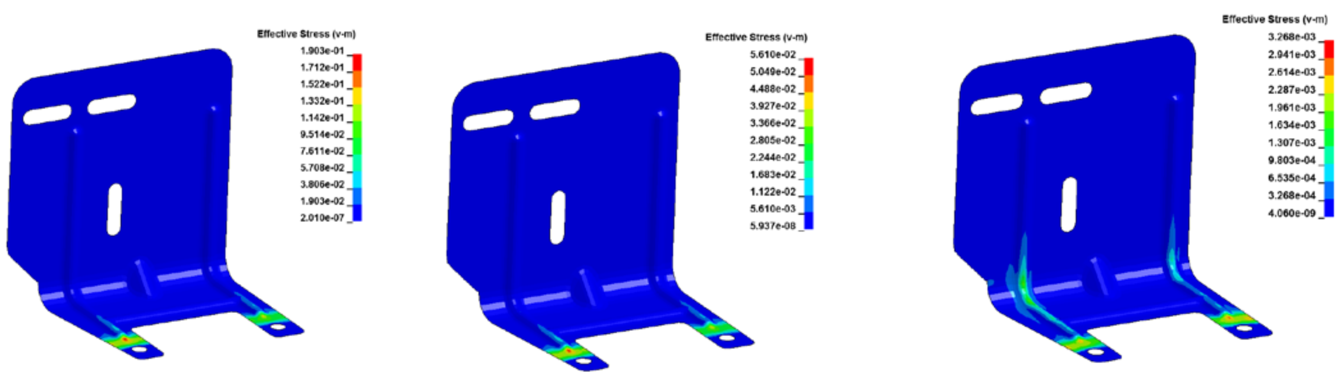


Figure 11: Stresses at 8, 16 and 40Hz

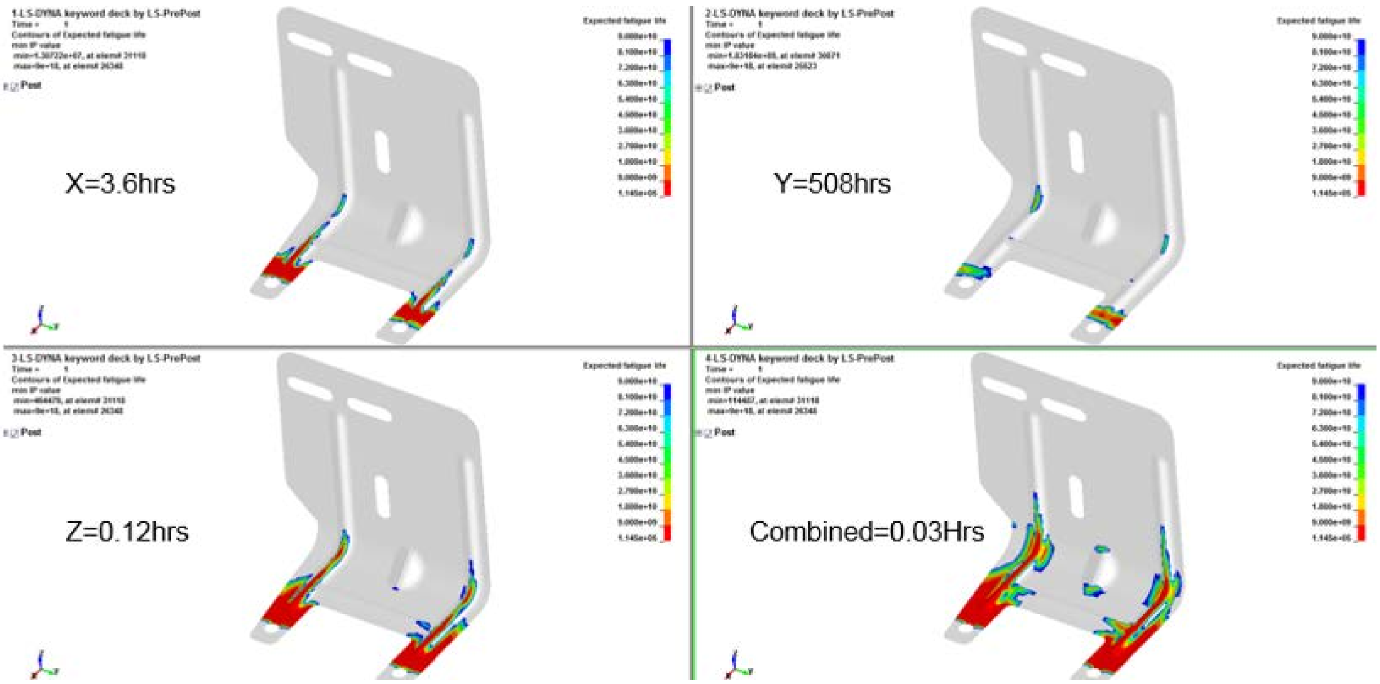


Figure 12: RVF Life Plot

Dirlik's method is used to calculate fatigue life. Method selection is specified by changing the parameter MFTG in the *FREQUENCY keyword. A 24-Hour exposure time is set for the analysis. The SN curve for the bracket material is specified as a log-log interpolation curve in Figure 9. Fatigue life results shown in Figure 12 are reported in milliseconds, and they are currently manually converted to Hours. RVF Life results are 3.6 in X, 508 in Y, 0.12 in Z, and 0.03 Hours in the combined loadcase, respectively. RVF Life contour is set to min in LS-PrePost as the smallest value is sough. Regions shown in red contour have the lowest life.

Conclusion

A simulation methodology for predicting RVF Life of Bolt-on Metal Brackets on vehicles using LS-DYNA is developed in this paper. The methodology takes into account (1) the Bolt Fastening which affects the RVF Life, and (2) Random Excitation which realistically represents vehicle rough road and powertrain vibration. LS-DYNA features in Modal Analysis and Fatigue were applied after Bolt Fastening using DYNA Implicit Solver. The RVF Life was calculated with PSD Input, PSD Stress from Steady State Dynamics, and Fastening Pre-Stress. In order to build confidence on LS-DYNA RVF Simulation, correlation study is needed to prove this simulation provides results that are realistic representation of reality. Also new methods of RVF Simulation will be studied and various Bracket Loads will be refined in the future.

References

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Acknowledgement

We would like to thanks developers Yun Huang of LSTC and Thomas Borrvall of Dynamore. We would also like to thank Satish Pathy of LSTC for his support. Also we would also like to thank Kurt Munson of nCode and Jeyavendeesh K. S. of GM for his support.