

High Voltage, Large Current Terminals for Hybrid Electric Vehicle Wire Harnesses

Sho Miyazaki*, Shigeru Sawada*, Masaharu Suetani*, Kiyoshi Hasegawa*,
and Kazumoto Konda°

In recent years, development of environment measure cars is an important theme of the earth environment protection and energy saving. Various kinds of hybrid electric vehicles increase the production rapidly. However, the vehicle price is one of the big themes for the hybrid electric vehicle's growth. High voltage harnesses necessary to connect between hybrid units (inverter to motor, battery) that must be fitted in a limited vehicle space. Especially, high voltage and high current wire harnesses for hybrid electrical vehicle need thicker cross section and higher connection reliability in comparison with wires for 12V.

In this paper, we set our goal of the terminal which is proof against vehicle vibration and is possible to apply high and continuous current. We successfully selected the structure and the material and developed the terminal at low cost, which is proof against vehicle vibration and is able to pass over 100A current. The developed terminals are used in Lexus GS450h.

Keywords: Connector, Harness, Terminal, Large Current, High Voltage

1. INTRODUCTION

In recent years, both consumers and automakers have shown increasing awareness of the necessity for new model automobiles to feature improved fuel economy and reduced carbon dioxide emissions, with one particularly strong driver of this trend being the rising price of automotive fuel. Although manufacturers have developed a number of approaches to improving the ecological performance of automobiles, hybrid vehicles—which feature a power plant that combines an internal combustion engine with an electric motor—have been readily accepted by the market, and sales of such vehicles are expected to increase steadily, in large part thanks to the fact that such vehicles can be operated in the existing infrastructure.

Given this background, automakers have been pressing for the development of inexpensive and easy-to-install (superior production efficiency) wire harnesses suitable for the electrical connection of the motor, inverter, battery, and other component elements in hybrid vehicles.

In this report, we discuss the types of connectors used,

the heat generated at connectors during application of current, and other aspects of the design and performance of large current connector terminals used in wire harnesses, taking the GS450h hybrid vehicle manufactured by Toyota Motor Corporation for an example.

2. LARGE CURRENT TERMINAL CONNECTOR STRUCTURE

First, let us classify the structure of typical terminal connections now in use.

2.1 Characteristics of Bolted Connectors and Mating Connectors

Harness connections can generally be classified into either of two types. *Bolted connectors*, as shown in Figure 1, secure contact using one or more bolts to hold the connector in place. In contrast, *mating connectors*, as shown in Figure 2, secure contact by mating two interlocking terminal housings.

Bolted connectors secure contact to the bus bar in a simple but secure manner that is resistant to the effects of vibration and other extremities found in automotive applications. Bolted terminals are not easy to install, however, and require extra time and effort to ensure that the bolts are all in place and have been tightened to the correct torque. The need to use a socket wrench

*AutoNetworks Technologies, Ltd., Sumitomo Electric Group, Japan

°Sumitomo Wiring Systems, Ltd., Sumitomo Electric Group, Japan

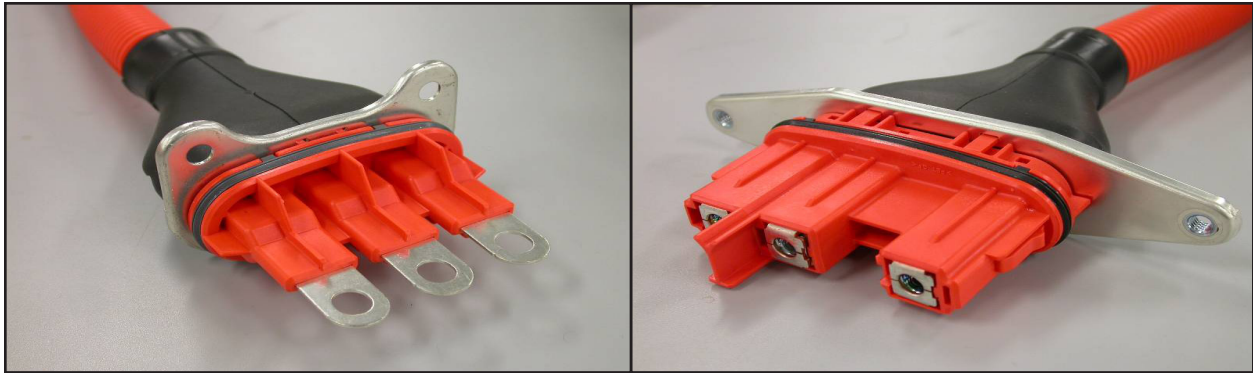


Figure 1: Bolted connector type (connection to inverter in the '03 Prius)

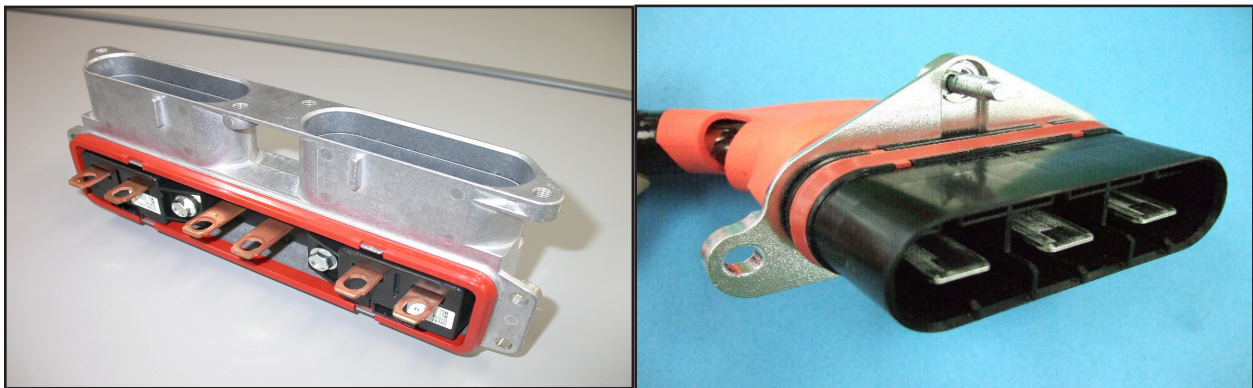


Figure 2: Mating connector type (connection to inverter in the GS450h)

or other tool also limits how closely the terminals can be placed to one another.

In contrast, mating connectors secure electrical connectivity simply by mating the two terminal housings, providing ready connectivity to the harness. And since mating connectors require the use of no tools, size reductions are always a possibility.

Also, whereas bolted connectors require application of a cover to ensure water-tightness, mating connector housings can be designed to be waterproof. Even though mating connectors often give the appearance of being costlier, there is plenty of potential for cost reduction depending on construction.

2.2 Types of Terminal Contact

There are a variety of terminal contact configurations already in general use. The results of a survey of existing terminal connectors used in large current power lines are shown in Figure 3.

The terminal contact configurations of the connectors shown in Figure 3 also fall into two major categories:

direct terminal-to-terminal contact, in which the conductors of both halves of the terminal connector come into direct contact and, terminal-to-spring contact, where an intervening spring is used to effect the connection between the two conductors.

What is important to note here is that both types contain a spring in the connector housing, but in a direct contact connector, the spring is not used for electrical connection but only to secure conductor contact. In contrast, in a spring contact connector, the spring intervenes between the conductors, and is itself an electrical conductor.

3. VERIFICATION OF TERMINAL ELECTRICAL CONDUCTIVITY

We next verified differences in electrical conductivity due to structure or construction, using model terminals.

3.1 Comparison of Differences in Electrical Conductivity between Direct Terminal-to-Terminal Connection and Connection with an Intervening Spring

Contact method	Direct contact				Indirect contact		
Spring contact	no	no	no (very little)	no	yes	yes	yes
Shape of Male-terminal	pin	pin	plate	plate	plate	pin	plate
Conductor resistance	Medium	Low	Low	Low	Low	Medium	Medium
Size	Medium	Small	Large	Large	--	Small	Large
Cost	High	Medium	Low	High	--	Medium	Low
Other	use slide door for 12V		9.5 type for HEV	ready-made	4.7 type for 12V		ready-made
Current path							

Figure 3: Typical terminal connectors used with large current power lines

Using models configured as shown in Figure 4, we compared electrical resistance and heat generation for both types of terminal contact to determine which was more suitable for large current power applications.

3.1.1 TERMINAL RESISTANCE

Formula 1 was used to calculate overall terminal resistance.

$$R_t = R_1 + R_2$$

(1)

where
R_t is the overall terminal resistance
R₁ is the conductor resistance
R₂ is the contact resistance

In so far as it is often extremely difficult to accurately assess contact resistance in design studies of overall

terminal resistance, and since there are many aspects of the product specifications that affect contact resistance, we felt that a direct comparison of different products would be unnecessarily confusing, and decided to perform a theoretical analysis of resistance for the two types of terminal contact shown in Figure 4.

Formula 2 was used to calculate conductor resistance.

$$R = \rho \frac{l}{S}$$

(2)

where
R is conductor resistance
ρ is electrical resistivity
l is the length of the conductor
S is the cross-sectional area of the conductor

Conductor resistance was calculated using the

contact method		Direct contact		Indirect contact	
Section	Female terminal				
	Male terminal				
material	case	pure copper or brass		pure copper or brass	
	spring	Stainless steel		Be-Cu	
Plating material		Sn		Sn	

Figure 4: Terminal contact configurations used to verify conductivity

cross-sectional area of the model terminals when the connector halves are mated.

Calculated results for the terminal cross-sectional area and conductor resistance of direct contact terminal connections are shown in Figure 5. An ambient temperature of 27°C and conductor resistance of 0.024 mΩ when mated were assumed.

Indirect contact connections have a complicated current path because of the arch-shaped spring intervening between the two conductors. We assumed a current path as shown in Figure 3, and considered the spring conductor resistance to be the combined resistance as calculated for a parallel resistance circuit comprising the two current paths through the spring.

The results of this calculation are shown in Figure 6. Just as with the direct contact connections, an ambient temperature of 27°C was assumed as well as a conductor resistance of 0.059 mΩ when mated were assumed.

These results indicate large increases in spring conductor resistance for indirect contact connections, which are designed with extremely small cross-sectional areas.

Conductor resistance for indirect contact connections can be lowered by increasing the cross-sectional area of the spring and by selecting spring material with higher electrical conductivity, but in actual practice this would result in larger springs, necessitating an increase in the overall size of the terminals, as well.

Figure 7 shows the measured values for overall terminal resistance for the model terminals, from which the theoretical values for conductor resistance can be subtracted to find approximate values for contact resistance.

The relative proportion of the theoretical value for conductor resistance to the mean measured value of overall terminal resistance is 39.9% for direct contact and 60.2% for indirect contact, indicating that the proportion of overall terminal resistance occupied by conductor resistance is high.

3.1.2 TERMINAL HEAT GENERATION

We next compared the amount of heat generated by the terminals. Terminal contact configurations are shown in Figure 4. In order to achieve a meaningful comparison of these two different configurations, we elaborated the models to have identical terminal surface areas and to generate identical levels of radiant heat from that surface.

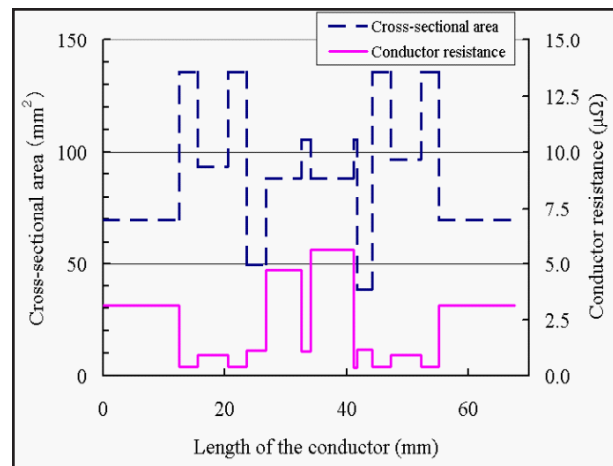


Figure 5: Calculated results for conductor resistance of direct contact connections

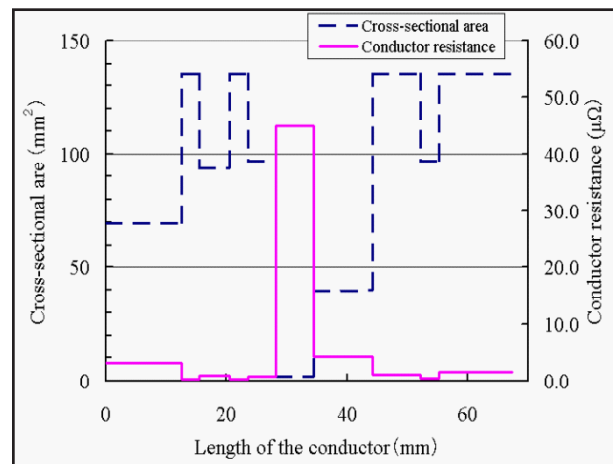


Figure 6: Calculated results for conductor resistance of indirect contact connections

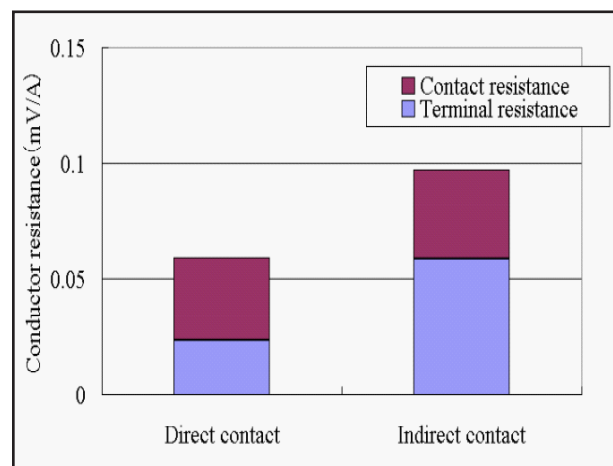


Figure 7: Measured values for overall terminal resistance

Formula 3 was used to calculate the rise in terminal temperature under steady-state conditions.

$$W_{ter} - (Q_{ter-wire} + Q_{ter-air}) = 0 \quad (3)$$

where

W_{ter} is the heat generated by the terminal and equal to $I^2 R_{ter}$

$Q_{ter-wire}$ is the heat dissipated from the terminal to the wire, and is proportional to $\Delta T_{ter-wire}$

$Q_{ter-air}$ is the heat dissipated from the terminal to the atmosphere, and is proportional to $\Delta T_{ter-air}$

The heat generated by the terminal is represented by $I^2 R$, however, if the wire diameter, wire temperature, and terminal surface area are assumed to be constant, differences in temperature of the terminal, wire, and atmosphere will require application of a radiant heat coefficient, where based on Formula 3, we get

$$\Delta T_{ter-wire} = \alpha I^2 R + \beta \quad (4)$$

and the rise in temperature under steady-state conditions is a linear function of terminal resistance.

Figure 8 shows measured values for terminal temperature.

These measured values also demonstrate the linear relationship between rise in temperature and terminal resistance, and how lowering the overall terminal resistance can help keep terminal temperature down. Thus low terminal conductor resistance can be considered a merit in the design of terminals for high-current systems.

4. LARGE CURRENT TERMINAL HYBRID VEHICLES

The 13.0-type terminals applied to the Toyota GS450h are significantly larger than the 9.5-type terminals applied to previous models due to the higher currents used in this more powerful hybrid system.

4.1 Terminal Structure

Figure 9 shows 9.5-type high-current terminal developed for hybrid vehicles as well as the 13.0-type terminal applied to the Toyota GS450h.

The 13.0-type terminal applied to the Toyota GS450h

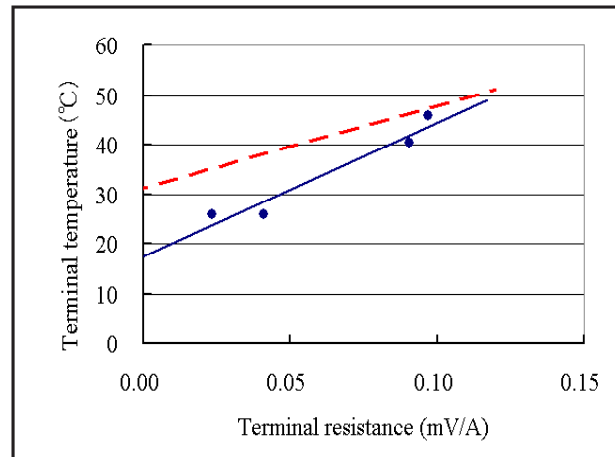


Figure 8: Measured values for temperature increases in 7 mm diameter model terminals

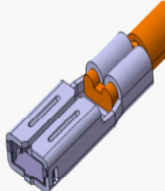
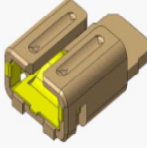
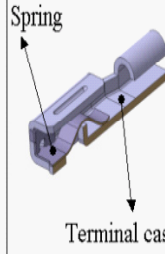
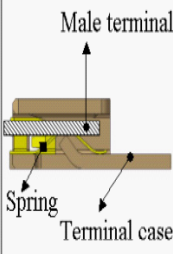
Terminal type		9.5-type	13.0-type
External view			
Section of terminal			
Material	case	Copper alloy	Copper alloy
	Spring	stainless steel	stainless steel
Plating material		Sn	Sn
applicable wire size		8~15sq	20sq

Figure 9: Structure of 9.5-type and 13.0-type terminals

comprises the same direct contact configuration used for 9.5-type terminals applied to previous hybrid vehicles. Both types required a thick terminal housing due to large current electrical system. This meant that, unlike the 12V terminals shown in Figure 3, it was impossible to build a spring into the terminal housing, so a separate stainless steel spring was used to secure contact between the male and female terminals of the two-piece terminal housing. Also, from a cost

standpoint, the final terminal shape can be formed with a progressing stamping process, which helps to maintain low cost production.

4.2 Terminal Performance

Figure 10 shows measured values for voltage drop across the 9.5-type and the 13.0-type terminals. Using calculations identical to those above, we found that the larger terminal demonstrated a 37.9% reduction in conductor resistance.

Also, Figure 11 shows measured temperature values for 9.5-type and 13.0-type terminals

5. CONCLUSION

With hybrid systems expected to continue to evolve into more powerful yet more compact ones, the need is apparent for smaller high-current terminal connectors for hybrid vehicles, and we feel that the use of direct connections is especially well suited to the design of smaller sized high current terminal connectors for hybrid vehicles.

REFERENCES

- [1] Ho, Seizaburo. Electrical Materials, 4th Edition. Kyoritu Shuppan
- [2] Miyata, Takahiro, ed. Basics of Electricity and Electronics. Gijutu Hyoronsha
- [3] Automotive parts-Current capacity of low tension cables, JASO D609 2001

AUTHORS



Sho Miyazaki, Manager, AutoNetworks Technologies, Ltd., sho-miyazaki@gate.sws.co.jp, phone: 81-59-354-6324.



Shigeru Sawada, Manager, AutoNetworks Technologies, Ltd., sigeru-sawada@gate.sws.co.jp, phone: 81-59-382-8634.



Masaharu Suetani, AutoNetworks Technologies, Ltd., masaharu-suetani@gate.sws.co.jp, phone: 81-59-354-6324.

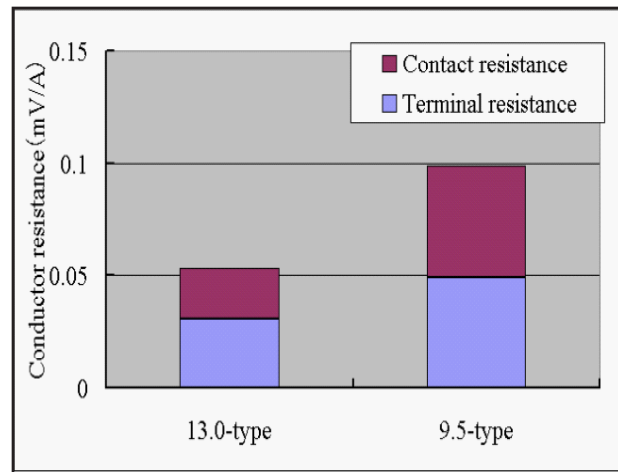


Figure 10: Measured values for conductor resistance in 9.5-type and 13.0-type terminals

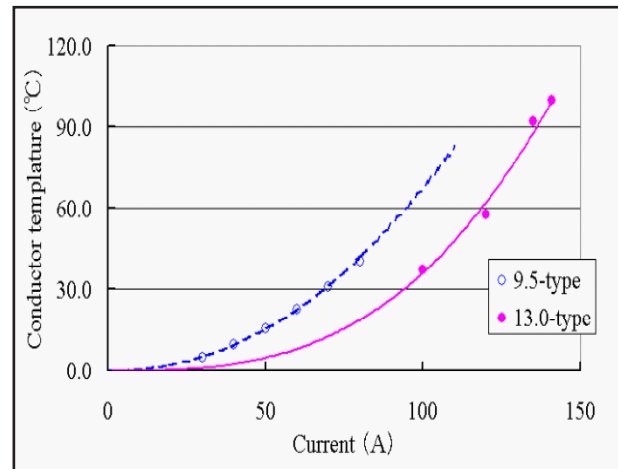
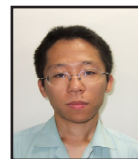


Figure 11: Measured temperature values



Kiyoshi Hasegawa, AutoNetworks Technologies, Ltd., kiyoshi-hasegawa@gate.sws.co.jp, phone: 81-59-354-6324.



Kazumoto Konda, Manager, Sumitomo Wiring Systems, Ltd., kazumoto-konda@gate.sws.co.jp, phone: 81-59-382-9587.