

Development of Transmission-mounted Transmission Control Unit

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ABSTRACT

A transmission control unit able to be directly mounted on the transmission has been developed for applications ranging from small to medium-sized vehicles.

Direct mounting of the unit has reduced the distance between the transmission and the control device, making it possible to reduce the length of the harnesses. In addition, hierarchical design of the control software and sharing of the solenoid driver have made it possible to apply the unit to the control of a variety of transmissions.

Vehicle tests and simulations were conducted in order to obtain a detailed understanding of the temperature of the electronic components inside the unit under the conditions it would be exposed to when direct-mounted and implement appropriate responses. As a result, the maximum operating temperature of the unit was increased against conventional body-mounting conditions. The rigidity of the mounting bracket and the connector terminals was also increased, increasing the maximum allowable vibration frequency to 2000 Hz. These measures made it possible to apply the unit to a wide variety of vehicle types, from small to medium-sized.

1. Introduction

The realization of increased fuel efficiency is an important issue from the perspective of reducing the burden automobiles place on the global environment. In the engine, the use of direct injection technologies and electronic devices, and in the transmission, the use of multi-stage and DCT technologies, are widely used methods of achieving this goal. As a result, the combinations of engines and transmissions are diversifying. Conventionally, the range of these combinations has been limited. Because of this, it was possible to reduce shared casing parts and electronic components by controlling the engine and the transmission using a single control unit (Fig. 1). However, today's diversification of the combinations of engines and transmissions means that the same number of integrated control units as the number of combinations is necessary (Fig. 2).

It was therefore considered that it would be possible to reduce the number of necessary types of control units by separating the control units for the engine and the transmission⁽¹⁾ (Fig. 3).

In addition, it would also be possible to share control units between different transmissions by examining transmission control specifications and clarifying which sections general-purpose specifications could be employed

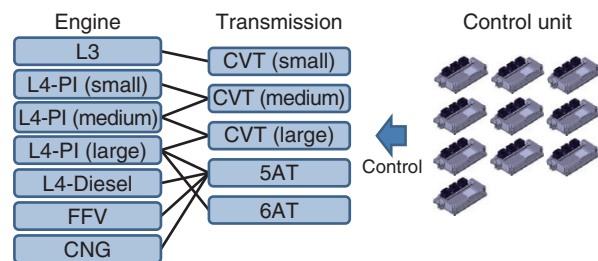


Fig. 1 Former integrated engine and transmission control unit

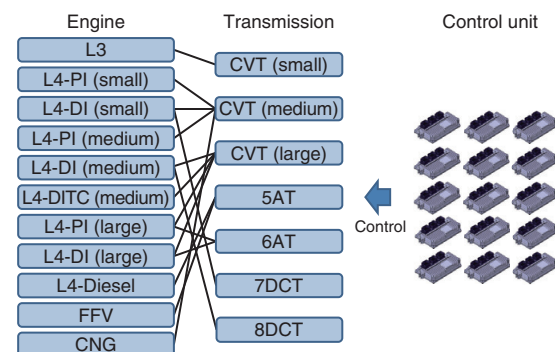


Fig. 2 Current integrated engine and transmission control units

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in and which sections necessitated specialized design.

Up to the present, Honda has fitted powertrain transmission control units (TCU) to the body of the vehicle, in the cabin or the engine compartment (Fig. 4). The TCU developed in the research discussed in this paper is directly mounted on the transmission. Direct mounting offers the merit of reducing the distance between the control device and the object of control, making it possible to reduce the length of the harnesses (Fig. 5).

In addition, when the TCU is fitted to the vehicle body, it is necessary to use a bracket to fix it in place on the body framework. When the same combination of engine

and transmission is used but the vehicle is changed, the effect of the positioning of the battery, lights, and other surrounding parts makes it necessary to use a special TCU bracket for each vehicle. Direct mounting on the transmission would make it possible to fix the mounting position. It was predicted that this would reduce the number of types of bracket in comparison to mounting in the engine compartment.

At the same time, direct mounting of the control unit on the transmission would necessitate the use of measures to protect the electronic components and the casing and other structural parts from environmental conditions, including heat and vibration from the engine and transmission.

This paper will discuss the development of a direct-mounted TCU able to control a variety of transmissions via a single unit.

2. Development Goals

Figure 6 shows the layout of the transmission-mounted TCU developed for application to a CVT for a 1.5L turbo-charged engine.

The following development goals were set for the design of the transmission-mounted TCU:

- (1) General applicability, making it possible to control multiple transmission types with minimal change to parts; and
- (2) Reliability of parts in relation to vibration and heat in vehicles ranging from small to medium-sized.

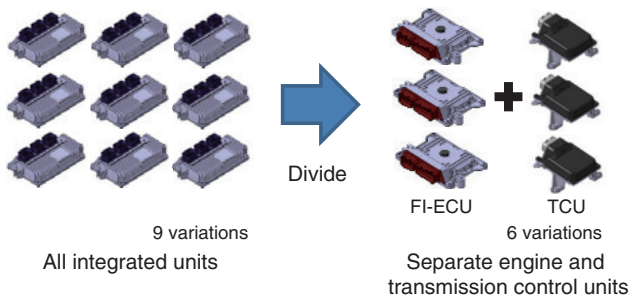


Fig. 3 Change in number of control units

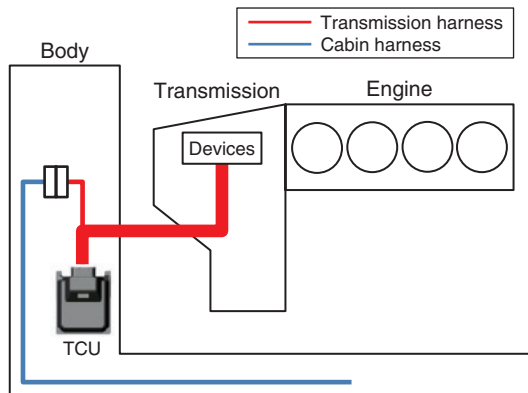


Fig. 4 Body-mounted TCU

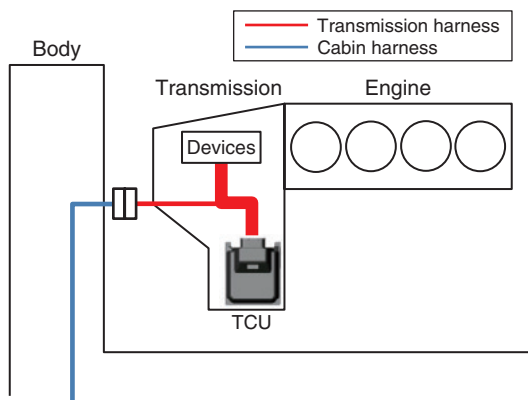


Fig. 5 Transmission-mounted TCU

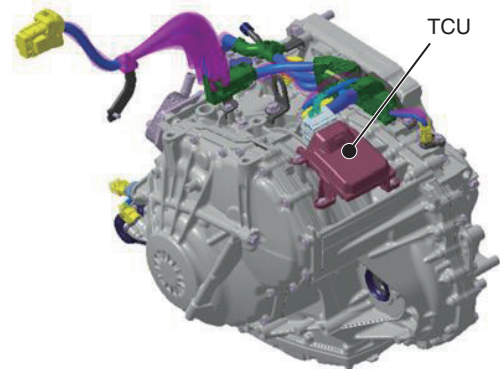


Fig. 6 Layout of transmission-mounted TCU

3. Design for General Applicability

Three types of functions are demanded of a TCU: Basic functions, including input and output and reprogramming; transmission control functions, to control the operation of the target transmission; and vehicle control functions, including meter display and cooperative operation with the engine. Conventional transmission control does not

clearly demarcate these functions, and when one function is changed, it is necessary to change the others. This means that TCU have possessed limited general applicability.

The present research, by contrast, clearly specified the domains of the TCU functions. Using a systems modeling language⁽²⁾, the functions were divided into three domains based on the AUTOSAR standard: A platform (PF) domain, an application (APL) domain, and an interface (I/F) domain (Fig. 7). This increased the independence of the functions, and made it possible to use the TCU for different transmissions simply by modifying the APL domain.

Conventional TCU also use current feedback control in the driver IC to control the current of the solenoid that controls the hydraulic channels in the transmission (Fig. 8). Applying feedback control in the driver IC has the merit of reducing the number of electronic components and doing away with the need for adjustment during the manufacturing process⁽³⁾. However, because current feedback control has an effect on shift responsiveness and durability and reliability, it is necessary to modify the control settings depending on the transmission type. At the same time, the range of modification of feedback gain and other settings for a driver IC without software is limited. Because of this, up to the present it has been challenging to apply the same driver IC to different types of transmission. In the method developed

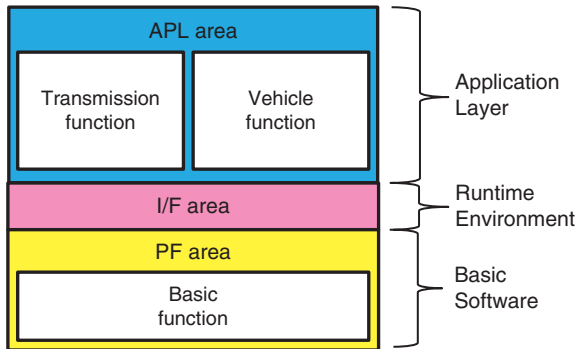


Fig. 7 Diagram of enhanced software system

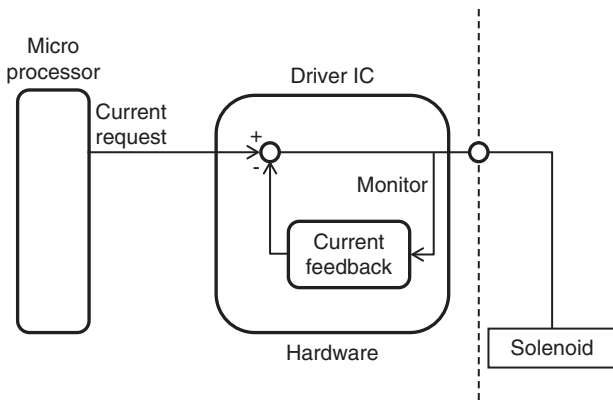


Fig. 8 Design of conventional solenoid current feedback control

in the research discussed here, the driver IC only measures current; current feedback control is conducted by a software program in a microprocessor (Fig. 9). As a result, it is possible to apply the TCU to different transmissions by modifying the program in the microprocessor.

As described above, it has been possible to develop a TCU able to control different transmissions without any change to the basic configuration of the hardware via hierarchical design of the domains of functions and the sharing of a solenoid driver.

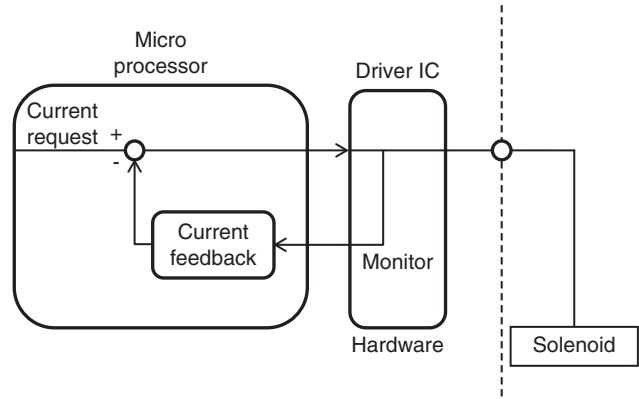


Fig. 9 Current design for solenoid current feedback control

4. Reliability of Parts in Vibration Environment

4.1. Vibration Environment

Powertrain vibration is damped by the engine mounts and transmitted to the body frame. Because of this, conventional body-mounted TCU were designed to resist the frequency domain up to 400 Hz, the frequency of second-order engine speed-related vibration.

When direct mounting of the TCU was under consideration, the vibration environment was first studied. The vibration acceleration at the mounting position of the unit against the vibration frequency of the engine was measured for 4-cylinder engines of various displacements fitted in a range of vehicle types (Fig. 10).

At close to 200 Hz and below, vibration acceleration is high, proportional to second-order engine speed-related vibration.

In the higher frequency domain, vibration acceleration peaks appear irregularly due to powertrain resonance, but in each case the vibration acceleration is less than half of second-order engine speed-related vibration. In addition, because the displacement that produces stress on the parts declines in inverse proportion to the square of frequency, input conditions for acceleration at the mounting position of the direct-mounted TCU were set based on second-order engine speed-related vibration, and the frequency band was set at 2000 Hz and below.

4.2. Vibration-resistance Measures

To help prevent damage to the electronic components fitted on the base plate, it was necessary to reduce the stress generated in each section to the allowable loading force for the component materials or below. A 3D model of the TCU assembly was therefore formulated, and a frequency response analysis was performed.

Vibration acceleration with second-order engine speed-related vibration as the base vibration was input to the TCU mounting points, and resonance frequency and response acceleration were measured in the 2000 Hz and below frequency band.

Rib shapes were added to the bracket between the transmission mounting bosses in order to increase the rigidity of the unit in response to resonance. A parameter study of the rib shapes was conducted using eigenvalue analysis in order to determine specifications realizing an optimal balance between mass and rigidity (Fig. 11).

Tapping screws were employed for the connection between the base plate and the connector casing in order to increase coupling rigidity.

In addition, the rigidity of the connector terminals themselves was increased, and their resonance frequency was set at 2000 Hz or above, outside the powertrain

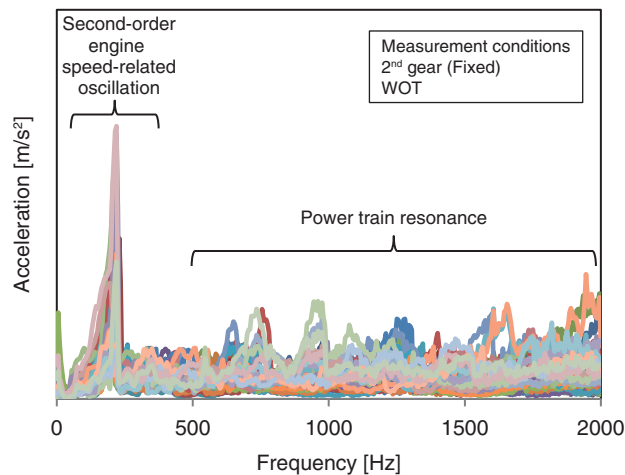


Fig. 10 Vibration acceleration at unit mounting point

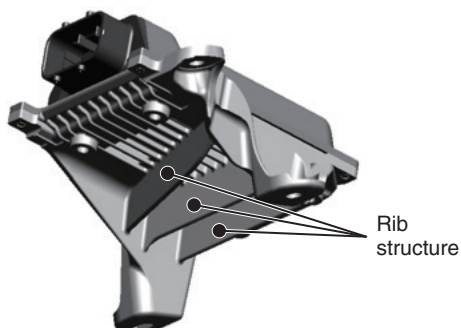


Fig. 11 Realization of enhanced unit rigidity

resonance domain.

A simulation study conducted in order to verify the effectiveness of these measures showed that the resonance frequency close to 690 Hz had increased to 740 Hz, and the overall vibration acceleration level had been reduced (Fig. 12).

4.3. Verification of Vibration-resistance Performance

Measurements of vibration acceleration in the connector section in an actual vehicle were conducted in order to compare the rate of change of acceleration in the connector section in relation to the unit mounting points before and after the application of the vibration-resistance measures (Fig. 13).

The increase in the coupling rigidity of the bracket and the connectors reduced the level of resonance at close to 700 Hz, verifying the effectiveness of the specification employed.

In addition, the results of vibration durability tests using direct-mounting input conditions showed that no issues such as dropouts of the electronic components or breakage of the connector terminals occurred, and the electrical

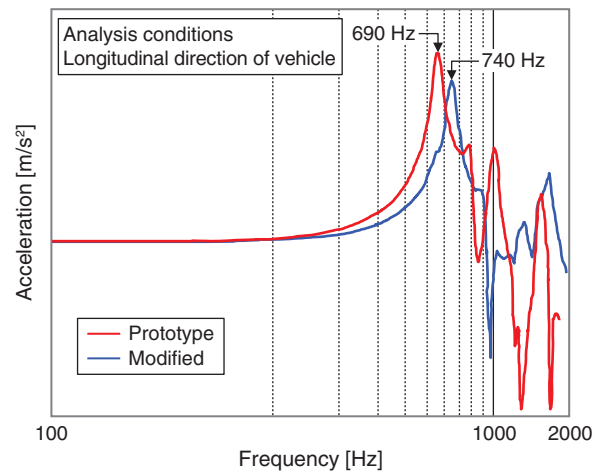


Fig. 12 Frequency response characteristic

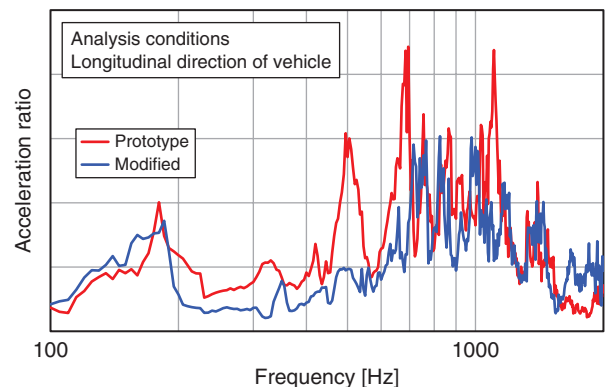


Fig. 13 Comparison of rate of change in vibration acceleration of connector in vehicle

characteristics following the test satisfied the performance demands from the unit.

5. Component Reliability in Heat Environment

5.1. Temperature Environment

The temperature of the engine compartment reaches its maximum point following the elapse of a fixed period of time after the vehicle has been stopped. The transmission case, on which the TCU is mounted, receives heat from the transmission fluid during high-load operation, and its temperature is at its maximum immediately after the vehicle is stopped. Self-heating due to power loss resulting from the driving of the actuator by the solenoid and other parts is also a factor in increasing the temperature of the TCU.

In the case of conventional positioning of the TCU in the engine compartment, the unit's design only took into consideration the temperature within the engine compartment. With the direct mounting of the unit, however, it was necessary to consider multiple factors in temperature increase, including the effect of heat received from the transmission case and the increase in temperature due to the self-heating of the TCU.

Factors involved in increasing the unit's temperature were divided into external factors including the temperature of the external environment and the wind produced during vehicle operation, and internal factors due to power loss in the TCU. The conditions to which the unit would be exposed were designed as follows. The most severe conditions were applied, based on the assumption of the fitting of the unit in vehicle sizes ranging from small to medium.

- (1) Driving mode in which internal temperature of engine compartment reaches its maximum
- (2) Driving mode in which temperature of transmission case reaches its maximum
- (3) No wind during vehicle operation
- (4) Driving mode in which solenoid current consumption reaches its maximum

A heat simulation of the temperature distribution in the engine compartment during soak following hill-climbing mode was conducted (Fig. 14). The area of the engine compartment in which the temperature was highest was close to the exhaust system, an area that is affected by radiant heat.

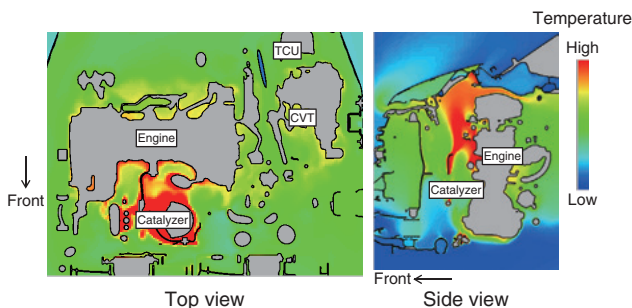


Fig. 14 Results of heat simulation

Based on these results, the highest allowable temperature for the transmission-mounted TCU was set 10% higher than had previously been the case for mounting in the engine compartment (Fig. 15).

5.2. Temperature-resistance Measures

Heat simulations were conducted in order to determine the heat produced by each of the electronic components in the different driving modes. Taking the effect of heat received from the transmission case into consideration, the simulations incorporated a transmission case model rather than using a TCU model in isolation. In addition, to help prevent the concentration of power in specific electronic components, a dispersed design was adopted in which functions were divided across multiple electronic components, and the power to each component was reduced. For example, the number of FET, a heat-producing component, was increased from four to six, and the power per element was reduced. The heat-producing components were also clustered on the heat dispersion side of the base plate, producing a configuration that promoted heat dispersion. As a result, the temperature of all the components remained below the maximum allowable temperature (Fig. 16).

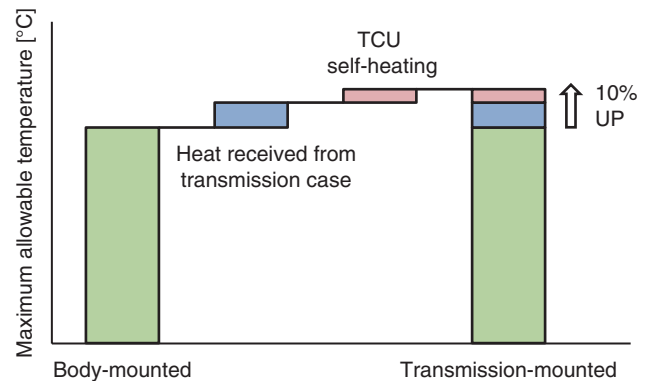


Fig. 15 Maximum allowable temperature

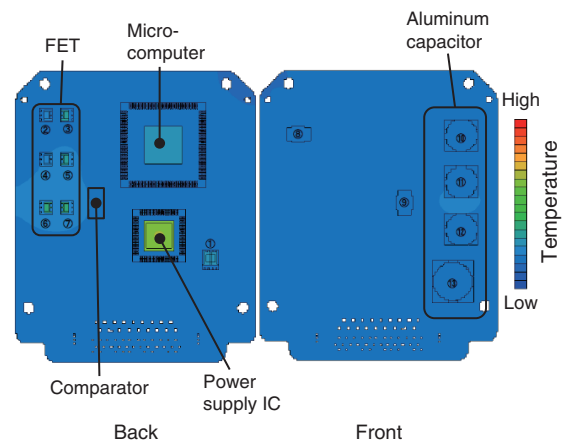


Fig. 16 Temperature distribution

5.3. Verification of Heat-resistance Performance

Tests were conducted in order to measure temperatures in an actual vehicle in different driving modes, including the driving modes in which the temperatures of the engine compartment and the transmission case reach their maximum. The results showed that the maximum temperatures of the electronic components remained below the maximum allowable temperature in all the driving modes (Fig. 17).

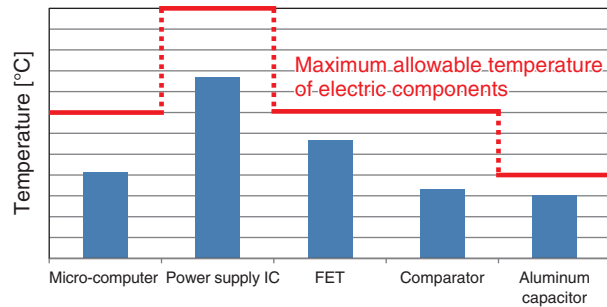


Fig. 17 Heat generation

6. Conclusion

During the process of development of a transmission-mounted transmission control unit, the couplings were reinforced in order to respond to issues due to the vibration environment, and the control software was hierarchically designed to help ensure a generally applicable design. The following results were obtained.

- (1) Hierarchical design of the domains of functions and optimization of the role of the solenoid driver IC has made it possible for the unit to control a range of transmissions.
- (2) The realization of increased rigidity in the mounting bracket and connector terminals and dispersed design of the electronic components has helped to ensure the reliability of the electronic components in use environments (heat and vibration) of vehicles ranging from small to medium-sized.

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