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**AN EXPERIMENTAL INVESTIGATION INTO NOISE AND VIBRATION OF AN
AUTOMOTIVE WIPER**

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AN EXPERIMENTAL INVESTIGATION INTO NOISE AND VIBRATION OF AN AUTOMOTIVE WIPER

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ABSTRACT

As modern passenger cars become increasingly quieter, wiper operation vibration and noise become more noticeable. As a result of the market information survey, most complaints about the wiper concern operation noise. Wiper vibration and noise is classified into three main categories namely, squeal noise, chattering, and reversal noise. Squeal noise is a high-frequency vibration of about 1000 Hz. Chattering noise is a low-frequency vibration of 100Hz or less and reversal noise is an impact sound with a frequency of 500 Hz or less produced when the wiper reverses. In this paper, we experimentally investigate vibration and noise of a passenger car's wiper. First, we determine natural frequencies of a wiper using modal testing. Later, noise and vibration characteristics are observed during wiper operation at the dry and wet conditions. Wiper noise and vibration is also examined at three different speeds, i.e., slow, moderate and fast.

Keywords: wiper; vibration; noise; passenger car, wiping speed

INTRODUCTION

Windscreen wipers are indispensable components to the maintenance of a safe and comfortable field of vision when driving on rainy days. A conventional wiper system as shown in Figure 1 comprises an electric motor and a linkage mechanism which converts the rotational movement of the motor into the back and forth motion of the wiper arms. The mechanical structure of the wiper blades is attached to the arm tips, holds the rubber blade, which drains the water off the windscreen or to smooth the water on the surface of the windscreen in order to create a thin film that allows light to pass through it without refracting or bending as shown in Figure 2.

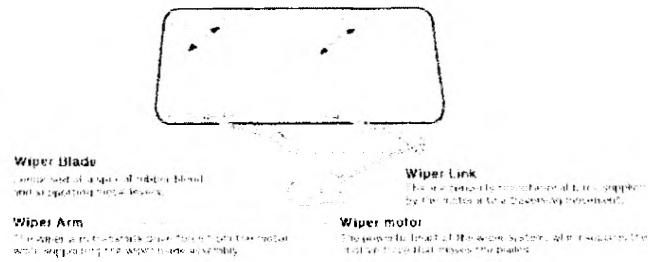


FIGURE 1 Wiper system on a windscreen (taken from Denso Product. Co.)

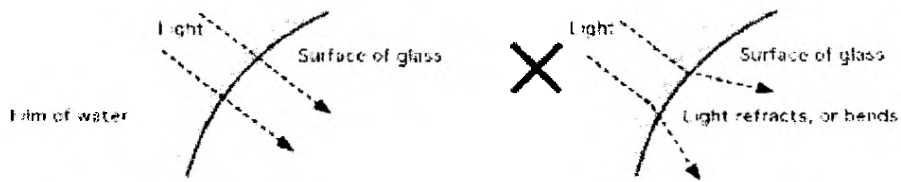


FIGURE 2 Load distribution of a wiper blade (taken from Denso Products Co.)

The purpose of a wiper system is to ensure a clear field of vision by wiping the windscreen clear. However, it is often that the wiper system generates unwanted noise and vibration. Goto et al. (2001a) classified noise and vibration in the wiper system into three groups, namely, squeal noise, chattering and reversal noise. Squeal noise, sometimes called squeaky noise, is a high-frequency vibration of about 1000 Hz. Chattering, or beep noise, is a low-frequency vibration of 100Hz or less. Reversal noise is an impact sound with a frequency of 500 Hz or less produced when the wiper reverses. These types noise and vibration phenomenon lead to visual and audible annoyance for the driver and passengers. Visual of deterioration effects such as streaking, jumping and uneven blade pressure are depicted in Figure 3.

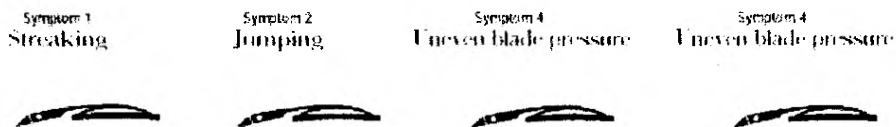


FIGURE 3 Signs of wiper deterioration visible on the front windscreen (taken from Denso Product Co.)

Numerous studies, using numerical and/or experimental approach, have been carried out to investigate noise and vibration of an automotive wiper system (Okura et al. 2000, Goto et al. 2001a, Goto et al. 2001b, Grenouillat and Leblanc 2002, Okura and Oya 2003, Stallaert et al. 2006, and Chevennement et al. 2007). Okura et al. (2000) studied dynamic analysis of blade reversal behaviour using a

three-dimensional mechanical model of a wiper system and a spring-mass model of an arm and blade were developed. From these two models they showed that by modifying the maximum rubberneck rotational angle and the rubberneck rotational spring constant reversal impact force could be reduced. They also showed that the reaction force at the top and bottom reversal points could be adjusted by modifying the arm head twist angle. In 2003, Okura and Oya extended their studies considering a complete 3-dimensional model. Comparison between 2D and 3D model for the arm and blade was made and they commented that the 3D model could simulate the reversal behaviour of the wiper system more accurately than 2D model.

Goto et al. (2001a, 2001b) investigated squeal noise reduction using a mathematical model. From the proposed model, material physical properties and design of the blade were varied and they found that those have significant contribution to the reduction of squeal noise. Experiments on squeal noise were also carried out to verify the effectiveness of the proposed material and design changes. Grenouillat and Leblanc (2002) used combined approach to study chatter vibrations for a wiper system. Wiper motion tests were carried out on a developed test rig. Different attack angles and pressure were used and their effect on the wiper motion was observed. They also developed a 2-dimensional mathematical model and used it to demonstrate the influence of the geometrical configuration of the wiper system on the generation of unstable motion. From both approaches they concluded that attack angle and pressure contributed significant effects on the unstable motion (chatter).

Stallaert et al. (2006) employed dither control to stabilize squeal noise in the wiper system. A finite element model was also developed in order to support the optimization of the control configuration. They showed that with a proposed dither control, wiper squeal noise was effectively suppressed. Chevennement et al. (2007) developed a finite element (FE) model to study dynamic instability of a flexible wiper system. The FE model was validated by experimental tests with different value of arm forces and attack angles of a rubber blade. They found that the predicted instabilities were close to those obtained in the experiments.

This paper attempts to investigate experimentally noise and vibration characteristics of a passenger car's wiper system. First, natural frequencies of a wiper system at free-free boundary condition are determined using modal testing. Then, noise and vibration characteristics are observed during wiper operation at the dry and wet conditions with different wiping speeds.

MODAL TESTING

The experimental study of structural vibration has made significant contributions for better understanding in vibration phenomenon and for providing countermeasures in controlling such phenomenon in practice. Typically, experimental observations are always to reach two-fold objectives (Ewins, 1984):

- Determining the nature and vibration response levels
- Verifying theoretical models and predictions

The first measurement objective is referred to as a test where vibration forces or responses are measured during structure normal service environmental operation while the second is a test where the structure or component is vibrated with a known excitation. The second test is much more closely carried out under control conditions and this type of test is nowadays known as modal testing or experimental modal analysis (EMA). In this paper, modal analysis is performed at free-free boundary condition for the blade and the primary yoke whilst at fixed boundary condition for the windscreen. The hammer test method is used to determine natural frequencies of those components. In doing so, a Kistler Type 9722A500 impact hammer is used to produce the excitation force while a Kistler Type 8636C50 uni-axial accelerometer is fix-mounted onto the tested components. Figure 4 shows overall set-up of the experimental modal analysis.

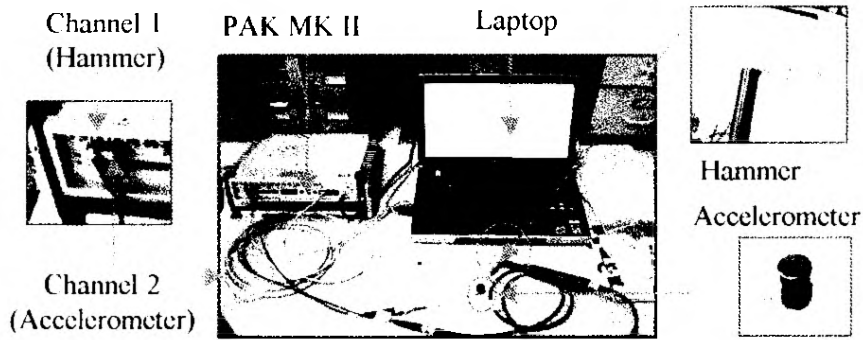


FIGURE 4 Experimental setup for modal testing

From the modal testing it is found that the blade, the primary yoke and the windscreen has six, three and five distinct natural frequencies, respectively within 1 kHz range as given in Table 1. It is seen that those three components have quite similar natural frequencies especially for the blade and the windscreen. In disc brake squeal studies, Kinkaid et al. (2003) commented that one of possible mechanisms for squeal to generate was due to mode coupling, which two different modes occur at the same frequency. Thus, it is interesting to see whether squeal noise is generated during the wiper operation in this work.

TABLE 1 Natural frequencies of the wiper system

| Component | Mode 1(Hz) | Mode 2(Hz) | Mode 3(Hz) | Mode 4(Hz) | Mode 5(Hz) | Mode 6(Hz) |
|--------------|------------|------------|------------|------------|------------|------------|
| Rubber blade | 44 | 130 | 242 | 388 | 648 | 775 |
| Primary yoke | 40 | 148 | 734 | - | - | - |
| Windscreen | 100 | 242 | 384 | 643 | 767 | - |

EXPERIMENT ON WIPER NOISE AND VIBRATION

The measurement set-up is shown in Figure 5, where two uni-axial accelerometers are attached to the primary yoke. The wiper used in the

experiments is of the uniblade type that typically found in the PROTON cars. Noise and vibration measurements of the wiper are carried out at two environmental conditions: wet and dry, and are measured at three different speeds of 1.8, 2.5 and 2.8 rad/s.

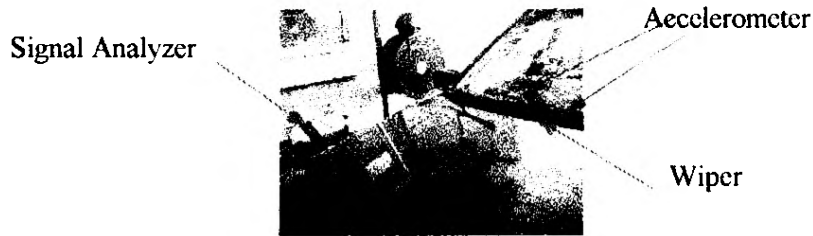


FIGURE 5 Setup for noise and vibration measurement

For a rotational speed of 1.8 rad/s and at wet condition, acceleration response is shown in Figure 6(a). It is seen from the figure that high vibration amplitude is occurred rightly at the beginning and end of the wiper stroke (see overall figure). In the middle of the stroke, the vibration amplitude is lower than that at the start and end of the stroke (see close-up). The vibration amplitude is higher at the beginning and end of wiper stroke may due to two reasons: stick-slip and/or negative velocity-friction characteristic mechanisms (Grenouillat and Lcblanc 2002). There is no idle time after one complete stroke for rotational speeds of 2.5 and 2.8 rad/s compared to 4s idle time for rotational speed of 1.8 rad/s. This vibration characteristic is seen similar for another two rotational speeds as shown in Figures 6(b) and 6(c). It seems to suggest that the results are concurred with the findings of Goto et al. (2001) where they stated that noise could easily be generated before and after wiper stroke as shown in Figure 7.

When the wiper is operated at dry condition, the vibration characteristics as shown in Figure 8(a) ~ 8(c) are almost identical to those found during wet condition except in the middle of wiper stroke. It is found that in this particular area, the vibration amplitude is quite small compared to that during the wet condition. This suggests that water film that sticks on the windscreen during wet condition can potentially disturb rubber blade motion by separating rubber blade and windscreen interfaces and hence produces a vibration. This needs to be examined in details and further investigations are required.

From acceleration responses in Figures 6 and 8 it is found in speed 1 that noise is dominated at frequency of 68 Hz and 36 Hz for the wet and dry conditions, respectively as shown in Figure 9(a). This shows that noise frequencies are higher in the wet condition compared to those in the dry condition. For speed 2, i.e., 2.5 rad/s as depicted in Figure 9(b) noise is generated at dominant frequency of 70 Hz for the wet condition and 36 Hz for the dry condition. This has similar trend with previous speed. Finally for the third speed, 2.8 rad/s the dominant frequency is found at 36 Hz for the wet condition and 32 Hz for the dry condition as shown in Figure 9(c). It seems that for higher rotational speed the noise frequency of the wiper is almost identical. From those measured frequencies, it can be concluded that current wiper system is

experiencing chatter noise based on the definition given in previous section. It is also suggested that those identical natural frequencies measured for individual components, which lead to mode-coupling mechanism, are not guaranteed for squeal noise generation since there is no squeal noise generated in current wiper system. It is also observed that the windscreen is experiencing streaking visual deterioration effect

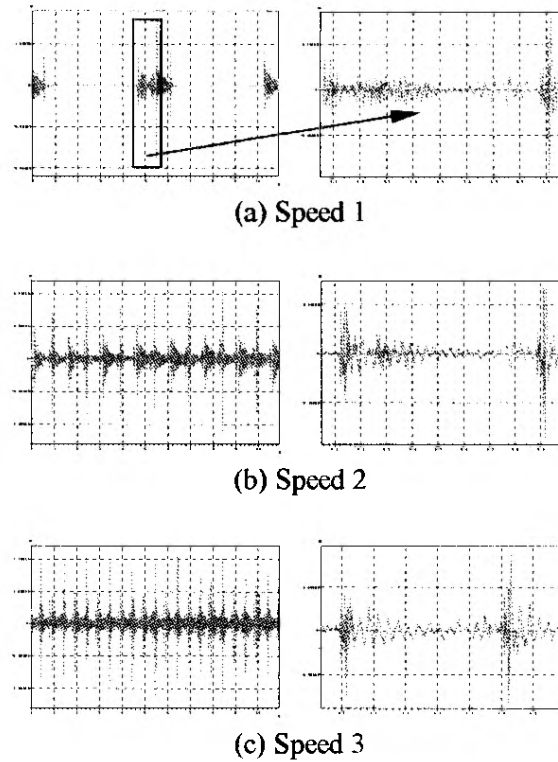


FIGURE 6 Acceleration responses during wet condition

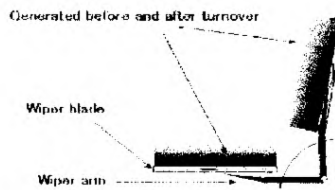
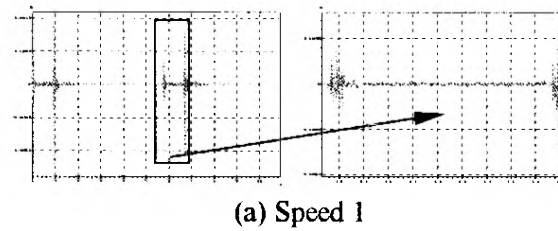
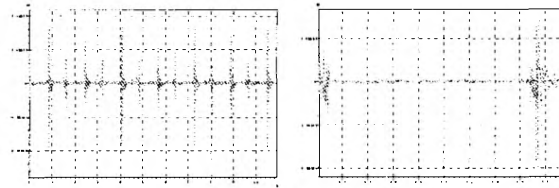
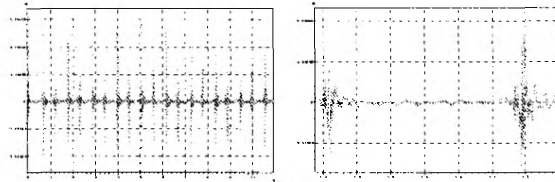


FIGURE 7 Locations of noise generation (Goto et al. 2001)



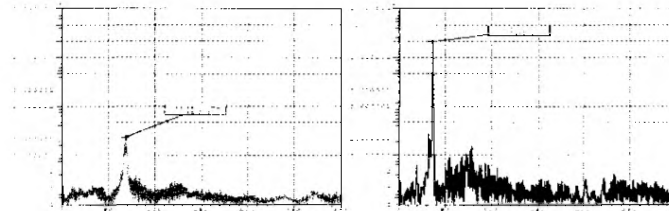


(b) Speed 2

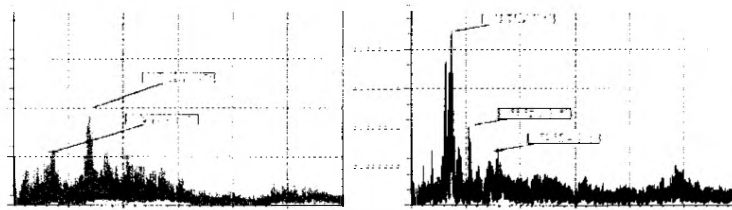


(c) Speed 3

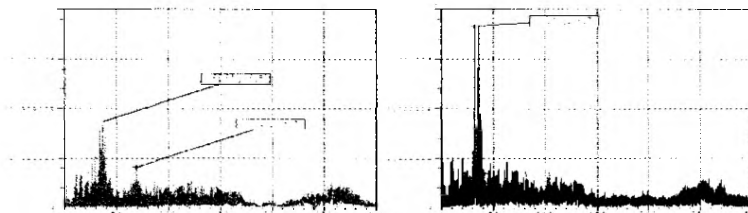
FIGURE 8 Acceleration responses during dry condition



(a) Speed 1



(b) Speed 2



(c) Speed 3

FIGURE 9 Noise frequencies measured from the rubber blade (wet: red colour and dry: black colour)

CONCLUSIONS

The wiper produces a low frequency vibration and noise called chatter, with a frequency below 100Hz, depending on environmental conditions and operating speeds. It is found that, regardless of wet or dry conditions and different wiper speeds, the chattering noise is generated before and after the wiper turnover. However, it seems that the wiper has steady motion in the middle of rotating stroke for the dry condition compared to the wet condition, which non-uniform water films on the windscreen may disturb contact between the rubber blade and the windscreen interfaces that lead to vibration. There is no single squeal noise appears in current investigation and it suggests that closest natural frequencies between wiper components do not guarantee for squeal generation. It is also observed that the windscreen is experiencing streaking visual deterioration effect.

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