

Development of Low-cost Card-edge ECU for Small Motorcycles

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ABSTRACT

In the development of ECU this time, the transfer molding of semiconductor manufacturing method and the card edge connector technology were applied to the ECU of electronic fuel injection system. In the ECU, whole components, except for the edge connector terminals, are sealed with resin. This ECU is transfer-molded using an epoxy resin specifically developed and mold die with a new mechanism. Furthermore, we developed a waterproof card edge connector to be mated with this ECU. Multi-contact terminals and vibration suppressing mechanism were applied to get a stable contact state. These enabled the equivalent vibration resistance as before and the detachability to the ECU in narrow space. With those measures, the developed ECU achieved more than five times higher productivity and 20% cost reduction compared to the conventional products.

1. Introduction

To cope with the global warming issues, Honda has been applying electronic fuel injection systems to small motorcycles since the beginning of year 2000 to reduce exhaust emissions and to enhance fuel economy. The steadily growing small motorcycle market is calling for further enhancement of production efficiency and cost reduction from the fuel injection system.

Figure 1 shows the structure of a conventional ECU. The printed circuit board (hereafter PCB), on which the electronic components and the male connector are mounted, is filled in the plastic case with the thermoplastic resin for protection from the outside environment. This ECU is mated with the waterproof female connector, and mounted in the small space between the engine and the frame body of the small motorcycle.

Upon the careful analysis of the component parts, the material, and the production processes of the said structure being in use from the early days of application of electronic components to motorcycles, we found a potential to enhance productivity in the male connector soldering process and the resin filling/hardening processes, and thought that the structures should be renewed for further cost reduction.

Figure 2 shows the newly developed card edge ECU and the connector. In this ECU, all parts except the edge connector terminals, which is an integral part of the PCB, are transfer-molded using the epoxy resin. This structure

requires no male connector, plastic case or filling resin. The edge connector terminals and the molded ECU serve as an alternative male connector.

This structure is recognized as an option of future ECU for automotive having an integrated mechanical/electrical systems and effective for productivity enhancement and cost reduction⁽¹⁾, and some practical applications are already seen in some areas⁽²⁾. However, none has ever realized high production efficiency and low cost while maintaining the performance and durability necessary for our motorcycles. We therefore started this project to satisfy such requirements.

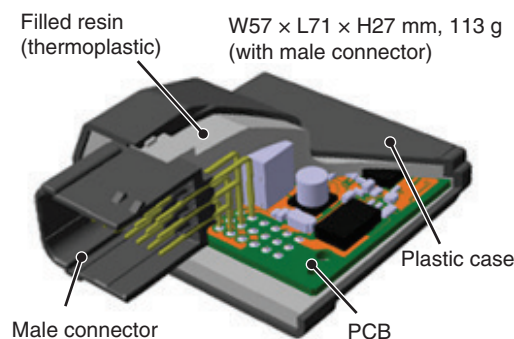


Fig. 1 Conventional ECU

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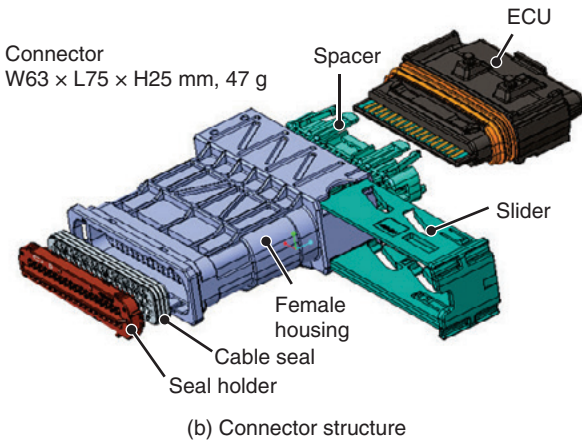
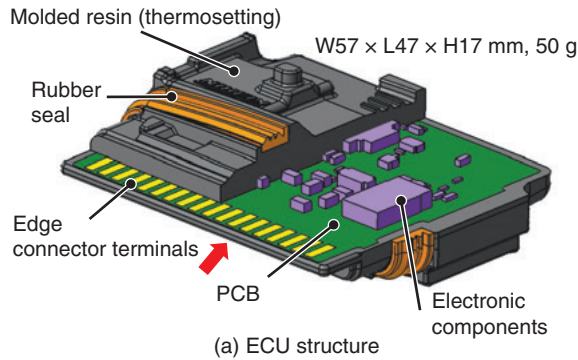


Fig. 2 Developed ECU and connector

2. Features of New Technology

Described hereafter is a comparison of the transfer molding and the card edge connector applied to the newly developed product with the conventional technology.

2.1. Resin Molding

Figure 3 shows the features of the two major resin molding methods; the transfer molding and the injection molding.

The transfer molding is such a method that uses the thermo-setting resin and free of deformation even when reheated after the molding. This method is applied to electronic components typically represented by the semiconductor package molded at low temperatures and low pressures using a low-viscosity epoxy resin. Figure 4 shows an example. Though silicon chips and bonding wires having a diameter of several tens microns are contained in the package, this method allows molding without causing damages to such vulnerable parts. However, the low viscosity resin tends to cause leakage from the mating surfaces of the die, which is not suitable molding of a complex shape. In many cases, a simple shape is molded using a horizontally split dies.

On the other hand, the injection molding using the thermo-plastic resin is applied to many kinds of electronic components and industrial products. Using a high viscosity resin, a complex shape can be molded. However, the high molding temperature and pressure cause damages to the electronic component itself and/or the soldered joint if the electronic components are directly molded. Taking into account such characteristics, we chose the transfer molding as the method for the direct molding of electronic components.

Item	Transfer molding	Injection molding
Outline	Low-viscosity resin is transferred into die while being heated by die	Melting resin, which is heated in cylinder, is molded with high pressure
Schematic of process		
Material properties		
Resin type	Thermosetting resin	Thermoplastic resin
Viscosity	Low	High
Molding conditions		
Pressure	< 10 MPa	30 MPa <
Temperature	< 180°C	250°C <
Cycle time	< 5 minutes	< few minutes
After cure	2-5 hours	None

Fig. 3 Comparison between transfer molding and injection molding

Code	TO220	QFP *	BGA *
External view			

* QFP: Quad Flat Package, BGA: Ball Grid Array package

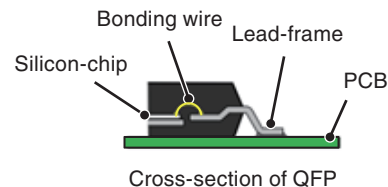


Fig. 4 Example of semiconductor packages (top) and internal structure (bottom)

2.2. Connector

Figure 5 compares features of the card edge connector and the conventional connector used in automotive applications.

The card edge connector was of such a design standardized by IEC603 in 1980's, referred to as "Edge-socket connector," and used for internal connections of communication devices, etc. Compared to the connectors of a through-hole type or a surface mount type, this design features the simple male connector structure. The edge connector terminal functions as a male connector terminal, and the molded ECU serves as a male connector housing. As the edge connector terminal is formed in the PCB production process, there is no need of male connector mounting on the PCB. Furthermore, as the surface area the edge connector occupies on the PCB is minimal, the PCB size can be reduced by approximately 20%. Due to these features, the card edge connector is advantageous from the standpoints of number of parts, production efficiency and downsizing.

On the other hand, due to its simple structure, the vibration resistance is low. Also, there is no waterproof structure. Moreover, the damages the female terminal sustains at the time of mating is an issue. Accordingly only a few examples are seen in the applications to automotive subjected to vibrations exceeding 98 m/s^2 and requiring repetitive attaching and detaching. We tried to solve these issues while maintaining the advantages of the card edge connector.

3. New Technology Applied to Card Edge ECU

Among the new technologies applied to the ECU, described hereafter are the waterproofness, the sealing of sheared end of PCB, the substitution to the ceramic capacitor, and the multi-piece molding.

3.1. Waterproof Structure

The rubber seal is wrapped around the molded ECU and the ECU is mated with the card edge connector. The watertightness in the edge connector is adequately maintained by having the rubber seal adequately compressed at the time of mating [Fig. 2 (b)].

As mentioned earlier, the ECU is transfer-molded with the horizontally-split, simple dies. At that time, the low viscosity epoxy resin tends to leak from the die mating surfaces, sometimes causing protrusion such as burrs and/or steps on the parting lines at the sides of the molded part (Fig. 6).

To help secure the waterproofness corresponding to IPX7⁽³⁾ necessary for the motorcycle ECU, we have found that the height of such a protrusion should be less than several ten microns (Figure 7 shows the relationship between the protrusion height and the waterproofness). As the waterproofness is not required in general semiconductor packages alone, there used to be no ways for realization of such a level of precision. It was therefore necessary to increase die-alignment accuracy in addition to the preciseness of the die used in the semiconductor production.

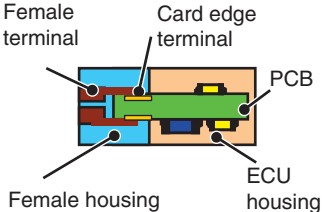
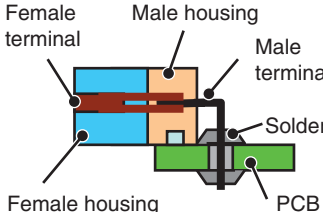
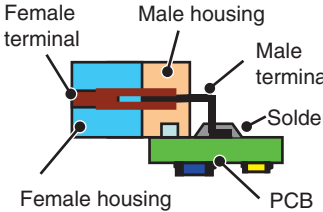
Name		Card edge type	Through hole type	Surface mount type
Structure	Terminal			
Housing	Contact type	Pressing	Pinching	Pinching
	Male terminal	Non-existing (PCB)	Copper alloy	Copper alloy
	Connection PCB	Unneeded	Flow soldering	Reflow soldering
	Occupancy area	Small	Large (both-sides)	Medium (single-side)
	Female terminal	Copper alloy	Copper alloy	Copper alloy
Connector cost	Male side	Non-existing (ECU housing)	Existing	Existing
	Female side	Existing	Existing	Existing
	Height	Low	High	High
Connector cost		Low (male connector less)	Medium	High

Fig. 5 Comparison of automotive connectors

Moreover, it is necessary to control the protrusion height because it changes in the mass production due to die deterioration, etc. Accordingly, the shape of the areas near the protrusion is designed flat as Fig. 6 (b) shows. The flat part serves as a reference surface, allowing high precision measurements and easy removal of excessive protrusion.

In addition, both ends of the rubber seal are also designed flat shape as Fig. 6 (a) shows with the wide protrusions provided to hinder misalignment from twisting or turning when mating with the ECU. On the other hand in the ECU side, the ribs are provided to hinder falling off of the rubber seal. These new design considerations help secure waterproofness that satisfies the requirements

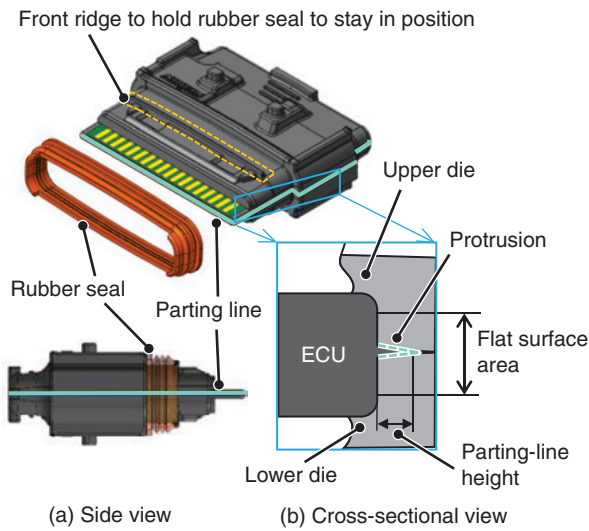


Fig. 6 Rubber seal straddling over parting line

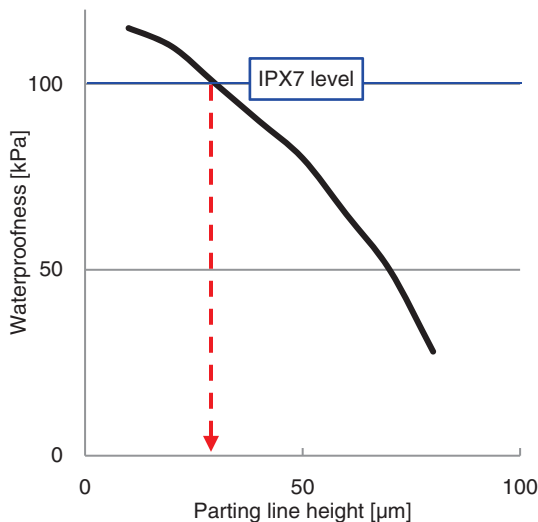


Fig. 7 Parting line height vs. waterproofness

corresponding to IPX7 even after repetitive attaching and detaching.

3.2. Sealing of Sheared End of PCB

Described hereafter is about the second issue. While the card edge connector having the simple structure as shown by Fig. 8 (a) is employed for enhancement of ECU production efficiency, there is an issue, which is the exposure of the sheared end of PCB that comes on the front end of connector terminal [Fig. 8 (b)]. If water, oil, dust or other contaminant adheres on that end of an ECU when removed for maintenance, the contaminant eventually penetrates the inner layer of the PCB, causing ECU malfunction.

To deal with this issue, such a structure is considered necessary that protects the sheared edge of PCB from an exposure to the atmosphere when the ECU alone before mated with the connector. Our solution to this issue is that the independent movable insert die is added to the simple die, horizontally split, transfer molding die to allow the resin to cover the sheared end. Figure 9 shows a cross sectional view at the time of transfer molding. The picture shows the conditions when the cavity is filled with the epoxy resin after setting the PCB in the die. The areas near the sheared surface of PCB are held by the movable insert die. The PCB near the runner is held by the support pins. The resin transferred by the plunger passes through the sides of edge connector and reaches the sheared end of PCB (Fig. 10).

One thing to note is that as the terminals are used for electric conduction from the female terminals, there should be no damage such as scratch, deformation or adhesion

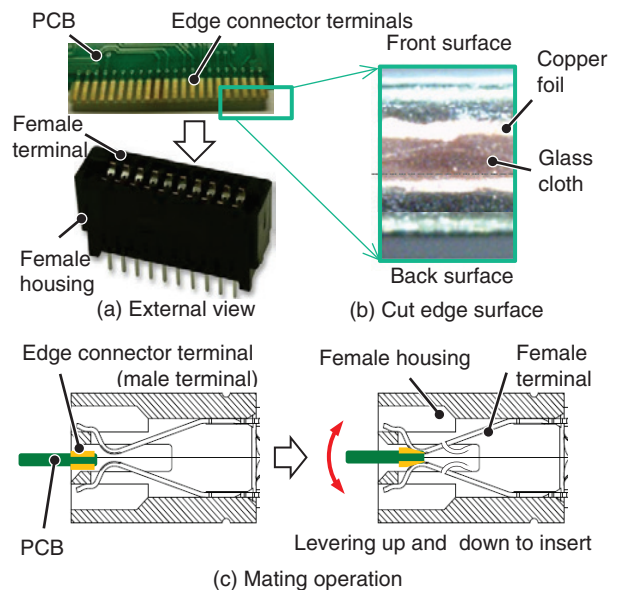


Fig. 8 Overview of card-edge connector

of resin during the molding. It is therefore necessary to pinch and cover that part with dies when molding. As the thickness of PCB has a manufacturing tolerance exceeding 0.1 mm, the additional die that only pinches the edge connector terminal is incorporated to deal with the thickness deviation. This die has a movable insertion die to allow control of pinching load depending on the thickness of PCB⁽⁴⁾. This technology allows sealing of sheared end of PCB to help secure waterproofness of ECU alone.

3.3. Substitution to Ceramic Capacitor

While it is mentioned in Section 2.1. that the transfer molding is less damaging to electronic components, the only remaining issue is such a possibility that the epoxy resin penetrates into the electrolytic capacitor, causing a change of its property. Figure 11 (a) shows the cross section of electrolytic capacitor before molding. On the other hand, after molding, the epoxy resin penetrating into the capacitor lifts the sealing plug, causing the electrolytic foil to deform as shown in Fig. 11 (b). Under such conditions, the electrical characteristics cannot be satisfied.

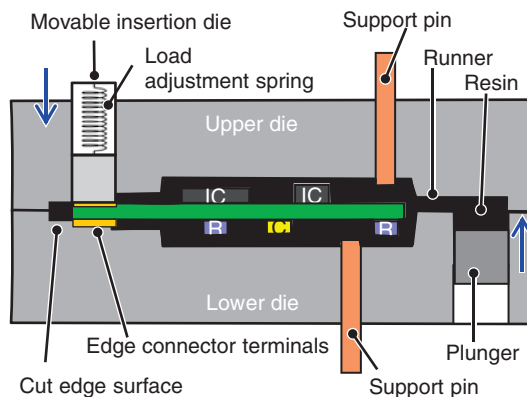


Fig. 9 Transfer molding dies

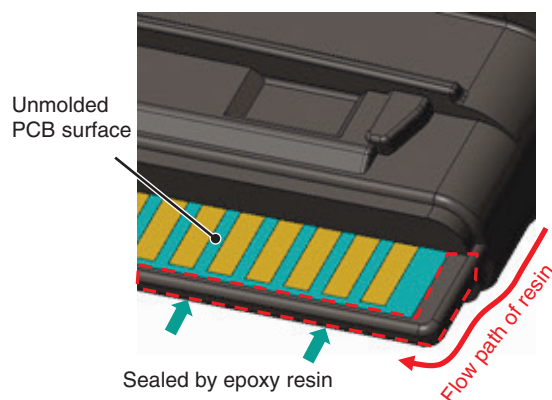


Fig. 10 Sealed PCB cut edge surface

Described hereafter is the role of electrolytic capacitor.

In small motorcycles, there are switches and connectors having contact points in the power supply route from the battery to the ECU. In such electrical devices for automotive, the contact is momentarily lost when subjected to an impact or vibration from outside, sometimes causing an interruption of electric current. The electrolytic capacitor stores necessary electric energy to operate the ECU functioning when the electric current is interrupted.

In the power supply system of small motorcycles, the momentary interruption of contact in the connector used in the conventional ECU is the longest, requiring an electrolytic capacitor to deal with it.

As the newly developed card edge connector is compliant as per ISO8092, the length of momentary interruption is reduced to less than 1 μ s. Accordingly, the new design allows substitution of the electrolytic capacitor to a small-capacity ceramic capacitor, eliminating the electronic component vulnerable to damages at the time of molding.

3.4. Multi Piece Molding

The most effective way to enhance ECU production efficiency is the multi-piece molding.

The transfer molding used in the production of semiconductor packages is such a high-productivity manufacturing method that produces more than several hundreds of integrated circuits at a shot of molding of silicon chips placed in the die cavities. To take the same advantages for the ECU, it is necessary to realize a multi-piece molding to produce as many pieces as possible per shot.

However, as the ECU is far more bulky than the semiconductor package, the conventional method used for semiconductor production cannot be applied as it was.

We therefore considered adoption of the multi-cavity molding method used for molding of large IC such as the power device. It is such a method that places a number of single-piece molding dies in the press die. The pod and the plunger are provided in each die. Using this method

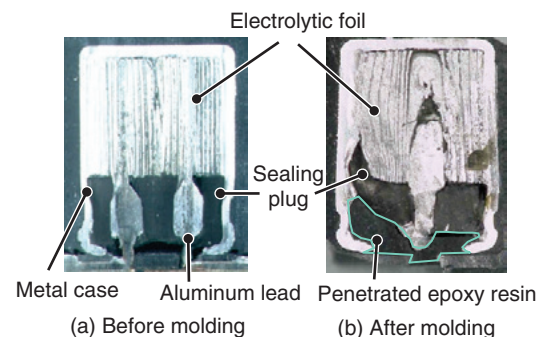


Fig. 11 Electrolytic capacitor deformation

as a basis, pods adequate for molding of large ECU are additionally provided, and placed parallel in the molding die⁽⁵⁾.

Figure 12 shows the melted resin in the two pods in each die being transferred from the runner and filling the cavity. Applying the molding conditions for single-piece operations established during the product development as they are, and using the newly-developed epoxy resin⁽⁶⁾, the high quality, high productivity molding method has been realized.

Placing more than 10 pcs of the PCB, which has been downsized by 20% by the card edge connector design, in the molding die, the production efficiency more than five times higher than the conventional ECU has been achieved.

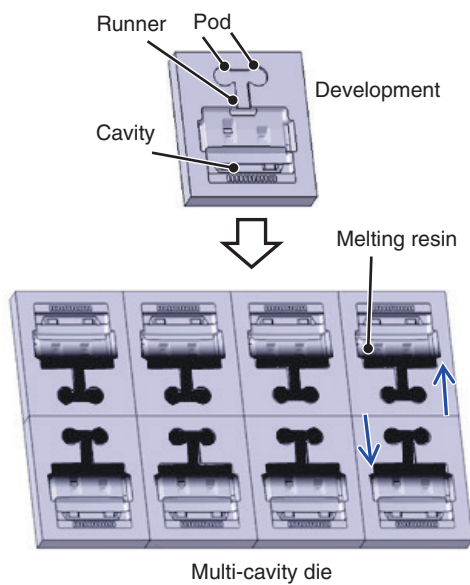


Fig. 12 Multi-cavity molding dies arrangement

4. New Technologies Applied to Card Edge Connector

Described hereafter is the enhancement of attaching/detaching durability, electric contact stability, and vibration resistance among the new technologies applied to the card edge connector.

4.1. Attaching/Detaching Durability

Figure 8 (c) shown earlier gives image pictures of an ordinary card edge connector being mated. It was mentioned that damages such as scratch and/or plating peeling occur on the female terminal surfaces due to the edges on the sheared surface of PCB. In the newly developed ECU, the sheared surface is sealed with the epoxy resin for waterproofness. However, the epoxy resin contains hard fillers such as silica,

which cause damages if adhering on the terminal surface.

We have developed the floated attaching/detaching system that keeps the sheared and sealed PCB end surface from contacting on the female terminal when the connector and the ECU are mated. What produces this floating effect is the spacer provided in the female connector housing [Fig. 2 (b)]. Figure 13 shows how it functions in details.

In the pictures, (1) shows the conditions before the ECU is mated in the connector. Though mating with the ECU into the female housing is starting at that time, the spacer remains at the initial position in the female housing. Accordingly, none of the ECU, the spacer, the female terminal or the edge connector terminals is in contact with each other.

Shown by (2) are the conditions when the ECU is being mated into the connector. As the ECU is gradually attached in, it comes in contact with the spacer, and pushes the spacer toward the far end of housing. Then, the spacer comes in contact with the female terminal at the point (a).

Shown by (3) are the conditions when the ECU is fully mated in the connector. As the ECU is further attached in and the spacer is pressed to the far end of the housing, the female terminal, which contacts at the point (b), is pressed downward in the picture. At the same time, the female terminal finally contacts the edge connector terminal at the point (c).

When detaching the ECU, the spacer moves to the opposite direction along with the mating with ECU, and the ECU comes off the connector after the pressure on the female terminal is released. As such, the spacer moves along with attaching/detaching of the ECU. Thus established is the structure that is free of damages even the ECU is repeatedly attached and detached for motorcycle maintenance.

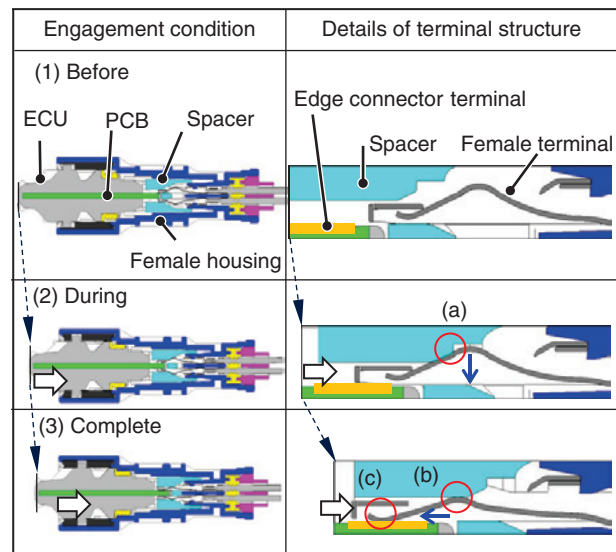


Fig. 13 Mating operation with spacer

4.2. Contact Stability

Next, the technology to stabilize the terminal contact state of the card edge connector is described.

Figure 14 shows image pictures of the terminals in contact in a conventional connector and a card edge connector. In the conventional connector, the female terminal pinches the male terminal. Both terminals are made of the same copper alloy material.

In the card edge connector, the female terminal made of copper alloy applies a load on the male terminal formed on the PCB. As the PCB is not designed for contacting of terminals, it deforms when a large load is applied. Furthermore, as the bending stiffness of PCB lowers under high temperature conditions, even more deformation occurs, causing a loss of contact stability.

To deal with this issue, the new technologies are employed in each of the female terminal shape and the PCB.

Figure 15 shows image pictures of the card edge connector being in contact. Figure 15 (a) shows the contact

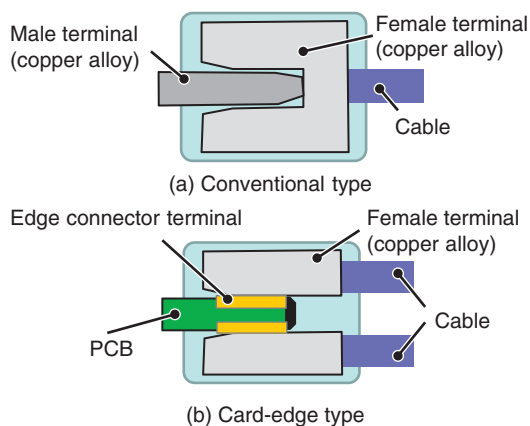


Fig. 14 Terminal contact structure

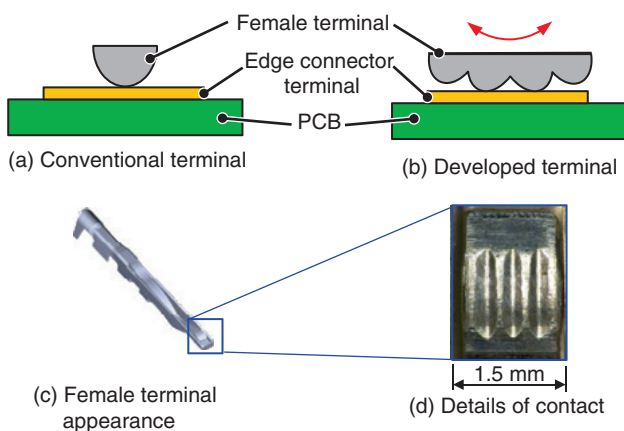


Fig. 15 Card-edge terminal contact structure

condition in conventional card edge connector. From the macroscopic viewpoint, the female terminal and the edge connector are in contact only at a point within the cross section of the terminal. Accordingly, all the applied load concentrates on the single point, causing PCB deformation when a large load is applied.

The newly developed female terminal shown by Fig. 15 (b) has a number of projections, and two of them are in contact on the edge connector terminal. Even when the motorcycle's wire harness clamping the female terminal swings, two contact points are always maintained on the edge connector. The projections are formed on the 1.5 mm-wide female terminal using the precision press [Fig. 5 (d)]. As this terminal design splits the load on the contact points, the deformation of PCB is restricted. Also, as a number of parallel current path is maintained, the contact resistance on the terminals has been lowered to less than a half of the conventional type⁽⁷⁾.

Mentioned next is the changes of PCB stiffness. Figure 16 shows the bending stiffness of PCB for general purpose and newly developed PCB at various temperatures.

In the PCB for general purpose when at 150°C, the stiffness lowers to less than a half of that at 25°C. This means for the card edge connector that a half of the load applied to the female connector deforms the PCB, and only the remaining load is applied to the terminal.

Employed in the newly developed PCB is the resin material having a high glass-transition temperature along with the inner layer structure that resists changes of stiffness. With these technologies applied, 80% of the stiffness at 25°C is maintained even at 150°C.

The application of the above mentioned two ideas realized the stable contact structure.

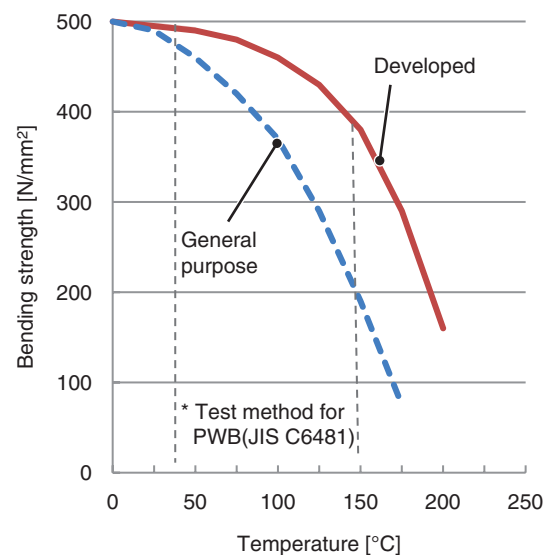


Fig. 16 Bending strength of PCB

4.3. Vibration Resistance

The last challenge in the development of card edge connector was how to increase vibration resistance.

This issue is addressed by applying the slider⁽⁸⁾, which is used in highly vibration resistant connectors. Figure 17 shows a cross-section of the waterproof card edge connector with the slider and the image picture of ECU when mated.

The center of gravity of ECU shown by the image picture is distant from the terminal contact point. Accordingly, when subjected to vibrations from outside, the end of ECU vibrates. The contact points on the terminal are affected, causing fretting wears to occur.

This phenomenon is due to the unique structure of the card edge connector. To increase vibration resistance, it is necessary to reduce relative vibrations between the ECU and the female connector housing.

We have therefore employed such a structure in that the ECU and the female housing are help securely held together by the slider at the location near the center of gravity of the ECU. Figure 18 shows an example of vibration suppression effect when the abovementioned technology is applied. In Fig. 18 (a) without the slider, a phase difference “ θ ” is seen between the acceleration at the front end of ECU and the acceleration at the rear of female housing. In Fig. 18 (b) with the slider, however, such a phase difference is unseen. That means that the ECU and the female housing become an integrated part, which enhances connecting stiffness between the two parts.

The basic technology of this slider is applied in the longitudinal and lateral directions to enhance connection stiffness between the ECU and the female housing.

Figure 19 shows an example of vibration analysis under such conditions. Figure 19 (a) without the slider indicates that the amplitude of oscillation is large at the red part, which corresponds to the front end of ECU. On the

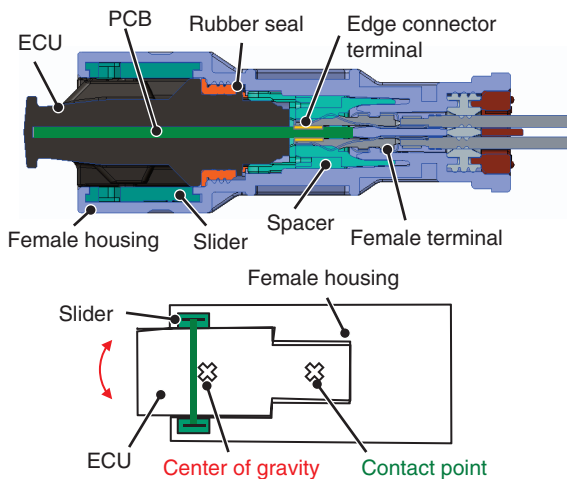


Fig. 17 Cross section of developed vibration-resistant connector with slider

other hand, in the female housing, the vibration amplitude is small as shown by the green color, which means that there is a relative displacement between the two parts. In Fig. 19 (b) with the slider, the ECU and the female housing are of the same green color, which means that there is no relative

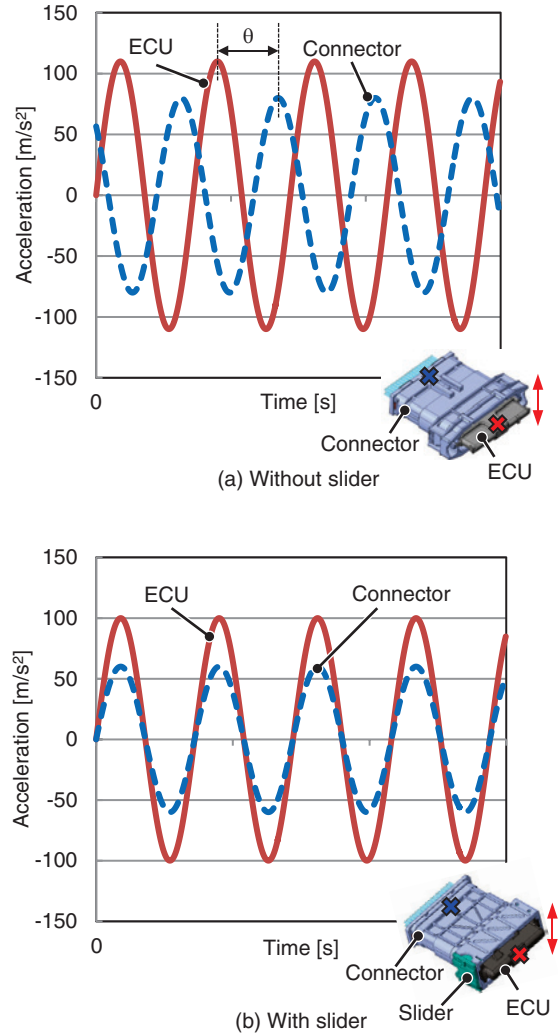


Fig. 18 Vibration suppression effect by slider

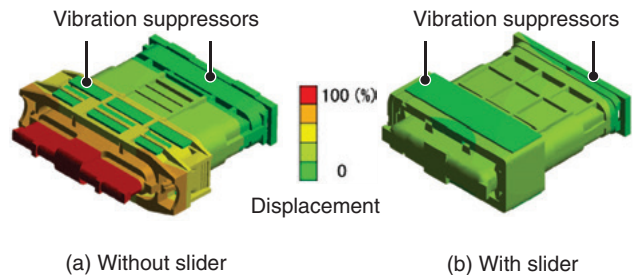


Fig. 19 Vibration analysis result by slider

displacement between the two parts in any direction.

Also, this slider system contributes to maintainability. Figure 20 shows attaching and detaching of the ECU. If there is a 20 mm space in the side of ECU, the slider can be drawn out. This design allows attaching and detaching of ECU in a space smaller than in the conventional type.

The technologies using the waterproof card edge connector with the slider has realized the vibration resistance as high as the conventional design while realizing the good maintainability.

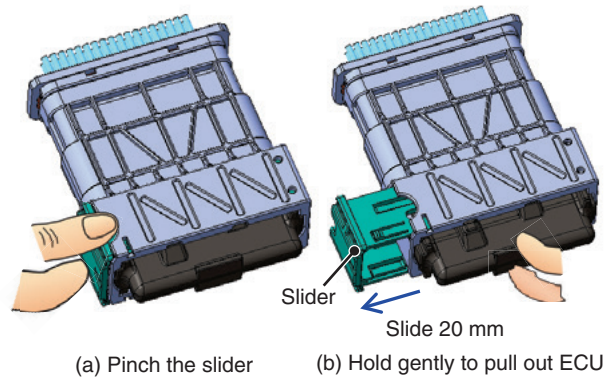


Fig. 20 Good workability by slider

5. Durability and Cost Reduction

Lastly described is the durability and the cost reduction.

5.1. Durability

The durability tests were conducted by the unit test under such conditions in that the ECU mated with the connector at the prescribed conditions along with the actual test runs of the motorcycle.

Mentioned hereafter is about the combined durability test, which is the hardest of all the unit durability tests. This test simulates the working environment of motorcycle by periodically altering the temperature, humidity, current, and vibrations. After the durability test, no fault was found in the electric properties and the waterproofness.

Actual running tests were conducted at the prescribed conditions, and the requirements were satisfied. Moreover, to clarify failure modes of the ECU and the connector, test runs were extended to the distance five times more than the test standard. There was no faulty contact in all the terminals when running. No fault was found in the ECU inspection after the durability tests.

5.2. Cost Reduction

Figure 21 shows the cost breakdown. Compared to the conventional ECU, the number of parts is reduced in the

newly developed ECU by eliminating the male connector and the case. Accordingly, soldering for male connector, resin filling and hardening processes are no longer required in this production process⁽⁹⁾, which contributes to the production efficiency more than five times higher and to the 20% reduction of production cost including the female connector from the conventional design.

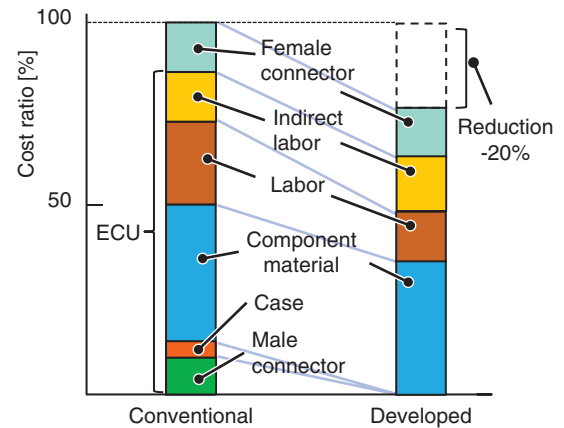


Fig. 21 Cost reduction result and contributing factor

6. Conclusion

With the transfer molding method and the card edge connector applied, the following has been achieved through the development of the new ECU for small motorcycles.

The waterproofness corresponding to IPX7 when the ECU is mated with the card edge connector is achieved by controlling the height of die parting lines on the ECU to under the prescribed level.

The card edge ECU molded by the new die having the movable insert practically realized the world's first waterproof structure as a unit part.

The employment of the card edge connector having a very short momentary interruption of connection permits substitution of the electrolytic capacitor to the ceramic capacitor, contributing to the downsizing and cost reduction of the ECU.

The target production efficiency is achieved by the use of the epoxy resin developed for the ECU along with the application of multi-cavity molding equipment.

The new technologies that helps secure steady connection and reduces vibrations is employed in the waterproof card edge connector to satisfy the vibration resistance requirements as well as maintaining a good maintainability.

With these new technologies applied, the production

efficiency of the new ECU is higher by more than five times than the conventional ECU. Also, the cost of ECU including the female connector is lowered by 20%. Applications of the new ECU to the mass production of small motorcycles having a single-cylinder engine started from the 2018-year model.

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