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Reduction of vibration forces transmitted from a radiator cooling fan to a vehicle body

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ABSTRACT

This article presents methods for reducing transmitted vibration forces caused by mass unbalance of the radiator cooling fan during vehicle idling. To identify the effects of mass unbalance upon the vibration characteristics, vibration signals of the fan blades were experimentally measured both with and without an added mass. For analyzing the vibration forces transmitted to the vehicle body, a dynamic simulation model was established that reflected the vibration characteristics of the actual system. This process included a method described herein for calculating the equivalent stiffness and the equivalent damping of the shroud stators and rubber mountings. The dynamic simulation model was verified by comparing its results with experimental results of the radiator cooling fan. The dynamic simulation model was used to analyze the transmitted vibration forces at the rubber mountings. Also, a measure was established to evaluate the effects of varying the design parameters upon the transmitted vibration forces. We present design guidelines based on these analyses to reduce the transmitted vibration forces of the radiator cooling fan.

1. Introduction

A radiator cooling fan is a part of the engine cooling system, which is installed in the front end module of the vehicle. The cooling fan serves to cool the hot coolant that has passed through the engine. During the cooling process, noise and vibration occur due to mass unbalance of the rotating part of the cooling fan, the rotating electromagnetic force of the motor, the air pressure change induced by the fan, and so on. Various methods for reducing noise and vibration have been continuously studied to improve vehicle ride comfort.

Among previous studies on the noise and vibration associated with radiator cooling fans, most have mainly focused on noise rather than vibration. The studies on the noise have been conducted in a variety of ways, including design and theoretical methods, for the various components that make up a radiator cooling fan. Reports have been published regarding

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prediction and reduction of fan noise [1–5], noise reduction through fan shape design [6–8], noise reduction through shroud shape design [9,10], noise reduction through motor shape design [11,12], and noise reduction by means of novel assembly methods and rotational speed control [13,14].

Although there have been many reports on the noise of radiator cooling fans, fewer studies have been published regarding the vibration of cooling fans relative to noise studies. Some notable papers related to the vibration of radiator cooling fans are summarized as follows. Morgan [15] studied various unbalances that cause vibration of a radiator cooling fan during operation and investigated the relative contributions of the unbalances that affect the vibration. Using the Taguchi method, he found that fan static imbalance was more prominent than fan couple unbalance and motor unbalance as a cause of vertical vibration. Zhou et al. [16] studied the steering wheel beating vibration that was caused by mass imbalance in a dual-fan cooling system. They investigated the mechanism of this beating vibration by using the theoretical model of a mass–-spring–damper system with a single degree of freedom, and analyzed the effects of varying frequency and vibration amplitude upon the beating vibration. They also proposed a method for evaluating the vibration level of the steering wheel and an excitation frequency control method to reduce this vibration. Park et al. [17] studied the effects upon ride comfort of beating vibration between the engine and the cooling fan. They examined how beating idle vibrations led to reduced ride comfort in passenger vehicles, finding that the beating vibrations induced greater discomfort than single-frequency vibrations. In addition, in their analysis results the level of discomfort varied with beating frequency and amplitude ratio. Kumar and Talwar [18] analyzed the effect of fan imbalance amplitude upon steering wheel vibration amplitude. They claimed that reducing the cooling fan imbalance was an effective way to reduce fan vibration, which helps to reduce steering wheel vibration. Wei and Ghoreishi [19] analyzed the cooling fan noise and vibration that arose from a switching power supply, finding that the front-to-back vibration of the fan shroud was caused by the torque change generated by the switching power supply and that a modified shroud design could reduce this vibration.

Vibration problems in automotive parts, which in the past were unrecognized or considered unimportant, have recently attracted the attention of automobile manufacturers. One such problem is the transmission of radiator cooling fan vibration to the passenger compartment. Particularly, because the radiator fan blades rotate very quickly during engine idling, the centrifugal force arising from any mass unbalance will greatly increase the radiator vibration. This vibration is often the main cause of decreased ride comfort. In addition, long-term use of the radiator cooling fan further increases its mass unbalance due to manufacturing error, uneven accumulation of dust on the blades, or cracks that form in the blades. The increased vibration arising from such unbalance is transmitted to the passenger compartment, and can thus worsen the ride comfort considerably. For this reason, reduction of the vibration caused by mass unbalance of fan blades is becoming an important task that must be solved for improving ride quality.

Until now, there has been no systematic study on how to prevent vibration of a radiator cooling fan with mass unbalance from being transmitted to the vehicle body. In previous studies related to cooling fan vibration, mass unbalance was identified as a main cause of vibration. To resolve the vibration problem, researchers have tried to reduce the mass unbalance or to avoid beating vibration. However, mass unbalance of a cooling fan is inevitable, arising from practical problems such as manufacturing error and dust accumulation. Given that this mass unbalance is inevitable, it is necessary to propose a theoretical background and practical methods for designing the cooling fan module so as to reduce the vibration transmitted from the cooling fan to the vehicle body as much as possible.

The aim of this paper is to present design guidelines for the cooling fan module, including the fan blades, motor, shroud, radiator, and rubber mountings, to reduce the transmitted force of vibrations arising from mass unbalance of the cooling fan and motor. For this purpose, we performed simulation analysis based upon a theoretical model that has not been previously presented. Performing these simulations allowed us to avoid the difficulty of making several experimental cooling fan modules and to overcome the disadvantage that sufficient experimental results are difficult to obtain using only one experimental fan module. For a simulation model to be able to successfully demonstrate the actual vibration characteristics, the physical properties of the components making up the model should be well evaluated. Accordingly, the equivalent stiffness and damping coefficients of the cooling fan components were extracted by means of modal testing and included them in the simulation model.

The rest of this paper is organized as follows. Section 2 describes the experimental measurement of vibration signals during operation of a radiator cooling fan having mass unbalance, and describes the modal testing of dynamic characteristics such as natural frequencies and mode shapes of the cooling fan module. Section 3 establishes the simulation model that is used to represent the vibration characteristics of an actual radiator cooling fan. As part of developing this model, we propose a method to obtain equivalent stiffness and equivalent damping coefficients of rubber mountings and shroud stators, and verify the validity of the simulation model by comparing simulation results with experimental results. Section 4 describes the use of the developed simulation model to analyze the vibration forces generated during vehicle idling by a cooling fan having a mass unbalance, and describes a study of the effects of varying design parameters, namely the stiffness of the rubber mountings, the stiffness of the shroud stators, the fan blade mass, and the mass of the radiator, upon the transmitted vibration forces. In Section 4 we also propose design guidelines, based on these analyses, to reduce as much as possible the vibration forces transmitted from the radiator cooling fan module to the vehicle interior. Finally, Section 5 summarizes the analysis results and presents our conclusions.