Development of Resin-Molded Reactor

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Sumitomo Electric Industries, Ltd. is working to develop low-cost and compact reactors, which contribute to the improvement of converters. We reviewed the conventional structure, which used aluminum cases, and have developed a resin-molded reactor that allows us to eliminate aluminum cases and some other parts. We have succeeded in downsizing of the reactor and lowering its production cost. This paper reports the details of our development.

Keywords: reactor, eco-friendly vehicle, resin-molded

1. Introduction

Global warming has become a serious social problem in recent years. Growing concerns over this issue have prompted us to develop environmental-friendly automobiles such as hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), electric vehicles (EVs) and fuel cell vehicles (FCVs). For these eco-friendly vehicles to be widely used, it is essential that their driving performance and acceleration performance must be at the same level of those of gasoline-fueled vehicles. To this end, high power electric motors are under development. For the electric motors to produce high power output, boost converters which increase battery voltage are required. Converters are also essential to recharge the batteries of EVs and PHEVs from household power outlets. Further, photovoltaic power generation systems, one of the main resources of renewable energy, use them to convert sunlight energy collected by photovoltaic panels into forms suitable for domestic power supply.

At Sumitomo Electric, we are working to develop low-cost and compact reactors with less core components. We have reviewed the conventional reactor structure to develop a new resin-molded reactor that allows the elimination of the aluminum cases and some of the other parts. Thus we have succeeded in downsizing the reactor and minimizing production costs. This paper reports the details of the development.

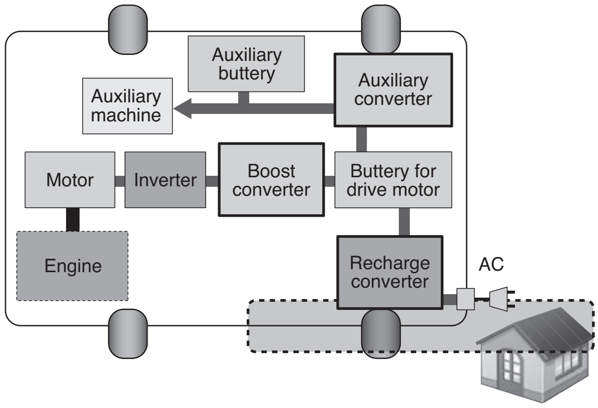

Fig. 1. HEVs, PHEVs, EVsSystems

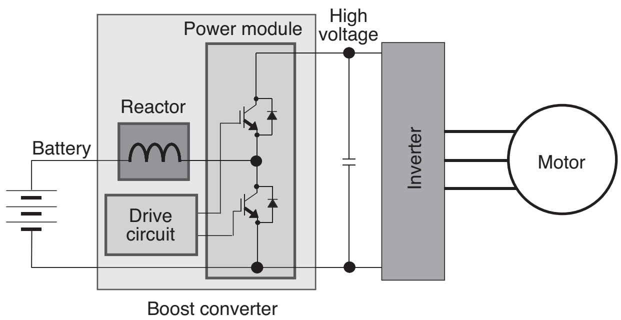

Fig. 2. Example of the Boost Converter

2. Reactor Structure

Figure 1 shows an example layout of a voltage converter for the HEVs, PHEVs, EVs etc. The boost converter is composed of a reactor, power semiconductor, capacitor, and circuitry for driving these components, 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**.

Table 1 gives example specifications for the reactor we have developed.

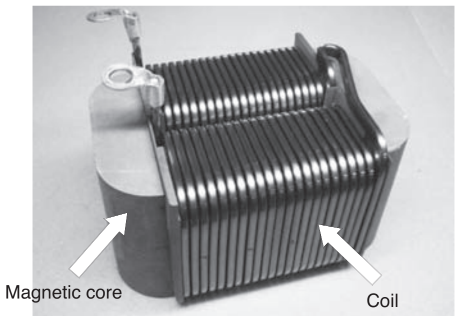

Photo 1. Internal Structure of Reactor

Table 1. Specifications of the Developed Reactor

Inductance	~ 500μH
Input current	~ 350A
Drive frequency	~ 100kHz

3. Concept of the Resin-Molded Reactor

3-1 Conventional reactor structure and its problems

The reactors we have developed are all intended for in-vehicle use and are structured to release the heat generated through the reactor bottom using the water-cooling system of the boost converter. In the conventional reactor structure, an iron core (powder magnetic core (pure iron or Fe-Si based powder coated with insulation then press-formed)) and a coil of copper wire are fixed in an aluminum case and potted with casting resin to ensure effective heat release and internal protection, as shown in **Fig. 3** (aluminum-cased reactor). This structure contains a lot of parts. One is parts that fix the powder magnetic core to the aluminum case. Another is a bobbin that secures the insulation clearance between the powder magnetic core and the coil. To reduce the cost, size and weight of the reactor, it is essential to reduce the number of parts.

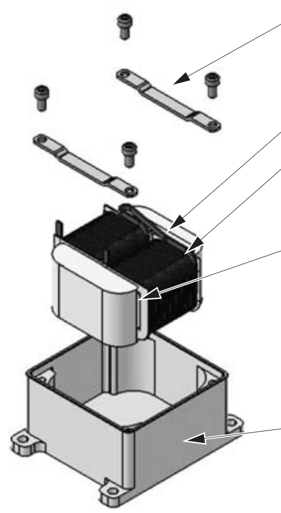

Fig. 3. Aluminum-Cased Reactor

3-2 Concept of the resin-molded reactor

A new reactor has been developed using the following three concepts with the aim of decreasing the number of structural parts in the aluminum-cased reactor:

(1) Elimination of the bobbin: Adoption of a molded coil (inside resin molding) to provide insulation between the powder magnetic core and the coil

(2) Elimination of the aluminum case: Adoption of a resin-molded structure (outside resin molding) with the same rigidity as the aluminum case

(3) Elimination of fixing parts: Use of molding resin to fix internal parts together

Figure 4 shows an example of the resin-molded reactor structure.

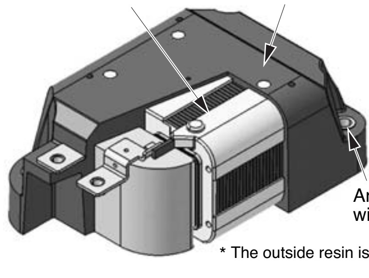

Fig. 4. Structure of Resin-Molded Reactor (The coil is molded with the inside resin, with the entire parts enclosed in the outside resin)

4. Development of a Resin-Molded Reactor

4-1 Engineering design

To exhibit the same or higher performance than that of the aluminum-cased reactor, a resin-molded reactor is required to have a high heat-release efficiency and a high-strength joint with the housing.

Our company's reactor features a sintered body used as the magnetic core, and a three-dimensional magnetic circuit achieved using the isotropic magnetization property of the powder magnetic core (**Fig. 5**). This magnetic circuit structure allows the powder magnetic core to be extended to the reactor bottom, enabling the heat generated due to iron loss

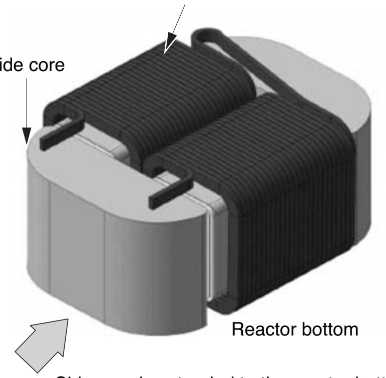

Fig. 5. Reactor Core Developed by Sumitomo Electric (3D magnetic circuit achieved by using the unique magnetization property of the powder core)

in the powder magnetic core to be effectively released into the water-cooled heatsink on the reactor bottom.

Thermal analysis[1] was carried out to study the flow paths of heat generated by iron loss in the powder magnetic core and of Joule heat generated by copper losses in the coil, clarifying the heat release path in each part. To ensure effective heat release, it is desirable that each side core and the coil be in direct contact with the water-cooled heatsink or a metal part that has high thermal conductivity. Although the side core can be positioned in direct contact with the water-cooled heatsink or a metal part, the coil cannot, since it must be insulated. To avoid direct contact with the water-cooled heatsink or a metal part, the coil needs to be enveloped in resin. Because of this, we have adopted a molded coil structure, and have devised and designed a resin-molded reactor with double mold structure in which the powder magnetic core and the resin portion of the molded coil are exposed to the bottom (the water-cooled heatsink side) of the reactor, as shown in **Fig. 6**.

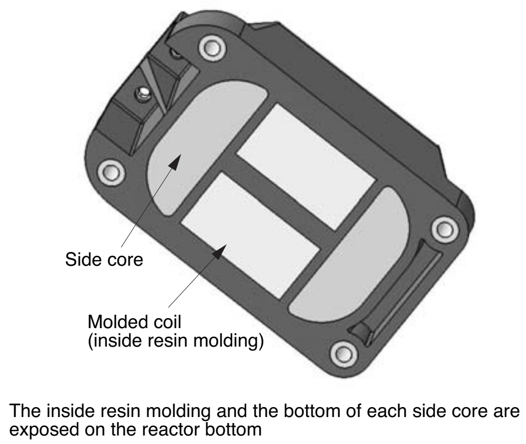

Fig. 6. Bottom View of Resin-Molded Reactor

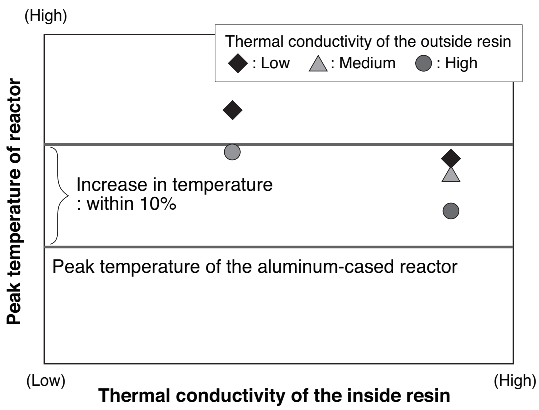

Fig. 7. Relation between the Peak Temperature of the Resin-Molded Reactor and the Thermal Conductivity of the Resin (Result of simulation by varying the thermal conductivities of the inside and outside resin materials)

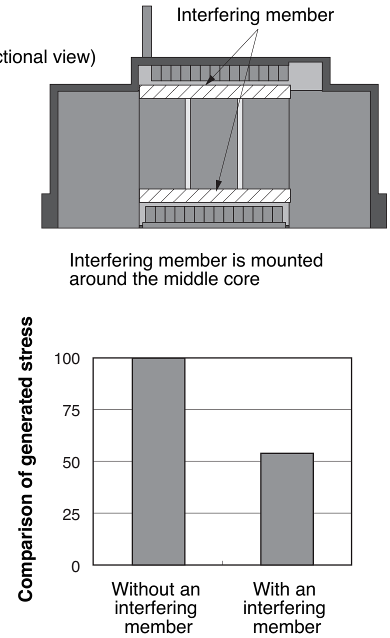

Fig. 8. Method of Reducing the Thermal Stress in the Inside Resin & Its Effect

A thermal analysis was conducted to select the optimal resin materials for the double mold structure, i.e., to select resin materials for which the peak temperature of the reactor during energization is equal to the peak temperature of the aluminum-cased reactor. First, the thermal conductivity of each of the candidate resin materials for the inside molding was studied to identify the resin material that can suppress the increase in reactor temperature within 10°C above the peak temperature of the aluminum-cased reactor regardless of the thermal conductivity of the resin material used for the outside molding, as shown in **Fig. 7**. The inside resin material was selected based on this study result, and a thermal stress engineering study was carried out on the structure using the selected resin. To support the strength of the selected resin, an interfering member is mounted around the powder magnetic core with the aim of mitigating the difference in the linear expansion coefficient between the selected resin and the powder magnetic core (**Fig. 8**). As the graph in **Fig. 8** indicates, the thermal stress analysis revealed that this interfering member reduces the thermal stress in the resin portion of the molded coil by 50%, thus effectively supporting the strength of the inside resin.

Next, an engineering study was carried out on the durability of the outside resin against thermal stress and external vibration in the operating environment. The rigidity of the outside resin portion connected to the water-cooled heatsink has been increased to reduce the stress caused by external vibration. On the other hand, the thermal stress, which is determined by the coefficient of linear expansion and Young's module for the resin, as indicated by Equations (1) and (2), cannot be decreased by increasing the rigidity of the resin.

$$\varepsilon = \alpha \times \Delta T \quad \cdots\cdots (1)$$

$$\sigma = \varepsilon \times E \quad \cdots\cdots (2)$$

in which
ε : thermal strain
ΔT: difference in temperature
α : coefficient of thermal linear expansion
E : Young' s module
σ : thermal stress

We therefore carried out a thermal stress analysis to select a resin material which has nearly the same coefficient of linear expansion as the internal powder magnetic core and coil and therefore generates a low thermal stress (**Fig. 9**).

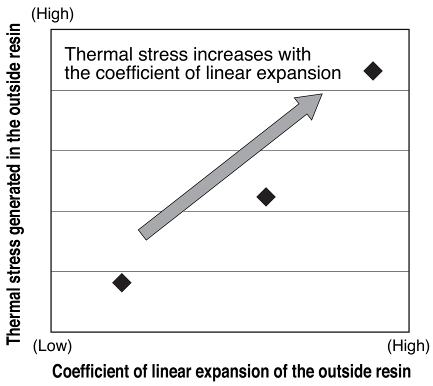

Fig. 9. Relation between the Thermal Stress and the Coefficient of Linear Expansion of the Outside Resin

4-2 Development of the molding technique

In the developed reactor, while the inside resin molding and the bottom of each side core are exposed on the reactor bottom to ensure effective heat release, the remaining portion of the reactor is completely enclosed in the outside resin for protection and to insulate the powder magnetic core and coil. To produce this reactor, a new molding technique has been developed in which a powder magnetic core and a coil inserted in a mold cavity for insert molding are supported by the molds only on part of the reactor top surface (molded coil) and on the reactor bottom.

For the outside molding, a resin material with relatively low flow properties has been selected to ensure that the molding has sufficient strength. Since the selected resin material requires a large molding pressure, it was necessary to develop a technique to minimize the molding pressure applied to the inserted powder magnetic core and coil so as to avoid damage to these inserts. In particular, it is essential to prevent the resin from flowing in the gap between the powder magnetic core (side core) and the coil (molded coil), since the resin in the gap would generate a stress in the direction that would push the powder magnetic core to the outer side. To these ends, we evaluated the flow path of the molding resin by producing a short shot of the resin and designed the optimal configuration of the gate to successfully minimize the movement of inserts under the molding pressure and to reduce the molding pressure applied to the powder magnetic core and coil.

4-3 Characteristics and long-term reliability test results for the developed reactor

The initial performance of the developed resin-molded reactor was tested. The inductance and energy loss are at the same level as the aluminum-cased reactor. The peak temperature of the developed reactor is within 10°C above the aluminum-cased reactor, verifying the high accuracy of our CAE analysis described in the preceding report (SEI Technical Review No. 175, released in July 2009). The long-term reliability of the developed reactor was examined by conducting the tests given in **Table 2**. The reactor has passed all these tests, verifying that the developed resin-molded reactor can be used under the same conditions as the conventional aluminum-cased reactor and can replace it.

Table 2. Reliability Testing of the Resin-Molded Reactor

Test item	Criteria	Judgment
Thermal cycle test	- External visual integrity - Electrical property (Inductance) - Thermal property (Peak temperature)	○
Power cycle test		○
Continuous operation test		○
High-temperature shelf test		○
High-temperature and high-humidity shelf test		○
Low-temperature shelf test		○
Vibration durability test at high temperature		○
Vibration durability test at low temperature		○

5. Conclusion

A resin-molded reactor has been developed and its high reliability in vehicles has been verified. The developed reactor is composed of a 35% smaller number of parts than the aluminum-cased reactor, and can be produced at a lower cost. The terminal block for connection to an external device is molded in one body with the outside resin molding, saving the space for the external device and achieving reduction in size and cost.

References

(1) Takuji KANTOU: "Electromagnetic and Thermal Design Technology for Reactor Development," SEI Technical Review No. 70, April 2010

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