Small and Lightweight Reactor for Boost Converter

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The number of motorized vehicles, such as hybrid and electric ones, are increasing rapidly due to environmental concerns, energy saving efforts and the increasing oil price. To promote the use of these vehicles, motors need to be reduced in size and weight, while also ensuring driving and acceleration performance comparable to that of gasoline vehicles. We have developed a small and lightweight reactor[*1], a key component for a boost converter used in a motor. Using a new magnetic material and heat dissipation structure, we have succeeded in a size and weight reduction of the reactor by 10%, while maintaining the same performance level as conventional reactors.

Keywords: reactor, boost converter, powder magnetic core of pure iron, insulated adhesive with high thermal conductivity

1. Introduction

The number of motorized vehicles, such as hybrid electric vehicles (HEVs), plug-in hybrid vehicles (PHEVs), electric vehicles (EVs) and fuel cell vehicles (FCVs), has been increasing rapidly. The size reduction of motorized system is required for higher fuel efficiency. On the other hand, boosting the voltage of system is needed while also ensuring driving and acceleration performance comparable to that of gasoline vehicles. So, there are increasing cases of applying a converter boosting the battery voltage (a boost converter).

We have developed a small and lightweight reactor, a key component for a boost converter used in a motor. Using a new magnetic material and heat dissipation structure, we have succeeded in a size and weight reduction of the reactor, while maintaining the same performance level as conventional reactors. We report the details as follows.

2. Constitution of a Reactor

Figure 1 shows an example layout of a boost converter mounted on a system of a motorized vehicle, such as HEVs, PHEVs, EVs, FCVs, etc. The boost converter consists of a reactor, power semiconductor, capacitor, and drive circuit, as shown in **Fig. 2**. The reactor comprises an insulated coil of copper wire wound on an iron core, as shown in **Photo 1**. The reactor is the core component of the boost converter, and alternately stores and discharges energy as the current flow to the coil is turned ON and OFF by the circuit shown in **Fig. 2**.

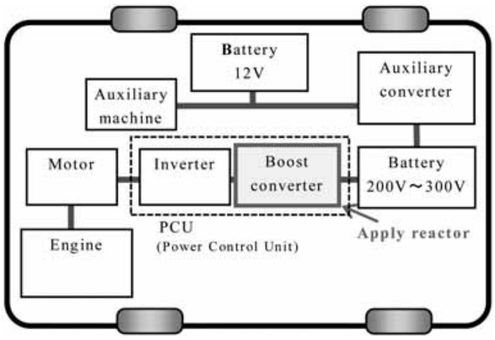


Fig. 1. Example of HEV system

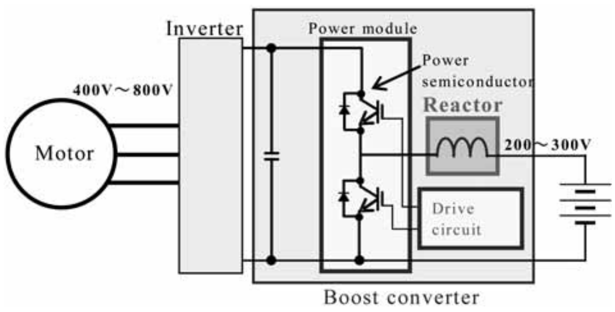


Fig. 2. Circuit schematic of boost converter

Photo 1. Internal structure of reactor

3. Concept of the New Structure Reactor

3-1 Development policy of the new structure

The reactor we have developed targets the boost converter and aims at a size and weight reduction in comparison with a conventional reactor.

The important specification of the reactor is inductance*2 and temperature rise by its self-heating. The inductance is the most basic parameter, and it is necessary for the reactor to keep the inductance higher than the specification value under any current. It is necessary to increase the saturated magnetic flux density of the magnetic core for size reduction of the reactor, while keeping inductance.

The temperature rise is the parameter determined with self-heating and heat dissipation, and it should be kept lower (or equal to) the heat-resistant temperature of each part. Reactor heating is very high as a few hundred amperes pass through the reactor coil. As the reactor needs high heat dissipation, its bottom is cooled by water.

A structure of a conventional reactor is shown in **Fig. 3**. The Magnetic core and coil are fixed to an aluminum case, and cast resin (potting resin) is filled in for the purpose of heat dissipation and internal protection. In this structure, the insulation between the coil and aluminum case depends on the potting resin. The heat dissipation is low because of the thickness of the potting resin to insure insulation.

The magnetic core occupies most of the interior of the reactor, and the size reduction of the magnetic core is directly linked to the size reduction of the reactor. A magnetic core with a highly saturated magnetic flux density enables the size reduction of the reactor while keeping the inductance of the reactor, but this core causes high energy loss and prevents cooling the reactor.

Therefore, higher heating dissipation is needed to decrease the temperature of the reactor.

Thus, a reduction in energy loss of the magnetic core and an increase in heating dissipation of the reactor are necessary to reduce the size of the reactor.

3-2 Outline of the new structure

We have developed a way to reduce the size and weight of the reactor by the following concept.

1. Size and weight reduction of the reactor by a powder magnetic core*3 using pure iron.

A powder magnetic core using pure iron has a slightly higher energy loss but higher saturated magnetic flux density than those of conventional magnetic cores, such as an electromagnetic steel sheet and powder magnetic core using an iron-based alloy.

2. Increase in the heat dissipation by an insulated adhesive with high heat conductivity.

Radiating the heat in the reactor through an adhesive improves the heat dissipation, while securing insulation characteristics, and decreases the temperature of the reactor. In this way, the temperature rise of the reactor can be controlled by the rate of the energy loss increase of the magnetic core.

3. Weight reduction by using a resin case.

Replacing part of the aluminum case with resin results in a lightweight reactor.

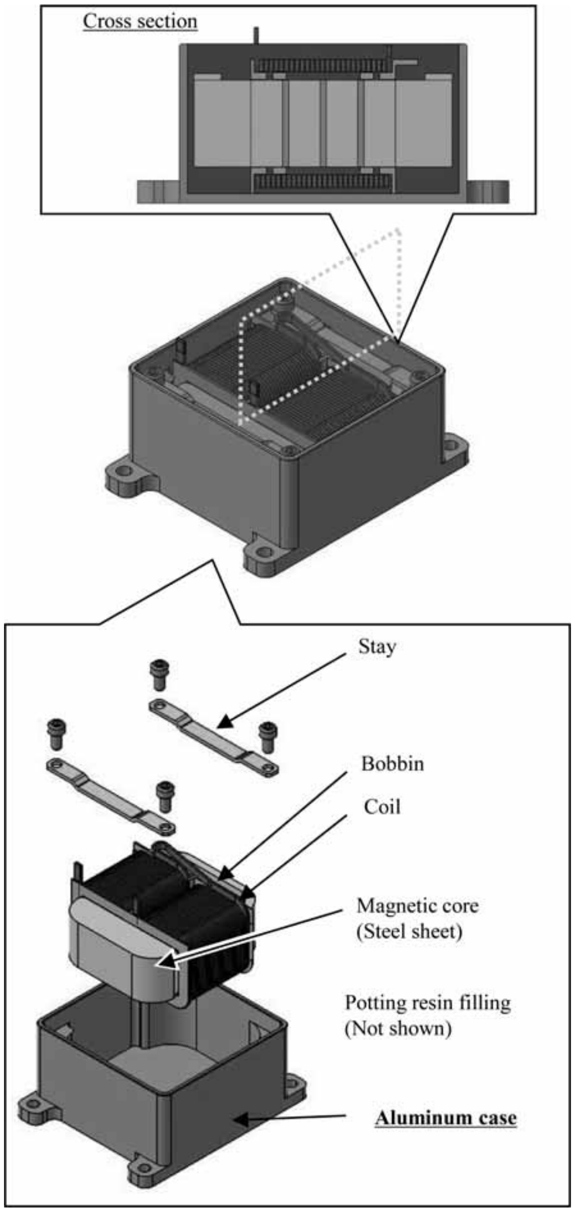


Fig. 3. Conventional structure of reactor

The new structure of the reactor is shown in **Fig. 4**. The details are explained as follows.

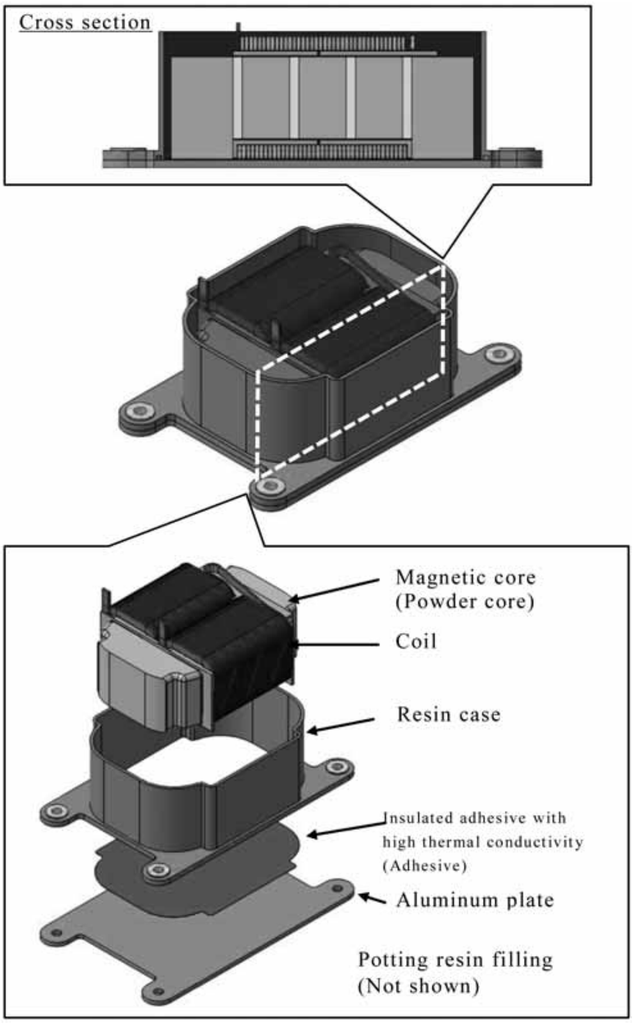


Fig. 4. New structure of reactor

4. Development of the New Structure

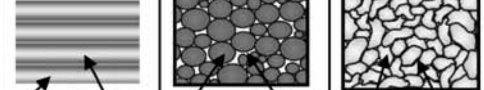
4-1 Development of the powder magnetic core with pure iron

Table 1 shows the comparison of the magnetic core materials for the reactor. An electromagnetic steel sheet, used as a conventional magnetic core, has low energy loss. However, due to its low saturated magnetic flux density, it is difficult to reduce the size of a reactor using it. A powder magnetic core with an iron-based alloy has low energy loss as the electromagnetic steel sheet, but low saturated magnetic flux density. On the other hand, a powder magnetic core using pure iron has a slightly higher energy loss than that with an iron-based alloy, but it is possible to reduce the size of the reactor more because it has a higher saturated magnetic flux density.

We have adopted a powder magnetic core with pure iron as the magnetic core to reduce the size and weight of the reactor. High dissipation structure to solve the high energy loss problem will be shown later.

In addition, the comparison of the structures with a magnetic steel sheet and powder magnetic core is shown in **Fig. 5**. For a magnetic steel sheet, it is easy for the magnetic flux to go along in a parallel direction to the plane of sheet, but hard to go along in a perpendicular direction. Thus, we cannot adopt a three-dimensional shape for the magnetic core. On the other hand, because it is equally easy for the magnetic flux to flow in any direction in a powder magnetic core, we adopted a three-dimensional shape for the magnetic core. In this way, a downsizing of approximately 10% was realized.

Table 1. Comparison of magnetic cores

Material	Steel sheet (Fe-6.5wt%Si)	Powder cores: Iron-base Alloy (Fe-3.0wt%Si)	Powder cores: Pure Iron (Fe)
Diagram	 Sheet, Insulated film	Alloy, Insulated coat	Pure Iron, Insulated coat
Energy loss (Iron loss)	Lowest	Low	Average
Saturated flux	Average	High	Highest
3-D shape	Not Applicable	Applicable	Applicable

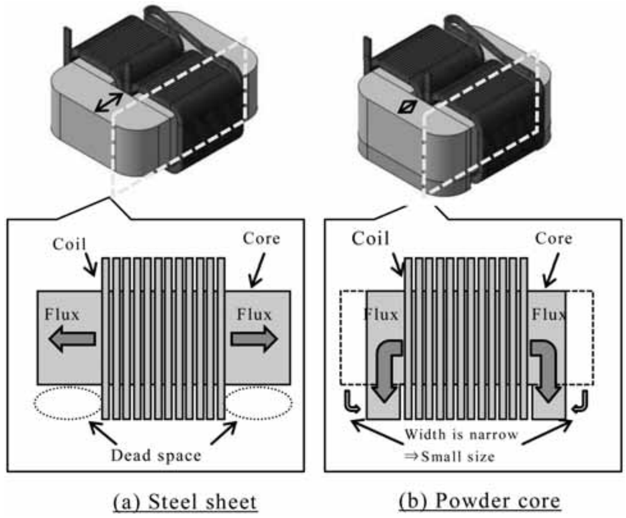


Fig. 5. Comparison of core shape

4-2 Development of the new structure

In the new structure of the reactor, a coil, magnetic core and aluminum plate are fixed with adhesive, and then potting resin is filled in it. The comparison of the conventional structure and the new structure is shown in **Figs. 6 and 7**.

The heat dissipation path from the coil and core to the water-cooling plate differs from the conventional structure to the new structure. The former uses potting resin, the latter uses adhesive. The difference of this part affects the heat dissipation property of the reactor.

The Comparison of potting resin and adhesive is shown in **Table 2**. The heat dissipation property is deter-

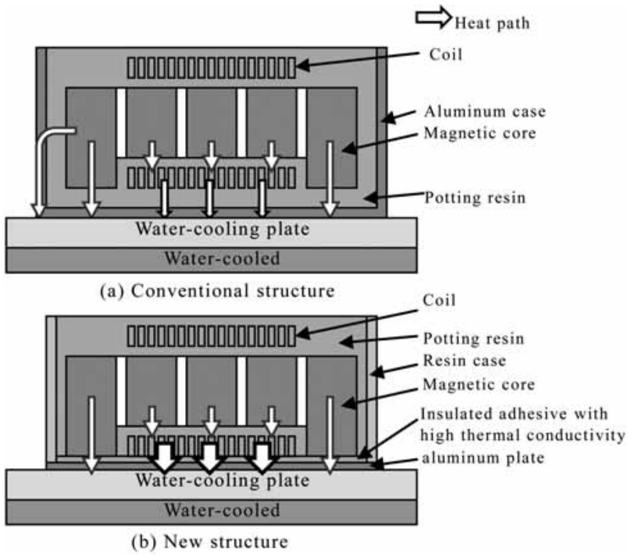


Fig. 6. Comparison of heat dissipation structures

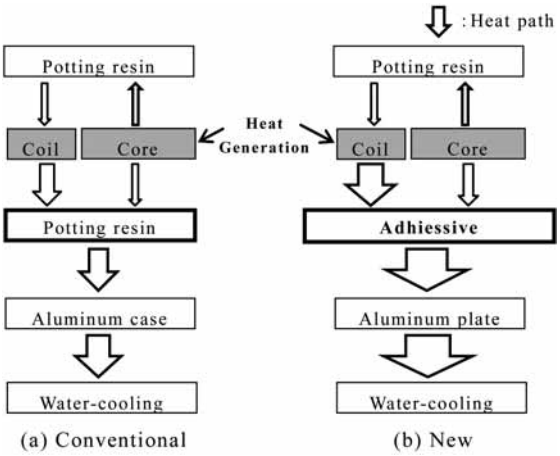


Fig. 7. Comparison of heat path

Table 2. Comparison of heat dissipation property

	Potting	Adhesive
Thermal conductivity	~2 W/m･K	3 W/m･K~
Thickness	1.5 mm~	0.3~0.5 mm
Heat dissipation (heat-transfer coefficient)	~1300 W/m^{2}K	6000 W/m^{2}K~

*Heat-transfer coefficient (W/m^{2}K)
= Thermal Conductivity (W/m･K)/Thickness (m)

mined by the thermal conductivity and thickness, and heat dissipation property improves when thermal conductivity is high and thickness is small.

The thermal conductivity of adhesive can be over 1.5 times greater than that of potting, depending on the difference in quantity of filler. It is necessary to lower viscosity to make it easier to fill potting resin, and it cannot increase the quantity of filler as an adhesive.

The thickness of adhesive can be no more than one third that of potting resin. Over 1.5 millimeter thickness of potting resin is needed as an insulation to secure against air bubbles generated in potting resin. However, an under 0.5 millimeters thickness can be controlled by a method mentioned later.

For the above reasons, the heat dissipation property of adhesive can realize an effectiveness 4.5 times greater than that of potting resin.

In addition, because the bottom of the reactor has higher heat dissipation in the new structure, the heat dissipation path of the side part can be omitted. The conventional structure has an aluminum case, but the new structure has an aluminum plate on the bottom and resin casing on the sides. The aluminum plate is to secure the heat dissipation, and the resin casing allows a lighter weight reactor in the new structure. For the same reason, the weight of potting resin can be reduced by reducing the quantity of filler.

The heat dissipation of the new structure can be 20% larger than that of the conventional structure, and can be lighter as well.

On the other hand, the insulation between the coil and aluminum plate must be reliable because high voltage is applied to the coil. In the new structure, the insulation of adhesive is important because of its small thickness. A round 0.1 millimeter thickness of adhesive is enough to secure the insulation, but there is the slight possibility that air bubbles (the pin hole) may be generated in the adhesive. As the existence of the pin hole decreases the insulation, insulation failure could occur.

In the new structure, a multilayer of adhesive has been adopted. The details are shown in **Fig. 8**. When the thickness of the insulation adhesive is a thin single layer, the insulation failure could more easily occur because of the existence of a pin hole. In a multilayer design, pinholes are very unlikely to stack, even if generated, so insulation failure has not occurred. Therefore, heat dissipation and insulation can be combined in such a thin multilayer adhesive.

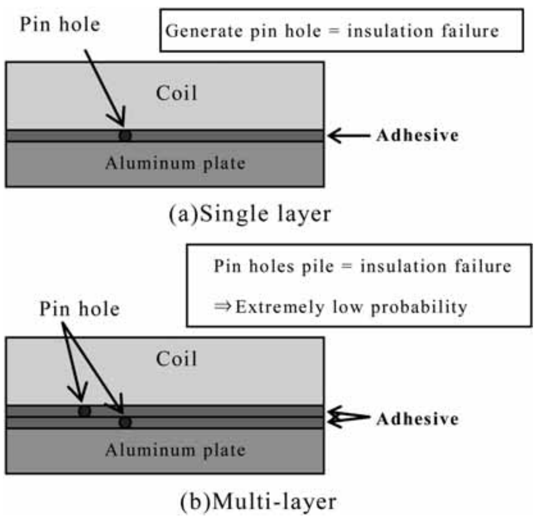


Fig. 8. Comparison of adhesive layers

4-3 Test production and evaluation of the new structure

(1) Initial characteristic evaluation

We produced a reactor experimentally using the above-mentioned technology, and compared it with a conventional structure. Although energy loss increased 10%, a 10% downsizing was achieved with the same inductance and temperature rise in the new structure using a powder magnetic core with pure iron and adhesive. Because of this result, the effect of a powder magnetic core with pure iron and insulated adhesive with high thermal conductivity was confirmed.

Table 3. Comparison of conventional and new structure

	Conventional	New
Size	1	0.9
Inductance	1	1
Energy Loss	1	1.1
Temperature Rise	1	1

(2) Long-term reliability evaluation

In the new structure, the powder magnetic core with pure iron, insulated adhesive with high thermal conductivity and resin case is newly adopted. It was concerned that the powder magnetic core might suffer property degradation by high temperature and external vibration, the adhesive might suffer degradation and peeling due to high temperature and thermal cycles, or the resin case might crack and break because of external vibration. However, as the result of carrying out a long-term reliability examination, shown in **Table 4**, all examinations were passed, and no problems arose.

Table 4. Results of long-term reliability examination

Item	Criterion	Result
Thermal cycle	-External visual integrity -Electrical property (Inductance) -Thermal property (Temperature rise)	Pass
Power cycle		Pass
Continuous operation		Pass
High-temperature shelf		Pass
High-Temperature and High-Humidity Shelf		Pass
Low-Temperature Shelf		Pass
Vibration Durability at High Temperature		Pass
Vibration Durability at Low Temperature		Pass

5. Conclusion

We have developed a new reactor using a powder magnetic core with pure iron and insulated adhesive with high thermal conductivity, and have realized a reactor size and weight reduction of 10%, while maintaining the same inductance and energy loss as conventional reactors. Furthermore, testing has confirmed that it has high reliability.

Technical Terms

*1 Reactor: A passive element used by electric winding for accumulating and releasing the energy in turn.

*2 Inductance: The index to express ability to accumulate the magnetic energy.

*3 Powder magnetic core: A magnetic core manufactured by compacting soft magnetic metal powder coated with an insulating film.

References

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