DEVELOPMENT OF A METHODOLOGY TO PREDICT THE ROAD NOISE PERFORMANCE CHARACTERISTICS

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ABSTRACT

This paper describes the development of a methodology for predicting the road noise performance characteristics of an automotive vehicle system. An MSC/NASTRAN finite element model of a complete suspension system was constructed and analyzed for dynamic response. In addition, a customized system simulation software package, GRADAM, was developed for combining the FEA and experimental results in order to assess vehicle structural sensitivity to noise and also to study the effect of suspension design modifications on the interior noise levels. In the model development stage, the FEM modal and frequency response results for all the relevant suspension components were validated by comparing with the corresponding experimental measurements. The interior noise levels were then obtained through the system simulation software. This customized software combines the MSC/NASTRAN force output at suspension-to-body attachment points with the corresponding pressure/force (P/F) experimental data in order to predict the interior noise levels. The methodology developed herein permits the noise pressure levels to be determined for desired frequency domains. Furthermore, this methodology allows design engineers to answer "what if" questions in order to evaluate the effect of suspension design changes on the interior noise levels. It is anticipated that the methodology presented herein will be instrumental in optimizing the noise and vibration (NVH) characteristics of future car lines.

INTRODUCTION

MSC/NASTRAN was used to simulate the vibration and noise characteristics of the vehicle in order to study the effect of suspension design on the interior noise level. The effect of design changes on the interior noise level was studied in order to optimize the NVH performance characteristics of the vehicle. The finite element model was first verified by comparing the finite element results with experimental data obtained from acoustic test measurements of the test vehicle. The model correlation was achieved at three levels.

1. Component modal analysis
   Each component was analyzed free-free for mode shapes and frequencies, and comparisons were made with the experimental data.

2. System modal analysis
   The components were assembled to form the front and rear suspensions. The front and rear suspensions were then independently analyzed for mode shapes and frequencies, and the results were compared with the experimental data.

3. Frequency response
   Frequency analysis of the front and rear suspension was performed. A unit load at the spindle was employed as the input in each case, and the corresponding accelerations at the suspension-to-body attachment points were obtained. This was then compared with the experimental frequency response functions (FRFs) in the form of acceleration per unit force (A/F). Four input directions were considered - vertical, fore and aft, lateral and 45° to vertical, for the purpose of isolating and identifying model related problems.

The model was modified suitably by incorporating justifiable changes so as to improve the correlation between the predicted results and the experimental results. The suspension model was used for vehicle simulation only after an acceptable degree of correlation with experimental results was achieved.

The simulation strategy involved obtaining the MSC/NASTRAN force output at suspension-to-body attachment points in response to a frequency dependent road input at the tire. The force output was then combined with the experimental noise transfer function, or P/F data, by GRADAM to give noise pressure levels. The noise pressure levels indicate the relative contribution of different suspension-to-body paths to interior noise, as well as its frequency dependence.

THE FINITE ELEMENT MODEL

The finite element model of the suspension system was developed for the purpose of vibration simulation. Several approximations were made in order to reduce modeling effort and size. To reduce computational costs, center plane symmetry was assumed, and only the half model was analyzed. Most of the components were modeled by shell and beam elements, with the exception of the knuckle and calliper assembly in the front suspension and the brake drum in the rear suspension. These were modeled by solid brick elements. Rubber bushings were modeled by spring-damper pairs in parallel. The mount rates were assigned frequency dependent rates obtained from experimental test data. The tire was represented by a simple spring-mass model. The front and rear suspension finite element models are shown in Fig. 1 and Fig. 2 respectively.

MODAL ANALYSIS

Normal modes analysis (SOL 103) was performed by using the modified Givens method and the Lanczos method. The two methods gave almost identical results, although the Lanczos method was faster. The components were analyzed free-free and modes up to 600 Hz. were obtained, and then compared with the experimental data. The assembled front and rear suspensions were first analyzed free-free to detect modeling errors. Suitable ground constraints and center-plane boundary conditions were then applied to obtain the normal modes for comparison with test results. Experimental modes were obtained only up to 60 Hz.

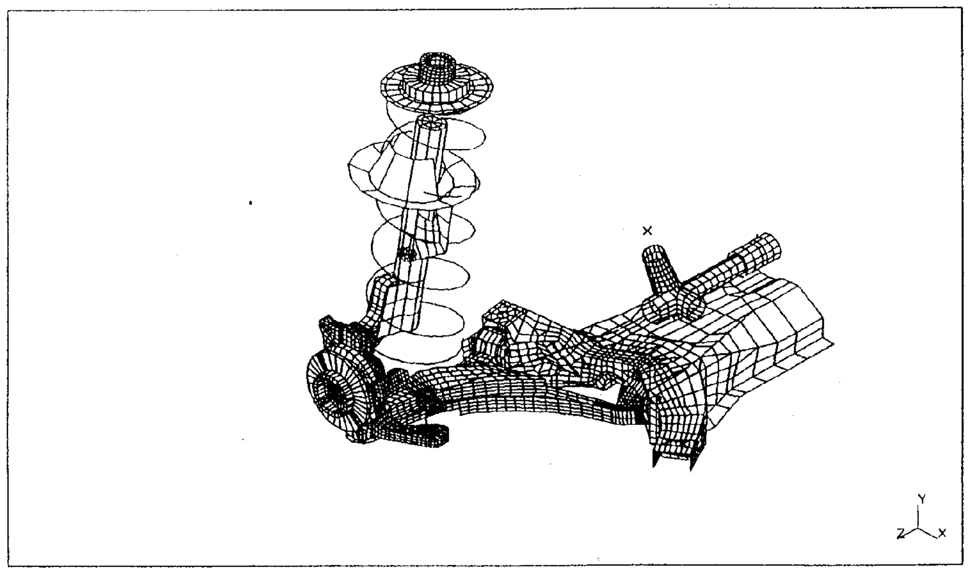


Fig. 1 : Front Suspension Model

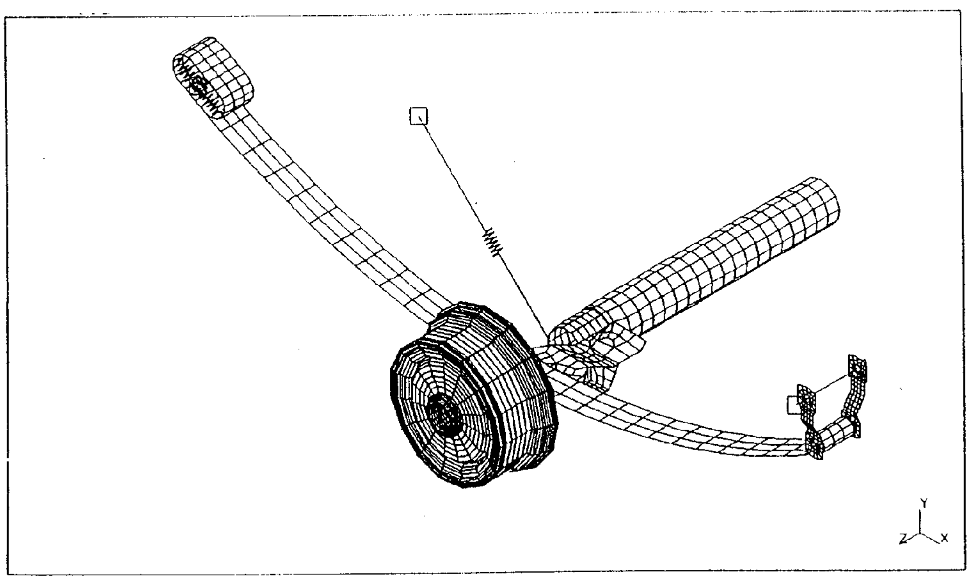
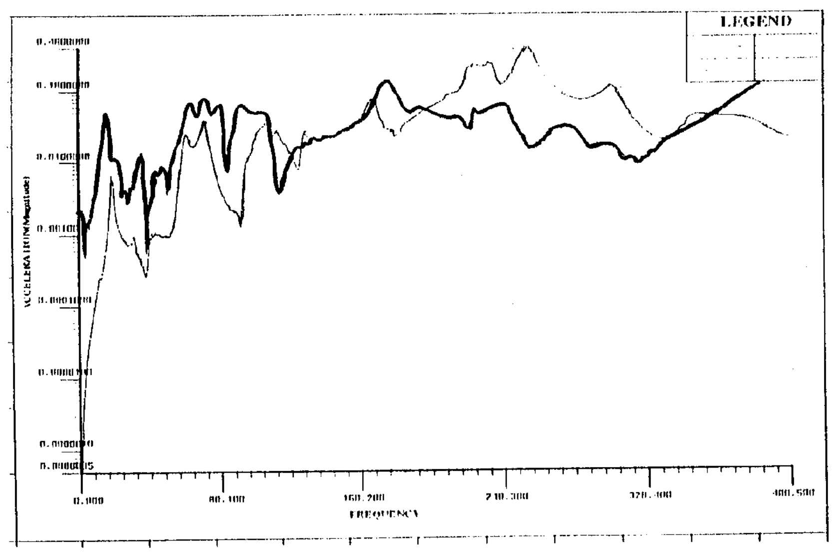


Fig. 2 : Rear Suspension Model

FREQUENCY RESPONSE

Frequency response (SOL 108) of the front and rear suspension to a unit input at the spindle was obtained from 0 - 400 Hz. The computed acceleration at the spindle and suspension-to-body attachment points was compared with experimental A/Fs. The correlation plots were obtained with the help of GRADAM. Fig. 3 shows the FEM and experimental A/Fs in the vertical direction at the leaf spring front eye.



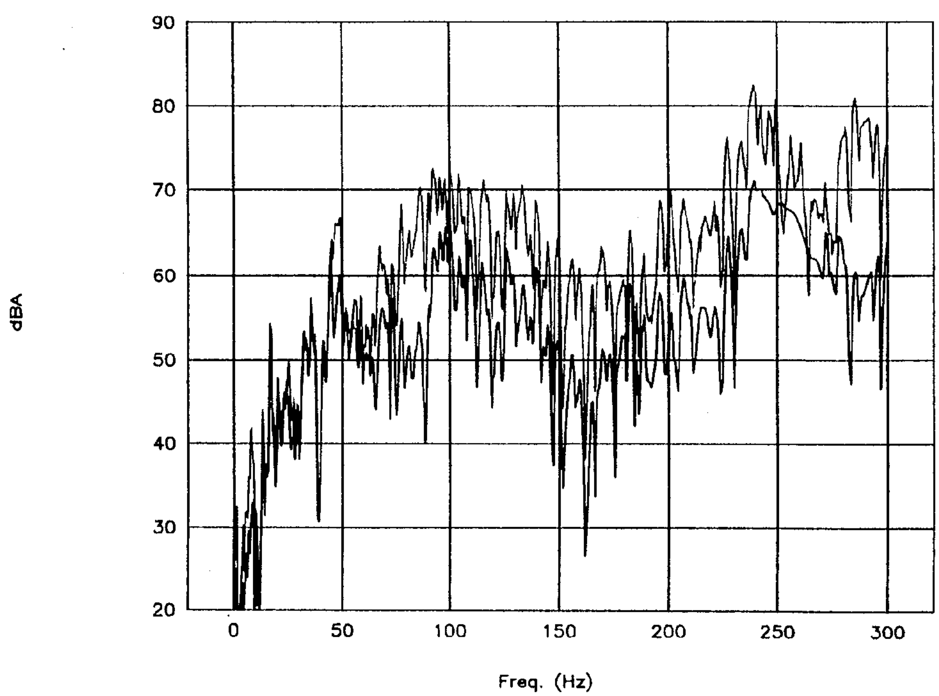
Experimental FEM

Fig. 3 : A/Fs: Leaf Spring Front Eye, Vertical Direction

To simulate the interior noise pressure level due to actual road input, tire displacement amplitude and phase data in the frequency domain was used to excite the model. The NASTRAN force output at suspension-to-body attachment points was combined with the corresponding P/F data from the body acoustic sensitivity data by GRADAM to generate noise pressure levels. Total noise pressure level representing the summation of noise pressure through different paths was obtained. Cumulative noise pressure levels were also obtained. In addition, band levels of 10 Hz. as well as user defined band levels were generated. The noise pressure response was also normalized against experimental pressure levels to yield normalized pressure response.

SUSPENSION SYSTEM DESIGN

The road noise simulation technique developed herein can be utilized to study the effect of suspension design and isolation changes on the vehicle interior noise levels. The proposed methodology provides an effective way to assess design changes analytically without the use of costly hardware. The effect of bushing rates and suspension geometry on the relative contribution of various suspension-to-body paths to the interior noise level, can be studied. In the base model, the cross member was not isolated from the body. The effect of isolating the cross member on the noise pattern can be determined. Fig. 4 shows the total noise pressure levels for the vehicle for the two cases. Clearly, the pressure levels are lower for the case with the cross member isolated. The relation between leaf spring configuration and interior noise can also be analyzed. In this manner, a designer can develop recommendations for changes in the suspension and body of the test vehicle.



Upper Curve = Non-Isolated   Lower Curve = Isolated

Fig. 4 : Total Noise Pressure Levels: Isolated and Non-Isolated Cross Member

CONCLUDING REMARKS

This paper reports on the development of a methodology to predict the road noise performance characteristics of an automotive vehicle system. An MSC/NASTRAN finite element model of a component suspension system was analyzed for dynamic response characteristics. These results were combined with experimental results in order to estimate interior noise levels. The methodology presented herein will allow design engineers to answer "what if" questions pertaining to design changes in order to optimize the NVH characteristics of future car liners.

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