

Thermal Management System for Electric Vehicles

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ABSTRACT

The thermal management system for electric vehicles is developed. Called the Thermal Link System, it consists of a heat-pump air conditioner, a system recovering waste heat from the electric power train, and a heat exchanger between the air-conditioner refrigerant and the power-train coolant water. The recovered heat is used for interior heating, so the amount of power consumed by the heat-pump air conditioner can be reduced. In this system the refrigerant for the heat-pump air conditioner and the coolant water for electric power trains are thermally linked by the heat exchanger, which can reduce the temperature of the coolant water to less than that of the surrounding air. This enhanced cooling function increases the power of electric power trains, or extends the amount of time at full power operation. Here we describe the Thermal Link System's mechanism and effects on energy efficiency.

INTRODUCTION

Electric vehicles are expected to be one of the advanced vehicles that can reduce CO₂ significantly. Although recent improvements of battery performance have greatly extended the distance an electric vehicle (EV) can be driven, EV performance must be further improved because vehicles with internal-combustion engines still have advantages in terms of driving distance and manufacturing cost. The number of on-board batteries is obviously limited, and the energy efficiency of components and the whole EV system is as important as the battery performance.

EV energy losses are broken down in [Figure 1](#), which is calculated by the authors' original vehicle simulator assumed

compact cars traveling. In this energy analysis, one sees that about one third of the total losses are due to interior heating because an EV has no strong heat source for interior heating. That is, it has no internal-combustion engine producing hot exhaust gases.

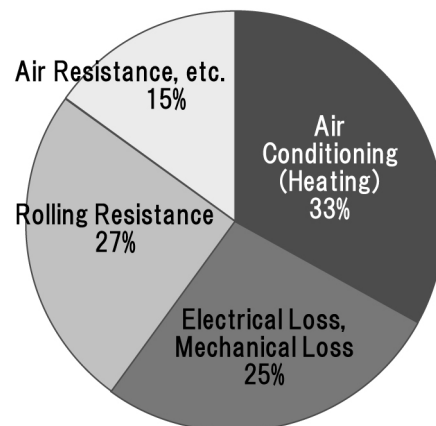


Figure 1. Breakdown of EV energy losses

To improve the energy efficiency of the whole EV system, it is important to manage thermal condition totally [1]. The authors are also developing a thermal management system for electric vehicles to reduce the air-conditioning loss. This Thermal Link System consists of a heat-pump air conditioner, a system recovering waste heat from the electric power train, and a heat exchanger between the air-conditioner refrigerant and the power train coolant water. The recovered heat is used for interior heating, so the amount of power consumed by the heat-pump air conditioner can be reduced. In this system the refrigerant of the heat-pump air conditioner and coolant water for the electric power train are thermally linked by the heat

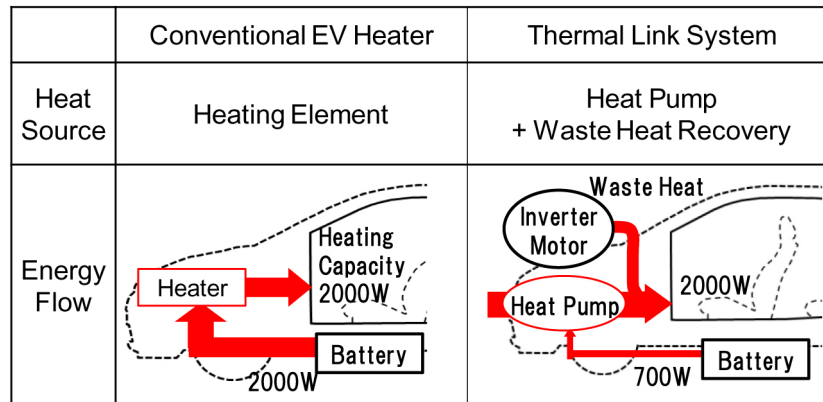


Figure 2. Effect of heat pump and the recovery of waste heat

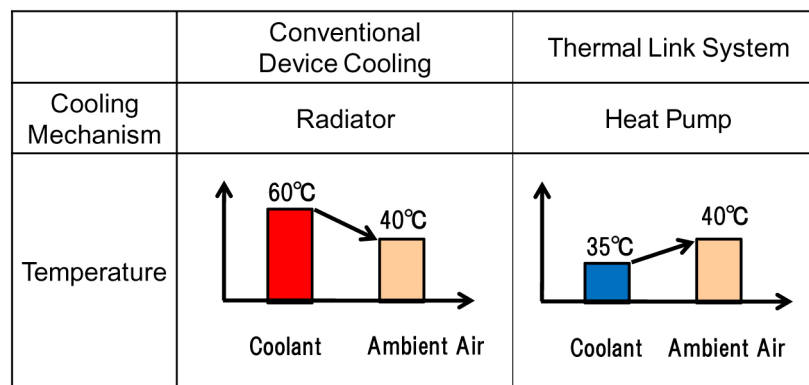


Figure 3. Effect of heat-pump cooling

exchanger, which can reduce the temperature of the coolant water below that of the surrounding air.

First the concept the system and the system's effects on energy efficiency are described. Then the system configuration, the heating mechanism, and the cooling mechanism are illustrated individually. Finally, the results of test-bench experiments measuring energy consumption are reported.

CONCEPT

The thermal Link System integrates a motor-cooling system and a heat-pump air conditioner, and it manages the motor cooling and the air conditioning simultaneously.

In [Figure 2](#) the Thermal Link System is compared with a conventional EV heater (like an electrically heated element). The conventional heater converts the electric energy into thermal energy directly, so it needs an amount of electric power equal to the heating capacity. For instance, 2000 W of electric power is needed for a 2000-W heating capacity when the outside temperature is 0°C.

The Thermal Link System, though, transfers heat from the exterior to the interior with a heat-pump cycle. The heat pump generally needs an amount of electric power that is less than half the heating capacity.

This system also utilizes the waste heat from the motor and an inverter for interior heating. This waste heat alone is not enough for interior heating, so the waste heat is used as a complementary energy source for heat-pump air conditioning.

An EV mass production model in the Japanese market consumes total energy about 2200W in Japanese 10-15 drive cycle [2]. If the total electric efficiency of motor and inverter is assumed to be 83%, about 600W electric loss can be expected. If half of this loss is recovered, 300 W would be available for interior heating. On the basis of these assumptions, we made 700 W the Thermal Link System's target power consumption target for 2000-W heating. This is only about one third of the energy a conventional heater would require for a 2000-W heating capacity.

Another feature of the Thermal Link System is its cooling function for electric devices and the cabin. The heat-pump air

Table 1. Summary of features and benefits of the Thermal Link System

		Conventional System	Thermal Link System
Heating Mode	Heat source	Heating Element	Heat Pump + Waste Heat Recovery
	Power Consumption (power for 2000-W heating capacity at 0° C)	- (2000W)	+ (< 700W)
Cooling Mode	Coolant temperature	> Ambient Air	> 0° C
	Motor power	-	+
	Motor size	-	+

conditioner can cool not only the cabin but also electric devices like motors and inverters.

Figure 3 illustrates an effect of device cooling with the heat pump cycle system. A conventional radiator cooling system dissipates the heat of high-temperature coolant water into the surrounding air. That is, the coolant temperature must be higher than the outside-air temperature. The coolant temperature is generally assumed to be higher than 60°C because the air temperature in hot regions can be higher than 40°C.

In contrast to the radiator system, the heat-pump cooling system can pump from low-temperature coolant into high-temperature outside air and can keep the coolant temperature below the outside-air temperature. When the air temperature is 40°C, this system can in principle chill the coolant down to freezing-point temperature.

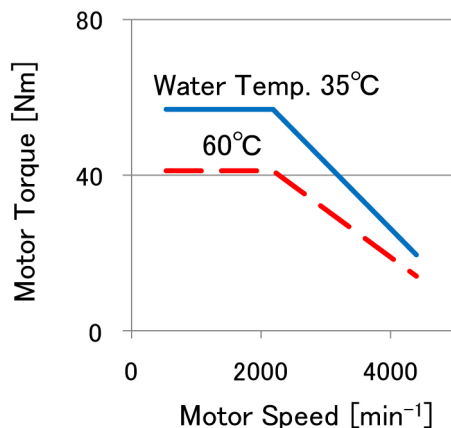


Figure 4. Power-up effect of heat-pump cooling

This powerful cooling capability could contribute to downsizing the motor and inverter. Figure 4 shows the power-up effect of heat-pump cooling by the maximum continuous torque. A thermal simulator is used to determine the maximum continuous torque, when the temperature of motor stators reaches the heatproof temperature. As indicated in Figure 4, if the coolant temperature is being kept at 35°C, the continuous torque rating can be increased by 50% over

what it would be if the coolant were being kept at 60°C. Therefore, the heat-pump cooling function has the potential to get more torque from the motor. In other words, that cooling system can downsize motors to obtain a target maximum torque. The features and benefits of the Thermal Link System are summarized in Table 1.

MECHANISM

Figure 5 shows the configuration of the Thermal Link System. This system consists of a heat-pump cycle system and two water cycles, one for air-conditioning and the other for device cooling. Each water cycle is connected to the heat pump cycle by a heat exchanger. The amounts of heat exchanged by the air-conditioning heat exchanger and the device-cooling heat exchanger can be controlled independently because the two heat exchangers are linked to the heat-pump cycle in parallel.

The heat-pump cycle, shown by solid lines in Figure 5, consists of a compressor, a four-way valve, an exterior heat exchanger, an exterior fan, a device-cooling heat exchanger, and three expansion valves. These parts are placed in the engine compartment. Its operation can be changed between the heating and cooling modes by switching the four-way valve. That is, the heat pump can transfer heat either from the outside air to the water or from the water to the outside air.

The device-cooling water cycle cooling the motor and inverter consists of a water pump, a device-cooling heat exchanger, two switching valves, and an interior heat exchanger. This cycle transfers heat to the heat-pump cycle through the device-cooling heat exchanger and to the cabin through the interior heat exchanger.

The air-conditioning cycle adjusting the cabin temperature consists of a water pump, an air-conditioning heat exchanger, and an interior heat exchanger. This cycle heats the cabin by sending the water heated by the interior heat exchanger to the interior heat exchanger. This cycle also cools the cabin by sending water cooled by the interior heat exchanger to the interior heat exchanger. The interior fan and two interior heat exchangers are in the cabin, and the other components are in the engine compartment.