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Reduced ride comfort caused by beating idle vibrations in passenger vehicles

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ABSTRACT

Idle vibrations that occur in passenger vehicles at a stop cause passengers to feel discomfort, thus leading to reduced ride comfort. Beating vibration takes place when the frequency of engine vibrations is similar to the frequency of vibrations due to auxiliary parts in the engine room, and this produces a rapid deterioration in ride comfort. This study analyzed beating idle vibrations in an actual vehicle, and performed experiments to assess changes in ride comfort in relation to the amplitude ratio of two vibrations having similar frequencies and their beating frequency. At most frequencies, ride comfort was poorer when the beating vibrations had higher amplitude ratios. A higher level of discomfort was found when the beating frequency fell in a range of 1–4 Hz. Beating vibrations with an amplitude ratio of 0.8 and a beating frequency of 1.0 and 2.0 Hz caused greater discomfort by 3.8 dB compared to single-frequency sinusoidal vibrations.

1. Introduction

The engine RPM of a vehicle at a stop must be set to optimize vehicle vibration and fuel efficiency while ensuring stable operation of the engine. Idle vibrations refer to engine vibrations occurring when the vehicle comes to a stop, such as when waiting for a signal change. The frequency of idle vibrations is determined by the engine type and engine RPM when idling. For general passenger vehicles, the frequency of idle vibrations falls in a range of 20–40 Hz. (Iyer et al., 2011).

The cooling fan of the radiator is triggered when the heated engine exceeds a certain temperature, and vibrations result from an imbalance of blades as the fan rotates. In general, the number of rotations of the cooling fan is determined in consideration of blade size and shape, which are designed to meet the requirements for engine cooling performance. Blade Pulsation Frequency (BPF), the main source of vibrations of the cooling fan, is determined by the number of fan rotations and the number of blades. The vibration frequency of the cooling fan is often inevitably designed to have a similar range as that of idle vibrations due to the engine. The two vibration types, with a slight difference in frequency, cause a regular variation in amplitude known as beating. (Rao and Yap, 1995).

The frequency range of vibrations associated with ride comfort in a seat with a seat back is between 0.8 Hz and 10 Hz. (Griffin, 1990; ISO, 1997). ISO 2631-1 assigns a high weighting(W_k) to a range of 4–10 Hz for top-bottom vibrations of the seat surface that comes into contact with the buttocks, and a high frequency weighting (W_d) to a range of 0.8–1.6 Hz for front-back and left-right vibrations. For the seat back that comes into contact with the back, a high weighting (W_d) is assigned to a range of 0.8–1.6 Hz for left-right and top-bottom vibrations, while a high weighting (W_c) is assigned to a range of 1–5 Hz for front-back vibrations. These frequency weightings should be applied with flexibility depending on the seat shape, seat material, and properties of the input vibrations. Basri and Griffin (2014) examined the relationship between SEAT(Seat Effective Amplitude Transmissibility) value and discomfort when seated subjects were exposed to white noise vibrations in a range of 0–50 Hz. This study, performed on various seat types, revealed slight differences in SEAT value by frequency, but the highest SEAT value was observed for most sheets at 2.5–6 Hz. Thuong and Griffin (2011) studied the discomfort experienced by subjects when exposed to vibratory forces of 0.5–16 Hz in various directions, and showed that both seated and standing subjects felt discomfort in similar frequency ranges. For vibratory forces in the longitudinal direction, the

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discomfort was proportionate to velocity in a frequency range of 0.5–3.15 Hz, and to acceleration in a range of 3.15–16 Hz. Langer et al. (2015) experimentally analyzed the occupational whole-body vibration of an agricultural tractor and found that the condition of driving downhill with 4WD influences the longitudinal dynamics and intensifies the whole body vibration exposure on the tractor. Sekulić et al. (2016) found that the middle part of an intercity bus is more comfortable than its front or rear part in terms of vibration exposure.

In the present study, the authors hypothesize that the level of discomfort caused by idle vibrations increases rapidly when the frequency of beating vibrations coincides with the frequency that the human body is sensitive to. Here, beating vibrations are vibrations that occur when idle vibration of the engine overlaps with vibrations of the cooling fan or other auxiliary parts. The purpose of this study is to conduct a quantitative evaluation of how changes in frequency and amplitude of beating vibrations affect ride comfort in a passenger vehicle. Beating idle vibrations were measured from an actual vehicle, and these measurements were used to generate various beating vibration signals. The beating vibration signals were entered into an exciter having the same seat as that of the vehicle used in measurements, and nine seated subjects were asked to provide a subjective evaluation.

2. Beating idle vibrations

2.1. Idle vibrations from an actual vehicle

This study measured and analyzed beating idle vibrations occurring in an actual passenger vehicle to ensure the effectiveness of the evaluation. Fig. 1 shows measurements of idle vibrations from the driver's seat track of a mid-sized sedan (Mileage: 200 km, Engine size: 2,000 cc) available in Korea and overseas. Comparisons are made between the idle vibrations before and after operating the cooling fan. The gear was in drive, and the vehicle was stopped for a certain period of time to heat up the engine, which then triggered the cooling fan. From the time-frequency map of Fig. 1 (a), we can see that the cooling fan operates at about 13.5 s, and vibrations (23.1 Hz) caused by fan imbalance are added to idle vibrations (21.7 Hz) of the engine. Beating is also observed in Fig. 1(b) and (c), which show the spectrum of acceleration and time signals before and after operation of the cooling fan. In Fig. 1(b), when the cooling fan was not in operation, a vibration of 98.6 dB was measured at a single frequency. When the cooling fan was in operation, vibrations of 99.5 dB and 97.1 dB were measured at two frequencies. Fig. 1(c), which shows time signals of vibrations measured from the test vehicle, gives an RMS of 101.2 dB when the cooling fan is not in operation and 103.0 dB when the cooling fan is in operation.

Vibrations measured before and after operation of the cooling fan differ by 1.8 dB, falling below the human-perceivable level of 3 dB. However, some experts and general drivers participating in a pilot test prior to this study apparently experienced beating vibrations after the cooling fan was triggered, and reported a significant reduction in ride comfort. These findings highlighted the need for research on reduced ride comfort in relation to beating idle vibrations arising from operation of the cooling fan.

2.2. Generation of beating vibration signals

This study generated beating signals to evaluate the extent to which ride comfort is reduced in relation to properties of beating vibrations. A beating signal is created when two sinusoidal signals having similar frequencies occur simultaneously, as shown in Eq. (1)

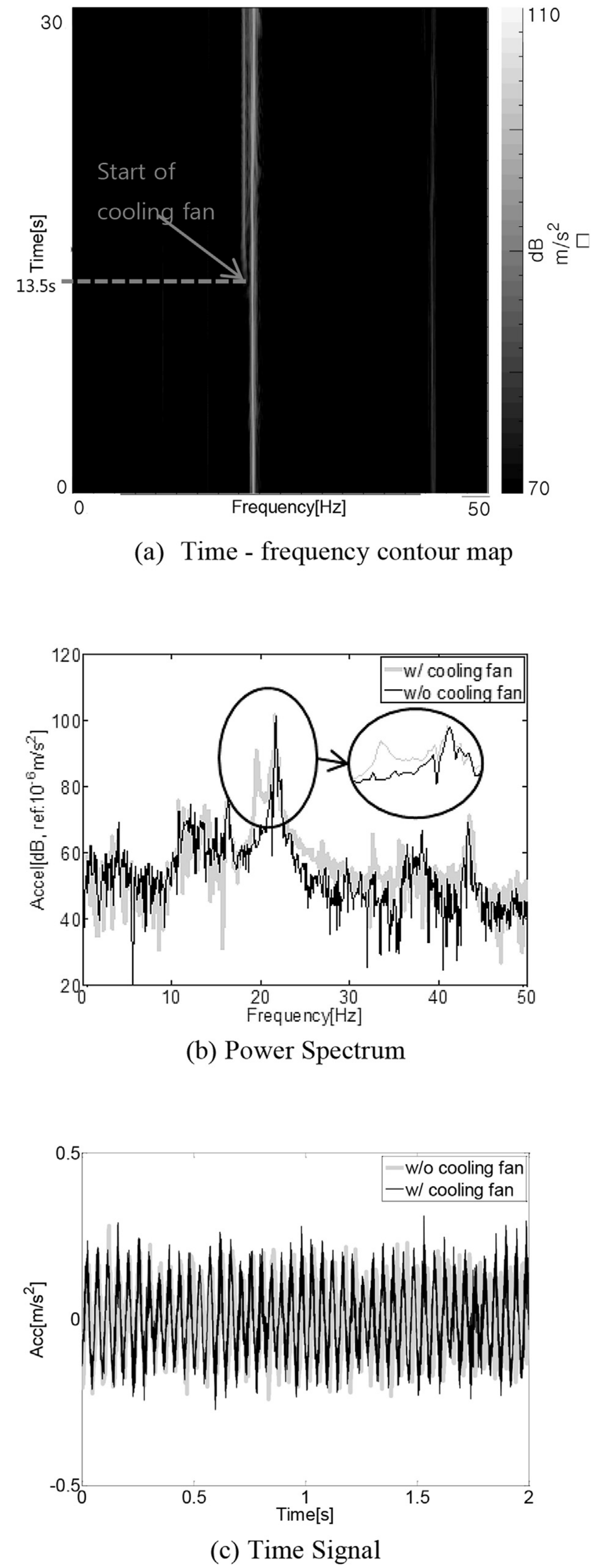

Fig. 1. Comparison of idle vibration measured on seat track of a passenger car with and without beating by cooling fan.