Reactor for Boost Converter for Electric and Hybrid Electric Vehicles

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The number of electrified vehicles, such as electric and hybrid electric vehicles, has been increasing rapidly due to concerns about the environment, energy savings, and rising oil prices. To promote the use of these vehicles, motorizing systems need to be reduced in size and weight while also ensuring running and acceleration performance comparable to that of gasoline vehicles. We have developed a compact and lightweight reactor, a key component for a boost converter used in the motorizing system. Using a new magnetic material and heat dissipation structure, we have succeeded in the size and weight reduction of the reactor by 10% while maintaining the same performance level as conventional reactors.

Keywords: reactor, boost converter, pressed pure iron powder core, high-heat conductive insulating adhesive

1. Introduction

With the recent growing popularity of electrified vehicles including hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), electric vehicles (EVs), and fuel cell vehicles (FCVs), the motorizing systems used in these vehicles are required to be smaller in size and lighter in weight to further enhance their fuel efficiency. Enhancement of operating voltage in these motorizing systems is also required, to achieve running and acceleration performances equivalent to those of gasoline vehicles. To meet these needs, an increased number of electrified vehicles are equipped with a motorizing system that includes a converter. The converter, which is called a boost converter, boosts the voltage from the battery.

Sumitomo Electric Industries, Ltd. has been involved in the development of reactors,*[1] which are key components of boost converters, with a focus on reducing their size and weight. We have recently succeeded in the development of a compact, lightweight reactor by using a new magnetic material and heat dissipation structure. This paper reports on the characteristics and performance of the new reactor.

2. Construction of the New Reactor

Figure 1 shows the locations of boost converters in the motorizing systems indispensable for HEVs, PHEVs, EVs, FCVs, and other vehicles. As shown in Fig. 2, a boost converter consists of a reactor, power semiconductors, capacitor, and a drive circuit that controls these components. As shown in Photo 1, the reactor comprises magnetic cores around which insulation-coated copper wires are wound spirally. The reactor boosts the voltage by alternately turning the power semiconductors on/off and thus repeating storage/release of magnetic energy in/from the reactor.

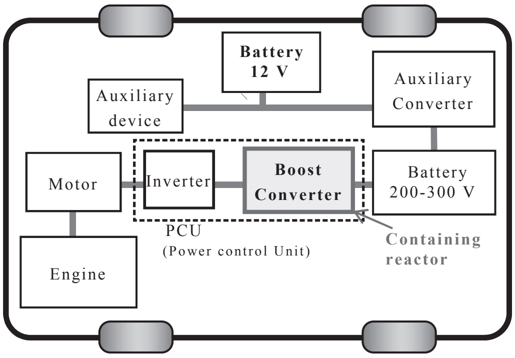

Fig. 1. Location of Converter in HEV system

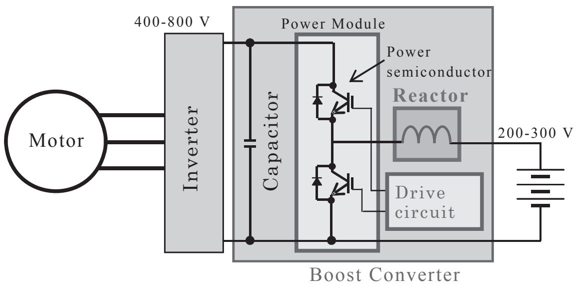

Fig. 2. Circuit Diagram for Boost Converter

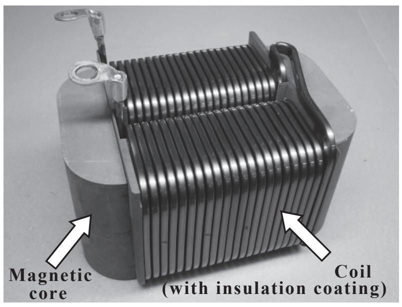

Photo 1. Internal Construction of Reactor

3. Development Concept for Reactor of New Construction

3-1 Development policy for reactor of new construction

We aimed to develop a new reactor that would reduce the size and weight of the boost converter from those of conventional converters. Inductance*[2] and temperature rise due to heat generation are two major parameters representing the performance of a reactor. Inductance, which is the most basic parameter of the reactor, needs to be kept above a certain value until the supply current reaches the maximum value. To reduce the size of a reactor without reducing the inductance, it is necessary to increase the saturation magnetic flux density of the magnetic core used in the reactor.

On the other hand, the rise in reactor temperature is a parameter that depends on heat generation (loss) and heat dissipation performance. The reactor temperature needs to be controlled to below the heatproof temperature of each component. The loss due to heat generation consists of copper loss and iron loss. Copper loss occurs in the coils, while iron loss occurs in the magnetic cores. Both losses tend to increase as the size of the reactor is reduced. To reduce the size of the reactor while maintaining its temperature rise at the same level of conventional reactors, it is indispensable to improve the heat dissipation performance of the reactor.

As discussed above, improving the saturation magnetic flux density of the powder core*[3] and improving the heat dissipation performance of the reactor itself are essential to reducing the size and weight of the reactor.

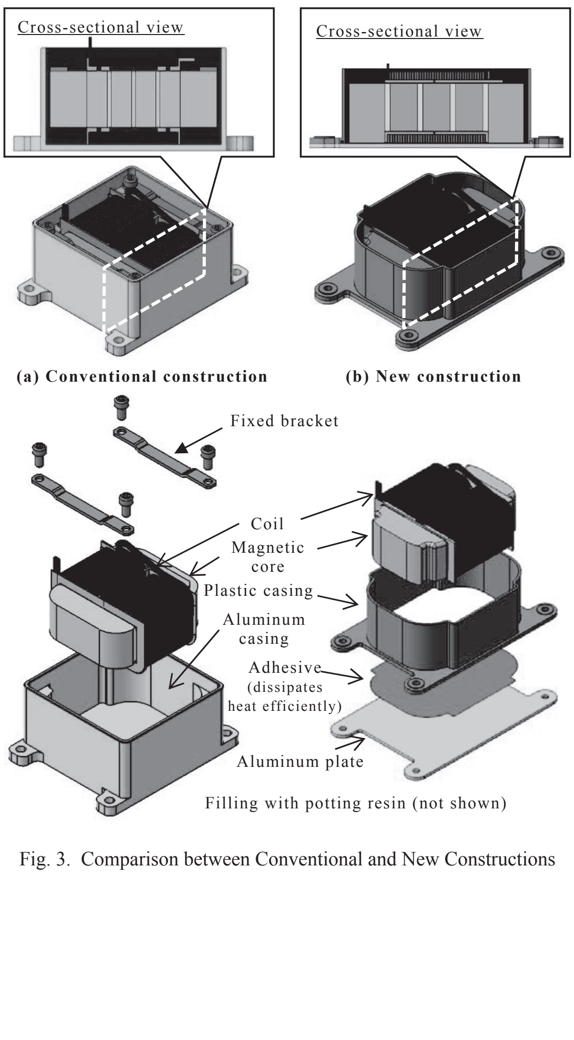

Fig. 3. Comparison between Conventional and New Constructions

3-2 Development policy for reactor of new construction

Figure 3 compares the new and conventional constructions. To develop a reactor of reduced size and weight by introducing a new construction, we established the following concepts:

(1) Reducing the size and weight of reactor using a pure iron powder core (Table 1)

Compared with a conventional electromagnetic steel sheet and alloy powder, a pure iron powder core has a higher saturation magnetic flux density and makes it possible to reduce the size of the reactor. Use of a pure iron powder core contributes to further reducing the size of the reactor since the powder core can be formed three dimensionally and this enables effective use of a dead space in the reactor.

However, a substantial amount of material is wasted when making a pure iron powder core. Reducing the size of the reactor also entails an increase in loss. As a result, the reactor tends to increase the loss as a whole. This loss is prevented by using a high heat-dissipation structure that is described later.

Table 1. Comparison of Magnetic Core Materials

Material	Electromagnetic steel sheet (Fe-6.5wt%Si)	Powder core: Iron-base alloy (Fe-3.0wt%Si)	Powder core: Pure iron (Fe)
Diagram	Steel sheet, Insulation film	Alloy, Insulation coating	Pure Iron, Insulation coating
Loss (Iron loss)	Lowest	Low	Average
Saturated magnetic flux	Average	High	Highest
3-D shape	Not applicable Coil, Magnetic core, Magnetic flux, Magnetic flux, Dead Space	Applicable Coil, Magnetic core, Magnetic flux, Magnetic flux, Possible to reduce the width ⇨Downsizing	

(2) Improving heat dissipation performance by using high-heat conductive insulating adhesive (adhesive)

Releasing heat from the reactor through an adhesive makes it possible to improve the heat dissipation performance of the reactor without sacrificing its insulation quality (Figs. 4 and 5). Thus, it becomes possible to control temperature rise attributable to an increase in reactor loss.

(3) Reducing weight through the use of plastic reactor casing

Replacing part of the aluminum reactor casing with a plastic casing reduces the casing weight from that of a conventional fully aluminum casing.

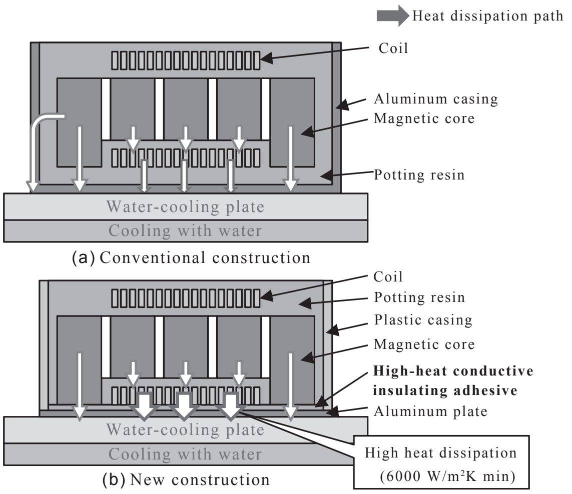

Fig. 4. Comparison of Heat Dissipation Structures

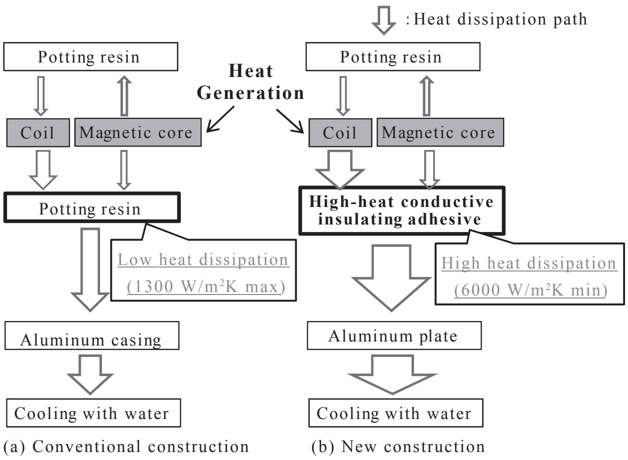

Fig. 5. Comparison of Heat Dissipation Paths

3-3 Trial manufacture and evaluation of reactor of construction

(1) Evaluation of initial characteristics

Using the method described in Section 3-2, we manufactured a reactor of the new construction on an experimental basis and compared its characteristics with those of reactors of conventional construction. The results are shown in Table 2. As this table shows, use of the new construction consisting of a pure iron powder core and adhesive reduced the reactor size by 10% while maintaining the inductance and temperature rise at the same levels as those of conventional reactors, albeit the new reactor increases the loss by 10%. Thus, we confirmed the effectiveness of a pure iron powder core and high-heat conductive insulating adhesive for reducing the size of the reactor.

Table 2. Comparison between New and Conventional Constructions

	Conventional	New
Size	1	0.9
Inductance	1	1
Loss	1	1.1
Temperature rise	1	1

(2) Evaluation of long-term reliability

The newly constructed reactor consists of a pure iron powder core, high-heat conductive insulating adhesive, and plastic casing. We were concerned about deterioration in the characteristics of the pure iron powder core when it is exposed to a high temperature or external vibration, deterioration or separation of the adhesive when it is exposed to a high temperature or heat cycle, and cracking or breakage of the plastic casing at the fixed portion when the casing is exposed to external vibration. However, the above concerns were completely dispelled after a long-term reliability test in which the test specimen met all evaluation criteria.

4. Conclusion

We have developed a reactor of a new construction type, consisting of a pure iron powder core and high-heat conductive insulating adhesive. The size and weight of the new reactor are reduced by 10% while maintaining the same levels of inductance and temperature rise as those of conventional reactors.

Technical Terms

∗1 Reactor: A passive device that uses a winding to alternately store and release energy.

∗2 Inductance: A parameter used to represent the capability of storing magnetic energy in a reactor. The reactor increases the amount of storable energy as the inductance increases.

∗3 Powder core (powder magnetic core): A material that is obtained by pressure-forming soft magnetic powder with an insulation coating.

References

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