Development of Electric Oil Pump for Automotive Drivetrain

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JTEKT has developed an electric oil pump for drivetrains. This is an internal gear type pump with a brushless DC motor and no sensor. Size and cost reduction has been achieved by unitizing the pump, DC motor and controller.

Key Words*: electric oil pump, drivetrain, DC motor, brushless motor, sensorless, idling stop*

1. Introduction

In response to the global environmental protection, automobile manufacturers have been working on various projects for improving fuel efficiency and reducing CO_2 emission.

To achieve these objectives, while many new technologies and new approaches, such as fuel cell driven vehicles, hybrid vehicles, lean burn engines, mirror cycle and continuously variable transmission (hereinafter referred to as CVT), have been introduced, ample attention has been paid to the idling stopping technologies for improving fuel efficiency relatively easily[1].

Since hydraulic pressure for clutch engagement is generated by a pump driven by the engine in vehicles with automatic transmission (hereinafter referred to as AT) or CVT, idling stop would inevitably cause the pressure to decrease. This can lead to a delayed hydraulic response causing gear shift shock when the vehicle is started immediately after igniting the engine. In order to avoid such a phenomenon, an electric oil pump that maintains a minimum hydraulic pressure during idling stop is required.

Electric oil pumps are necessary in hybrid vehicles with conventional AT or CVT, to maintain hydraulic pressure while the driving motor is inactive.

JTEKT has been developing electric oil pumps for drivetrain using the experience from manufacturing electric pumps for hydraulic-electric power steering systems[2), 3)].

In this report, we introduce an electric oil pump with optimum forms of an electric motor and oil pump taking into account the application to vehicles with an idling stop system.

2. Concept of Product

2. 1 Compact Design

Electric oil pumps for drivetrain have been developed and commercialized not only for idling stop, but also for some of 2WD-4WD switching clutches, manual transmissions and automatic clutches. These electric oil pumps are mostly comprised of a motor and a pump integrated using a joint system. In addition, brush type motors are normally applied to vehicle-mounted motors.

Due to the limited engine compartment space available in compact FF cars, the class of cars selling in high volume, it is critical that the electric pump that controls the idling stop system is a compact design. The target size for the new design is a half of the conventional design in volume. **Figure 1** shows the relationship between the development target and the size of the conventional electric oil pumps.

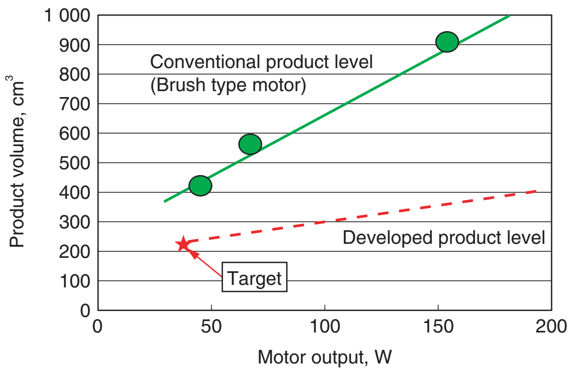

Fig. 1 Development target

2. 2 Cost Reduction

In a country like Japan, where traffic jams are ubiquitous, the idling stop is expected to provide great improvement in fuel efficiency. The cost is required to be maintained to a level justifiable for the amount of improved fuel efficiency.

The idling stop system is composed of an electric pump, a lithium ion battery, idling stop controller, etc.[4)] The largest portion of its total cost is accounted for by the electric pump. Therefore, development of the electric oil pump was advanced so that its cost should be kept within the framework of total cost allowed for system. Specifically, the target cost of the electric pump was set at 80% of the conventional product.

3. Outlines of Developed Product

3. 1 Pump

Oil pumps currently used in automotive drivetrains are either the external gear, internal gear or vane type. Characteristics of these pump types are shown in **Table 1**.

Table 1 Characteristics of each pump

	External gear pump	Internal gear pump	Vane pump
Characteristics	· Simple structure, low cost · High pressure (Side plate) · Resistant to contaminant · Resistant to impact pressure · Noisy (Meshing noise) · High pulsation	· Simple structure, low cost · Compact, light weight · Low noise (Low confinement) · High leakage · Low pulsation with internal gears	· High efficiency · High volume performance · Multiple channeling available · Variable capacity available · High pressure available · High number of components, high cost · Liable to be affected by contaminant

Taking account of the fact that the oil pump for idling stop is required to generate an oil pressure as low as 0.5 MPa and that it is used while the engine stops, the type of oil pump for idling stop should be selected on the basis of quietness, compactness and low cost. The vane pump has many component parts, and hence is costly.

In **Fig. 2**, the two low cost type oil pumps, the internal gear pump and the external gear pump, are compared in terms of efficiency vs. generalized parameters for pressure, viscosity and rotational speed. From the diagram efficiency characteristics diagram of each type of oil pumps, it is shown that the internal gear pump has higher efficiency in the operating parameters of the idling stop. In addition, **Fig. 3** shows noise frequency characteristics generated from the internal and external gear pumps. While the external gear pump produced marked peaks at frequencies corresponding to the order of gear meshing, and generally high audible noise levels, the internal gear pump showed moderate peaks of vibration, which means better noise characteristics.

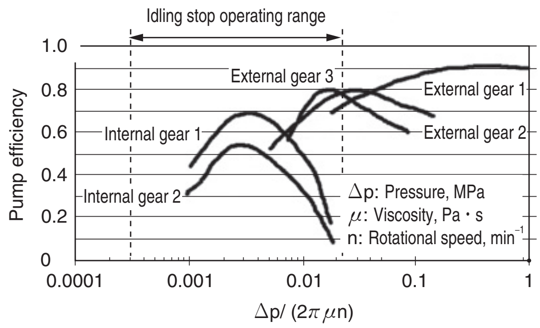

Fig. 2 Efficiency comparison between internal gear pump and circumscription pump

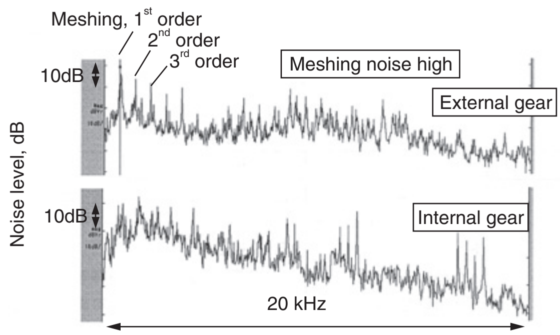

Fig. 3 Noise level comparison between internal gear pump and circumscription pump (0.5 MPa, 3 500 $\min^{-1}$, Oil temperature: 80℃)

In view of high efficiency at low pressure, noise level, compactness and low cost, the internal gear type was selected for the electric oil pump. Also for further improvement in efficiency, consideration was given to the shadow port, pressure balance, clearance and housing stiffness.

3. 2 Motor

As a result of the trend for motorized features, recent models of automobiles carry a bunch of electric motors, mostly brush type motors. Although brush type motors have an advantage of inexpensive cost, they include some technological problems, such as noise from the brush area, mechanical power loss, limited service life due to brush wear and limitation of maximum operating temperature.

The electric oil pumps for drivetrain are in particular required to withstand high temperature and vibration because they are installed around the AT or CVT. When it comes to the electric oil pump for idling stop system, it is further desired to have high efficiency to reduce the load on the battery because it is operated while the engine stops. Therefore, a brushless motor was selected for the development of electric pump taking account of reliability and efficiency.

Brushless motors are normally used with a rotational position sensor such as a resolver or a Hall effect IC. However, in this development we have selected a sensorless motor taking account of compactness, heat-resistance and low cost. Although sensorless drive of a brushless motor has been successfully commercialized for household appliances, its actual use in automobile is limited.

3. 3 Controller

The controller receives power supply of 12 V from the battery. The motor actuation part incorporates a three phase inverter circuit to constitute a sensorless actuation system that detects the counter electromotive force.

The FET (Field effect transistor) is available either with N channel or P channel. Although the N channel FET is used broadly due to its lower on-state resistance than P channel, it requires a boosting circuit. In this development project, P channel FET with low on-state resistance on the high side is used so as to simplify the gate drive circuit and thereby to make the circuit board compact.

The motor driving signal is given from the upper ECU (Electronic control unit) through PWM (Pulse width modulation) that enables the motor to be driven at variable speeds. In order to provide a fail-safe function that would prohibit switching to the idling stop mode if the electric oil pump fails to operate correctly, a software control is incorporated by the use of general-purpose CPU (Central processing unit).

The software was built on the basis of task structure using simple OS (Operating system) so that other function can be added later.

3. 4 Integration

The pump section, the motor section and the controller section, described above, are integrated into a one-piece structure in order to make the unit compact as well as to reduce the number of component parts. **Figure 4** shows the structure of the integrated unit.

As the motor shaft is designed to also serve as the pump shaft, disusing the joint, the end plate of the motor is also made to serve as the pump housing.

While motor casings are usually made of deep drawn steel, this application employs the aluminum die cast which facilitates formation of arbitrary configuration required to integrate the motor with the controller. Aluminum die cast is better for heat radiation.

As far as the integration between the motor and the controller is concerned, there are three challenges to be addressed: electrical connection, mechanical connection and heat radiation out of FET.

Such standard electrical connection methods as soldering, fusing or resistance welding are difficult to use because of inaccessibility of the electrode head in the narrow space. Therefore, a new structure incorporating several bus bars penetrated from the motor side to the controller and thereby allowing the U, V, W phases to be fastened with screws on the circuit board, is adopted. This method serves the both purposes of electrical connection and mechanical connection, while it is instrumental to make the unit compact in the longitudinal direction (**Fig. 5**).

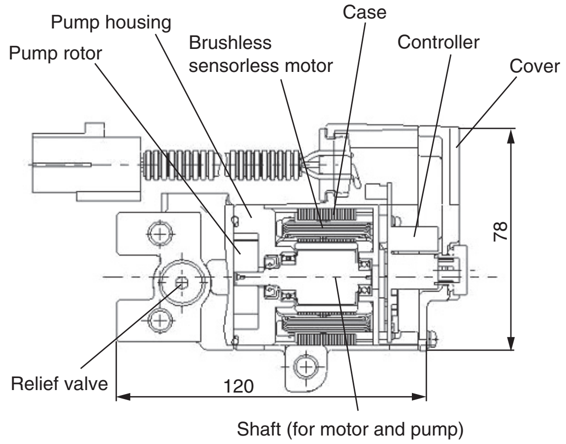

Fig. 4 Structure

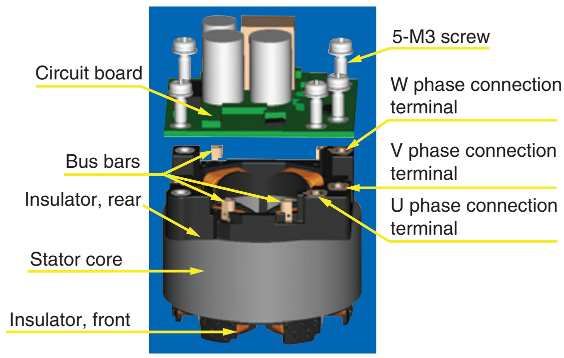

Fig. 5 Connection of motor with controller

For heat radiation out of FET, a heat radiation sheet is inserted between the aluminum cover and FET so that the heat in the FET may be radiated from the cover. In addition, the cover is provided with fins.

Thanks to the above technological development and integration, the volume of the electric oil pump unit has been kept at approximately 200 cm^3, which clears the initial target of a half of the conventional (240 cm^3). The initial target of cost has also been satisfied.

4. Basic Performance of Developed Product

4. 1 Efficiency

Figure 6 shows the efficiency of the electric oil pump measured at 80℃, which is the operating temperature of AT, CVT, etc. The tested units were adjusted so that the peak efficiency would be obtained in the pressure range of 0.2 ~ 0.4 Mpa, which is dominant for the idling stop operation. For comparison, the efficiency of the conventional brush type motor for the same purpose is also shown.

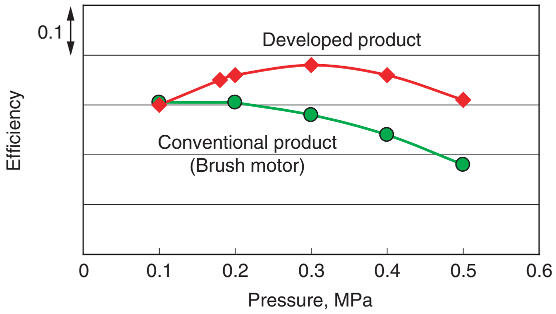

Fig. 6 Performance of developed electric oil pump

4. 2 Reliability

As the electric oil pump is used for drivetrain, it is subject to all types of loads. Typical durability tests and reliability tests are listed below:

(1) Continuous operation durability
(2) On-Off cycle durability
(3) Vibration durability
(4) Muddy water durability
(5) Salt spray test
(6) Thermal shock test
(7) EMC (Electromagnetic compatibility)

In addition to the above tests, the product has been subjected to electric disturbance, such as voltage fluctuation, as well as mechanical disturbances to ensure that the product has satisfactory characteristics for application in the idling stop system.

4. 3 Fail Safe Function

If the electric oil pump is not functioning correctly while the idle stop system is in operation, gear-shifting shock occurs during start up. In order to avoid this problem, it is necessary to make a countermeasure to prevent the system from shifting into the idling stop mode when the electric oil pump is not functioning properly.

To this end, the newly developed electric oil pump is equipped with a fail safe function that is able to detect overcurrent, voltage drop, short or open circuit in the signal line or faulty start as well as to send signal to the upper ECU.

5. Conclusion

The idling stop system is spreading throughout the automotive industry to improve fuel efficiency. The most compact electric oil pump has been successfully developed at reasonable cost, which keeps minimum required hydraulic pressure to avoid shocks in acceleration immediately after ignition.

This technology will be advanced to develop products with even higher performance at a lower cost.

References

1) The Energy Conservation Center, Japan Homepage "Let's Try Idling Stops While Driving Vehicles 2002, JAPAN Running Through."
2) T. SAKATA, Y. YOKOI: Koyo Engineering Journal, 159E (2001) 67.
3) M. HATTORI, K. YOSHINAMI: Koyo Engineering Journal, 164E (2004) 53.
4) Toyota Motor Corporation: Vitz New Car Features (2002).



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