Structural Durability Analysis of Passenger Car Exhaust System using FPM Approach in Radioss

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Abbreviations: CAE: Computer Aided Engineering, FPM: Fatigue Process Manager, UTS: Ultimate Tensile Strength, RLD: Road Load Data

Keywords: Exhaust System, Muffler, Resonator, Road Load, Hanger Bracket.

Abstract

This paper deals, to evaluate the durability of exhaust system components by CAE Simulation. Finite element simulation are carried out and the results are explained for the typical exhaust system components considering the durability loads such as engine vibration loading, proving ground road loads. The durability issues associated with the exhaust system components such as muffler-pipe system, brackets and hanger designs are analyzed. Detailed analysis of exhaust components are explained.

Finite element modelling is carried out for passenger car exhaust system using Altair's pre-processing tool HyperMesh. Static analysis is performed by using Radioss for exhaust components to determine the high stress region, followed by S-N approach for calculating the fatigue life of exhaust system components with the help of HyperWorks, Fatigue Process Manager (FPM) in Radioss. The results are viewed through Altair's post-processing tool HyperView. It is observed that this approach produces comparable results with simplified pre and post processing as well as reduction in solving time.

Introduction

Ever increasing demands for durability, lighter and cost effective designs of automotive products have lead to more frequent usage of powerful Numerical techniques for solving structural durability problems. In the automotive industry, the detection of structural durability failures has traditionally relied on proving ground durability tests. It is generally recognized that developing designs through testing & retesting using several prototypes is not helping in accelerating the product development. Hence virtual fatigue/durability calculations of automotive components have become an essential part for vehicle manufacturers. Hence designing the exhaust system for durability is extremely important. The automotive exhaust system Physical tests offer durability evaluation of all the exhaust system components. There are several different tests for validating the exhaust component designs under different loading conditions. For example, oscillating load test is used to test all welds under bending loads, the road load rig test is used to test the entire exhaust system and components under road and thermal loads, and engine dynamometer test is carried out under exhaust and thermal loads. The laboratory test offers durability evaluation for the exhaust system, which could provide pass/failure information. Comparing to laboratory tests, CAE is another tool, which could be employed for improving durability performance of exhaust components while reducing significant product development costs and time. CAE not only evaluate durability performance, but also explores many possible design options and promises to yield optimum design with significant experimental cost and time savings. Several examples of critical components and designs are considered in this paper to explain the durability issues involved in a typical exhaust system development cycle and how CAE
usage enabled in obtaining improved designs. FPM of Altair HyperWorks is used to predict the durability performance in this paper. Some of the design elements of Exhaust system considered for the evaluation are:

1. Muffler - pipe system.
2. Hanger design.
3. Muffler Bracket design.
4. Resonator - pipe system.

![Schematic Diagram Of Small Car Exhaust System](image)

Figure 1: Schematic Diagram Of Small Car Exhaust System

[Note: The Images Shown Are Proprietary And Should Not Be Used, For Any Purpose, Without Prior Permission Of Sharda Motor Industries Limited.]

Methodology:

The durability of the exhaust system sub-components is carried out with the RLD. The exhaust system is mapped with sensor and load cell to acquire load data from the road. Then the acquired load data is applied to the exhaust system sub-components. A CAE simulation is carried out to address fatigue sensitive design area in the exhaust system components. Altair HyperWorks FPM is used to determine the durability of the exhaust system components. The methodology helps in virtual testing and to reduce physical testing of the sub-systems. This virtual testing using FPM will reduce the development time and cost.

Fatigue Process Manager (FPM):

The S-N approach is suitable for high cycle fatigue, where the material is subject to cyclical stresses that are predominantly within the elastic range. Structures under such stress ranges should typically survive more than 1000 cycles.

The S-N approach is based on elastic cyclic loading, inferring that the S-N curve should be confined to numbers greater than 1000 cycles. This ensures that no significant plasticity is occurring. This is commonly referred to as high-cycle fatigue.
The following steps are followed to evaluate fatigue life of the system with the S-N method through Fatigue Process Manager (FPM).

1. Launching Fatigue Process Manager
2. Importing model
3. Creating fatigue subcase
4. Defining fatigue analysis parameters
5. Defining fatigue elements and S-N properties
6. Defining load-time history and loading sequence
7. Submitting the job
8. Viewing results summary and launch HyperView for post-processing

**Muffler-Pipe System:**

This CAE Simulation is designed to address fatigue sensitive design in the area of exhaust pipe entry into the forward end of a Muffler in a vehicle exhaust system. This CAE Simulation is used to evaluate the bending fatigue durability of the forward pipe entry of muffler. The muffler pipe system, considered in this case, have baffles and internal pipes whose diameter is slightly smaller than the pipes outside the muffler. Hence there is a transition zone in the muffler inside pipe. A CAE analysis of the muffler-pipe system is carried out to calculate the stresses due to oscillating loads. Figure 2 shows the Von-Mises stress contour near the transition due to two perpendicular bending moments. The average maximum Von-Mises stress due to this loading is around 449 MPa. A durability analysis is performed to predict the life and damage of the Muffler-pipe system. The S-N Curve is generated on basis of UTS in the Fatigue Process Manager. The Durability analysis is carried out with the load data from road load, mathematically transported the load signals to the centre of mass of the specimen, assuming My(t) and Mz(t) are significant factors in pipe entry fatigue. The FPM approach is followed to determine the damage and life of the components. The damage is found to be < 1 so the system will not fail to the applied loading condition. Figure 3. shows the Damage contour.
Hanger Design:

This CAE Simulation is designed to address fatigue sensitive Hanger design in the area of the Intermediate pipe when installed in a vehicle exhaust system. This simulation is used to evaluate the vertical direction fatigue durability of hanger on Intermediate pipe. Hanger design in this case has a hanger rod which is welded to the bracket as shown in Figure 4. The hanger is the critical part in the exhaust system as it carries the whole system. The road load and engine vibrations are transferred to the system through the hangers. A CAE analysis of the hanger is carried out to calculate the stresses due to oscillating loads. Figure 4 shows the Von-Mises stress contour due to vertical loading. The average maximum Von-Mises stress due to this loading is around 383 MPa. A durability analysis is performed to predict the life and damage of the hanger. The S-N Curve is generated on basis of UTS in the Fatigue Process Manager. The Durability analysis is carried out with the load data from road load as Fz. The FPM approach is followed to determine the damage and life. The damage is found to be < 1, so the system will not fail to the applied loading condition. Minimum life of the component found to be 142200 cycles. Figure 5 & 6 shows the Life and Damage contour.
Figure 4: Stress Contour Of Hanger For Vertical Loading

Figure 5: Life Contour Of Hanger For Vertical Loading

Figure 6: Damage Contour Of Hanger For Vertical Loading
Muffler Bracket Design:

This CAE Simulation is designed to address fatigue sensitive Muffler Bracket-Hanger design in the area of the muffler when installed in a vehicle exhaust system. This simulation is used to evaluate the vertical direction fatigue durability of Bracket-hanger on and adjacent to the muffler. Muffler bracket design in this case has a hanger rod which is welded to the bracket. The muffler bracket is the critical part in the exhaust system as it carries the whole system through hanger rod. The road load and engine vibrations are transferred to the system through the hangers. A CAE analysis of the muffler bracket is carried out to calculate the stresses due to oscillating loads. Figure 7 shows the Von-Mises stress contour due to vertical loading. The average maximum Von-Mises stress due to this loading is around 235MPa. A durability analysis is performed to predict the life and damage of the muffler bracket design. The S-N Curve is generated on basis of UTS in the Fatigue Process Manager. The Durability analysis is carried out with the load data from road load as Fz. The FPM approach is followed to determine the damage and life. The damage is found to be < 1, so the system will not fail to the applied loading condition. Minimum life of the component found to be 2.5e19 cycles. Figure 8 shows the Life contour.

Figure 7: Stress Contour Of Hanger Bracket For Vertical Loading

Figure 8: Life Contour Of Hanger Bracket For Vertical Loading
Resonator - Pipe System:

This CAE Simulation is designed to address fatigue sensitive design, in the area of exhaust pipe entry into the forward end of a resonator when the resonator is mounted as the third component of a flex coupling in a vehicle exhaust system. This CAE Simulation is used to evaluate the bending fatigue durability of the forward pipe entry of resonator. The resonator-pipe system considered in this case, have internal pipe whose diameter is slightly smaller than the pipes outside the muffler. Hence there is a transition zone in the resonator inside pipe. A CAE analysis of the resonator-pipe system is carried out to calculate the stresses due to oscillating loads. Figure 9 shows the Von-Mises stress contour near the transition due to two perpendicular bending moments. The average maximum Von-Mises stress due to this loading is around 611MPa. A durability analysis is performed to predict the life and damage of the resonator -pipe system. The S-N Curve is generated on basis of UTS in the Fatigue Process Manager. The durability analysis is carried out with the load data from road load mathematically transported load signals to the centre of mass of the specimen assuming My(t)and Mz(t) are significant factors in pipe entry fatigue. The FPM approach is followed to determine the damage and life. The damage is found to be > 1, so the system will fail to the applied loading condition. The damage found in the end cap fillet region. Figure 11 shows the damage contour. To confirm the result, physical biaxial test conducted and the system fails in the end cap fillet region. The life estimated using FPM and life observed during testing are comparable with each other.

![Stress Contour Of Resonator-Pipe For Biaxial Loading](image1)

![Life Contour Of Resonator-Pipe For Biaxial Loading](image2)
Benefit Summary:

1. The FPM step by step approach of including input data is user friendly and helps in getting better results.
2. Time taken for the durability analysis of the system by FPM approach is very less.
3. The FPM step by step approach for durability analysis reduces Product development time and Cost.

Conclusions:

Structural durability analysis of passenger car exhausts system components using FPM approach were explained in this paper. The durability issues with the exhaust system components such as Muffler-Pipe system, Hanger design, Muffler Bracket, Resonator-pipe system are addressed and solution to avoid failure has been considered for future work.

Altair HyperWorks FPM approach is very effective tool to calculate life and damage of component using available load data. This methodology saves the product development time and cost with reliable component design.

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