inter•noise 96
25th Anniversary Congress – Liverpool

INCE: 76

VALIDATING A STATISTICAL ENERGY ANALYSIS MODEL OF A SALOON CAR

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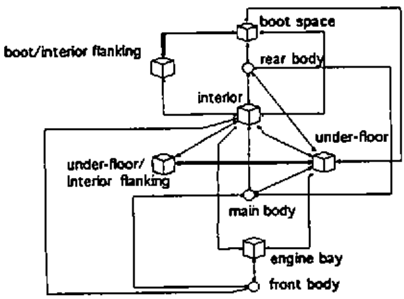
1. INTRODUCTION

Statistical Energy Analysis is playing an increasingly useful role as a tool for predicting the source of interior noise in motor vehicles. This paper continues the development process of which references [1] and [2] are a part. The first of these discusses experimental SEA methods and shows how a comprehensive set of measured transfer functions can be used to determine the damping and equivalent masses on a complete vehicle. Reference [2] considers the relationship between test-based and analytical SEA models, and shows how the measured parameters can be used in the analytical model.

2. OUTLINE DESCRIPTION OF THE MODEL

Figure 1.
Outline SEA model showing main acoustic subsystems, body structure and flanking paths



The aim of this study was to develop an analytical SEA model of a family saloon car, and to use this to identify trim modifications which would either reduce interior noise, or which would save weight and cost with no noise penalty. It was necessary to identify both dominant and relatively unimportant paths and so the model needed to be both comprehensive and thoroughly validated. The final model comprised more than 70 structural and acoustic subsystems, many items of trim, and 8 power inputs. This was twice the number subsystems in the experimental SEA model used for validation. Figure 1 shows the general form of the model which was developed using the AutoSEA code [3].

3. POWER INPUTS TO THE MODEL

One particular area of importance in the validation studies was to identify the best method of exciting the model.
When a force with spectral density $G_{FF}(\omega)$ at frequency ω is applied to a structure of mobility $M(\omega)$, the true power/Hz, $P(\omega)$, is given by:

$$P(\omega) = G_{FF}(\omega) \ \mathrm{Re}\{ M(\omega) \} \qquad (1)$$

It is common in SEA models to approximate this by either the mobility of either an equivalent infinite structure or an idealised finite structure and this can give rise to large errors.
A second way of way of exciting the model is to impose a measured velocity response, which for a subsystem of mass M_0 gives energy:

$$E(\omega) = M_0 \ \langle v^2_{meas.} \rangle \qquad (2)$$

When the loss factor is η, and the subsystem is disconnected from the network the effective power input is given by:

$$P(\omega) = \omega \ \eta \ E(\omega) \qquad (3)$$

However, when the source is reconnected to the network the power input may change depending upon the damping of other subsystems.
A third method of exciting the model is to specify a subsystem energy level by using the measured equivalent mass in equation 2, the effective power input may then again be calculated from equation 3.

$$E(\omega) = M_{eq} \ \langle v^2_{meas.} \rangle \qquad (4)$$

Considering for example a front suspension housing which may be idealised as a simple shell or plate subsystem figure 2 shows the energy calculated from equations (2) and (4) for a unit power input. The two curves diverge at low frequencies as the equivalent mass becomes very different to the true mass, and so equation 2 grossly underestimates the true power input to the model. Accurate modelling of the power input was found to be a major factor in the ability of the model to predict transfer functions in the 200-800Hz frequency range, and it was considered that the best way of exciting the model was to use a power input given by:

$$P(\omega) = \omega\, \eta\; M_{eq}\; \langle v^2{}_{meas.} \rangle \qquad (5)$$

thus achieving a correct power input for the base model, whilst removing the dependence of the power input on the damping of other subsystems if equation 3 is used.

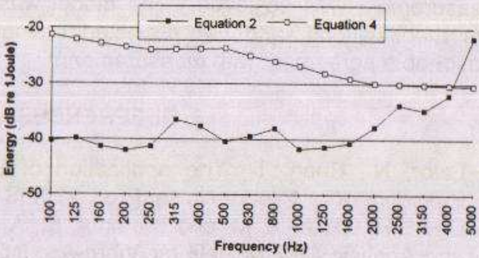


Figure 2.
Estimates of the energy level on a suspension housing

A second problem in the specification of power inputs occurs when a force is applied at the boundary between two subsystems, i and j. In this case it is necessary to apportion the power input between the subsystems, and this was achieved using an impedance model approach

- the SEA model was used to estimate the power flow into each subsystem in isolation.
- this was used to estimate the subsystem impedance, Z_i.
- the power into subsystem i is calculated from $P_i = P_{total} \,.\, Z_i/(Z_i + Z_j)$

4. MODEL RESULTS AND THE EFFECT OF DESIGN MODIFICATIONS

After extensive refinement and validation the model was shown to be capable of predicting the energy level of the vehicle interior to within 10dB, and generally better than 5dB, over a wide frequency range (200-5000Hz) for a unit power into any of the operational power input points. Figure 3 shows the predicted energy level of the interior for an on-road condition.

Using the model several trim modifications were identified which would offer either a significant reduction in interior noise, or a reduction in weight with no noise penalty. These were then tested on the vehicle and compared with predictions (figure 4). The effect for this road condition may be summarised as follows:

- installing a thick floor mat was predicted and measured as giving a significant interior noise reduction
- reducing the carpet thickness in the boot was predicted and shown to have no effect on interior noise
- removing some trim from the doors was predicted to have no effect, but in practice significantly increased noise above 1Khz.

In the last case it was clear that removing the door trim had opened up a flanking path which was not adequately represented in the model.

5. CONCLUSIONS

It was found that correctly specifying the power input by using equations 5 and 6 extended the frequency range over which good agreement with measurement was achieved. The model was used to identify suitable trim modifications, and the predicted changes were found to be in reasonable agreement with measurements

6. REFERENCES

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2. Chen, H., O'Keefe, M. and Bremner, B., A comparison of Test-based and Analytic SEA Models for Vibro-Acoustics of a Light Truck, Proc. SAE N&V conference, 1995
3. AutoSEA user guide, Vibro-Acoustic Sciences, 1994.

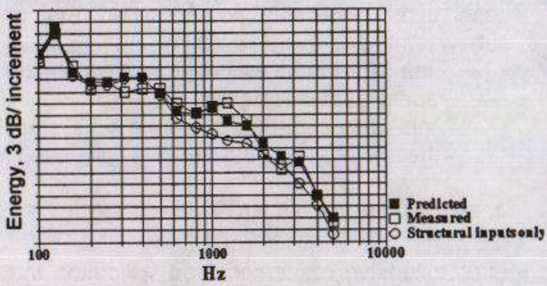

Figure 3.
Comparison of predicted and measured interior energy for one on road condition

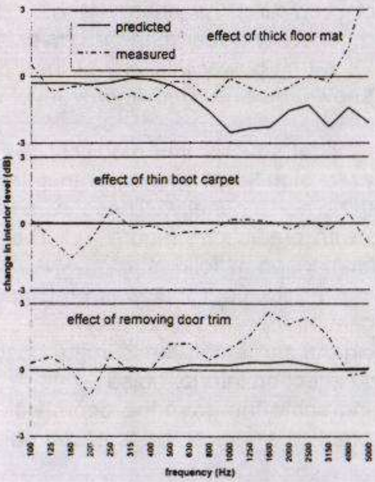

Figure 4.
Measured and predicted effect of design modifications