

Virtual Rig Simulation in the Exhaust System Development

Fulun Yang, Jason Hamilton and Henry Cheng
Tenneco Company

Copyright © 2008 SAE International

ABSTRACT

A newly developed approach, Virtual Rig Simulation for exhaust, is introduced in this paper. An OEM exhaust system durability performance is simulated and simulation results are correlated to test results. The correlation results prove that the Virtual Rig Simulation predicates critical locations very well. The modal transient analysis is applied and input loading is from full event RLDA data. The advantage of the approach is that it can be applied in upfront design stage to predict exhaust system durability performance so that test cost and time are reduced significantly. Also, the presented approach is not only useful for exhaust system development but also useful for other product development.

INTRODUCTION

Durability performance is one of the critical aspects for an exhaust system. Both CAE and testing methods are used to predict the exhaust system durability. As of today rig test is a popular and effective approach to verify full exhaust system durability. However, it takes significant time and cost. In addition, rig test generally is conducted in late design verification stage, and misses the opportunity to minimize risk upfront. Thus, a different approach for upfront design stage is required. Finite Element Analysis (FEA) is very useful simulation approach to study exhaust system durability performance virtually and is playing more and more important role in the exhaust system development today. The advantages of FEA include: a) upfront study, b) quick turn around time, c) less cost. A short coming of FEA application is that stress analysis typically is conducted under generic load cases, which is not able to provide high confidence level for fatigue life prediction. For example, Road Load is the most important loading related to exhaust durability. Frequency components and amplitudes of accelerations (displacements) input into exhaust system through wheel and chassis will be different under different road surfaces. Transient analysis is the best approach to simulate the Road Load process. However, it is difficult or impossible to simulate all road surfaces under one transient analysis to obtain all stress time history due to computer capability (analysis time and hard disc space). And, stress based analysis can only catch stress contour at certain moment

or worst case of exhaust system, for instance, all element peak stresses consists of a peak stress contour although they may not occur at same time to catch critical locations. Thus the virtual rig is developed to address those issues.

Since the virtual rig takes real world loading into FEA to conduct fatigue life (damage) prediction, it provides better confidence level than typical FEA. The virtual rig still has the advantage of quick turn-around and low cost so that it is feasible to be utilized at early design stage

Fatigue analysis has been developed for 100 years or so. The first technique was the S-N or stress-life method. These techniques were relatively simple initially. With the introduction of strain based techniques to deal with local plasticity effects, fatigue techniques have become progressively more sophisticated. Variable stress responses can be dealt with today, for example, vibrating structures where responses are predicted as Power Spectral Density's of stress. Most of the techniques were developed to calculate fatigue life using experimental data and have now been implanted into FEA based analysis programs, for example, Ncode and FE-Safe. The FEA based fatigue analysis introduces additional considerations relating to how input data is processed and how fatigue life, or damage, results are post processed. More and more researchers and engineers apply FEA based fatigue approach to study product durability performances. [1 – 6]. Dr. Bishop discussed the issues associated with how fatigue techniques can be incorporated into the FE environment [1] and vibration fatigue life [2]. Dr. Vellaichamy published a few papers to address how to apply FEA based fatigue to predict fatigue life of automotive structures [3, 5, 6]. David Jordan at General Motors Company also applied modal transient dynamics to calculate body fatigue life [4].

There are several FEA based fatigue analysis methods such as time step method, quasi static method, random vibration method, and modal transient method. Inertia relief method is computationally efficient but it suffers from a lack of dynamic fidelity and may not provide reliable results. Modal transient method is viewed by Tenneco as a best approach related to exhaust system.

Virtual durability/fatigue life prediction has been applied in a full vehicle analysis [7]. Compared to testing, virtual durability/fatigue life prediction is a more efficient and less expensive approach to investigate product durability performance in upfront design stage to optimize product design.

Tenneco has developed a new approach so-called Virtual Rig Simulation. The Virtual Rig Simulation is a FEA and testing hybrid approach. The modal transient analysis is applied and input loading is from full plan RLDA data. MSC Nastran software is used to conduct modal transient analysis. Ncode software is utilized to process RLDA data and Design Life is for damage calculation.

Why the Virtual Rig Simulation is developed in Tenneco? (a) Most of exhaust structural failures are due to fatigue. (b) Measurement of strain data at certain critical locations is impossible sometimes but the Virtual Rig can help. (c) Prediction can provide guidance to RLDA - where to take data? (d) The Virtual Rig can help to develop component bench testing spec to simulate the real world loading. (e) The Virtual Rig takes much quicker turn around time and lower cost compared to physical testing. (f) The Virtual Rig is more meaningful and has higher confidence level than typical FEA stress analysis. (g) The Virtual Rig is more valuable to our customers (time and cost reduction, and enabling upfront set-based design optimization).

The modal transient fatigue method is well known. It is not difficult to apply the modal transient fatigue method to calculate fatigue life for a perfect product design. However, durability performance relies on not only structure design but also manufacturing and application environment. Then, how the method is effectively applied in industry to accurately predict product durability capability is challenging due to complicated industry environment. Weld is a major part to part connection method in exhaust system. Stress concentration, residual stress, and uneven material deformation in weld zone introduce complicity in fatigue analysis. Temperature at different locations is different in exhaust system application, and material property is a function of temperature, which introduces another complicity factor in fatigue analysis. In addition, nonlinear properties of rubber mount, loading profile, and time-consuming for analysis are other challenging aspects. To make The Virtual Rig Simulation successful, notch factor and temperature scale factor are applied to consider weld and temperature effects on exhaust durability performance based on Tenneco's engineering expenses and testing results.

FEA BASED FATIGUE ANALYSIS METHOD

In general, there are four types of FEA based fatigue analysis methods.

1. FE Time Step

As shown in Figure 1, Finite Element solver conducts static stress analysis at each time step. Fatigue solver conducts life calculation at each time step. The advantages of the method are: (a) it is the most accurate method for highly transient events, and (b) it can consider the dynamics of rubber. The shortcomings of the time step method include (a) time consuming (only small number of time steps can be analyzed), and (b) extensive disc space to store results is required.

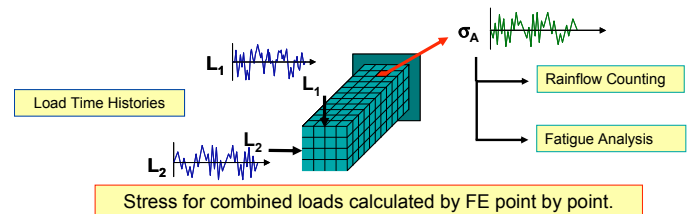


Figure 1 FE Time Step Method.

2. Quasi Static

As shown in Figure 2, the Quasi Static method scales static stress or strain tensor by time histories. The advantages of this method include: (a) it is extremely fast for large models and long time histories – full vehicle simulation on body in white conducted on complete proving ground load history in 24 hours, (b) it is accurate for stiff structures with little or no resonances. However, this method is only applicable for structures with significant modal responses over 5 times the frequency of system input.

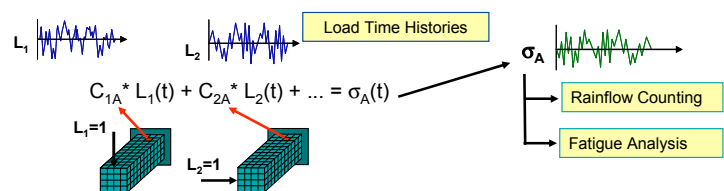


Figure 2 Quasi Static Method.

3. Random Vibration

As shown in Figure 3, random loading and responses are categorized by Power Spectral Density (PSD) functions and a dynamic structure is modeled using a linear transfer function in the random vibration analysis. The random vibration analysis converts PSD to expected cycles of stress. Its advantages include: (a) it is very fast for large