OPTIMUM DESIGN OF ENGINE MOUNTS BY INTEGRATING TRIAXIAL TEST DATA AND ANALYTICAL ADAMS MODEL

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1.0 Introduction

In the engine mount industry today, computer-aided engineering (CAE) is being integrated into the product development cycle on a regular basis. This integration would typically involve the use of finite element analysis (FEA) as the main development tool. FEA would provide initial designs that would then be built and tested. Once these designs met the customer specifications, the final product would be released for production.

Although engine mounts are designed for use in a power train system, the majority of the CAE analysis is focused on the component level. The effect of these component characteristics on the overall system behavior is rarely analyzed. In most cases, there are difficulties in linking the component test data with an analytical model of the full system. In other cases, where it is possible to link the test data to the full system model, time constraints from the products' release schedule allow only limited use of the test data.

2.0 Motivation

The overall objective is to develop optimum designs of engine mounts. By using integrated tests and system level analysis, the engineer is able to consider the effects of stiffness, manufacturability, location, and orientation of the mounts while seeking to minimize transmissibility of engine-induced vibration into the vehicle.

3.0 Purpose

In order to reach this objective, there is a need to develop an efficient design process that allows fast and accurate data exchange between the test equipment and the CAE tools, namely FEA software and ADAMS system analysis software. Not only would this enhance the product development process, it would also maximize the company's return-on-investment (ROI) on the

CAE tools and test equipment. Therefore, the challenge is to bridge the gap between testing and analysis, from product concept to product completion, in order to make smart decisions throughout the design process.

4.0 Partnership

Combining the expertise of Cooper Engineered Products in the design of engine mounts; the expertise of MTS in building of Elastomer Test Equipment; and the expertise of MDI in systems' modeling and analysis, we have a full knowledge base to develop and implement an innovative design process. In addition, feedback from this development project will influence future enhancements of the software and test equipment, particularly in terms of format and structure of the imported and exported data.

Cooper, MTS and MDI have collaborated over the last few months to begin developing this innovative design practice. In February, the concept was introduced at the SAE Congress in Detroit, Michigan. Because the concept was so well received, it was decided to complete a two phase plan. Phase I included the development of the design process which will be outlined in this paper. Phase II, which is planned for later this quarter, includes the implementation of the design process in a mock-up product design.

5.0 Suggested Approach

5.1 Comparison to Current Design Process

When compared to many design processes today, this suggested approach has five major differences which are as follows:

1) Use of multi-axis triaxial test system versus uni-axial test machine
2) Provide engine mount preload from ADAMS for triaxial test machine setup
3) Incorporate a frequency dependent bushing in ADAMS model
4) Accommodate durability effects in ADAMS model from test data
5) Optimize engine mount parameters using the ADAMS model

These differentiators will be discussed in more detail in section 5.4.

5.2 Benefits of Suggested Approach

Besides meeting the overall objective of an optimum engine mount design, this design process will provide several additional benefits that will significantly improve product development time and cost. First, testing will be more efficient and accurate due to better setup parameters and easier data exchange between analysts. Second, the CAE models, both FEA and ADAMS, will be based on actual test data and therefore will provide more accurate results and insight into system behavior. Third, with a development process based on parametric computer models, the engineers can quickly react to customer specification changes. Lastly, with the results from integrating testing and system modeling as suggested, the development team can make smart decisions in order to provide a high quality component that is tuned to the customer's final product.

5.3 Flowchart of Design Process

See Figure 1.

5.4 Brief Description of Design Process Steps

There are 9 steps in this suggested approach to designing engine mounts.

***Step 1: Design Specifications*.**

Typically, the customer provides a core of design specifications to the engine mount designers. These specifications include position, orientation and dynamic stiffnesses for the both the left and right engine mount. An example of a specification is shown in Figure 2.

Vehicle Platform	Positions (mm) wrt elastic center			Orientation (degree) wrt z-axis	Dynamic Stiffness * [N/mm]		
	x	y	z	angles	Kxx	Kyy	Kzz
Left Mount	1600	-200	1750	47	300	230	1800
Right Mount	1600	300	1715	45	370	300	2250

Figure 2. Example of Customer Specifications for Engine Mount Design

***Step 2: ADAMS Analysis*.**

Once the customer has provided the design criteria, a baseline ADAMS model is created in conjunction with the next step, the CAD geometry. The analyst will request additional information from the customer such as appropriate engine mass and inertial properties and idle RPM for model input. The analysis can now verify the validity of the dynamic stiffnesses provided by the customer and then provide preloads for the multi-axis triaxial test machine. These preloads are determined with respect to the global axis of a standard vehicle (x = longitudinal, y = lateral, z = vertical). Dynamic loading can also be provided to the test operator which is defined in terms of displacement amplitude determined by the vibration mode of the engine at idle RPM.

Step 3: CAD.

As mentioned above, the CAD geometry and the baseline ADAMS model are being created simultaneously. Based on the design envelope provided by the customer, the engine mount bracket geometry and then the mount geometry are created. These CAD models are passed to the FEA analyst.

Step 4: FEA.

The FEA analyst reads in the CAD geometry into an FEA preprocessor. A model for linear and non-linear analysis is created. The boundary conditions, such as force, moment and displacement, are determined with the help of the baseline ADAMS model. After performing several runs, the analyst reviews stress, deformation, modal parameters, static rates and dynamic rates of their FEA model. If these results satisfy the design criteria, the model is ready for prototyping.

Step 5: PROTOTYPE.

In the prototyping stage, the bracket design is typically sent to an outside vendor for manufacturing. The prototype material specifications determined from the theoretical FEA model are passed to the test lab for development. When the developed material is acceptable, the mount is created based on the geometry specified.

Step 6: TEST.

Once the engine mount prototype is complete, the tests can be performed with the multi-axis triaxial machine. This machine allows the test operator to test sequenced or simultaneous static and dynamic properties in all three axes. Additional static and dynamic tests are performed on prototypes which have endured fatigue cycle runs. It is important to note that all tests are performed at ambient temperatures.

The critical parameters available from the numerous tests are: test frequency (Hz), complex or dynamic stiffness (K* or Kd), static stiffness (Ks), and damping coefficient (C).

Step 7: ADAMS Analysis:

The baseline ADAMS model is enhanced in several ways. First, updated customer specifications and engine data are added to the model. Next, the linear bushings, which represented the engine mounts in the baseline model, are replaced with a frequency-dependent bushing. The characteristics of these non-linear, frequency based elements, are determined by the test data from the multi-axis triaxial tests. Actual test data is inputted into ADAMS and plotted for verification in Figure 3 and Figure 4.

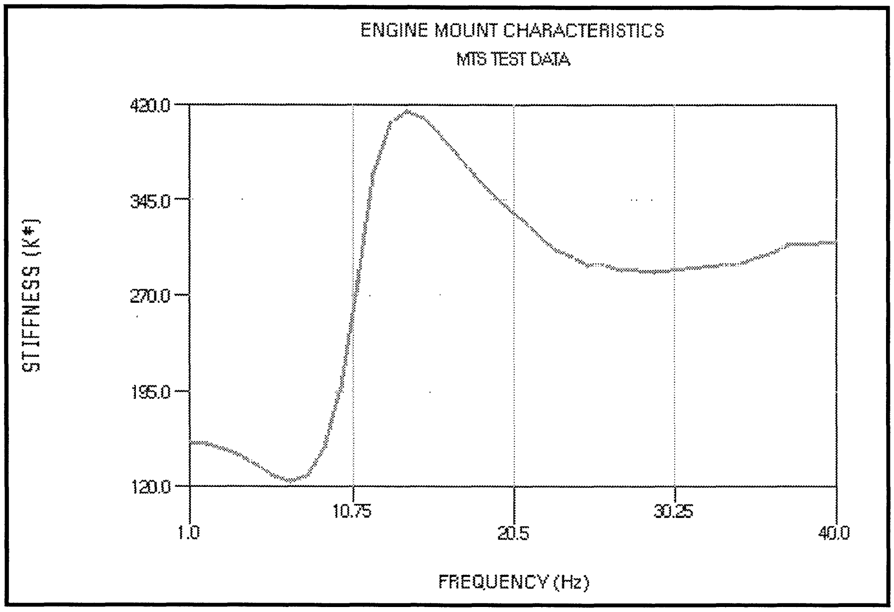

Figure 3. Frequency Dependent Bushing Stiffness from Test Data

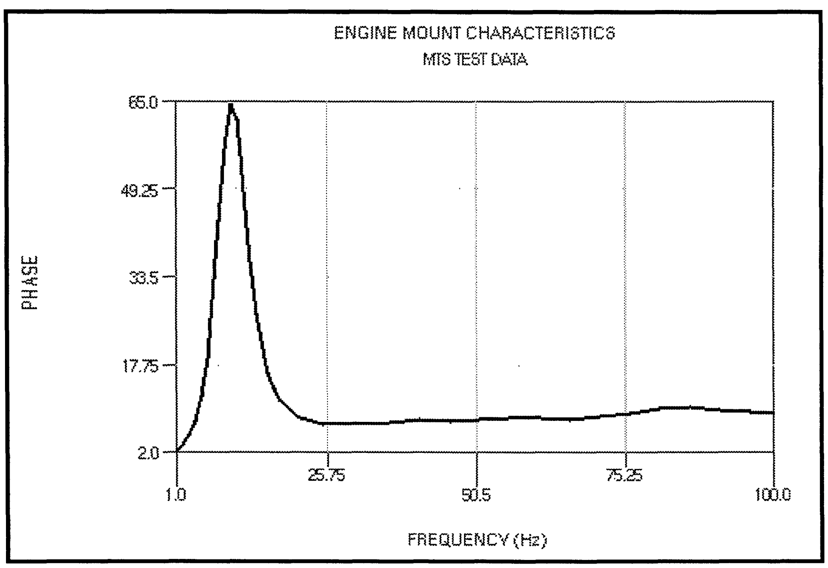

Figure 4. Frequency Dependent Bushing Damping from Test Data

With this enhanced ADAMS model, the analyst can monitor a variety of engine and chassis behaviors to verify expected results. Additional tests are run to understand the effects of durability on the system by replacing the original test data with fatigued-induced test data.

***Step 8: ADAMS Optimization*.**

Once the ADAMS model is validated within an acceptable range, the model can be setup for a series of design studies using optimization and Design of Experiments (DOE). First, the bushing locations are parametrized for easy relocation. Design variables with a set range of values are then created for engine mount location, orientation, engine properties and engine vibratory behavior. Additional design variables could be based on a manufacturability constraint. Finally, an objective function, such as minimizing the transmissibility of engine-induced vibration, is created for the series of tests.

With the results from the optimization and DOE studies, the analyst can understand the positive, negative, or minimal effects of several parameters in the engine mount design. Design changes which significantly enhance the system behavior can be confidently suggested to the customer.

Step 9: Production.

After the completion of the CAE analysis and multi-axis testing, the development team can make the final decisions on the production specifications for the engine mount design.

6.0 Conclusion

An efficient design process incorporating testing and analysis as described above can have a significant impact on the product development time and cost. In addition, this process provides the design team with the information needed to make a quality component highly integrated with the entire system.

Because of the outstanding benefits this approach can provide, the implementation of this design process, Phase II of the project plan, will be completed. All procedures will be recorded and presented to the MDI and MTS for future enhancements.