Wiring Harness and Connector for Electric and Hybrid Electric Vehicles
- Pipe Shielded Wiring Harness, Power Cable, and Direct Connector -

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Sumitomo Electric Industries, Ltd. has developed and produced high-voltage wiring harnesses and connectors used for electric drivetrains, and these products have been used in many hybrid electric vehicles (HEVs). For the past quarter century, HEVs have been actively developed to prevent global warming caused by CO_2 emissions. The development of electric vehicles (EVs) that require no internal combustion engines has also been accelerated. An electric drivetrain used in an EV mainly consists of a high-voltage battery, inverters, and motors. This paper introduces our products that have been developed for HEVs and are also applicable to EVs. These products include a pipe shielded wiring harness applied to the aluminum wire between the high-voltage battery and the inverters as well as a power cable and direct connector that connect the inverters to the motors.

Keywords: high-voltage wiring harness, pipe shielded wiring harness, power cable, high-voltage connector

1. Introduction

In the last twenty years, the development of hybrid electric vehicles (HEVs) and electric vehicles (EVs) has been accelerated for the purpose of improving fuel efficiency and reducing CO_2 emissions to prevent global warming and depletion of fossil fuels. In particular, HEVs have spread rapidly because existing gasoline service stations can be used for refueling. The sales prohibition policies for internal combustion engine vehicles recently announced in each country are shown in Table 1, and the CO_2 emission regulations have tightened. As a result, electrified vehicle sales demonstrate an increase as shown in Fig. 1. For the time being, it is predicted that the ratio of HEVs to electrified vehicles will continue to be high. However, the development of EVs without internal combustion engines is accelerating. Therefore, the percentage of EVs in electrified vehicle sales is expected to increase as batteries and charging technologies evolve.

An electric drivetrain of an HEV or EV mainly consists of a high-voltage battery and motors. They are connected by high-voltage wiring harnesses to perform power transfer. Sumitomo Electric Industries, Ltd. has been producing these high-voltage wiring harnesses for nearly 20 years.(1)-(4) Also, in the wave of electrification, Sumitomo Electric is promoting the development of high-voltage wiring harnesses in view of the increasing motor power of HEVs, weight reduction for improving fuel efficiency, and further application to EVs.

Table 1. Sales prohibition policies for internal combustion engine vehicle

Countries	Scheduled moment of sales prohibition for internal combustion engine vehicle
Norway	2025
Netherlands	2030
Germany	2030
India	2030
France	2040
England	2040
Sweden	2045

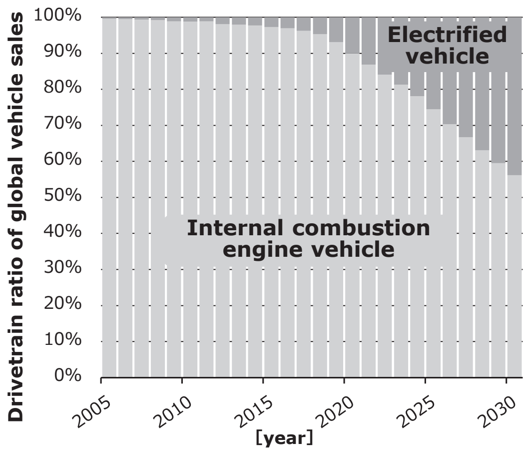

Fig. 1. Prediction of sales ratio of internal combustion engine vehicle and electrified vehicle

In this paper, we describe the structures and characteristics of the following parts that were developed for HEVs and can be used for EVs as well: power cables, direct connectors, and pipe shielded wiring harnesses applicable to aluminum wires.

2. Electric Drivetrain System and High-Voltage Wiring Harness

The electric drivetrain of an HEV or EV is mainly composed of a high-voltage battery, inverters, and motors. As shown in Fig. 2, they are connected to each other with high-voltage wiring harnesses. The high-voltage wiring harness connecting the high-voltage battery and inverter is called an under-floor wiring harness, and its wire length is relatively long. The high-voltage wiring harness connecting the inverter and motor is called a power cable, and its wire length is relatively short. Both the high-voltage harnesses require shielding performance so that electromagnetic noise does not affect their surrounding electronic devices and signal lines.

The under-floor harness is arranged under the floor of a vehicle, therefore the protector for protecting wires from external damage such as stone chipping is very important. Resin protectors and metal pipes are used for the protector.

Recently, there has been a trend that the length of power cable is becoming short since the distance between the inverter and motor is getting shorter. Sumitomo Electric developed two products based on this trend. One is a downsized and weight reduced power cable. The wire length of the power cable has been reduced to about 10 cm from approximately 100 cm. The other is a direct connector that directly connects the inverter and motor with high-voltage connectors. These two products are used depending on the characteristics of the vehicle.

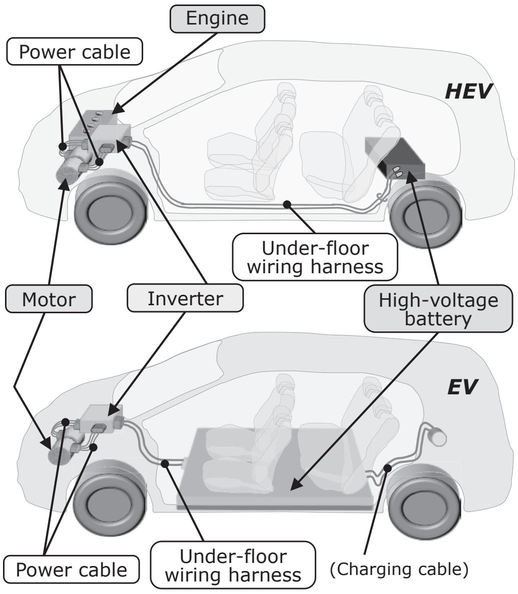

Fig. 2. Electric drivetrain of HEV and EV

3. Developed Products for HEVs Applicable to EVs

In this section, we introduce the developed HEV products that are also applicable to EVs.

3-1 Pipe shielded wiring harness and positive negative (PN) connector*1

The protection for under-floor harness is important as previously mentioned. Sumitomo Electric has been producing the pipe shielded wiring harnesses using aluminum pipes other than resin protectors as protective material since 2005.(1) One of the characteristics of the pipe shielded wiring harness is that the aluminum pipe works as both protection and shielding. In addition, it has good heat resistance and thermal conductivity, and is adaptive to various layout shapes of the pipe shielded wiring harness utilizing three-dimensional bending process, etc.(3),(4)

Regarding the conventional pipe shielded wiring harness, the wires inserted through the pipe were copper wires. However, larger current was required in accordance with the power increase of HEVs, which resulted in the enlargement of the cross sectional area of wire conductors. As a result, wire weight increase became a problem. From the viewpoint of fuel efficiency improvement, wire weight reduction was required. In order to resolve these problems, we developed an aluminum wire. The aluminum wire for the pipe shielded wiring harness requires both flexibility resistance for withstanding vibration and good electrical conductivity. We have achieved weight reduction using new aluminum material satisfying both requirements (Photo 1 (a), (b)).

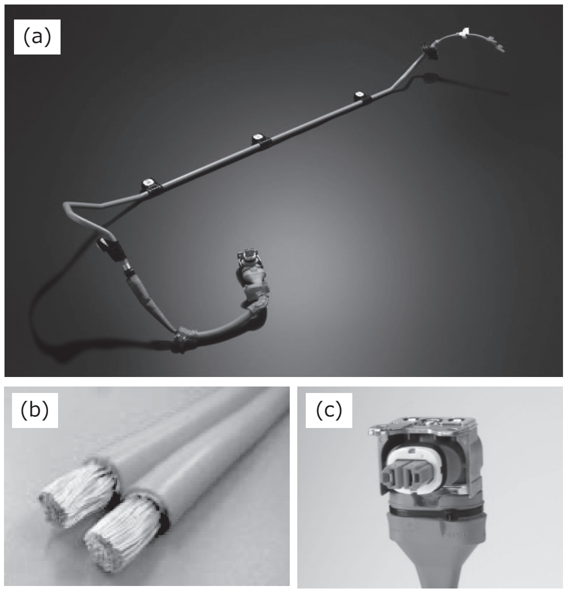

Photo 1. Pipe shielded wiring harness and PN connector

On the other hand, another development product in this pipe shielded wiring harness is a high-voltage connector, called a PN connector, used on the inverter side (Photo 1 (c)). A thick wire with a large cross-sectional area is used for the pipe shielded wiring harness since large current flows through it. When a vehicle is driven, the thick wire installed in the vehicle vibrates in association with the vibration of the vehicle. This wire vibration acts on the connector via the thick wire. As a result, this action could cause abrasion of the electrical contacts of the connector, which may lead to heat generation of the terminals. In order to suppress this vibration, it is necessary to rigidly fix the wires, the connector, and the inverter to each other. However, this may lead to abrasion of the electrical contacts of the connector since expansion and contraction of components of the connectors caused by temperature change may not be absorbed. Figure 3 shows the PN connector developed in consideration of these. As shown in Fig. 3, although the PN connector has a rigidly fixed structure, the flexible conductor absorbs the dimensional change of the components due to thermal expansion and contraction. This structure enhances the reliability of the PN

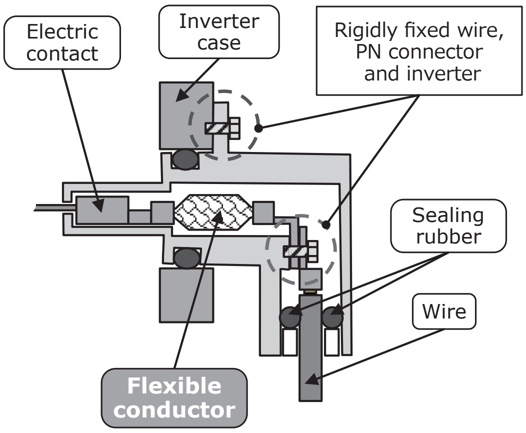

Fig. 3. Absorption of dimensional change of PN connector

connector. Since the connector employs the one-touch assembly structure instead of the conventional bolted structure, it significantly improves workability in connecting the pipe shielded wiring harness to the inverter.

3-2 Power cable

As mentioned, the distance between the inverter and motor is becoming short. This section describes the power cable that we have developed as one of the measures to respond to this trend.

The power cable of this development target vehicle connects the inverter and two three-phase alternating current (AC) motors (one used for driving the vehicle and the other for generating electricity). The power cable consists of three thick wires for each motor (six thick wires in total), high-voltage connectors at both ends connected to the inverter and motors, and a shielding layer for shielding electromagnetic noise. In order to apply this power cable to a short distance section between the inverter and motors, it was necessary to reduce its size and weight.

In the conventional high-voltage connector, resin molded housings were assembled to both ends of the three thick wires with sealing. The conventional power cable used two sets of these. In order to reduce the size of this power cable, we adopted six-phase integral molding technique (Fig. 4) in which insert molding of six wires is processed at a time. Due to this, the use of rubber sealing is avoided and the two sets of power cables are integrated. As a result, miniaturization is achieved.

In the shielding layer of the conventional power cable, the wire is wrapped by the tubular braided shielding. Therefore, due to the terminal connection of the shielding layer, the size reduction of the power cable was limited. This time, we adopted cloth-like shielding material by taking advantage of application to a short distance. As a result, we achieved a reduction in the size and weight of the new power cable (Photo 2).

These measures for downsizing and weight reduction made it possible to develop the power cable shown in photo 3, which can be installed to a narrow and limited space.

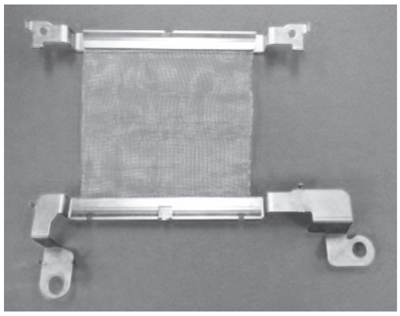

Photo 2. Copper cloth shield

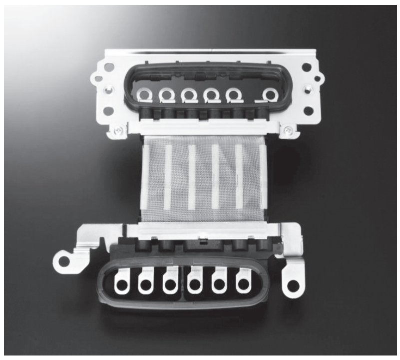

Photo 3. Appearance of power cable

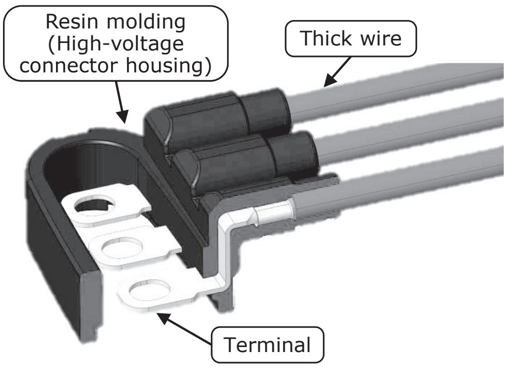

Fig. 4. Conceptual illustration of six-phase integral molding technique

3-3 Direct connector

In this section, we describe a direct connector that directly connects the inverter and motors with high-voltage connectors.

As a vehicle layout, there is a trend to install the inverter directly on top of the motors. In order to improve the workability in automobile assembly plants, there has been a demand for a technology capable of connecting the inverter to the motors at the same time as installing it on top of the motors without using cables. As a solution, we have developed the direct connector in which the high-voltage connectors are integrated into the inverter and motors respectively (Photo 4).

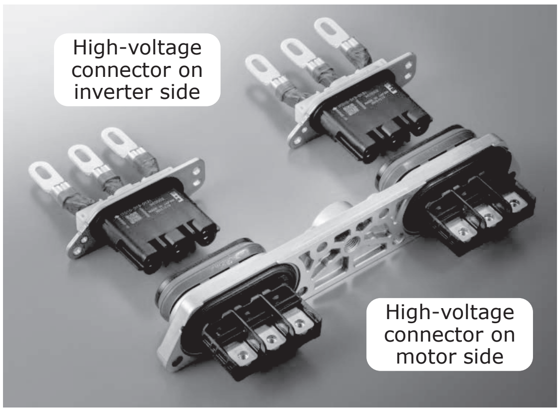

Photo 4. Appearance of direct connector

In order to connect the inverter and motors while installing it on top of the motors, high precision alignment is required. However, it is difficult to install the heavy inverter while making fine adjustment. Therefore, the high-voltage connectors of the inverter and motors should be able to be mated with each other based on rough alignment. In order to respond to this requirement, a two-step guiding structure was adopted. The first step is the initial stage of connector mating when the inverter is moving toward the motors. We set positioning pins on the inverter case, adjusted the shape of the pin, and set the appropriate guiding margin, so as to achieve optimum positioning while avoiding interference of the high-voltage connectors (Fig. 5).

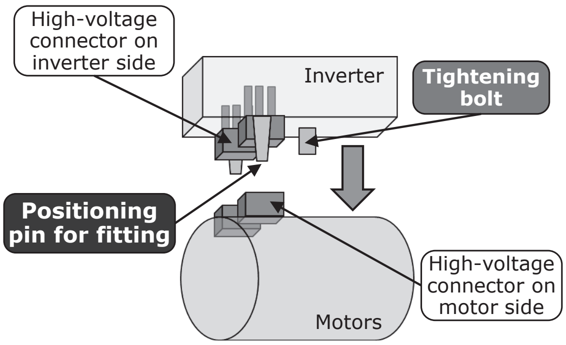

Fig. 5. Inverter and motors installing operation (First step)

The second step is the stage just before the start of the terminal engagement. At this stage, further high precision alignment is required for terminal engagement. In order to satisfy this requirement, guiding parts were set on the high-voltage connector of the motor side. Also, a floating structure was adopted for the high-voltage connector of the inverter side. These measures made self-alignment possible. In addition, flexible conductors were applied inside the high-voltage connector on the inverter side to absorb the gap generated in the bolted terminal connection positions inside the inverter due to the movement of the connector on the inverter by the self-alignment (Fig. 6).

These measures make it possible to mate two high-voltage connectors in one motion and with one bolt fastening. As a result, the workability of installing the inverter and mating high-voltage connectors has been greatly improved.

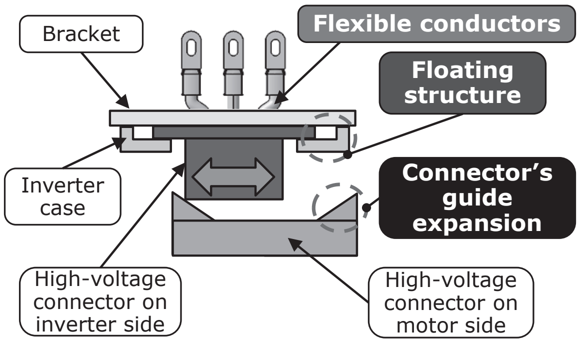

Fig. 6. High-voltage connector mating (Second step)

4. Conclusion

All of the products reported in this paper have been developed considering the application to EVs. Also, they contributed to size and weight reduction of products, and improvement of products reliability and workability in automobile assembly plants. They have already been installed in HEVs in mass production.

Technical Term

*1 Positive negative connector (PN connector): A 2-pole connector that connects positive/negative terminals of high-voltage battery and inverter.

References

(1) “High-Voltage Wiring Harness Employed in New Model Hybrid Vehicle,” SEI WORLD, vol. 340 (January 2006)

(2) Sho Miyazaki, Souji Kihira, Takao Nozaki, “New Shielding Construction of High-Voltage Wiring Harnesses for Toyota Prius – Winning of Toyota Superior Award for Cost Reduction-,” SEI Technical Review, no. 61, pp. 21-23 (January 2006)

(3) Yoshio Mizutani, Oliver Weiss, “Pipe Shield High-Voltage Wiring Harness,” World Electric Vehicle J., vol. 5, issue 2, pp. 581-587 (2012)

(4) Yasushi Itani, Yoshio Mizutani, Masanori Kuwahara, Shogo Hashimoto, “Aluminum Pipe Shielded High-Voltage Wiring Harness,” SEI Technical Review, no. 79, pp. 18-21 (October 2014)

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