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Pipe Shield High-Voltage Wiring Harness

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Abstract

The conventional high-voltage wiring harness for HEV is composed of wires and plastic protectors. Because of low heat transfer of the plastic protector, the larger sized wire is needed for high-voltage wiring harness to reduce the Joule-heat loss. Furthermore, high design cost and long lead-time are required to make the mould for a new or modified protector. We have developed the pipe shield wiring harness to eliminate these problems. The pipe shield wiring harness is already in mass-production for Honda CIVIC HYBRID, INSIGHT, CR-Z and FIT HYBRID etc.

In this paper, we explain the characteristics and the structure of the conventional high-voltage wiring harness against those of the innovative pipe shield wiring harness. Heat resistance against an external source, weight reduction, simplification of wiring harness assembly and sheath design, electromagnetic shielding performance, and resistance to stone chipping, are described.

Keywords: HEV (hybrid electric vehicle), component, thermal management, noise, cost

1 Introduction

HEVs and EVs rapidly became widely used since the 2000’s. Many units which are mounted onto these HEVs and EVs, e.g. the motor, the inverter and the high-voltage battery, have been developed and improved due to their popularity. The connecting high-voltage wiring harness between units has also been progressed. This advance produces challenges to cost reduction, weight reduction and space saving.
We have one innovative solution for these challenges.

2 Overview of high-voltage technology

High-voltage wiring harness technology within the Sumitomo Electric Group is explained here to provide a better understanding of our competence in this field and its historical development. Fig.1 shows the timeline for the mass production of high-voltage wiring harness products. Our company started the first mass production of high-voltage wiring harness products in the year 1999 for the Honda INSIGHT. The first full-scale high-voltage components development like wires, terminals and connectors, started in the year 2001 for the Toyota ESTIMA HYBRID. Based on these initial high-voltage wiring harness projects, Sumitomo further developed additional components for HEV projects for Toyota and Honda and supplied the related high-voltage wiring harnesses for these vehicles.
This timeline also shows additional information about the historical development of certain key requirements of high-voltage wiring harness products such as connectors / terminals,

electromagnetic shield and the maximum temperature requirements for the high-voltage wire. With regards to the terminal, we have developed 2 more types – bolt-type moulded version and the plug-type connector – which are both in use depending on the technical requirements of the connection interface. The electromagnetic shield was initially achieved with individual shielded wire, and then we introduced the braided wire bundle shield wiring harness into the Toyota PRIUS in 2003, and in 2005 the first pipe shield technology for the Honda CIVIC HYBRID. The maximum wire temperature requirement also changed from initially 120[°C] to 150[°C].

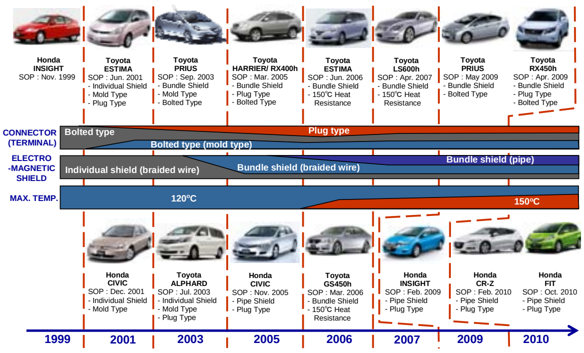

Figure 1: The timeline for the mass production of high-voltage wiring harness products

Fig.2 shows some pictures of high-voltage technologies within the Sumitomo Electric Group and their location in a HEV. On the right side, it shows high-voltage wiring harnesses with bundle shield technology using a braided wire or a pipe shield. On the lower left is pictured a smaller high-voltage wiring harness called power harness, which is used to connect the power electronics with the motors. Additionally, we develop high-voltage components like terminal blocks as interfaces for the motors or busbar modules as a part of the motor itself.

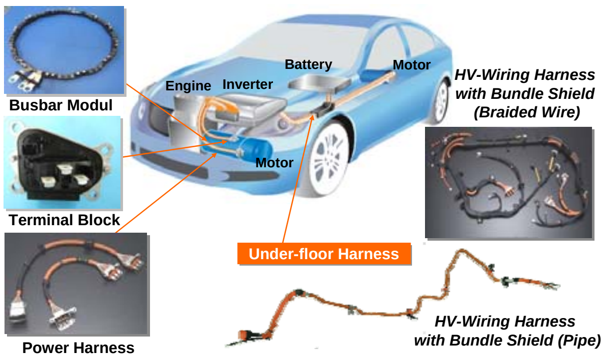

Figure 2: High-voltage technologies within the Sumitomo Electric Group and their location in a HEV

3 High-voltage wiring harness concept

This chapter describes the basic technical requirements for a high-voltage wiring harness and the advantages and disadvantages of different high-voltage wiring harness concepts and why we have developed the pipe shield high-voltage wiring harness system.

One of the key requirements for high-voltage wiring harnesses is its sheath or protection performance. The main requirements of a high-voltage wiring harness are its electromagnetic shielding and the mechanical protection. The electromagnetic shielding is required due to the electromagnetic field which is created by the high voltage and high current flowing through the harness. Additionally, the power electronics also generate some high frequency noises, which can be introduced also into the high-voltage wiring harness. Therefore, the electromagnetic shield acts mainly as an EMI (Electromagnetic Interference) shield to avoid any electromagnetic influence to the low-voltage wiring harness applications like the radio or other high-frequency systems inside the vehicle. To prevent a close proximity to the low-voltage wiring harness, the high-voltage wiring harness is routed mainly under the floor of the vehicle using the vehicle body as an additional EMI shield. Due to this under-floor routing of the high-voltage wiring harness, a mechanical protection is also required to avoid any damage to the wires due to chipping stones or accidents.

3.1 Conventional high-voltage wiring harness

How is a conventional high-voltage wiring harness usually designed to fulfill these sheath and protection requirements? For the electromagnetic shielding, the wire is covered with a braided shield made out of copper. Fig.3 shows the shield designs of the individual shielded wires and the common bundle shield structure. While the individual shielded wires have been mainly used for the 1st generation of high-voltage wiring harness, the braided bundle shield high-voltage wiring harness designs was introduced for the Toyota PRIUS in 2003 to simplify the wiring harness structure which reduced the number of necessary components and therefore the overall wiring harness system costs.

The mechanical protection of a conventional wiring harness is usually done with large plastic protectors and additional plastic convoluted tubes, which are produced via injection and extrusion moulding processes. If these protection parts are used for individual shielded or bundle shielded high-voltage wiring harness systems, they look like those shown in Fig.4. The mechanical protection design for the individual shielded wires requires a single convoluted tube over every individual wire and the use of a large plastic protector, which is mainly used in the under-floor area of the vehicle. The design for the braided bundle shield however already shows some improvements. Only one larger convoluted tube is used over the common braided copper shield, and just 1 simple plastic protector is providing the mechanical protection feature in the under-floor vehicle area.

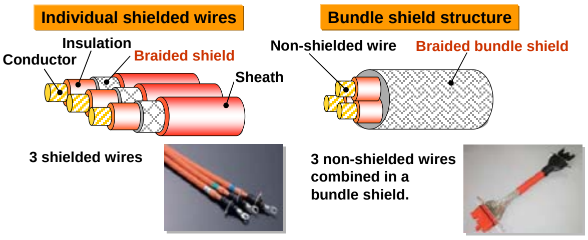

Figure 3: The electromagnetic shield designs

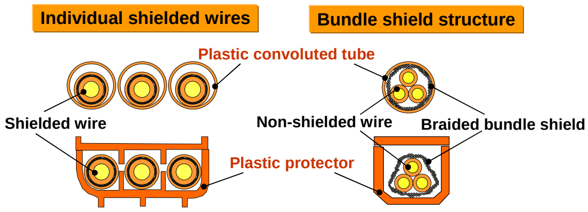

Figure 4: The mechanical protection designs

As a summary, the major demerits in the standard design of a conventional high-voltage wiring harness are as follows:

(1) Low heat transfer: A low thermal conductivity caused by the plastic material used by the protector and the convoluted tube. Additionally, the thermal conduction of the wiring harness in axial direction is low.
(2) As a consequence of this low heat transfer the wire size has to be increased causing an increase in the weight of the high-voltage wiring harness.
(3) Protector for the mechanical protection: If the wiring harness layout is changed, the design of the protector may also have to be changed, resulting in a modification or even a completely moulding tool. This increases the costs and causes a long development lead time.

3.2 Pipe shield wiring harness

In order to eliminate these demerits of a conventional high-voltage wiring harness, we have developed a new concept in order to functionally integrate the mechanical protection and the electromagnetic shielding feature. We call our solution the pipe shield wiring harness, which means that the non-shielded high-voltage wires are placed into a metal pipe made out of aluminium alloy as shown in Fig.5. This aluminium pipe provides both the mechanical protection of the high-voltage wires and the EMI shielding.

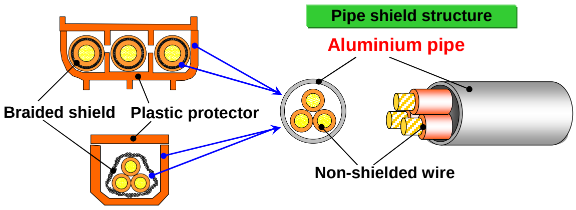

Figure 5: The concept of pipe shield wiring harness

The pipe shield high-voltage wiring harness structure offers the following major merits compared to the previously explained conventional high-voltage wiring harness design using individual shielded wires or a braided bundle shield,:

(1) High heat transfer due to the aluminium alloy material,
(2) Weight reduction of the overall high-voltage wiring harness system,
(3) An easier and more flexible wiring harness layout.

Our new concept is in mass-production for our customer Honda starting in 2005 with the CIVIC HYBRID. Since then we have continuously developed the pipe shield wiring harness for use in the Honda INSIGHT (2009), the CR-Z and the FIT HYBRID (2010), the FREED HYBRID (2011).

4 Features of the pipe shield wiring harness

This chapter describes the features and technical details of the pipe shield wiring harness system and explains the advantages of this concept.

4.1 Heat resistance against an external source

Due to the wiring harness routing in high temperature areas of the vehicle, e.g. in the engine compartment or near the exhaust pipe, the high-voltage wires have to be protected against heat.

The aluminium alloy pipe was compared against the standard plastic protector made out of PP (polypropylene) to establish their ability to transfer heat in the axial direction of the wiring harness. The test setup is shown in Fig.6. Both components were placed on top of a heating system which generates approx. 350[°C]. Fig.7 shows the result of measured temperature of protector surface and pipe surface. The difference is significant. The aluminium alloy pipe has better thermal conductivity and transfers the heat much better than the plastic protector in axial direction, therefore its material surface is much colder that the plastic protector surface.

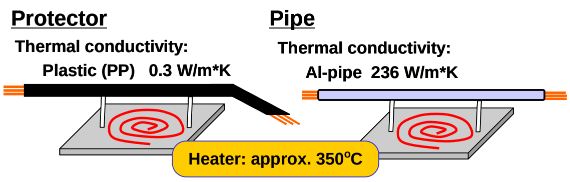

Figure 6: The test setup ability to transfer the heat in axial direction of the wiring harness

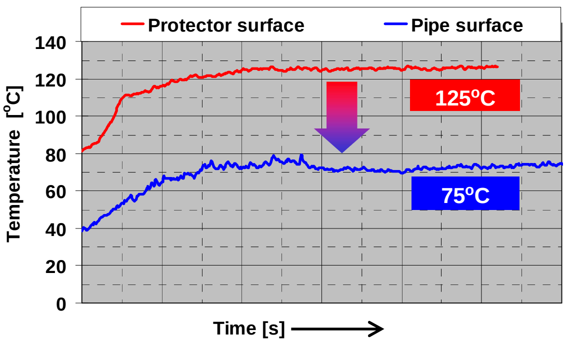

Figure 7: the result of measured temperature of protector surface and pipe surface

This better heat transfer in axial direction and the higher heat resistance in radial direction provide the opportunity to decrease the wire size or reduce the heat resistance classification of the high-voltage wire by using lower temperature resistance insulation. These 2 possibilities reduce the wire costs.

Furthermore, the degree of freedom in the wiring harness design layout increases since the pipe shield wiring harness can be placed closer to vehicle hot areas like the exhaust pipe, and a heat shield panel is also not required (Fig.8). The new design freedom makes it also easier to achieve a minimum ground clearance in the vehicle under-floor routing area.

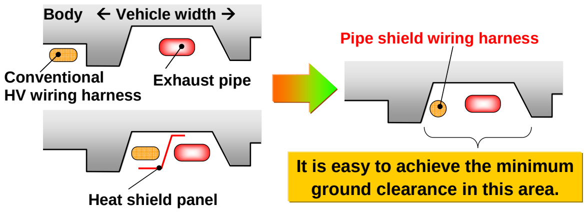

Figure 8: The advantage of the pipe shield wiring harness for against external source

4.2 Weight reduction

Fig.9 shows a high-voltage wiring harness component weight breakdown chart comparing the conventional design with individual shielded wires against the pipe shield wiring harness concept. The conventional high-voltage wiring harness includes individual shielded wires, the covering parts such as protectors, convoluted tubes, clips and other parts such as connectors and terminals. If the high-voltage wiring harness is redesigned using the pipe shield concept, significant weight reduction is achieved by replacing the individual shielded wires with non-shielded wires and the plastic covering parts with the aluminium alloy pipe and the braided shield. Also the connection interface has a simpler design and is therefore lighter due to the use of a bundle shield. Overall a weight reduction of approx. 18[%] could be achieved. But the actual achievable weight reduction is dependent on the applicable wiring harness specifications and requirements.

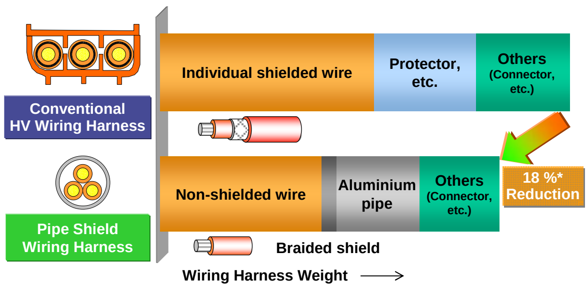

Figure 9: Weight reduction comparison

In addition to the weight reduction effect, the pipe shield concept also offers the possibility to save assembly space. This benefit is explained using a simple comparison between the individual shielded high-voltage wiring harness with its large plastic protector, and the pipe shield high-voltage wiring harness design. As shown in Fig.10, the space required is reduced by 60[%] when using just the 3-phase wires in an aluminium pipe with a diameter of 23[mm]. However if additional high-voltage applications are included like e.g. the circuits for the electrically driven HVAC (heating, ventilating, air conditioning) compressor, an even higher space saving effect of approx. 70[%] can be achieved.

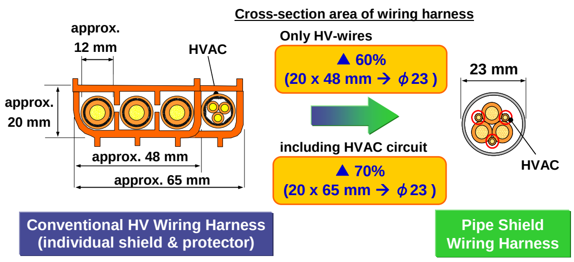

Figure 10: Space saving effect

4.3 Simplification of wiring harness assembly

Another advantage of the pipe shield wiring harness is the ability to simplify the wiring harness assembly. Fig.11 shows a conventional high-voltage wiring harness with plastic protection parts, and the aluminium pipe shield wiring harness. The sagging of the rigid aluminium pipe is substantially smaller compared to the conventional high-voltage wiring harness.

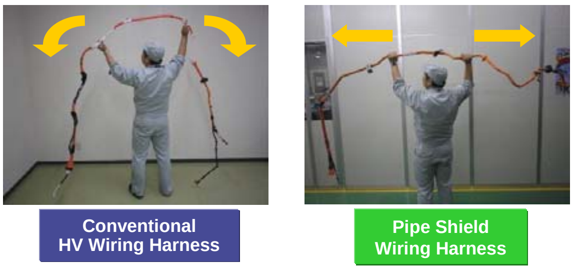

Figure 11: The difference of sagging behavior

Due to this lower sagging property, the pipe shield concept can reduce the number of wiring harness fixing points on the vehicle body. As shown in Fig.12, the conventional high-voltage wiring harness design with its higher sagging, it is difficult to maintain the minimum ground clearance. This characteristic limits the wiring harness routing options in the under-floor area of the vehicle. However, by using the pipe shield wiring harness concept these issues can be overcome which makes this particular high-voltage wiring harness design a real smart solution for all high-voltage applications.

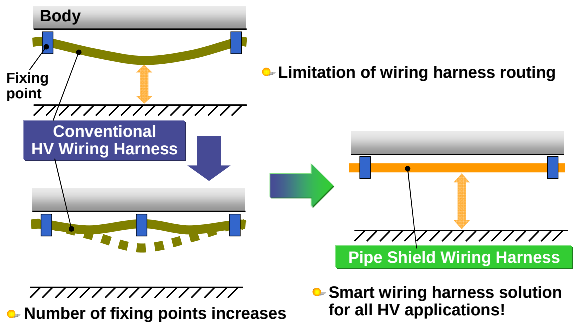

Figure 12: Reduction of the fixing points & assurance of the ground clearance

An additional benefit of the simplified wiring harness assembly process is the reduction of the assembly time needed to fix the high-voltage wiring harness to the vehicle body. When the final assembly process using a conventional high-voltage wiring harness with its higher sagging and more fixing points is analyzed as shown in Fig.13, it is evident that more process steps are required to fix this high-voltage wiring harness structure to the vehicle body compared to the pipe shield wiring harness. In addition to this time saving benefit, the handling of the pipe shield wiring harness is also much easier due to its higher rigidity and lower weight. Therefore, the pipe shield wiring harness concept provides an additional benefit of saving cost at the final vehicle assembly line.

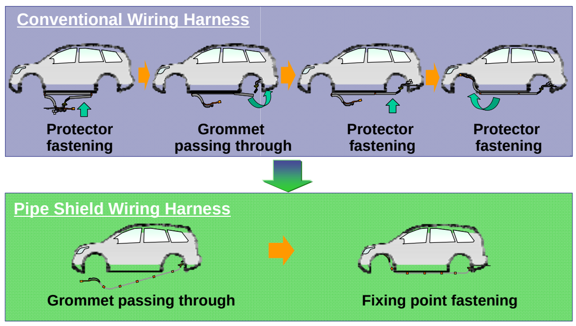

Figure 13: Reduction of assembly time

4.4 Simplification of wiring harness sheath design

The conventional high-voltage wiring harness usually requires a large plastic protector to provide mechanical protection in the under-floor wiring harness routing area. Therefore a wiring harness routing change would normally require a modification to the shape and / or size of this plastic protector as shown in Fig.14. This would result in a modified or completely new design of the moulding tool for this plastic component, and increases the parts cost and extending the development lead time. In comparison, any modification to the wiring harness layout in the pipe shield wiring harness concept can be easily achieved by a simple modification of the pipe bending parameters, using the same bending tool. This easy procedure guarantees a minimum cost increase and offers a short development lead time.

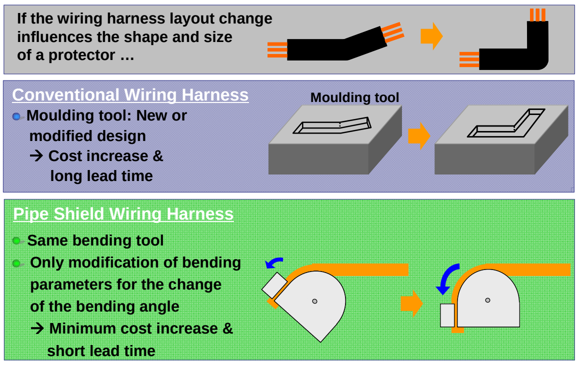

Figure 14: Simplification of wiring harness sheath design

Fig.15 illustrates how the development lead time for the wiring harness protection parts can be significantly reduced by using the pipe shield wiring harness concept. The large plastic protector on the conventional high-voltage wiring harness is shown in the upper time line in Fig.15.

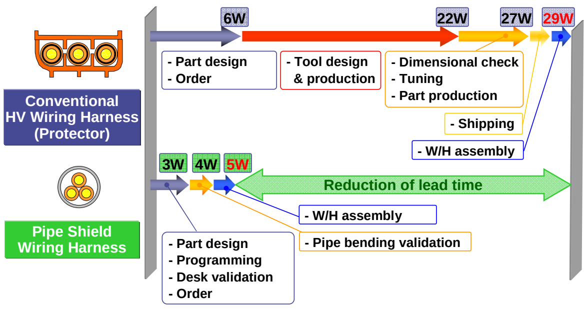

Figure 15: Reduction of lead time for development due to layout change

All conventional processes including the protector design and ordering, the tool design and its production and the dimensional check and fine tuning, take much longer than the development lead time of the pipe shield wiring harness concept. Using the standard aluminium alloy pipe, the part design and the programming of the bending parameters, including a desk validation, can be done relatively easily and quickly. A final pipe bending validation is done before the pipe is used in the wiring harness manufacturing process. A significant reduction in the development lead time for the high-voltage wiring harness protection parts is achieved by using the pipe shield concept.

4.5 Electromagnetic shielding performance

Another key characteristic is the electromagnetic shielding performance of the high-voltage wiring harness system. Fig.16 shows the test setup which we used to measure the EMC (electromagnetic compatibility) performance of the different high-voltage wiring harness concepts. This system configuration and test method were prepared according to the international standard CISPR 25.

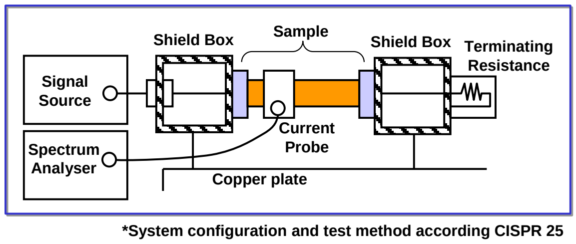

Figure 16: EMC performance measuring method

Fig.17 shows the EMC performance of different high-voltage wiring harness concepts. A test frequency range of 0.1 to 100[MHz] was used to match the range of EMI most likely to affect the radio reception in a vehicle. The results show that the pipe shield wiring harness design (including the terminals) has the best shielding effect up to 0.8[MHz] which is similar to the shielding performance of the bundle shield, while the individually shielded wires have the best shielding effect above the 0.8[MHz] range. Since the terminal shield connection also influences the shielding performance to a large extend, we think that it is quite difficult to make a clear comparison.

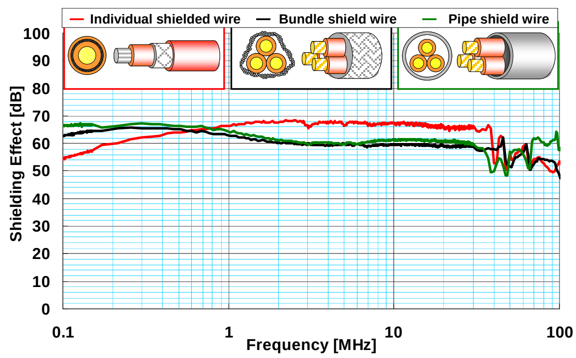

Figure 17: EMC performance of different high-voltage wiring harness concepts

However with regards to our customer's EMC performance specification, either shielding type provides sufficient protection against interferences with automotive radio reception.

4.6 Resistance of stone chipping

The final beneficial feature of the pipe shield wiring harness is its resistance to stone chipping which is required due to its under-floor routing of the high-voltage wiring harness. A painted aluminium alloy pipe sample was tested for its resistance against stones and a later additional exposure to a corrosive salt environment. Fig.18 shows the results of these tests. After the first stone chipping test, scratches on the painted surface were observed and limited paint peeling occurred. However after the additional salt spray test according to one of our customer's specifications, no further spread of paint scratches and peeling occurred. So the pipe shield w/h concept also provides a very good abrasion protection.

Figure 18: Results of stone chipping test and salt spray test

5 Conclusion

- Due to many years of experience in the development & mass-production of HEV wiring harnesses, Sumitomo has optimized the high-voltage wiring harness design and the related high-voltage components.
- Further development targets are to reduce costs, weight & size of components to improve assembly space and ease assembly into vehicle. One of Sumitomo's solutions is the pipe shield wiring harness, which has significant benefits and its performance is comparable with or better than conventional high-voltage wiring harness systems.

Authors

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