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REDUCTION OF VEHICLE POWER ASSISTED STEERING NOISE

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1. INTRODUCTION

To achieve low levels of noise and vibration in the interior of a vehicle, the noise levels from major sources such as the engine and transmission have been greatly reduced in recent years. Unfortunately, this has meant that the noise from ancillary components has become relatively more prominent. One such component is the power assisted steering (PAS) system, the noise from which is a problem on nearly all vehicles. This paper reports an investigation into the moaning noise produced when the steering wheel is turned at idle, commonly known as PAS moan. The major factors involved in PAS moan are: the transmission of structure-borne and air-borne noise through the vehicle; the transmission of pressure ripples in the hydraulic circuit of the PAS system; and the generation of flow ripples at the PAS pump. In section 3 the results of a study into the reduction of PAS moan is reported. Section 3.1 outlines the experimental set-up and measurement technique. Section 3.2 reports on the effect on vehicle interior noise of the installation of the of the PAS system. Section 3.3 reports on the influence of tuning hoses in the PAS hydraulic circuit and section 3.4 gives an assessment of the reduction in interior noise due to a modification of the power steering pump. The findings outlined in this paper are part of more detailed study into power steering noise reported in reference [1].

2. POWER ASSISTED STEERING NOISE

The main components of a PAS system are the pump, a control valve and a ram cylinder. The double-acting ram piston is connected to the steering arm to supply the appropriate force to assist the steering manoeuvres. The fluid pressure, which is modulated by the control valve determines the amount of assistance given by the ram. Flexible pipes connect the control valve to the ram cylinder and to the pump. The integration of the PAS system into the vehicle and the positioning of the hydraulic components in the engine compartment is generally determined by the mounting of the engine and its further ancillary components. Additionally cost implications, reflected in fixtures or lengths of hoses and tubes, may also be considered.

Hence, subsequent noise emission is often not taken into account the initial design stage. This leads to an unsatisfactory condition, with regard to PAS noise, and requires development work on prototypes to reduce these noise levels.

PAS noises are primary influenced by operation of the steering wheel and, therefore, are most annoying when conducting steering manoeuvres at low engine speed. At higher engine speeds the PAS noises are overridden by the noise from other ancillary components or by the noise from the engine itself. The moaning and the whining noises are generated in the PAS pump and the hydraulic pressure lines. With increasing engine speed, and hence pump speed, the generated moaning noise will change to a whining noise. The perceived noise, which is described as "moan", is a low to mid frequency noise in the range from 120 to 850 Hz.

3. REDUCTION OF PAS MOAN

3.1 Measurement of PAS moan. For measurements of PAS moan the steering wheel was turned from lock to lock, with a mean steering wheel velocity of 15 °/s. Simultaneously, the engine speed was swept from idle speed up to 2000 r.p.m. using a remote-controlled handcrank on the throttle linkage. Vehicle interior noise was measured using an artificial head situated in the front seat of the vehicle. Based on the recorded time histories, frequency spectra were calculated at successive r.p.m. speeds. This resulted in 3D waterfall diagrams of vehicle interior sound pressure level (SPL) against engine r.p.m. and frequency.

An analysis of vehicle interior noise due to PAS moan showed that the effect was related to the tonal frequencies of the PAS pump. Noise due to the pump showed a fundamental frequency at the 10^{th} power steering order and its associated harmonics (20^{th}, 30^{th} and higher). This can be explained by the ten vanes of the PAS pump causing ten pressure ripples per revolution. As the speed ratio from the PAS pump to the engine was 1.1, the PAS moan at the 10^{th} PAS pump order was equivalent to the 11th engine order.

3.2 Reduction of PAS moan by isolation. One potential source of PAS moan occurs when components of the PAS system are unintentionally in contact with other parts of the vehicle. By investigating the routing of the PAS high pressure line in a standard production vehicle, it was found that the PAS high pressure line was accidentally in contact with the brake line at the lower right hand side of the subframe. The cause of this condition was the minimal package area to route the high pressure line through the engine compartment. To remove this faulty condition, the angle of the high pressure line was changed from 38° to 30°. Measurements of interior noise were then taken for the vehicle with the modified PAS high pressure line, and compared to measurements of interior noise for an unaltered vehicle. Figure 1 shows how the interior noise level is affected by this touch condition. The engine, and hence the pump, was recorded at idle speed. It can be seen in Figure 1 that the sound pressure level of the three major pump orders was slightly reduced by the modification of the angle of the high pressure line.

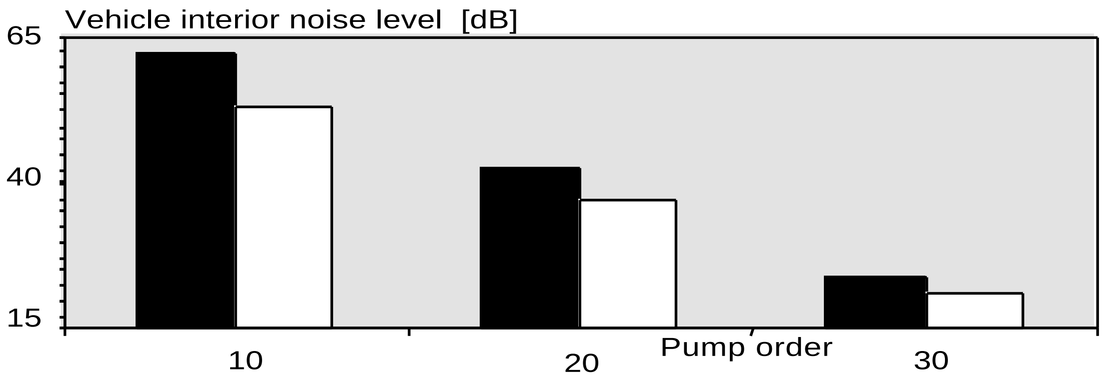

Figure 1. The effect on vehicle interior noise of contact between the PAS high pressure line and the brake line (black = components in contact, white = components separated).

3.3 Reduction of PAS moan by tuning of the high pressure hose. The dependency of the PAS system's noise emission on pressure pulsation in the hydraulic pipe system has been reported previously in reference [2]. To attenuate these pressure pulsations the pressure hoses can also be tuned to operate as a pressure wave interference device. The attenuation device consists of a flexible, permeable channel placed inside a flexible rubber hose. The annular cavity formed between the outer diameter of the inner conduit and the inner diameter of the hose provides a quarter wave side branch which can be tuned to a specific frequency. Unfortunately, PAS moan does not occur at a specific frequency, therefore, the length of the tuning hose always has to be a compromise. In general, the correct cable length is determined through experimental evaluation of several cable of different lengths.

To determine the effect of the length of a cable on interior noise levels, a pressure line with a lengthened hose was installed and tested. The modified hose was identical to the standard hose except that its overall length was increased from 748 mm to 885 mm. The tuning cable was also extended by 137 mm so as to maintain the previous gap size. Figure 2 shows the effect on interior noise levels of the new design. In figure 2 the interior noise level of a vehicle fitted with the modified hose is compared with the interior noise level of a vehicle fitted with the standard hose. The data were recorded at idle speed. It can be seen in Figure 2 that a noise reduction of about 10 dB was achieved for the three major pump orders.

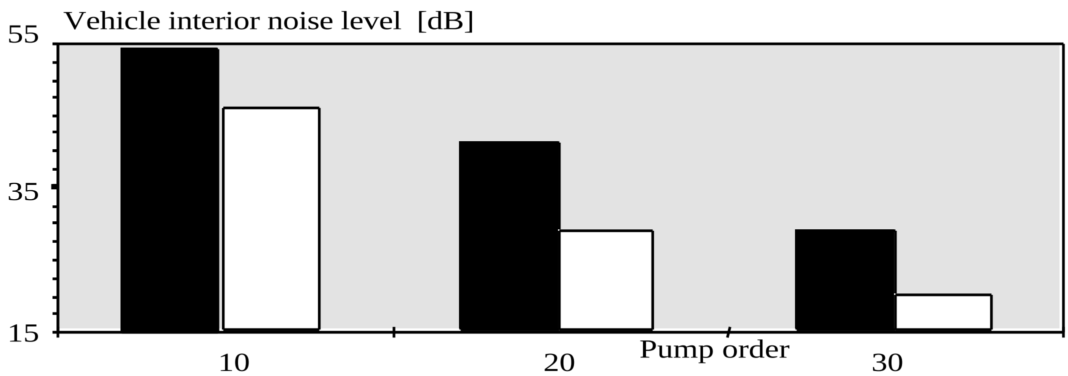

Figure 2. The effect on vehicle interior noise of the length of the PAS high pressure line (black = standard length, white = extended length).

3.4 Reduction of moan by modification of the PAS pump. In order to reduce the noise from the PAS system the pump flow pulsation has to be minimised. In the power steering fluid the pressure ripple is a combination of three categories of waveforms: kinematic flow ripple, which is a function of the geometry of the rotating parts; compression flow ripple, which is a result of the compression of a trapped fluid volume; and leakage flow ripple, which is the result of a pressure differential across leakage paths. One such leakage path is the vane slot clearance. To investigate this effect further, a prototype pump with rotor slots 0.005 mm wider than standard pumps was built. This was installed in a test vehicle and measurements of the interior noise recorded and compared to noise from a standard production vehicle. Figure 3 shows a comparison of the interior noise levels at idle. It can be seen in Figure 3 that the noise level of the 10th and the 20th order was reduced by 6 and 5 dB, respectively. However, the 30th order was increased by 1 dB.

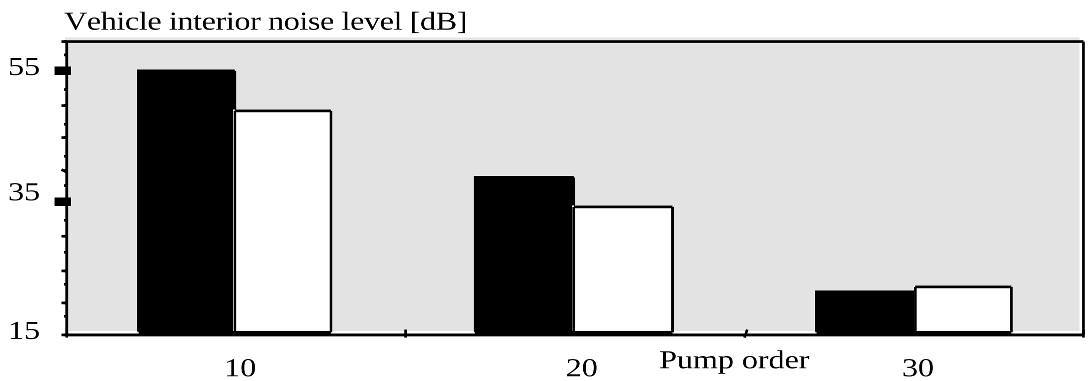

Figure 3. The effect of PAS pump rotor slot size on vehicle interior noise (black = standard production unit, white = 0.005 mm wider rotor slots).

4. SUMMARY OF FINDINGS

This investigation has shown that multiple factors influence the interior noise phenomenon of PAS moan. In this paper three different contributors to PAS moan were investigated. By increasing the clearance of the power steering components contact between the PAS high pressure line and other parts of the vehicle was avoided. This resulted in a reduction in interior noise levels. The attenuation of pressure waves in the PAS hydraulic circuit was another factor investigated. This revealed that tuning cables are capable of attenuating the pressure pulsation at idle speed, the most critical condition, but a complete attenuation over a broad speed range was not achieved. An analysis of the PAS pump showed that a smooth flow delivery could not be achieved by a vane pump. Therefore, a modified pump was designed which achieved the desired flow rate but minimised the pulsation level. This modified pump resulted in a reduction in PAS moan for the most severe orders of the pump.

5. REFERENCES

1. T. J. Duscha, *Power steering noise investigation* (M.Sc. Thesis, Loughborough University, 1998)
2. “Analysis of tuning cables for reduction of fluid-borne noise in automotive power steering hydraulic lines”, M. C. Hastings, *Society of Automotive Engineers,* SAE 931295 (1993)