inter-noise 2002

The 2002 International Congress and Exposition on Noise Control Engineering
Dearborn, MI, USA. August 19-21, 2002

Deriving SEA Trim Properties from APAMAT II Insertion Loss Measurements

Allan Aubert, Dr. Ed Green, Rob Crawford
Roush Industries, Inc., Anatrol NVH Engineering Group
12011 Market Street, Livonia, Michigan 48150, USA

Abstract

This paper reports on work done to further understand the outputs of the Rieter APAMAT II Insertion Loss testing machine [3]. This machine has received acceptance among automotive OEMs, and carpet and trim manufacturers, as a good method to compare the effectiveness of various trim and barrier treatments in automotive interior applications. However, the exact combination of treatment properties which produce "good" results, and the corresponding sound transmission mechanisms, have not been well understood. In addition, the data output of the machine does not relate to any readily usable physical properties.

An SEA model was developed of an APAMAT II machine and compared to a variety of measurements. These results are discussed and provide insight into the energy flow and noise reduction properties being measured in an APAMAT II test. Next, standard SEA trim modeling guidelines are adapted to better predict the structural excitation case. Finally, new derived outputs from APAMAT II measurements and the SEA model are described. Such derived outputs are intended to be directly useful in vehicle SEA models which make use of, and attempt to model, the sound transmission properties of measured barrier and trim materials.

1. Introduction

The Rieter APAMAT II, automotive trim sample testing machine, has received wide acceptance among OEMs and trim manufacturers in testing the acoustic properties (termed “Insertion Loss”) of carpet barrier materials (See Figure 1). These test results are not in a form which can be used directly in vehicle acoustic models, such as SEA. An SEA model was created of the APAMAT II machine, including some typical trim samples, to better understand the acoustic properties being measured. The goal of this work is to model the APAMAT II machine with SEA methods to gain insight into the system, and to determine what are the important sources, paths and parameters which contribute to making a trim material “good” when measured in this manner. The final goal is to develop new derived outputs of an APAMAT test, which could be used directly in SEA models of trimmed vehicles.

The APAMAT II machine is designed to produce rich transient noise, which simulates the noise produced when objects, such as rain, or stones, impinge upon the floor pan of a car. The "Steel Plate" (in Figure 1) is square, 33" on a side and approximately 1mm thick. The machine tests a square trim sample, 33" wide, which can be of any thickness. A steel frame (sample holder) rests on the sample, and the reverberant chamber sits on this frame. A square opening in the steel frame is 25 ¼" on a side, which is the area of the sample that radiates into the upper space. The upper and lower chambers, and sample, are enclosed in a steel cabinet, which has some sound absorbing material applied to its inner surfaces. The walls of the lower chamber are 4mm thick sheets of polypropylene.

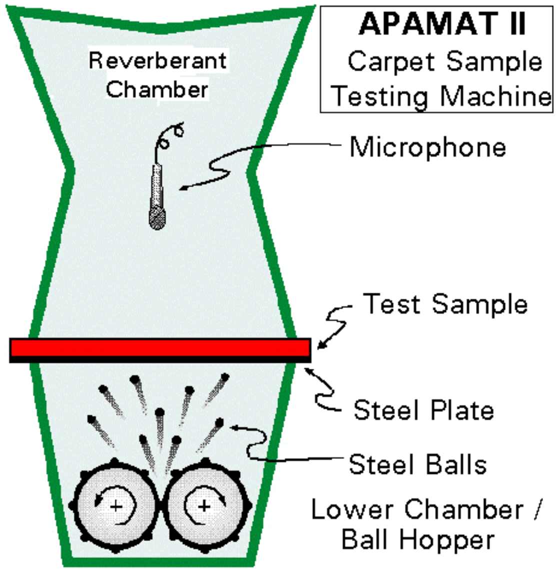

Figure 1: APAMAT II Machine Schematic

2. Problem Formulation

Several sets of measurements were taken on the APAMAT II machine, to assist in properly modeling it. Frequency dependent T_{60} times were measured on the upper and lower chambers, and on the bare plate, as installed. A microphone was installed in a protective box in the lower chamber. For each sample, a set of measurements were taken with speaker excitation in the lower chamber, and another set with the steel ball excitation. In each case, noise levels were measured with the upper microphone, and with a microphone in the lower chamber. Plate vibration response levels were measured at ten random locations to give a good space average response for the bare plate case with ball excitation.

It was decided to study three representative trim samples. The first was with no trim sample, or a bare plate condition. Next, a sample of 1.4cm thick, shoddy trim material was tested. Finally, a 1.1cm thick sample of recycled plastic (from soft drink containers) fiber material, or PET, was tested. For these last two samples, a polypropylene mass layer was added to make these more realistic examples of trim design, which might be used in automotive applications. The measured material properties are given in Table 1.

Table 1: Sample Material Properties

	PET	Shoddy	Mass Layer
Thickness	1.1 cm	1.4 cm	0.3 cm
Mass	.38 kg	.87 kg	2.81 kg
Density	57.6 kg/m^3	94.05 kg/m^3	1333. kg/m^3
Young's Modulus	7,599N/m^2	13,748N/m^2	1.e7N/m^2

3. SEA Modeling Description

A preliminary model was developed which included only the receiver space, an acoustic space for the lower chamber, and subsystems for the plate and sample. It rapidly became clear that this model was over-simplified, and left out significant paths in the energy flow of this system. The final SEA model included the cabinet, its absorption, and the important leaks in the system. This model, as executed in SEAM® v 3.15 and visiSEAM® v 1.61[1], included 12 Subsystems, 19 junctions, and 1 excitation. A crucial path in the model was added after careful examination of the machine revealed that the edges of the sample are exposed to the acoustic spaces in the cabinet. Similarly important was the inclusion of leaks past the gasket which seals the upper reverberant chamber to the top of the mass layer. Further issues of the subsystems used for the plate and sample are discussed in Section 5.

Another crucial assumption involves the manner in which the ball excitation is modeled. Since the balls strike the bare underside of the plate, the assumption was made that the power input provided by the balls is not significantly affected by which sample is installed above the plate. The acceleration at ten locations on the bare plate was measured (not simultaneously) with an accelerometer while the ball excitation was active. This data was averaged, and used with SEAM®'s plate model to calculate a frequency dependent power input to the plate under ball excitation. This excitation spectrum was used for all cases and gave reasonable results.

4. SEA Model Correlation, Speaker Excitation

Measuring the SPL in the lower chamber was an early issue in the experiment. Measurements at six microphone locations were taken with speaker excitation in the lower chamber and the PET sample installed above the plate. This was compared to a single microphone installed in a protective housing and fastened along the wall of the lower chamber. This data set was, from then on, used to correct SPL readings from this single microphone to estimate space averaged SPL data in the lower chamber. This data set further reveals that there is little measured difference in the lower chamber SPL in the various cases of samples placed on top of the plate.

The upper chamber SPL measurement presented a similar challenge. A single microphone in the upper chamber is always used in APAMAT II measurements. This did not prove to be a good measure of the space averaged SPL in a few of the low frequency 1/3 octave bands. By roving a microphone in the upper space, it was determined that, in the 125 to 315 Hz frequency range, the acoustics of the upper space were such to make the single microphone reading significantly lower than readings elsewhere in the space. Consequently, a correction was applied to the SEA predictions to allow comparison of the SEA space averaged SPLs to the standard APAMAT II measurements.

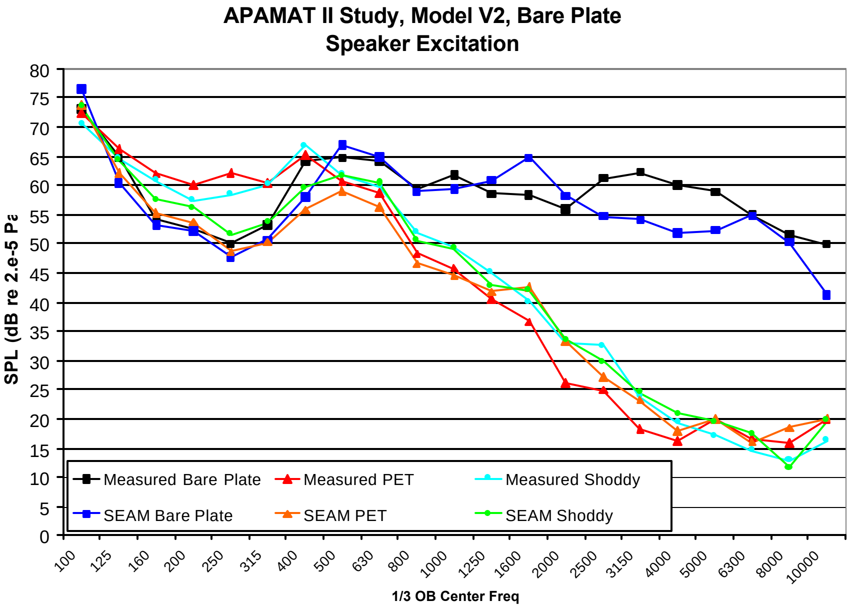

Figure 2: Speaker Results for Bare, PET and Shoddy

The final results for speaker excitation are shown in Figure 2. This correlation was most sensitive to leak sizes and the acoustic losses in the APAMAT cabinet. This experiment bears some resemblance to a TL test. However, under ball excitation, changes to the SPL in the lower chamber had no effect on the level of sound in the upper chamber. This implies that the TL of the sample actually does not strongly affect its performance in an APAMAT test. This set of measurements did, however, help to validate the values being used in the model for cabinet absorption and leak sizes.

5. SEA Model Correlation, Ball Excitation

Given the model parameters needed to achieve correlation in the speaker excitation case, the following comparison to measured data was achieved for the bare plate case (Figure 3). The controlling parameter for APAMAT response is plate damping. The loss factor values are in a reasonable range, given the boundary condition, which is a pair of gaskets on the sample holder frame.

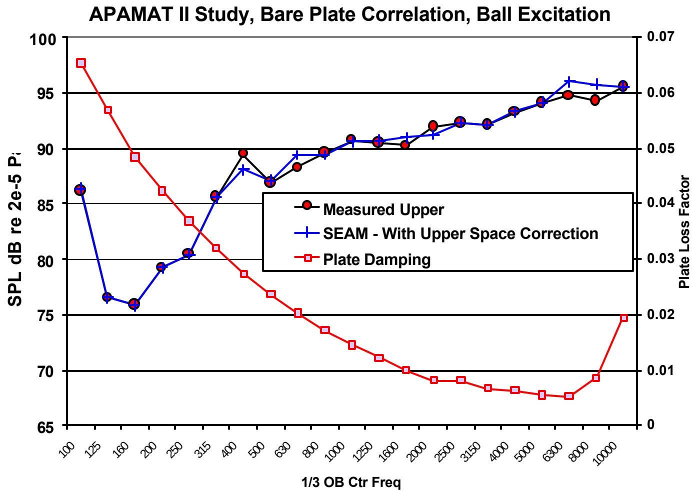

Figure 3: Bare Plate Results w/ Ball Excitation

The correlation of the SEAM® model to the APAMAT results for the PET and Shoddy samples was the final and most challenging part of this study. Standard SEA modeling practice for automotive trim [2] makes use of three subsystems and two junctions, as illustrated on the right of the dashed line in Figure 4. One area junction connects the lower air space through the steel plate to the trim air space, and the second connects the trim air through the mass barrier (a plate subsystem) to the receiver space. This model approach has proven to work well in predicting the TL across a trimmed panel. While trying to achieve correlation of the SEA model of the APAMAT II machine to measured data it became apparent that this model strongly under-predicted the measured result for the ball excitation case. Another troubling issue is that this approach models the trim as an acoustic space only. The structural and mass properties of the trim material are neglected. After careful study of the measured APAMAT results for the various trim samples, it became clear that the only apparent explanation which could reasonably account

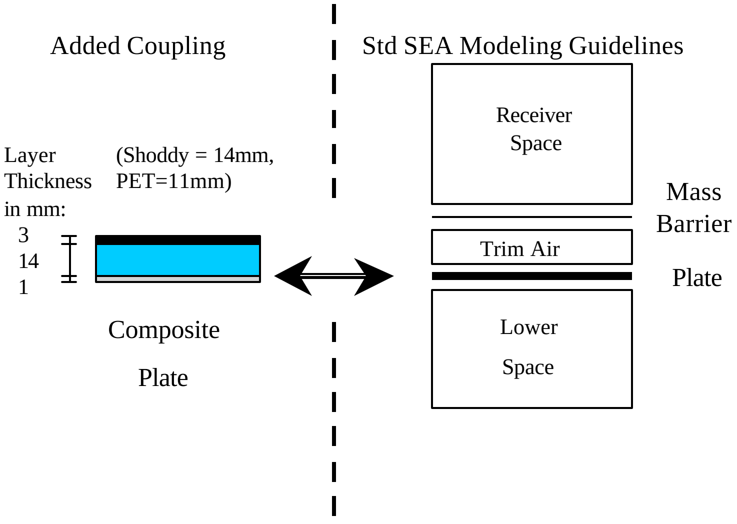

Figure 4: SEAM Model of PET & Shoddy

for the differences in performance of the various samples, was the structural properties. Adding point coupling between the plate and mass barrier failed to improve the correlation.

The final approach used was to add a bending subsystem to the SEA model, which better modeled the bending of the trimmed panel as a single unit (see the left side of Figure 4). The layered plate element model in visiSEAM® was used. Simple estimates of the stiffness and density of the trim materials were made, and are reported in Table 1. In many ways this approach is analogous to the concept of adding a separate mode group for the bending properties of a stiffened plate, with composite modes and subpanel modes separated. To avoid double counting the mass law transmission into the receiver space, the new subsystem was only connected to the receiver space and not the lower space. A line junction was added to represent reflection of plate bending energy at the plate boundaries from the bare plate modes into the modes of this composite subsystem. This model of trimmed panel response and radiation gave very good results for the cases tested. In certain frequency ranges the power flows indicate that radiation from these modes dominate transmission into the receiver space, the very frequency bands in which the earlier model strongly under-predicted the response.

The final controlling variable studied was the damping of the trimmed panel. After stiffness and mass properties of the composite panel are entered and resulting leak sizes are adjusted, the values of plate damping used exercise strong control over the prediction of radiation into the receiver space. This is particularly the case since the panel itself is the excited subsystem in the ball excitation case, as well as the source of radiation. Our study of the APAMAT II machine and this modeling exercise has resulted in the conclusion that a major cause for the difference in effectiveness between trim samples is the structural damping they provide to the trimmed panel assembly. For example, the PET material was lighter and thinner than the Shoddy material studied, yet examination of the results in Figure 5 shows that it performs better in an APAMAT II test than the Shoddy material, from 630Hz through 8kHz.

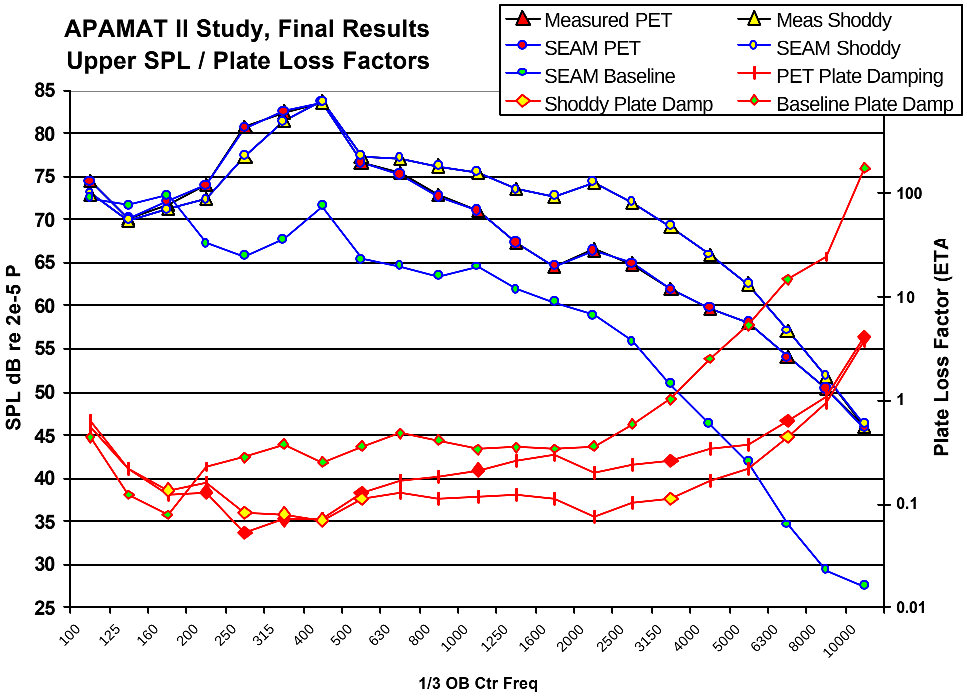

Figure 5: Final Measured Results vs Model Results

Figure 5 displays the final measured and predicted results of this study. In the PET and Shoddy models, the upper acoustic response can be made to line up exactly with the measured values through use of the plate damping values displayed on the lower section of the plot. These damping values were applied to both the steel panel and the composite bending subsystems. Restated, the primary explanation suggested by the SEA model for the improved performance of the PET material over the Shoddy is in the damping it provides to the plate. Although time did not allow for a thorough experimental study of the damping of the trimmed plate, the values depicted in Figure 5 seem to fall in a reasonable range for the PET and shoddy trim samples.

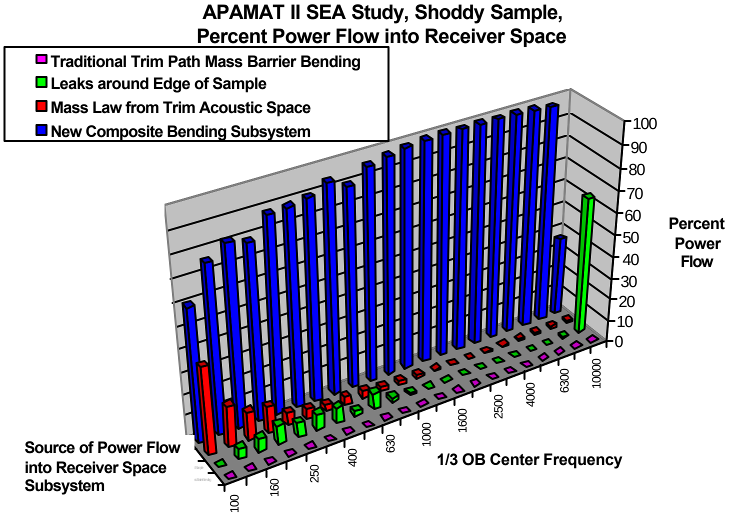

Figure 6: Shoddy Sample Power Flows

As a final correlation test, the SEA model was adjusted to produce a prediction of the APAMAT II "Baseline Sample". This is a very heavy sample of trim, with a 7mm mass barrier, and approximately 5.3 cm of heavy trim material, which is similar to the shoddy material tested previously. These properties were entered into the SEA model as described above. Again, the SEA prediction can be made to exactly match the measured result through application of the plate damping values displayed in Figure 5. Because of their redundancy, the measured results from the Baseline sample are neglected from Figure 5. Our explanation of the very high apparent loss factors in the Baseline Sample prediction above 4kHz is due to friction losses and other unmodeled loss mechanisms, and losses in the compression of the material itself as the wavelength gets shorter.

6. Conclusion

Comparison of measured results to an SEA model of the APAMAT II machine have resulted in the suggested addition of a "Composite Bending" mode group to the SEA model of a trimmed panel, for cases including direct structural excitation. Excellent correlation has been achieved, which explains the differences in performance of various trim samples in an APAMAT II test. It allows the modeler to take into account the structural stiffness, density and thickness of trim materials. This model suggests that frequency dependent panel damping is the controlling parameter, and is a more generally useful derived result of an APAMAT II test of a trim sample. It is suggested that the trim mass density, Young's modulus and the derived loss factors are directly useful in an SEA model of a trimmed vehicle, to produce more accurate TL and structural radiation predictions from trimmed panels.

References

1. Cambridge Collaborative, Inc., SEAM® User's Manual, v3.15, 2001. (Note that SEAM® and visiSEAM® are registered trademarks of Cambridge Collaborative, Inc.)
2. R. Powell, J Zhu and J Manning, SEA Modeling and Testing for Airborne Transmission through Vehicle Sound Package, *SAE Paper* **971973**, 1997.
3. Rieter Automotive, APAMAT II Operators Manual, 1996