DEVELOPMENT OF BLDC MOTOR AND MULTI-BLADE FAN FOR HEV BATTERY COOLING SYSTEM

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ABSTRACT—Hybrid Electric Vehicles (HEVs) have become one of the solutions to the environmental and fuel-consumption issues in current cars. However HEVs are quite complicated due to their combined power trains which may use both internal combustion engines and electric drive motors. HEVs' thermal management system is very important for good energy use. Thermal management of HEV batteries, such as Ni-MH or Li-Ion, is especially essential for effective operation under load-drive conditions. Reliable battery operation thermal design is even more important. A variety of battery thermal control modules are currently on the market. In this paper, air cooling types for battery thermal management system have been chosen because of their simplicity, cost effectiveness, and easy applications. The performance of the blower unit as major part of the battery cooling system is studied by experiment and on a numerical basis. A prototype BLDC (brushless DC) motor is made, performance is examined and analyzed, and multi-blade fans are optimized using numerical analysis. The overall efficiency of a prototyp BLDC motor is 72%. Also, the effects of the leading edge angle, trailing edge angle, chord length and chord angle on the performance of the multi-blade fan were investigated numerically for the optimal design by using the FLUENT. Finally, the battery cooling system, characteristics of the torque, static pressure, and airflow volume at each specific rotational speed of the fan are examined and analyzed at blowing system.

KEY WORDS : Hybrid electric vehicle, Battery cooling system, BLDC motor, Blower unit, Performance, Efficiency, Multi-blade fan

NOMENCLATURE

\[ D \quad : \quad \text{fan diameter (mm)} \]
\[ i, j, k \quad : \quad \text{tensor} \]
\[ I_m \quad : \quad \text{motor input current (A)} \]
\[ N \quad : \quad \text{rotational speed (rpm)} \]
\[ P \quad : \quad \text{pressure (mmAq)} \]
\[ P_m \quad : \quad \text{motor power (W)} \]
\[ R \quad : \quad \text{resistance (Ω)} \]
\[ T_m \quad : \quad \text{motor torque (N-m)} \]
\[ V_m \quad : \quad \text{motor input voltage (V)} \]
\[ \eta \quad : \quad \text{efficiency (\%)} \]
\[ \rho \quad : \quad \text{density (kg/m³)} \]
\[ \mu_t \quad : \quad \text{eddy viscosity coefficient (kg/m·s)} \]
\[ \Gamma \quad : \quad \text{diffusion coefficient} \]
\[ \omega \quad : \quad \text{angular velocity (rad/sec)} \]

1. INTRODUCTION

The global warming and emission issues are of great concern and the depletion of fossil fuels is significantly global concern. Also, emission regulations are becoming more stringent, and it is quite difficult for car makers to reduce pollution and carbon dioxide emissions.

In recent years, the automobile industry has electrified cars. The revolution of electrified cars will be dramatically fascinating to consumers. From this change, enormous opportunities will come for automobile makers and components suppliers, like battery makers and electricities supplies. The economic, regulatory, and technological advantages of hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), electric vehicles (EVs), and fuel-cell electric vehicles (FCEVs) mean that slow growth in their adoption and usage will be seen in the automobile industry, and there is hope that this will be one of the solutions to issues of carbon dioxide emission (Ao et al., 2007).

HEVs use an electric motor as its power train in addition to a combustion engine to reach high efficiency and low emissions. Power train is complicatedly linked electrically and mechanically with a lot of electric components including the motor, power control unit, high voltage and low voltage inverters, and battery. However, the already launched Prius from Toyota is a HEV with dual power train, with an internal combustion engine and an electric motor. Therefore, HEVs seem to be competitive future alternative vehicles in the same realm as other electrified vehicles due to their high fuel economy and the requirement for less development investment in technology.
The battery will be the key technology in future HEVs in addition to PHEVs, EVs, and FCEVs. The nickel-metal hydride (Ni-MH) battery is currently dominant in the HEV market because of its first launch in the Prius with an air-cooling type of battery thermal management system. Moreover, lithium-ion and lithium-porimer batteries with their high energy density are under development in the chemistry industry. This study does not consider the benefits of battery technologies because the lithium-ion battery is currently in progress as a chemical or battery maker, but Ni-MH soon will be replaced by the lithium-ion or lithium-porimer battery (Murray, 2007).

Hybrid electric vehicles make great demands on electrical storage systems with respect to specific energy, power, life, safety, and cost. The electrical, thermal, and mechanical designs of a battery system have to fulfill a variety of requirements. The electrical design of a battery system has to consider the power and energy demands in different driving scenarios. A proper thermal design, which is dependent on the batteries charge’s acceptance and capacity, is even more important for power capability, availability, and the life of the battery. If batteries exceed their capabilities, then excessive heating will occur (Chang and Yoo, 2008).

The battery’s thermal management is very important for meeting the long lifecycle, steady electricity output, and performance requirements of the battery. In the recent years, automakers and battery suppliers have increased their monetary investments in the development of a good battery thermal management system (Blake et al., 2007). Vlahinos et al. (2005) analyzed the Ni-MH battery module’s and cells’ thermal behaviors under various operating conditions in the Toyota Prius HEV using 6-Sigma.

Kim and Pesaran (2006) analyzed the thermal behaviors of batteries with different types cooling systems, like air cooling, direct contact liquid cooling with oil, and the indirect water-glycol jacket cooling system. The high performance and thermal balance of the battery is dependent on the batteries’ module and cells with the highest temperature. Some systems with cooling designs may adapt a water-glycol cooled type using engine coolant. Some cases such as the air-cooled type may use cabin air to reduce the battery temperature.

The drawback of the air-cooled type of thermal management system is its minimal heat removal capacity due to the lower heat transfer coefficient of air. Therefore, the increase of the cooling performance is limited by blower power and fan size. However, the air-cooled type has advantages, such as structurale simplicity, lighter weight, no air leakage, and low costs, the air-cooled type is widely used in current HEVs’ battery cooling systems and specific fan design for battery cooling systems is demanded to overcome the inside battery pack air resistance and to remove the heat. Multi-blade fans have been used in many industries, because of their quiet noise, compact size, and increased airflow volume compared to other types of fans. For decades, there has been a lot of research for conducted on multi-blade fans. Moreover, in the last year, numerical analysis methodology has been widely used for the development of the airflow characteristic and performance on the multi-blade fan (Fischer, 1995).

Lee and Yoo (2004) investigated numerically and experimentally the multi-blade fan, the effects of the scroll cut-off starting angle, and the expansion angle of volute in the automotive blower systems.

Toksoy et al. (1995) carried out experiments on pressure versus airflow volume and air rush noises at various fan design parameters, blade starting angles, leading edge angles, trailing edge angles, and lengths of the blade. Also, a numerically analyzed multi-blade fan, as decoupled, explicit coupled, implicit coupled, and 3-dimensional has been considered in relation to the effect on the number of meshes, and mesh skew has been considered in relation to the performance achieved by using Star-CD.

In this study, the air-cooled type of battery thermal management system of HEVs with brushless-DC (BLDC) motors and multi-blade fans are investigated experimentally and numerically.

For successful design of the air-cooled type of battery cooling system, the prototype BLDC motor has been developed and the multi-blade fan was analyzed numerically. Finally, methodology set up the forecast of the fan performance such as airflow volume, rotational speed and operating torque at optimal point for battery thermal management is achieved by using coupled experiment and analysis results.

2. EXPERIMENTAL APPARATUS FOR BLDC MOTOR

2.1. BLDC Motor for Battery Cooling Blower Unit

The thermal management of the battery is one of the most significant factors impacting both the battery performance and life. The battery usage temperature in HEV is higher than in normal cars due to the frequent battery charge and discharge in the driving condition. The large thermal gradients caused by the enclosed battery pack design have the potential problems of reduction of vehicles’ life. These issues cannot be addressed by the chemical company alone.

The BLDC motor for air-cooled battery cooling system requires compact size, simple structure, and quiet operating noise. To reduce electric operating noise, various design parameters such as the number of slots and pole of motor and off-set value, which is radius between the magnetic inner and outer centers are considered (Hanselman, 2004).

In this study, prototype BLDC motor specifications are listed in Figure 1. The outer rotor type was chosen for its compact design, 6-pole magnet, and 18-slot stator.