A Junction Block Incorporating a Micro Heat-Pipe

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ABSTRACT Recent progress in automotive technologies has been remarkable and has been accompanied by a steady proliferation in electric circuitry and auxiliary equipment, leading to a growing need for electrical devices for the vehicle.

Junction boxes are generally the means used to simplify increasingly complex circuitry but the strong trend in recent years to incorporate more circuits and components has brought about a heightened need for more compact, higher-density designs.

In addition the heat generated by relays, fuses and other components has become a major issue, and for the first time a micro heat-pipe has been used to address the problem of heat from automotive electrical equipment. Further development work is expected to make this a priority technology for Furukawa Electric.

1. INTRODUCTION

More than 20 years have already passed since a junction block was developed to simplify the complicated car electric circuits of a wire harness, and nevertheless the junction block has been used until now with its structure remaining almost unchanged. The rising temperature in the block has always been a problem, and the various methods required for the preventive measures have become the main cause of the increase in cost. This excessive rise in temperature not only causes such troubles as degrading or malfunction of parts due to overheating but also, at worst, might eventually cause a fire in the car. Although the temperature rise problem of the junction block, which is one of the most important safety parts, was expected to be solved as soon as possible, no drastic preventive measures have been found until now.

The micro heat-pipe mounted to the junction block is expected to give a drastic solution to the rising temperature problem.

Following are the advantages of the micro heat-pipe:[1)]

(1) Simple structure and simple operating principle, trouble-free,
(2) Excellent isothermal property and high heat transfer performance,
(3) Low heat resistance and good thermal response,
(4) Operating by non-motive force (by temperature difference only) and noise-free,
(5) Excellent workability and free in mounting shape, and
(6) Very compact, occupies a small amount of space.

Thus, the mounting of the micro heat-pipe to the junction block is deemed to provide many advantages. However, this was the first time to employ the micro heat-pipe to a car under a severe environment, and various problems were thought to arise. The authors introduce hereunder the micro heat-pipe, which they started to develop several years ago and succeeded in putting into practical use in a new model car that was launched into mass-production in January, 1998.

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2. ON MICRO HEAT-PIPE

2.1 Construction and Working Principle

The heat-pipe is generally defined as a heat transfer device which is a closed vacuum vessel containing a small amount of a volatile medium called operating liquid enclosed in a wick having capillary force to circulate the medium and performs heat transfer by the medium which repeats evaporation and condensation continuously[2)]. The micro heat-pipe is the generic name of heat-pipes for micro device heat radiation, and heat-pipes of 3 mm, 4 mm and 6 mm in diameter are currently put into practical use. A heat-pipe of 3 mm in diameter is adopted in this experiment.

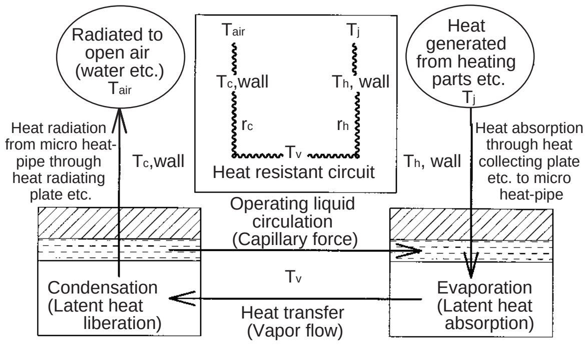


Figure 1 Working principle of micro heat-pipe

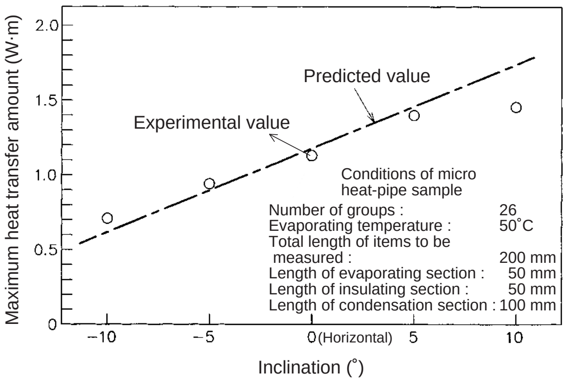


Figure 2 Maximum transferable heat of micro heat-pipe

A micro heat-pipe is made of pure copper and its inside is kept highly depressurized. Figure 1 shows the working principle which illustrates that heat transfer is performed by circulation of pure water i.e. the operating liquid which repeats evaporation and condensation.

2.2 Maximum Heat Transfer Amount

Figure 2 shows a comparative graph of the calculated value and measured value of the maximum heat transfer amount for a micro heat-pipe[3]. It is understood from the graph that the maximum heat transfer amount increases as the tilt of the pipe increases while the heat transfer amount per micro heat-pipe is approximately 9 W when the pipe is held horizontally(at zero inclination).

2.3 Long-Term Reliability

For employment of a micro heat-pipe as a car device, not only its performance but also its long-term reliability under diverse environmental conditions is essential. The standard for manufacturing the micro heat-pipes developed by Furukawa are based on manufacturing methods inclusive of various special types of processes to improve the long-term reliability. They have established the reliability of over 60 years under the same definite operating condition[4]. The 60-year reliability can be said " to be enough" in terms of a car's life.

2.4 Problems in Employment to Car

2.4.1 Breakage by Freezing

A micro heat-pipe which uses pure water as its operating liquid may break by freeze-expansion when the temperature goes below 0°C. Since micro heat-pipes used in cars are longer in length than those used generally (such as a personal computer), more operating liquid is required. The temperature inside a car engine room is lowered to the outside air temperature when the car is parked, this temperature drop becomes serious especially in winter. Therefore, the authors have taken up this problem as one of the essential issues which requires countermeasures in view of quality assurance.

2.4.2 Heat Collecting/Radiating Structure

We have already studied the micro heat-pipe to give it a certain heat transfer performance as a heat transfer device. However, the structure for heat collection to micro heat-pipe and that for heat radiation from micro heat-pipe are important points for efficient heat transfer, and it is also necessary to consider a structure bearable even under the severe environmental conditions as well as a mounting structure to the junction block. Hence, the authors have taken up the problem as their technical task for a solution.

3. APPLICATION OF JUNCTION BLOCK, USING MICRO HEAT-PIPE

3.1 Background and Objective of Development

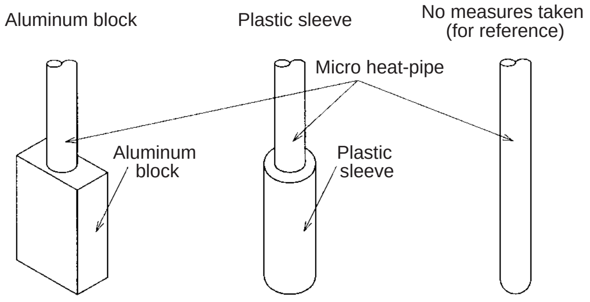
The automation of a car wire harness manufacturing process is behind the times, however the improvement of productivity and reduction of fraction defective have always been important tasks. Besides, in the case where a large number of circuits are used, the enlargement of diameter in the wire harness as a trunk line and the increase in weight are inevitable, resulting in lower production and deterioration in quality at the car manufacturer plant. In particular, a car model which has been developed at this time has a large number of circuits and the manufacturer was keenly in need of the quality improvement of a wire harness, capable of making production easier than before.

At this time, various measures have been taken to decrease, as much as possible, the number of splice joints and complicated branches in a wire harness that are the causes of lower production. Also, as our goal of this development, simplification of a wire harness was set by accumulating circuits into junction blocks. The application of the micro heat-pipe to the junction block is a step for realization of the optimum form of a wire harness. Thus, the development has been proceeded mainly to solve the problems as cited in 2.4 above.

3.2 Major Development Items (1)

3.2.1 Measures against Breakage by Freezing

It was found in the freeze-breakage test of a micro heat-pipe that it was not broken, even though its length elongated to a certain extent, unless it was tilted at an angle of over 15 degrees from the horizontal. It is extremely hard, however, to manage and keep the angle of heat-pipe al-



* All the micro heat-pipes used have 200 mm length
* Conditions of sample such as dimensions etc. are omitted. (Tests conducted on several types of samples.)
* Test conducted on several types of samples for anti-freezing measures other than the above. (Details are omitted.)

Figure 3 Test samples for prevention of breakage by freezing

Table 1 Evaluation test results for prevention of breakage by freezing using partial samples

Aluminum block	Plastic sleeve	Measures not taken (for reference)
Cleared 1,000 cycles	Broken at around 200 cycles	Broken at only several cycles
· No change in appearance · Adhered to aluminum block due to the expansion of the micro heat-pipe · Good in post-test operation	· No change in appearance · Adhered to plastic sleeve due to the expansion of the micro heat-pipe · Broken at sleeve	· The part slightly above the end of the micro heat-pipe was broken due to the expansion
Judgement ○	×	×

* The micro heat pipe used is 200 mm in length.

ways level, especially in the conditions of parking lots. Moreover, it is impossible to always ensure the performance of a unit junction block as a spare part and also keep it safe in the event of car accidents. At this time, various types of samples have been made as shown in Figure 3 and the verification tests by heat cycles have been carried out.

3.2.2 Method, Conditions and Standards for Evaluation

Under the test of heat cycle, the samples were held in a vertical position in evaluating conditions where the temperature was repeatedly changed from -14°C to +10°C / one cycle (30min). We set a standard value for the test of evaluation. This was obtained from the formula shown below, on the basis that the frequency of freezing for a day was once, winter season for a year was three months, the period of guarantee was 10 years.

Once(frequency) × 3(months) × 30(days) × 10(years)
= 900 = around 1000 cycles

3.2.3 Test Results and Measures against Freeze-Breakage

Table 1 shows the results of the evaluation test. Only an aluminum block cleared the evaluation standard of 1,000 cycles, and the other blocks were broken due to the expansion by freezing around the end of the micro heat-pipe. Since the aluminum block is expensive and requires ample space, the development was carried out using a copper sleeve, and the optimum dimensions such as the thickness and length of the sleeve were determined according to the evaluation in various aspects.

3.2.4 Appropriate Operating Liquid Volume for Micro Heat-Pipe

As our development of the micro heat-pipe progressed, the length to be used was determined as 316 mm. It was revealed, however, that this size did not protect the micro heat-pipe against breakage by freezing even using a copper sleeve, since the size of the heat-pipe required more amount of internal operating liquid not to lower the maximum heat transfer. It was also found that, with a 316 mm micro heat-pipe length and with such an operating liquid volume so as not to decrease the maximum heat transfer

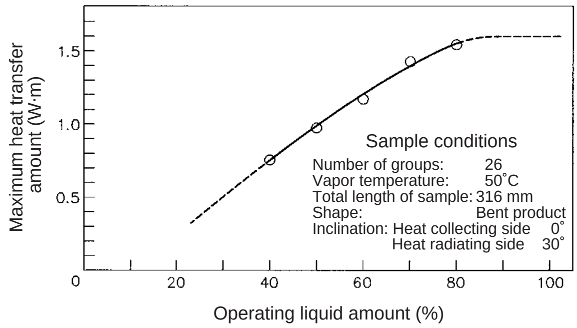


Figure 4 Relationship between working fluid volume and maximum transferable heat

amount (the amount will be referred to hereafter as V), a breakage took place at the bottom end of the micro heat-pipe even though the sleeve length was elongated for enlarging its protective portion. It finally became necessary to determine the amount of operating liquid to establish the measures by a copper sleeve against freeze-breakage.

A sample of a micro heat-pipe was made, having its length of 316 mm and the before said appropriate operating liquid amount V was decreased to 40-80%, and a heat cycle test was conducted to verify the operating liquid amount.

The result of the test revealed that in the case where a 316 mm long micro heat-pipe was held in a vertical position for a long period of time, the threshold value with which the measure against freeze-breakage to be effective was 60% of V or less. In this consequence, it was decided that the operating liquid amount for the micro heat-pipe to be used in the junction block should be 40-60% of V (a marginal range was set, taking the yield into consideration).

3.2.5 Change in Maximum Heat Transfer Amount vs. Change in Operating Liquid Volume

Since the decrease in operating liquid, as measures against breakage by freezing, directly affects the heat transfer performance, the maximum heat transfer amount was measured in the specification of a new product. Figure 4 shows the relationship between the operating liquid amount and the maximum heat transfer amount.

As the result of measurement, it was found that the maximum heat transfer amount of the sample having the operating liquid amount of 40-60% of V was about 4-6 W when the micro heat-pipe was mounted to a car. The heat transfer performance of the sample was lowered as compared to the performance in standard operating liquid amount, however this is the only solution for the freeze-breakage problem which directly affects the total quality of the micro heat-pipe at the moment, it was therefore decided to proceed with the development in this specification.

3.3 Major Development Items (2)

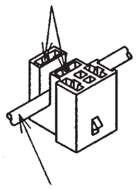
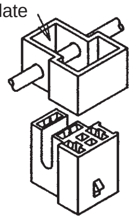
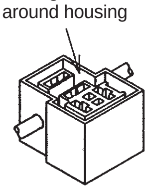
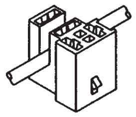
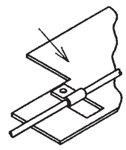
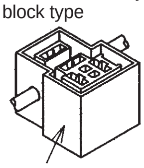
3.3.1 Investigation of Heat Collecting / Radiating Structure

Regarding the pipe positioning, we studied a wire connected type relay block, integrated bus bar type junction block and other various block units. In the present development, the mounting structures for each relay block and junction block were investigated and the differences in the effects between them were confirmed.

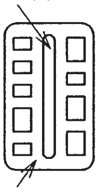
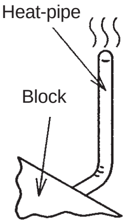
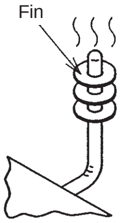
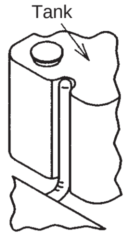
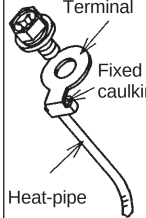
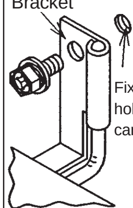
First, the heat collecting structure and heat radiating structure for each type of blocks were examined and the evaluation of the effect was carried out using model

Table 2 Optimum structures of heat collecting and heat radiating sections

(1) Structure of heat collecting section

	Relay block type			Junction block type		
	Direct insertion	Heat collecting plate	Potting	Direct insertion	Heat collecting plate	Potting
Structure views (Images)	Contact terminal  Heat-pipe	Heat collecting plate 	Potting resin is filled around housing 	Same as for relay block type 	Heat collecting plate  Arranging heat collecting plate over the junction block	Same as for relay block type  Outer wall of housing
Heat collectability	△	○	○	×	○	△
Reliability	○	△	○	○	○	○
Possibility of establishment	○	○	○	△	○	○
Ease in assembly	○	○	×	○	○	×
Cost	○	△	×	○	△	×
Total judgement	○	△	×	△	○	×

(2) Structure of heat radiating section

	Closed	Air cooling		Water cooling	Mounting to car body	
	Built-in	Natural air cooling	Fin	Washing tank	Terminal locked by screw	Fixed by bracket
Structure views (Images)	Heat-pipe  Block	Heat-pipe  Block	Fin 	Tank 	Terminal  Fixed by caulking Heat-pipe	Bracket  Fixing hole on car body
Heat radiatability	×	△	△	○	△	○
Reliability	○	△	△	△	○	○
Possibility of establishment	○	○	○	×	○	○
Ease in assembly	○	○	△	△	△	○
Ease in mounting to a car	○	△	△	△	○	○
Cost	○	○	×	×	△	○
Total judgement	△	△	×	×	△	○

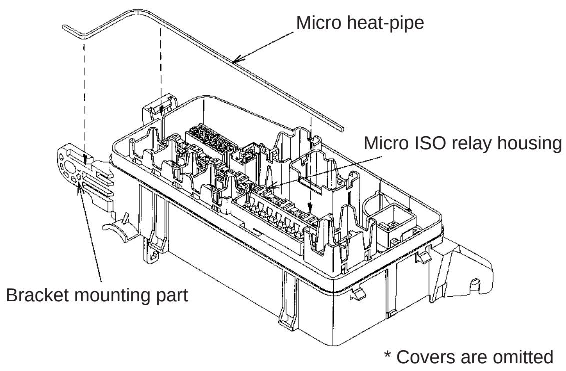


Figure 5 Prototype of relay block for evaluation of assembly into car structure

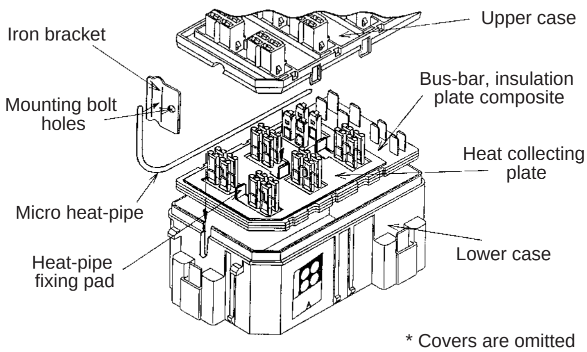


Figure 6 Prototype of junction block for evaluation of assembly into car structure

samples. As shown in Table 2, in the relay block type, the direct insertion method was desirable; in the junction block type, fixing the micro heat-pipe to a heat collecting plate was desirable for heat collecting. For the heat radiating structure, fixing the micro heat-pipe directly to a car body by bracketing was the most effective.

3.3.2 Consideration of Mounting Structure to Car by Block Types

After consideration on the automotive block applications of the above confirmed heat collecting / radiating structures, the mounting structure was investigated using existing blocks of several different types.

(1) Mounting structure of a relay block type

A partly remodeled relay block having a general structure was used as a sample. As shown in Figure 5, the heat collecting section is inserted directly between the terminals on the contact side of the micro ISO relay, and the heat radiating section is extended to a bracket portion so that contact is made with the iron plate of the car body by tightening the bracket.

(2) Mounting structure of a junction block type

A partly remodeled junction block having a general structure was used as a sample. As shown in Figure 6, a heat collecting plate is used for the heat collecting section and the heat radiating section is extended to another iron plate bracket and tightened by this bracket so that contact is made with the iron plate of the car body. Then the micro heat-pipe is made to contact with and fixed to the heat collecting plate by clamping the micro heat-pipe fixing portion with this plate's curled hook portion.

Table 3 Comparison of the effect of micro heat-pipe in the block

Items	Relay block type		Junction block type	
	Lowered temperature	Lowering rate	Lowered temperature	Lowering rate
Maximum effect	3.7˚C	5.0 %	8.9˚C	21.9 %
Minimum effect	0.3˚C	0.6 %	4.3˚C	10.7 %
Average effect	1.6˚C	2.8 %	6.6˚C	17.1 %

* The lengths of micro heat-pipes used are about 250 mm for relay block type and about 150 mm for junction block type, depending on the structure difference in blocks

3.3.3 Result of Evaluation on Effect Comparison

Table 3 summarizes the test result of comparison among the samples. In the relay block type, the temperature lowering effect of a maximum of 3.7°C (5.0%) and an average of 1.6°C (2.8%) was observed. This effect was limited only to the vicinity of the micro heat-pipe and less effect was observed at a distant place. The fact-- that the temperature lowering effect is less for comparatively high heat transfer performance of the micro heat-pipe-- may be due to the lowering of heat collecting efficiency by such a structure where resin and air layers exist between the micro heat-pipe and heat source.

While in the junction block type, a significant temperature lowering effect of a maximum of 8.9°C (21.9%) and an average of 6.6°C (17.1%) was observed. Besides, this effect was observed all over the block as compared to the relay block type, from which it may be concluded that the heat collecting plate worked effectively.

It can be said that the junction block type, which uses a heat collecting plate, is superior to the relay block type for making the micro heat-pipe work effectively. It was, therefore, decided thereafter to proceed with the development of the junction block type.

3.4 Thermal Simulation and Calculation of Heating Value

In the design of the junction block-- in order to estimate the number of micro heat-pipes required, the temperature rise distribution and the effect of the micro heat-pipe were confirmed by thermal simulation. This was carried out in the case where specified circuits and parts were assembled within the dimensions of a junction block designated by car manufacturers. Since the internal structure and other details were not specified, the simulation test was conducted using a simplified model. It was hard to analyze the complicated internal structure using limited data, and the simulation was not able to give the same results as shown in 3.3.3 where the effect was checked. Car manufacturers also express a strong request for the establishment of the thermal simulation technology. It is, therefore, necessary to immediately develop software which enables the analysis precisely even with limited parameters during the initial period of development, and this is deemed as an important future task.

The number of micro heat-pipes required was estimated by the heating value calculation of the junction block.

From equation (1), the total heating value of a new heat-pipe is estimated to be about 23 W.

$$Q_{ALL} = Q_R + Q_F + Q_B + Q_C \text{ ------------------------- } (1)$$

Where, Q_{ALL} is a total heating value, Q_R is the relay heating value, Q_F is the fuse heating value, Q_B is the bus bar heating value and Q_C is the connection heating value.

Next from equation (2), the junction block internal temperature rise is estimated to be about 50°C.

$$Q_{ALL} = 1.78 S_{eq} \times \Delta T_m^{1.25} \text{ ---------------------------- } (2)$$

$$S_{eq} = S_t + S_s + S_b /2 \text{ --------------------------------- } (3)$$

Where, ΔT_m in equation (2) is the junction block internal temperature rise, S_t in equation (3) is the upper area, S_s is the side area and S_b is the bottom area of a junction block respectively[5)~6)].

The junction block standard temperature rise designated by the car manufacturer (to be mentioned hereafter) is below 40°C, and the heat transfer amount of a micro heat-pipe required is estimated to be approximately 4.5 W from equation (4).

$$Q_X = Q_{ALL} \left(\Delta T_m - T_k \right) / \Delta T_m \text{ ------------------------ } (4)$$

Where, Q_x is the heat transfer amount required and T_k is the junction block standard temperature rise designated by the car manufacturer.

Comparing the results with the data on the maximum heat transfer amount cited in 3.2.5, the heat transfer may seem to be a little insufficient; however, the number of micro heat-pipes required for the junction block was decided at one, taking into consideration the temperature lowering effect due to the thermal equalization work by the heat collecting plate.

3.5 Structure of Junction Block with Micro Heat-Pipe

Figure 7 shows an outside view of the new product developed at this time, i.e., the junction block to which a micro heat-pipe is applied (a lower cover is not illustrated). It was designed according to the results of the previous consideration. Figure 8 shows a rough illustration of the component parts excluding covers; Figure 9, the structure of a heat collecting section; Figure 10, the structure of a heat radiating section.

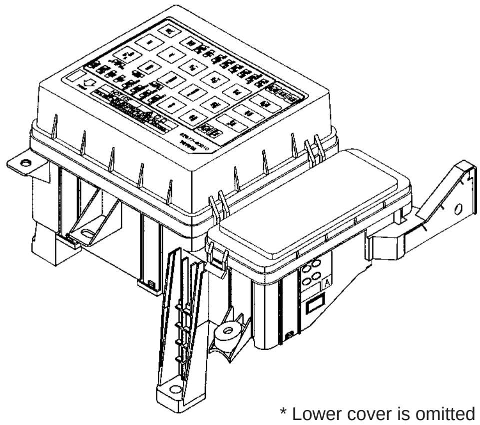
For freeze-breakage prevention, copper sleeves were soldered at both ends of the micro heat-pipe and a bending process was done to the pipe considering the heat transfer efficiency when it is mounted to a junction block, so that the heat radiating section is directed upward.

The heat collecting plate was layered at the top of a one-pieced circuit layer composite in the junction block. The micro heat-pipe was fixed by caulking to a curled part of the heat collecting plate and a TOX process (generally a thin plate jointing method by deep drawing using punch and die) was made at the curled spot.

The heat radiating plate was mounted to a fixed bracket portion of a car body, and by fixing the junction block the heat radiation plate came in contact with a car body. For the fixing of the heat radiating plate to the pipe, a part of the heat radiating plate was curled and caulked and then fixed by soldering.

Hereunder are given the principal advantages of the junction block incorporating the micro heat-pipe which has been developed at this time.

(1) The world's first mounting of a micro heat-pipe to the junction block has realized a compact and high density assembly of many circuits and parts into the block and contributed to the simplification in the wire harness of the power source system in the car.



* Lower cover is omitted

Figure 7 Appearance of developed product

* Covers are omitted

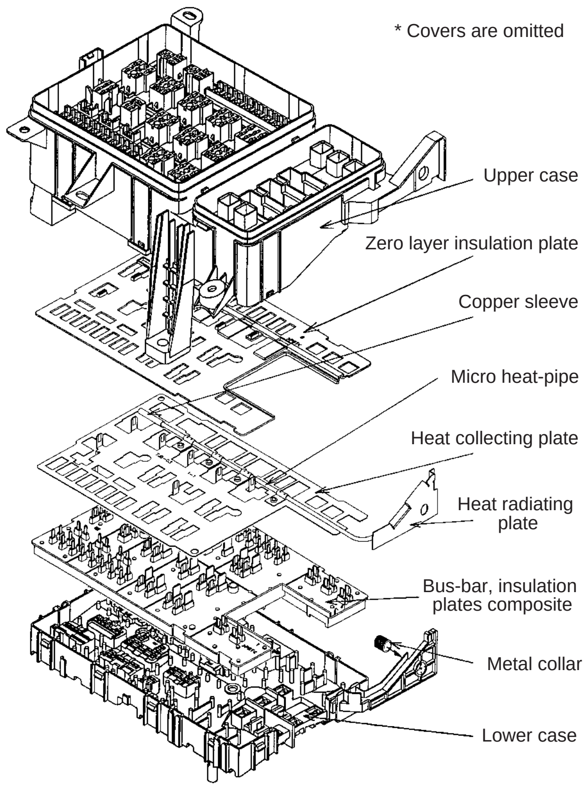


Figure 8 Components of developed product

(2) The heat collecting plate, which is also used as a grounding bus-bar, reduces the joints of several relay coil circuits. The micro heat-pipe connected to the heat collecting plate and the heat radiating plate functions as the grounding bus-bar, thus the multi-functional property of the micro heat-pipe has increased its value.
(3) With the consideration that heat generally moves upward in the junction block, the heat collecting plate and the pipe are placed on top of the layered circuits to improve heat collecting efficiency.
(4) Owing to the measures taken against freeze-breakage of the micro heat-pipe, the long-term reliability was enhanced by taking into consideration the quality, not only during the mounting period to an actual car, but also during the storage period as a supplemental part.
(5) Making the heat radiating plate come in contact with the iron body plate of a car, heat can be dissipated from the junction block directly to a car, thus enhancing heat radiating efficiency.
(6) The high-temperature, high-strength solder, excelling in an anti-crack property, was used on the micro heat-pipe fixing part and sleeve fixing part of the heat radiating plate which protrudes outside of the junction block. It improves resiliency against the environment as well as reliability in the electrical and thermal connection.

3.6 Method, Conditions and Standards of Evaluation as a Junction Block

Based on the method, conditions and standards of evaluation on the junction block specified by the car manufacturer, various evaluation tests have been conducted including tests on initial characteristics, durability etc. Confirmation has been made for the performance and the effect of the micro heat-pipe.

Here, criteria for evaluation in the temperature rise test will be described which is of the utmost importance among various evaluation tests. The critical temperature rise of below 40°C is decided on the basis of stress relief performance of a brass terminal against temperature. The heat-resistant limit temperature at which the electric brass terminal can maintain its performance is 120°C, and the engine room temperature is 80°C in general. Thus the limit temperature rise is calculated, 120°C minus 80°C equals to 40°C.

3.7 Results of Various Evaluations and Effect of Micro Heat-Pipe

It was confirmed that the junction block developed this time finally cleared all the criteria for evaluation designated by the car manufacturers and no problems exist with regard to mounting it to a commercial car.

The verification was carried out on the effect of the micro heat-pipe incorporated into junction block by conducting the temperature rise test on both the junction blocks, with and without the micro heat-pipe. Figure 11 shows the test result.

The effect of the micro heat-pipe covered the entire junction block by the heat collecting plate, and the lowering of temperature was observed by a maximum of 9.4°C (19.7%) and an average of 3.5°C (6.8%). The effect was conspicuous particularly in the proximity of its mounting portion where relays are concentrated. This is due to the effective and synergetic action of both collecting local heat by the micro heat-pipe and the heat equalizing by the heat collecting plate over the entire junction block.

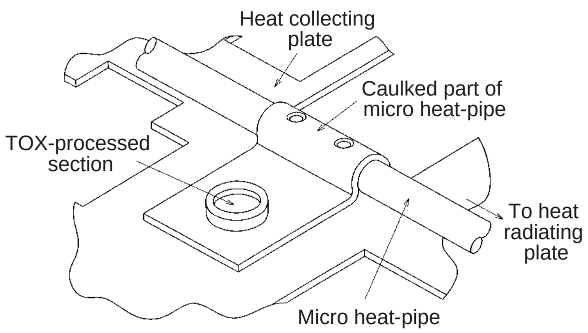


Figure 9 Heat collecting structure of developed product

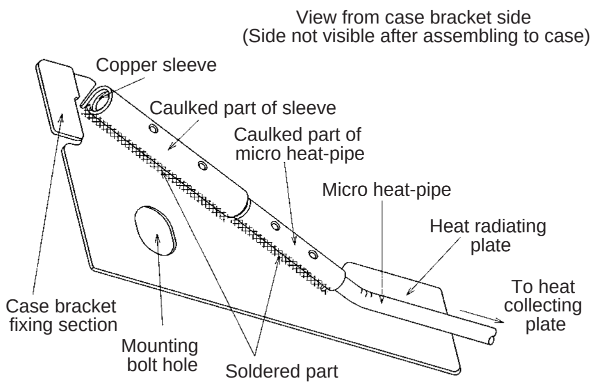
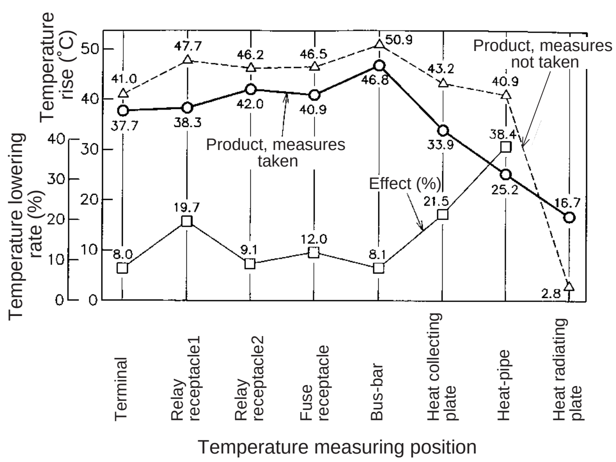


Figure 10 Heat radiating structure of developed product



* Figure shows only representative temperature measuring positions where temperature lowering effects were remarkable
* For J/B without measures, ordinary copper pipe was used in place of heat-pipe
* At the heat radiating plate, J/B with measures shows higher temperatures due to the effect of micro heat-pipe

Figure 11 Validation test results of micro heat-pipe in developed product

4. CONCLUSION

In this development, the followings are confirmed: the performance of the micro heat-pipe incorporated into junction block (in a car under various environmental conditions), applicability of a micro heat-pipe to a car(under a severe environmental conditions), and its effect to temperature (rising and lowering). It was revealed that the measure using the micro heat-pipe was superior to others and was able to contribute to the solution for many technical problems.

However, in this development, there still remain several points to be reviewed in the future:

(1) Establishment of a thermal simulation method
(2) Further improvement of heat collecting / radiating efficiency and the structure of the micro heat-pipe
(3) Measures against freeze-breakage by operating liquid amount which maximum heat transfer volume does not decrease
(4) Further cost reduction
(5) Search for and investigation of heat radiating technology other than by application of a micro heat-pipe

The solution of these problems will lead to the establishment of a technology superior to those of competitors and the advancement in technical development in the future is eagerly required.

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