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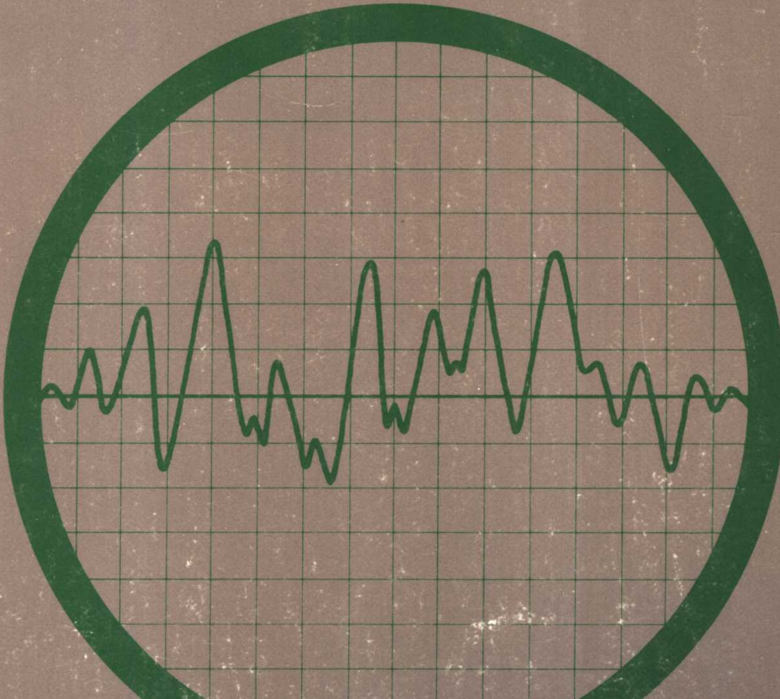

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A Study of Vehicle Interior Noise Using Statistical Energy Analysis

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ABSTRACT

The noise and vibration of an automotive vehicle is studied using Statistical Energy Analysis (SEA). Three sources of interior noise - the engine, tires, and air flow - have been measured and used as inputs to the SEA model. The flow of acoustic energy through various structural components is calculated in order to determine the dominant paths of noise transmission to the passenger compartment. The predicted interior noise levels are compared to those measured under different operating conditions. The SEA model also evaluates the expected variation of the interior noise as the result of changes in the design configuration of the vehicle.

THE USE OF STATISTICAL ENERGY ANALYSIS (SEA) in the study of automotive noise and vibration is motivated by two factors. First, since the early development of SEA in the 1960's [1],* it has been most frequently applied to dynamic systems with too many modes to warrant evaluating each mode separately. Instead, SEA groups the modes into subsystems and evaluates their interaction statistically. It has been shown that this gives reasonably good results for a reasonable cost [2,3].

This factor is useful for automotive noise in the frequency range of interest, say from 50 - 2000 Hz. The vehicle body has a large number of resonant modes in this frequency range. Rather than attempt to evaluate the response of each mode separately, SEA can be used to evaluate the average response of a group of modes. Since there are a large number of modes to average over in the vehicle body, the results will be a good representation of the actual system. One exception to this is the passenger compartment which typically has its first few modes in the 50 - 100 Hz range.

The second factor is that SEA can be used to evaluate the reponse of systems with a small number of modes, but the statistics of the results must be carefully understood. The fundamental principles of SEA have been derived from the interaction of two resonators with their resonant frequencies considered random variables [4]. The statistics of the response of the resonators gives not only the mean value but also the variation of the response as the resonant frequencies change [5].

For a system consisting of two substructures, each with only one resonant mode in the frequency range of interest, the interaction of these modes can be evaluated statistically using SEA. The average value and the standard deviation of the response of the substructures can be evaluated for randomly varying resonant frequencies. This is particularly useful in the early design stages of a system when a prototype is not available for measurements and the design is not yet tied down enough to calculate the resonant frequencies exactly using a model such as finite elements. Then the range of possible systems response levels can be estimated using SEA in order to identify potential problem areas.

This second factor is useful in studying automotive noise in the lower frequency range where, for example, the passenger compartment does not have a large number of resonant modes. These modes are variable due to uncontrolled factors such as the number of people in the vehicle. SEA can be used to evaluate the range of noise levels expected in the passenger compartment resulting from excitations such as the engine, suspension, or air flow, considering changes in the configuration of the interior or the number of passengers. When a more exact answer is needed for a particular case (e.g. whether or not a resonant frequency in the

*Numbers in brackets designate references at end of paper passenger compartment will exactly match the engine firing frequency in a particular speed range) it will still be necessary to use measurements or finite element models. But the statistical estimates from SEA can still be used to determine if a particular case studied is representative of the average or not.

The purpose of this paper is to give an example of the application of SEA to the study of the interior noise of an automotive vehicle, using the computer program SEAM (© 1984, Cambridge Collaborative, Inc.). SEAM is an implementation of SEA which allows a user to model a dynamic system by dividing it up into subsystems represented by idealized dynamic systems such as beams, plates, rods, pipes, and acoustic spaces. Based on a geometric description of these subsystems, SEAM calculates the necessary statistical parameters of the modes and their interaction. Then based on a description of the type of dynamic excitation of the system, SEAM calculates the average response of each subsystem and the standard deviation expected in a given frequency range. It also calculates the relative levels of dynamic energy flow through each subsystem in order to identify the major transmission paths of the dynamic power.

SEA MODEL OF VEHICLE

An SEA model of a mid-sized, front wheel drive station wagon with an automatic transmission was developed using SEAM. Figure 1 shows a schematic diagram of the subsystem divisions used in modeling the vehicle. Although not all shown, a total of 36 subsystems were used, taking advantage of an assumed left-right symmetry. The sources of interior noise were considered to be the engine/drive train noise and vibration, the suspension vibration, the tire noise, and wind noise.

Two types of calculations were made using SEAM. First, a unit force (or pressure) was applied to each source subsytem independently. This was used to identify the important transmission paths from each source to the interior noise. The response of each source subsystem was also used to determine the actual level of excitation when compared with measurements of a vehicle under different test conditions (described in the next section). These results were then used in a second set of calculations in which the amplitude of all the excitations were adjusted to give the same source levels as those measured in a particular test condition. The resulting predictions of the interior noise were then compared to the measured levels.

Focusing on the first source - the engine/power train noise and vibration - the engine and transmission housings are considered to be the sources for the model. It is not necessary to model the details of these structures, since their actual vibration levels will be used as the source level. Therefore they are

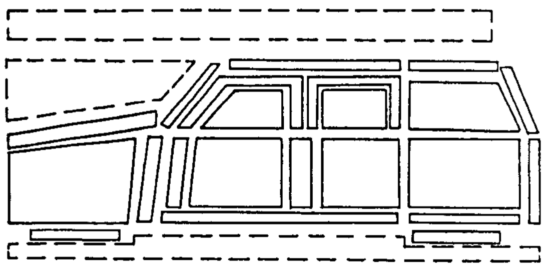

Fig. 1 - Diagram of SEA Model of Vehicle Showing Subsystem Divisions

modeled as a plate and a cylinder, respectively. With a unit force applied to them, the paths of vibrational and acoustic power can be traced to the passenger compartment. There are two paths for the power to get into the vehicle body: one through the mechanical connection of the rubber isolation mounts; and the other through the acoustic coupling of the air in the engine compartment.

Figure 2 shows the power flow through the various paths into the passenger compartment in the 63 and 1000 Hz octave bands. These data are plotted as a percentage of total power with positive values for input power and negative values for output power. In the 63 Hz frequency band the dominant path of engine noise to the interior is the acoustic coupling to the engine

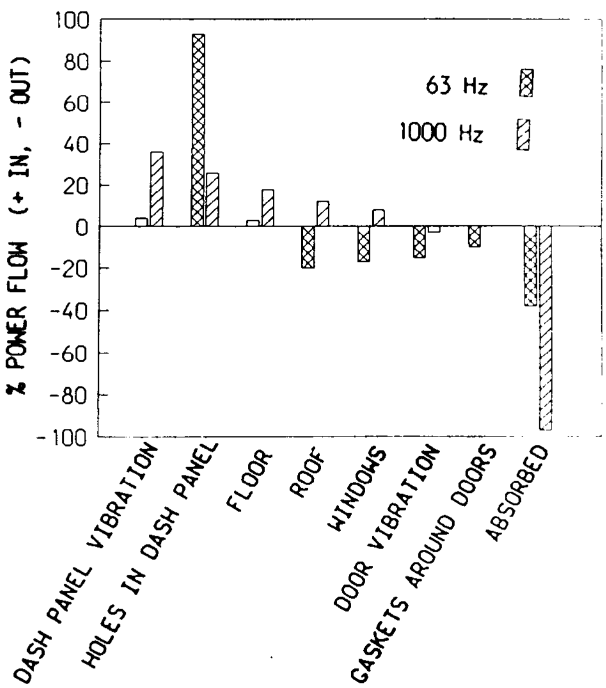

Fig. 2 - Relative Power Flow into the Passenger Compartment with the Engine Noise and Vibration as Source

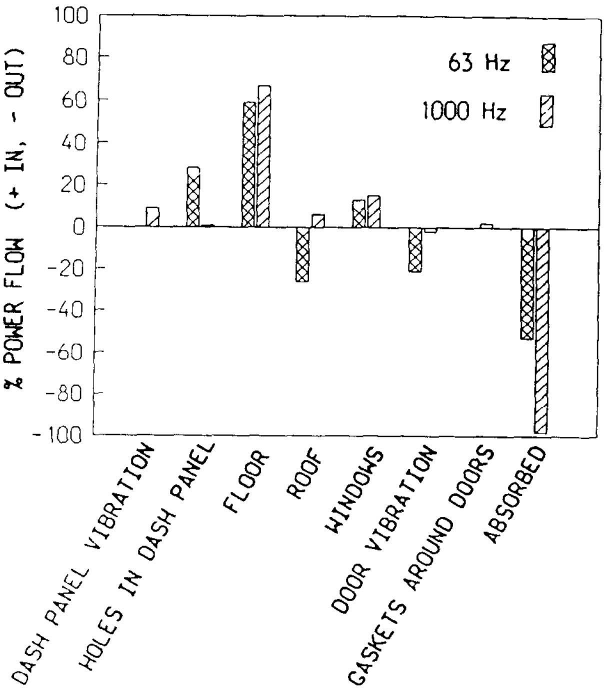

Fig. 3 - Relative Power Flow into the Passenger Compartment with the Tire Noise and Vibration as Source

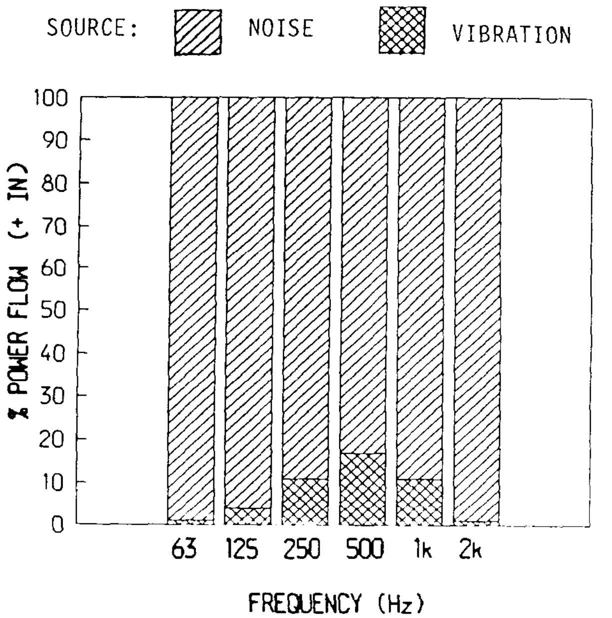

Fig. 4 - Relative Contribution of Tire Noise vs. Vibration to the Interior Noise

compartment through the holes in the dash panel (or fire wall). About 40% of this power is dissipated by absorption in the passenger compartment, and the rest is transmitted to the vehicle body components. In the 1000 Hz band the power flow of engine noise is more distributed among the structural components. However, the acoustic coupling to the engine compartment still accounts for about 60% of the power flow.

For the second source - the tire noise and vibration - the air cavity in the wheel housing and the suspension arm are considered to be the source subsystems for the noise and vibration, respectively. The wheel housing is modeled as an acoustic volume, and the suspension arm as a beam. The amount of excitation applied to each of the two source subsystems is determined by matching their predicted noise and vibration levels to those measured in tests described in the next section. Then, the relative contributions of the various source paths to interior noise can be evaluated.

Figure 3 shows the power flow of tire noise and vibration through the various paths into the passenger compartment in the 63 and 1000 Hz bands. In both frequency ranges the floor is the major transmission path. In order to evaluate the relative contribution of the tire noise versus vibration to the interior noise it is necessary to make two calculations, each with one of the source subsytems excited individually, since they share common transmission paths. This result is shown in Figure 4 where the percentage of total interior noise is plotted versus frequency. It is seen that the tire noise is the dominant part of the source with the tire vibration reaching a maximum of 17% at 500 Hz.

For the third source - the air flow noise - the acoustic energy is assumed to be generated in the acoustic spaces along the side of the vehicle, simulating the turbulence generated by the rear view mirror and window frame molding. By putting a unit excitation in these subsystems the power flow into the passenger compartment can be traced. This is shown in Figure 5 for the 63 and 1000 Hz octave bands. For both frequency ranges, the roof and windows are the dominant transmission paths (assuming the door gaskets are sealing properly).

In order to predict the total interior noise levels at any one operating condition it is necessary to combine these three sources with appropriate levels in the SEA model. This has been done for three operating conditions, and the results are compared to measured levels described in the next section.

VEHICLE MEASUREMENTS

Three test conditions were specified for the measurement of the three source levels described above. In the first test the vehicle was operated at 30 mph (50 km/hr) in second gear up a 10 degree incline over a smooth asphalt surface. The engine speed was about 1800 RPM with a firing rate of 60 Hz. This test condition was chosen to emphasize the engine/power train source. A microphone in the engine compartment and accelerometers on the engine mounting points were used to monitor the source levels.

Figure 6 shows some typical measured levels in A-weighted octave bands from 63 to 2000 Hz.

In the second test the vehicle was operated at 30 mph (50 km/hr) in third gear on a level road with a coarse asphalt surface (12 mm average aggregate size). The engine speed was about 1200 RPM with a firing rate of 40 Hz. This test condition was chosen to emphasize the tire and

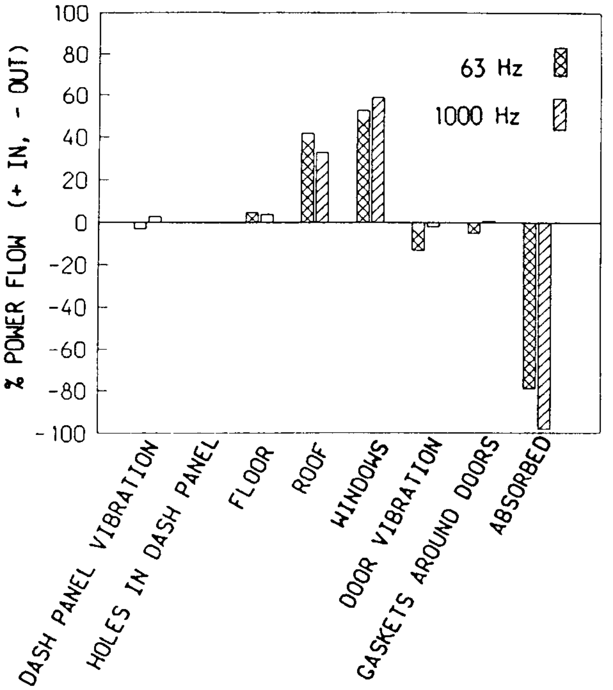

Fig. 5 - Relative Power Flow into the Passenger Compartment with the Air Flow Noise as Source

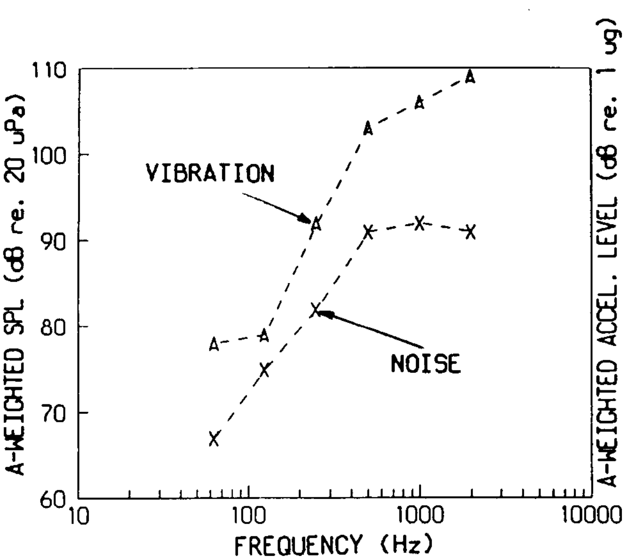

Fig. 6 - Measured Levels of Engine Noise and Vibration at 30 mph, 2nd gear, uphill, smooth road

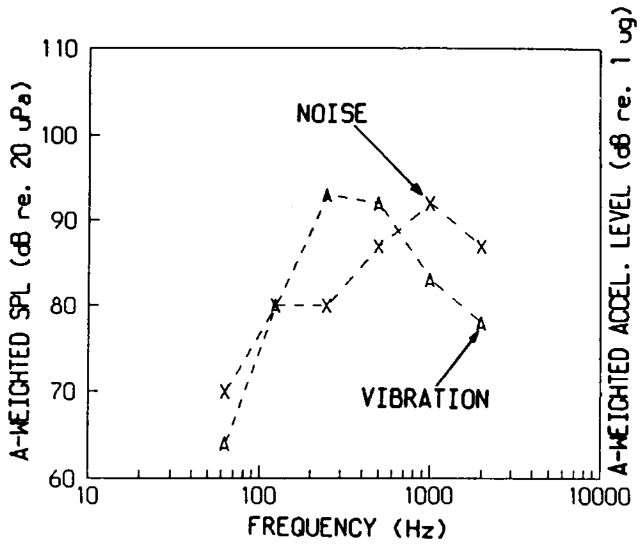

Fig. 7 - Measured Levels of Tire Noise and Suspension Vibration at 30 mph, 3rd gear, level, coarse road

suspension source. A microphone was mounted in the front left wheel well, shielded from the air flow, and accelerometers were mounted on the front left suspension arm and strut in order to monitor the source levels. Figure 7 shows some typical measured levels in A-weighted octave bands from 63 to 2000 Hz.

In the third test the vehicle was operated at 55 mph (90 km/hr) in third gear down a 5 degree grade over a smooth asphalt surface. The engine speed was about 2200 RPM with a firing rate of 73 Hz. This test condition was chosen to emphasize the air flow noise. A microphone was mounted behind the left side mirror, shielded from the air flow, in order to monitor the source levels. Figure 8 shows a typical measurement of the flow noise in A-weighted octave bands from 63 to 2000 Hz.

The measured source levels were used with scaling laws to obtain source levels for all three sources at all three test conditions. It is not possible to accurately measure each source level at each test condition because of contamination from other sources when they are dominant. The engine noise and vibration varies in a predictable manner with changes in the speed and load of the engine [6]. Using this scaling law along with the estimated changes in the vehicle load (due to wind resistance, rolling friction, and incline weight), it is estimated that the engine noise measured in test #1 will be reduced by about 10 dB for test #2 and increased by 5 dB for test #3.

For the tire noise no generally applicable scaling laws are available. However, it has been found that a reduction of 5 dB in tire noise is typical when changing from coarse to smooth asphalt [1]. Therefore this value is assumed

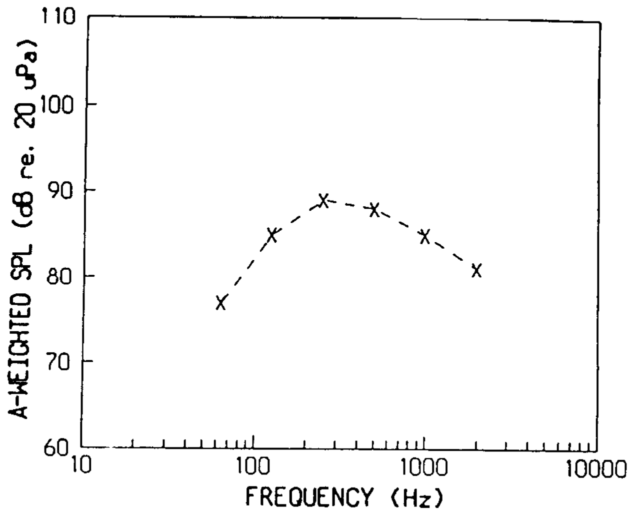

Fig. 8 - Measured Levels of Flow Noise at 55 mph, 3rd gear, downhill, smooth road

here. For the flow noise, it is assumed that the mean-square pressure varies with the sixth power of the flow velocity. Then the flow noise at 30 mph would be about 15 dB lower than the measured levels at 55 mph.

The combination of these measured source levels and the scaling laws for other conditions provides a complete source model for the SEA model of the vehicle. The predicted levels of the interior noise are compared with the measured levels in the next section.

COMPARISON OF MEASUREMENTS AND PREDICTIONS

The SEA model of the vehicle transmission paths and the source models described above can be used to predict the response of the vehicle. In particular, the noise levels in the passenger compartment have been calculated and compared to

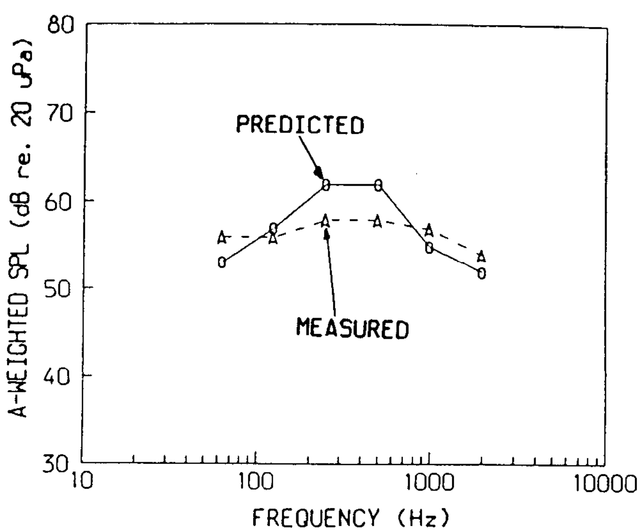

Fig. 9 - Comparison of Measured and Predicted Interior Noise Levels at 30 mph, 2nd gear, uphill, smooth road

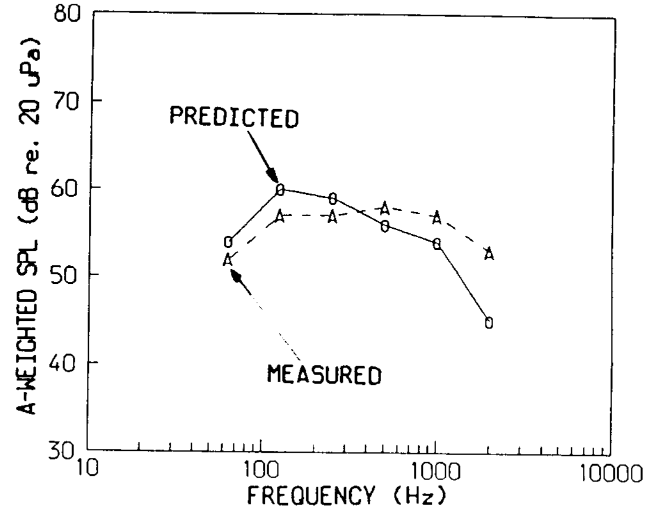

Fig. 10 - Comparison of Measured and Predicted Interior Noise Levels at 30 mph, 3rd gear, level, coarse road

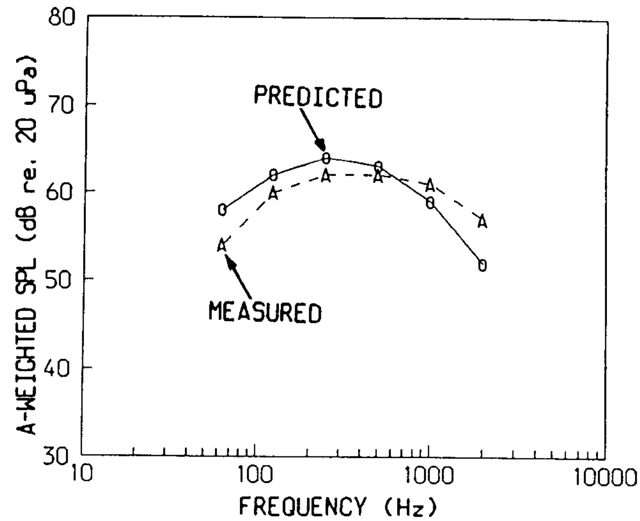

Fig. 11 - Comparison of Measured and Predicted Interior Noise Levels at 55 mph, 3rd gear, downhill, smooth road

the measured levels in the three vehicle test conditions. These are shown in Figures 9 - 11. There is generally good agreement in the results. There is a tendency for the model to over predict the measured levels in the low to mid frequency range. This is most likely due to the presence of contamination in the source levels measurements causing the source levels in the model to be too high.

The SEAM program also computes the standard deviation of the predicted levels. For the octave band levels the standard deviation is about 3 dB over the entire frequency range. This value can be considered to be either the range of possible errors in the model when compared to a specific measurement on the vehicle, or it can be viewed as the expected variation in the measured levels obtained from a number of similar vehicles.

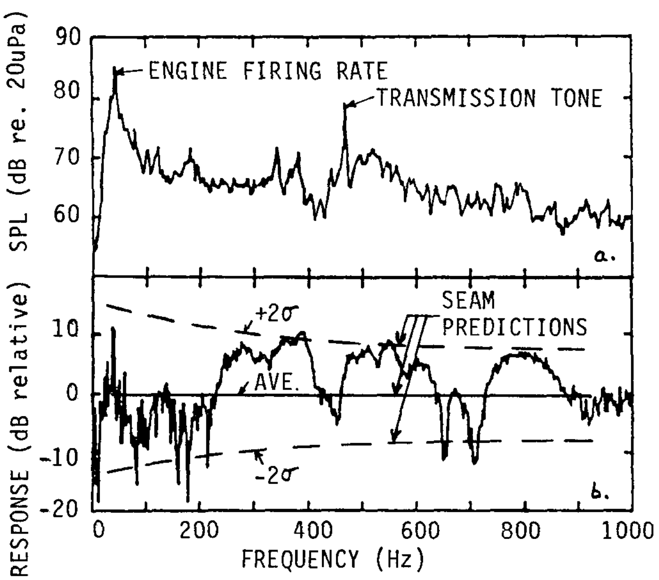

Fig. 12 - Measured Frequency Spectra of a.) Engine Noise (30 mph, 3rd gear), and b.) Passenger Compartment Transfer Function Relative to Free Field (2.5 Hz bandwidth)

The SEAM program can also be used to evaluate the expected variation of the vehicle response to a narrow band excitation. For example, the response of the passenger compartment acoustic space to the engine firing rate tone is an important factor in the determination of the overall interior noise level. This can be visualized using Figure 12 where the narrow band spectra (2.5 Hz) of the engine noise and the passenger compartment transfer function are plotted. The interior noise coming from the engine is the sum of the log values of these two curves (plus a constant).

As the engine speed varies, the frequency of the engine firing rate peak moves accordingly. However, the peaks in the transfer function remain fixed in frequency for the same configuration of the same vehicle. The result will be fluctuations in the interior noise as the firing rate frequency passes over the peaks and dips of the transfer function. The SEAM program accurately predicts the amount of this variation with frequency, although the locations of the peaks and dips are not calculated.

Another way of viewing this variation is to consider the engine speed to be fixed in the data shown in Figure 12, and consider the effects of changes in the characteristics of the passenger compartment. If there are small changes due to different interior configurations, or different numbers of passengers, or random manufacturing differences among a group of similar vehicles, then the overall level of the compartment transer function will not change very much, but the frequencies of the resonant peaks will change. And in a similar manner as before, the interior noise at the firing rate frequency will vary as the peaks and dips in the transfer function move relative to that frequency. Again, the SEAM program accurately predicts the amount of this variation.

CONCLUSIONS

The noise and vibration of an automotive vehicle have been studied using SEA. The SEAM program predicts the flow of acoustic energy through the vehicle modeled as a collection of interconnected, idealized subsystems. Using a model of the sources of excitation of the vehicle, the noise and vibration response of the vehicle can be estimated. Both the mean value and the standard deviation of the response are given. These results agree well with measurements of the passenger compartment noise for test conditions where the dominant sources are the engine/power train noise and vibration, the tire noise and suspension vibration, or the air flow noise. The accuracy of the SEA model is sufficiently good to be used in design or diagnostic work to estimate the range of noise levels that will occur in a statistical sample of similar vehicles.

ACKNOWLEDGEMENTS

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REFERENCES

1. Lyon, R.H., "Statistical Energy Analysis of Dynamic Systems: Theory and Applications," The M.I.T. Press, Cambridge, MA, 1975.
2. Remington, P.J., and Manning, J.E., "Comparison of Statistical Energy Analysis Power Flow Predictions with an 'Exact' Calculation," J. Acoust. Soc. Am., Vol. 57, No. 2, Feb. 1975, pp. 374-379.
3. Lu, L.K.H., et.al., "Comparison of Statistical Energy Analysis and Finite Element Analysis Vibration Prediction with Experimental Results," The Shock and Vibration Bulletin, No. 53, Part 4, May 1983, pp. 145-154.
4. Lyon, R.H., and Maidanik, G., "Power Flow Between Linearly Coupled Oscillators," J. Acoust. Soc. Am., Vol. 34, No. 5, May 1962, pp. 623-639.
5. Lyon, R.H., "Statistical Analysis of Power Injection and Response in Structures and Rooms," J. Acoust. Soc. Am., Vol. 45, No. 3, Mar. 1969, pp. 545-565.
6. Priede, T., "The Problems of Noise of Engines in Different Vehicle Groups," SAE Paper 750795.
7. Thrasher, D.B., et al., "Effect of Pavement Texture on Tire/Pavement Interaction Noise," SAE Paper 762011.

850962

Development of an FM Multiplexed Telemetry System for Obtaining Dynamic Data from Operating Tank Track

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ABSTRACT

A system using FM multiplexed radio telemetry was developed and built to provide a data link between operating tank track and the tank hull. Field tests of the system showed that attention to details of the design of the antenna and battery system were successful in avoiding analytical problems.

The field test also demonstrated that the data obtained with the link correlated well with the results of computer modelling.

THE USE OF FLEXIBLE, linked track on armored vehicles is a well-known practice. As heavier, higher-powered tanks have evolved, greater demands have been put on the track. Because of greater loads and higher speeds, development of improved track is an important aspect of vehicle research. In order to assess the areas of track design in which changes would produce improved performance, researchers have needed data on the loads, temperatures, and acceleration forces experienced by track components. Specialized sensors have been designed and installed on track but the conditions under which the data could be recorded have limited by the difficulty in establishing a data link between the moving track and the recording equipment. These limitations have made it impossible to determine such things as the dynamic forces and loads experienced by track components when the vehicle is operating at high speed, or in complex maneuvers.

One of the conclusions reached by Battelle in The Track Dynamics Program sponsored by the Advanced Concepts Laboratory (ACL) of The U.S. Army Tank-Automotive Research and Development Command (TARADCOM) in 1976-1978 was that there was a definite need for a way to obtain dynamic data from the track of an operating tank without the use of wired electrical connections between the moving track and the tank hull. Prior attempts by various investigators to obtain track data involved the use of bundles of cables running from the track to an adjacent vehicle, or complex mechanical linkage to support cables running between the track and the tank hull. Both these approaches had serious limitations in the areas of tank speed and mobility, and in the ability of the wires and linkage to survive the stresses imposed by the tank's movement.

RELATED PREVIOUS WORK

Based on the recognized need for a telemetry-type instrumentation system, a feasibility study was conducted by Battelle as part of the Track Dynamics Program. A state-of-the-art survey of radio telemetry produced information on the military use of shock-hardened miniature telemetry systems used to monitor artillery projectiles in flight. The conclusion reached was that it would be possible to design, build and use a system using off-the-shelf miniature telemetry components of the type identified in the survey.

TRACK-MOUNTED COMPONENTS

Using field-proven components and following standards established by the Inter-Range Instrumentation Group (IRIG) the track-mounted portion of the telemetry link was designed. The system was designed to fit on the T-142 shoes which had been instrumented for the track dynamics studies of the ACL program. The sensors on the track shoe include strain gages to measure sheer-stress in the pins which permit the "hinge" action between shoes, and piezo-resistive accelerometers for monitoring the impact loads on the shoe body. The components described below comprise the track-mounted portion of the FM-FM telemetry system.

TRANSDUCER CONDITIONING MODULES - These provide excitation for the strain-gage based tension sensors and amplify the tension signal to a level at which it utilizes the full range of the telemetry system.

VOLTAGE CONTROLLED OSCILLATORS - Each data channel has one of these circuits which generate continuous constant-amplitude pulse trains in which the frequency of the pulses is proportional to the signal to be transmitted. Each data channel operates in a different range of frequencies to permit later separation and sorting of the signals in the data recovery process. The three IRIG channels used are 1A, 3A, and 5A, with center frequencies of 16 kHz, 32 kHz, and 64 kHz respectively. These constant bandwidth channels have a full-scale deviation of 2kHz and a data bandwidth of 400 Hz.

SUB-CARRIER MIXER - This signal summing amplifier performs the function of mixing the subcarrier signals from the three voltage-controlled oscillators to create a single multiplexed subcarrier signal. This signal is connected to the input circuit of the 2222.5 mHz FM radio-frequency transmitter.

FM TRANSMITTER - The transmitter generates a frequency modulated signal which is radiated by a slot antenna mounted on the outboard end of the track shoe on which the transmitter is mounted.

BATTERIES - Power for the electronic components and the strain-gage sensors is provided by rechargeable nickel-cadmium batterys. There was concern that the batteries selected for the track telemetry system would become intermittent under the influence of track vibration. To reduce likelihood of battery failure because of shock and vibration, batteries with welded cell-to-cell connections were chosen. No intermittent operation traceable to the batteries occurred, however.

MECHANICAL DESIGN

The mechanical design of the shoe-mounted portion of the telemetry system employs a modular package concept to secure and protect the electronics sub-systems. A flexible inter-shoe wiring system provides a parallel bus system for all of the circuits. Similar modular packages also protect and support the battery array.

MODULAR CONCEPT - Modules containing the electronic components of the shoe-mounted portions of the FM telemetry system are distributed between two T-142 track shoe assemblies. Figure 1 shows three contiguous track shoes. The center shoe is equipped with the FM transmitter module and slot-type transmitting antenna. The shoe on the left is the instrumented shoe. In addition to four strain-gage bridges on each of its two pins, the shoe carries the electronics module containing the transducer conditioning and mixer electronics packages. The shoe to the right carries one of the six battery modules.

BATTERY SYSTEM - The rechargeable battery system occupies six shoe assemblies. Each of the battery modules contains two 9.6-volt battery units. During operation two series-connected sets of three batteries provide the 26-to-30 volts required for the transmitter. The remainder of the batteries supply power for ten-volt circuits and the transducers.

The charging connectors on the battery modules are wired to permit on-shoe charging of the batteries using a parallel circuit and operation with the series circuit needed for the 28-volt requirement. The battery charging connector was wired in such a way that when the charging cable connector is

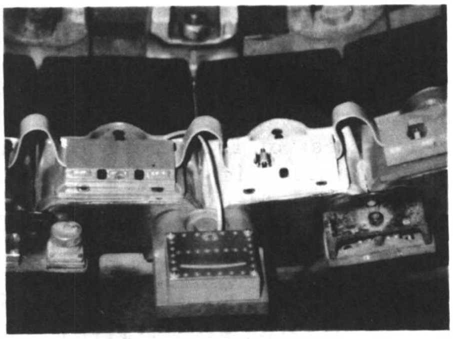

Figure 1. Close-up View of Track-Mounted Components, Including Transmitter Module (center), Analog Multiplex Module (left), Battery Module (right), and Slot Antenna (lower center)

plugged into a battery shoe, each battery is connected across the 10-volt charging circuit. Bench tests showed that, using the 12-battery set, it should be possible to operate the shoe-mounted system for 90 minutes.

INTERSHOE CONNECTIONS - Each shoe module is fitted with two 20-pin connectors for the inter-shoe cables. An on-shoe wiring bus ties these two connectors together and provides tie-in points for the on-shoe electrical circuits. Between shoes, the bus is in the form of a 20-conductor ribbon cable, configured with sufficient loop to accommodate the relative motion of the adjacent shoe assemblies as they traverse the track path. The inter-shoe loop is electrically shielded by an enclosing braided wire cover and mechanically protected by a durable plastic sheath. This cable configuration was selected because of its satisfactory performance in robotics and machine-tool application. The loop is terminated at each end by a 20-conductor connector which mates with the corresponding connector on the track module. The inter-shoe cable loops can be seen in Figure 1.

THE HULL-MOUNTED SYSTEM

The hull-mounted portion of the telemetry link consists of four sub-systems:

(1) Receiving Antenna
(2) FM Receiver
(3) Sub-carrier De-multiplexing Filters
(4) FM Discriminators

Except for the antenna which is shown in Figure 2, these items are conventional rack-mounted devices, powered by 115 volts AC. The antenna is a simple stub on a 4-inch square ground plane, and is mounted on an outrigger adjacent to the track loop. A length of coaxial cable connects the antenna to the FM receiver.

The FM receiver is a rack-mounted unit intended for bench use. To adapt it to the relatively severe vibration environment of the tank hull, the receiver was mounted in a shock isolation cabinet which was in turn installed on a vibration isolating mounting base.

The demultiplexing filters and demodulation units, which extract the respective subcarriers from the multiplexed subcarrier, are also rack-mounted in the vibration-isolation enclosure with the FM receiver.

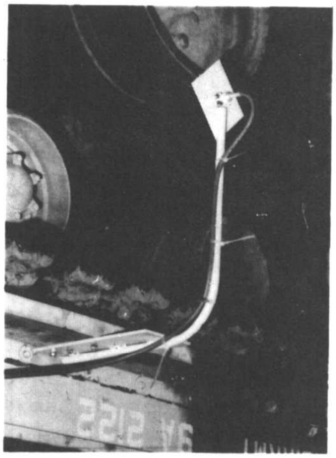

Figure 2. Hull-Mounted Receiving Antenna

CHECK-OUT AND FIELD TEST

Prior to installation on the test vehicle the telemetry system was functionally checked and calibrated by installing the instrumented track with the track-mounted telemetry system in a hydraulic tensile test machine.

Upon completion of the calibration the instrumented track section, telemetry modules, and hull-mounted components were taken to Waterways Experiment Station (WES) of the U.S. Corps of Engineers at Vicksburg, Mississippi. There the instrumented track sections were installed in a new T-142 track loop on an M48 tank. The installed shoe-mounted portion of the link is shown in Figure 3.

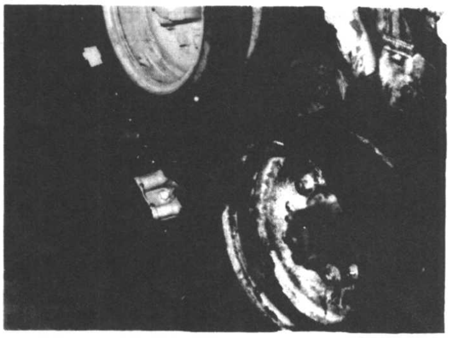

Figure 3. Track-Mounted Telemetry System Shown Installed on the Left-Hand Track of an M48 Tank

With the track-mounted components installed in the appropriate shoe modules and the hull-mounted units installed on the front fender of the tank, a series of test runs was carried out. The data transmitted by the telemetry link was recorded with an instrumentation recorder and an on-line recording oscillograph, both of which had been installed inside the tank.

RESULTS

Figure 4 is a segment from one of the oscillograph recordings. In the test run shown in the recording one of the strain-gage sensors had been replaced by an accelerometer mounted on the track. In addition to the pin stress (longitudinal tension) and vibration acceleration traces, the chart shows the reference signal from the third telemetry channel, two track-position pulse trains and the output of an accelerometer monitoring vibration of the hull-mounted components.

To illustrate one of the applications of data obtained via the telemetry link, field validation of computer models of the track, a computer-drawn plot of the output of model of track tension is shown in Figure 5. Although the data from the computer are inverted, relative to the field data, it can be seen that the time-history of a single track cycle, shown in Figure 5, has the same general shape as the single cycle shown in the windowed area of Figure 4.

SUMMARY

The feasibility of using radio telemetry has been demonstrated and the potential problems with the performance of battery and antenna systems have been circumvented by attention to design details. The data transmitted by the telemetry link correlate well with computer-generated track performance data. The capability which the telemetry data link will provide for obtaining dymanic data from an operating tank track will facilitate the development of track with greater service life and dependability.

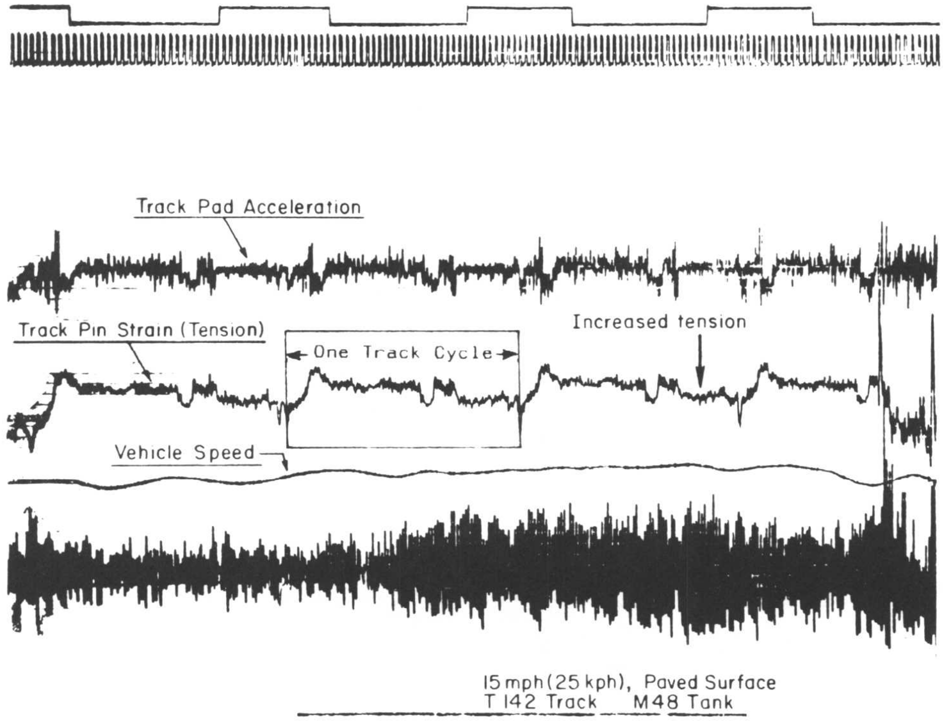

FIGURE 4. TRACK DATA OBTAINED VIA FM MULTIPLEXED TELEMETRY LINK

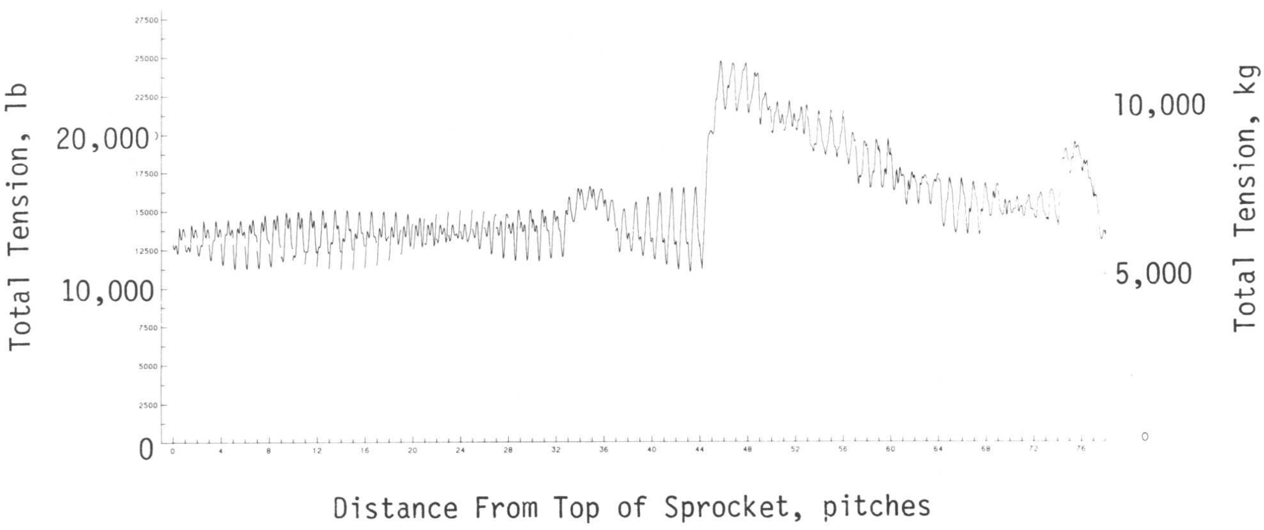

FIGURE 5. COMPUTER DRAWN PLOT OF TENSION AROUND TRACK CIRCUIT