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VEHICLE ACCESSORY TONAL NOISE: EXPERIMENTAL DETERMINATION AND SUBJECTIVE ASSESSMENT

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1. INTRODUCTION

There is a general trend in the motor industry towards reduced noise levels inside vehicles. Low frequency vehicle interior noise, below 500 Hz, is mostly generated through structure-borne vibration emanating from the powertrain and transmitted through the various connection points to the vehicle body and into the passenger compartment. This noise contribution has been reduced dramatically over the past few years by control of the vibration levels generated by the powertrain, engine mount isolation and improved body structures. The consequence of this is that high frequency noise has become much more intrusive because of the reduction in the masking effect of low frequency noise. High frequency noises come from a variety of sources, and are generally airborne rather than structure-borne. Possibly the most annoying to the driver are narrow band high frequency noises, classified as 'whine' noises, the majority of which are attributable to noise radiated from the powertrain and the various auxiliary components attached to it. Engine radiated noise has also been reduced significantly over recent years, which means that the contribution of auxiliary components has become more important. A component such as the alternator can produce more overall radiated noise than the rest of the powertrain, if badly designed. So that an accessory will not give rise to unacceptable noise inside a vehicle the component suppliers must develop their parts such that radiated noise levels are sufficiently low. This can only be achieved if the suppliers know what levels of radiated noise are acceptable. This paper presents the results of an investigation into the influence of accessory noise on the overall interior noise of a vehicle, and the setting of tonal noise targets for vehicle accessories, concentrating on an automotive alternator.   The investigations are based on detailed transfer function measurements carried out using a wideband sound source and the principle of acoustic reciprocity. A subjective target setting experiment is then described which allowed rig based target values to be derived.

2. INTERIOR NOISE INVESTIGATION

Method and equipment
To determine the contribution of the alternator to the overall interior noise the means by which this noise enters the vehicle interior must be considered. The alternator radiated noise is attenuated by the vehicle body structure on its way to the passenger compartment, and this is characterised by the noise transfer function, between the alternator position and the passenger compartment. To measure this a suitable omnidirectional noise source is needed with the capability of providing a known signal over the range of frequencies of interest. Ideally the source should be placed in the engine compartment at the alternator mounting position, the response at the driver's ear position measured and a transfer function derived. To make instrumentation and measurement easier, the principle of acoustic reciprocity was used, whereby the noise source was positioned inside the passenger compartment and the response measured in the engine compartment. The transfer function, H, is then obtained from the acoustic reciprocity relationship [1,2]

$$\frac{SPL(x)}{qs(y)} = \frac{SPL(y)}{qs(x)} \tag{1}$$

where SPL is the sound pressure at the receiver position, qs is the source volume velocity, x denotes the position in the vehicle interior and y is the position in the engine compartment. The sound pressure at the driver's ear due to the alternator, SPL(x), was then predicted using the formula

$$SPL(x) = H.qa(y) \tag{2}$$

where qa(y) is the operational alternator volume velocity. The source used for this work was a prototype system developed by the Automotive Design Advisory Unit at the Institute of Sound and Vibration Research, University of Southampton, which gave a signal of suitable strength and omnidirectivity over the frequency range of interest. Having verified that the principle of acoustic reciprocity would give accurate results, transfer functions between various possible alternator positions and the passenger compartment were derived, the source volume velocity being obtained from a free field calibration. Alternator noise was measured on a simple rig designed to mount a typical alternator such that access was not obstructed nor radiated noise significantly influenced by the structure. The alternator was driven using an electric motor via a long drive belt. Noise measurements were taken round the alternator and volume velocities derived. The contribution of the alternator to interior noise was then calculated using equation (2).

Results
Transfer functions measured between the passenger compartment and various positions in the engine compartment are shown in Figure 1. The most notable aspect of this is the peak in the transfer function at about 3000Hz for position B which is at the bulkhead side of the engine near the bottom of the vehicle. As the vehicle was right hand drive, and the front of the engine is at the right hand side of the vehicle, it is thought that this peak is attributable to noise transmitted through the steering column bush, and so this mounting position for accessories should be avoided. The contribution of the alternator to overall interior noise at

6450 rev/min is shown in Figure 2. This clearly shows that at this relatively high speed the alternator makes a very significant contribution, particularly at high frequencies, with the alternator 6th and 11th rotational orders being clearly visible. These peaks are caused by the alternator having six poles in the rotor and eleven blades in the cooling fan.
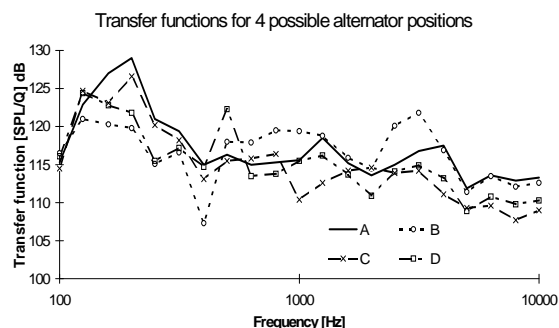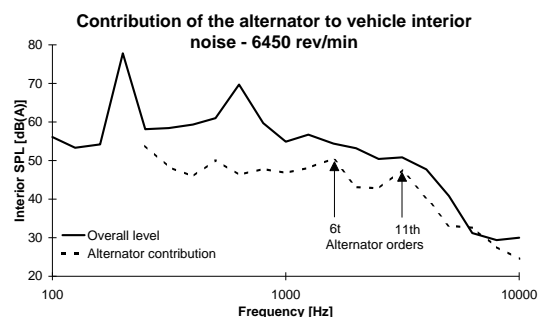

Figure 1.

Figure 2.

3. TARGET SETTING

Method and equipment

The object of this part of the work was to develop targets such that an accessory meeting them will not give rise to unacceptable noise inside a vehicle. Previous experience has shown that an overall level target is not sufficient, and that targets should be set for the spectrum of frequencies of interest. It was decided to set up an experiment in which such targets could be derived directly from a subjective assessment inside a vehicle. A signal would be introduced into the engine compartment whose level and frequency could be altered by a subject sitting in the vehicle. With the engine running at a set speed a noise of a particular frequency could be introduced and the threshold of its audibility determined by the subject adjusting the level. This could be repeated for a range of engine speeds and frequencies, so developing a map of threshold levels. The noises were introduced by means of a compression driver unit with a long flexible tube attached to it which had a suitably sized nozzle at the end to ensure omnidirectivity over the frequency range of interest. The frequency of the noise was linked to alternator rotational speed so that the frequency would change as the engine speed was changed to give the subjects an impression of typical alternator noise problems.

Results

Generally the repeatability between different subjects was considered good for this type of experiment and so sufficiently good quality data were available for processing into target values. The readings obtained during the experiment were averaged and then related back to the strength of the noise source. This relationship was determined by a calibration exercise in free-field conditions. By this means a map of acceptable noise levels for various speeds and frequencies was obtained. Figure 3 shows target curves at various engine speeds, expressed as SPL which would be measured at 0.5m from the source on a test rig. These levels relate to engine speed and so when deriving rig

targets for rotating accessories the drive ratio has to be taken into account. As alternators are known to produce noise at certain rotational orders determined by their design, target curves for these orders can be derived. The effectiveness of these targets can be demonstrated by Figure 4 which shows how the targets for 36th order relate to alternator noise from a machine which caused an unacceptable noise in a vehicle and a modified machine which eliminated the problem. An alternator meeting the target levels would not have caused a noise problem in the vehicle.
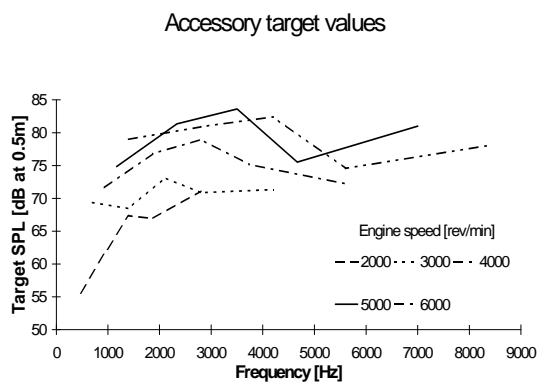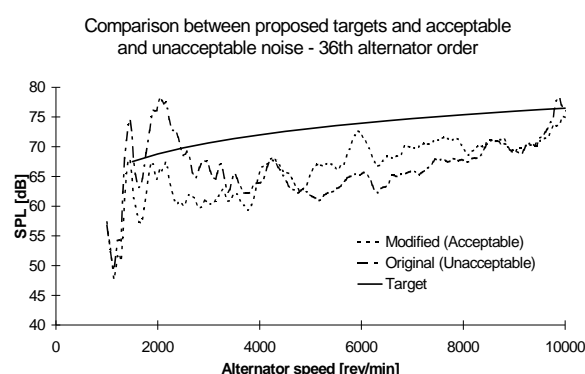

Figure 3.   Figure 4.

Although this work concentrated on an automotive alternator, the targets could be applied to any component producing noise of a tonal nature mounted in the engine compartment.

4. SUMMARY AND CONCLUSIONS

This paper has summarised a detailed accessory tonal noise investigation and target setting process. It has shown how the contribution of the alternator to overall vehicle interior noise can be calculated, and has described a suitable technique for deriving tonal noise targets for accessories mounted in a vehicle engine compartment. The main conclusions are as follows.

- The positioning of the accessories in an engine compartment is important. A location towards the front of the vehicle would give lower interior noise.
- At high engine speeds the alternator makes a major contribution to the overall interior noise of this type of vehicle at high frequencies.
- The principle of acoustic reciprocity can be used successfully in this type of investigation.
- The target noise levels derived would be effective in ensuring that interior noise problems due to accessories would not occur.

5. REFERENCES

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