JURY EVALUATION OF ELECTRIC POWER STEERING SOUNDS

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1. INTRODUCTION

The present study explores the sound generated by a brushless motor-assisted steering system. The objective of the investigation was to determine the acceptable levels of in-vehicle structure-borne induced noise (SBN) and airborne radiated noise (ABN) contributors relative to the current baseline system. These acceptable levels will then later be cascaded down to the electric motor requirements.

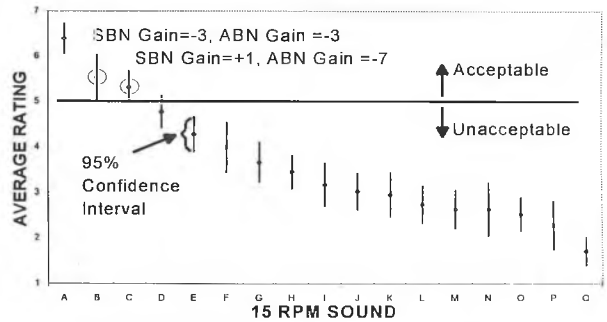
2. METHOD

The electric power steering under investigation consists of a brushless motor connected to the steering column to provide assist. The electric motor generates a static torque to assist the driver. Due to the commutation of the motor, numerous commutation events occur per motor rotation. Switching of the current between phases generates an impulse that results in a broadband airborne sound. The torque fluctuation caused by each commutation event generates a lower frequency tonal noise that is synchronous with the motor RPM and is structure-borne. The structure-borne and airborne contributions were determined through an airborne acoustic noise wrap study.

Jury evaluations of acceptability using semantic differential category scaling [1] were conducted to determine the levels of acceptance of the tonal structure-borne and broadband airborne sound contributors. This was accomplished by applying Kalman filters to extract the commutation orders to approximate the structure-borne component. The airborne noise was estimated by highpass filtering the sound. Sounds for the evaluation were then generated by summing weighted versions of the structure-borne and airborne contributors in the presence of an engine idling background. The sounds were presented to a jury, and the jury was asked to rate the acceptability from extremely unacceptable to extremely acceptable. Seventeen sounds at three handwheel rotational speeds were generated: 15 RPM, 30 RPM, and 45 RPM.

3. DISCUSSION AND RESULTS

Jury evaluation raw data were transferred to a seven point scale and averaged over the 28 subjects, consisting of both technical and non-technical employees. Sounds with an average rating of five or greater were considered acceptable. Results indicate that a wide range of acceptability levels were found. Below is an example for a 15 RPM handwheel rotational speed.



In general, results indicate that at lower handwheel rotational speeds the airborne sound dominates the perception, while at higher rotational speeds the structure-borne component becomes a large contributor. However, at each handwheel speed at least two sounds were found to be acceptable by reducing SBN more than ABN, or ABN more than SBN. The table below shows the reduction from baseline that resulted in acceptable sounds.

Speed	Average	SBN Gain	ABN Gain
15 RPM	5.5	-3 dB	-3 dB
	5.3	+1 dB	-7 dB
30 RPM	5.5	-7 dB	-4 dB
	5.1	-3 dB	-8 dB
45 RPM	5.1	-10 dB	-3 dB
	4.9	-6 dB	-7 dB

Two-variable regressions were calculated using the structure-borne and airborne dB level adjustments from baseline to predict the average jury ratings, as shown below:

$$\textit{average rating} = b_0 + b_1 * \textit{SBN Gain} + b_2 * \textit{ABN Gain}.$$

R^2 results at the three rotational speeds were equal to 0.84 (15 RPM), 0.87 (30 RPM), and 0.89 (45 RPM). High correlation allows system specifications to be set that are correlated to jury acceptance results.

4. CONCLUSIONS

Acceptable electric power steering levels were found that allow tradeoffs between structure-borne and airborne noise sources. Changes in electric motor structure-borne and airborne sound levels were highly correlated to jury acceptance results.

5. REFERENCES

[1] Meier R. C., Otto N. C., Pielemeier W. J., Jeyabalan V., *A New Tool for the Vibration Engineer*, SAE Paper 971979