Trends and Outlook of Drive Units for Automobiles

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In recent years, there has been a strong demand for improvements in automobiles, particularly in environmental friendliness and safety, due to changes in the environment surrounding automobiles. This report describes the technical trends in drive units associated with JTEKT products following these changes, including trends in ITCC, torsen differentials, drive shafts, propeller shafts for drivelines, mechanical pumps, electric pumps, and linear solenoid valves for transmissions, and introduces the actions taken by JTEKT in response.

Key Words: *automobile, driveline, transmission, hydraulic, AWD*

1. Introduction

In recent years, technologies for automobiles have been developing at an astonishing pace. The major issues automobiles are expected to address are responding to global environmental issues, such as improving fuel efficiency and reducing substances of concern, as well as improving safety. Development activities to achieve the former include weight reduction of vehicles, diversification of power sources such as those adopted in hybrid vehicles (HV), electric vehicles (EV) and fuel-cell vehicles (FCV), technology to improve the fuel efficiency of engines, downsizing of the engine and addition of a start-stop function. Regarding the latter, technological developments are underway for driving support systems and automatic driving as preventative safety.

JTEKT's drive unit business, one of our major areas, is also engaged in technological development utilizing the fundamental technologies of tribology, materials, control, analysis, visualization and so on in order to respond to these advancements in automobile technologies.

This paper introduces the trends of drive unit-related technologies such as Intelligent Torque Controlled Coupling (ITCC), Torsen, drive shafts, and propeller shafts for drivelines and mechanical pumps, electric pumps and linear solenoid valves for transmissions as well as JTEKT's initiatives.

2. Trends of All Wheel Drive (AWD) Systems

2. 1 Increase of On-Demand Systems

AWD was developed and deployed on special-purpose vehicles such as those used by the military or civil engineering companies as it increases drive power in rough terrain such as sand, mud, snow or icy roads and enables stable vehicle operation. Later, AWD began being adopted in common passenger vehicles due to its good traction performance, etc. and grew in popularity due to an increase in Sport Utility Vehicle (SUV) needs spurred by the boom in outdoor entertainment. Also, with the abolishment of spiked tires, AWD began being used in vehicles for urban use. The major AWD systems currently sold commercially can be categorized as shown in **Fig. 1** by drive force distribution method.

Figure 2 shows the results and forecast of global AWD sales. The electronically-controlled on-demand AWD represented by ITCC is currently mainstream and is predicted to grow more popular in the future. The electronically-controlled on-demand method uses inputs from various sensors to optimally control the torque transferred via the coupling to the driven wheels and is an excellent method with both superior AWD performance and improved fuel efficiency. It also reduces the required strength of driveline components on the driven wheel side by limiting the maximum torque distributed to the driven wheels, thus contributing to weight reduction of the driveline. This has created the new markets of around-town AWDs and daily-use AWDs.

Even in developing nations, the condition of roads is gradually improving and the need for high traction performance is decreasing on a regular basis. However, even on maintained roads, AWD may be required in the event of snow buildup. Therefore, it is predicted the

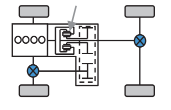
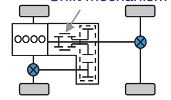
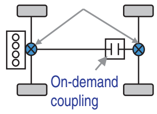
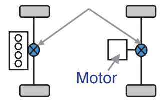
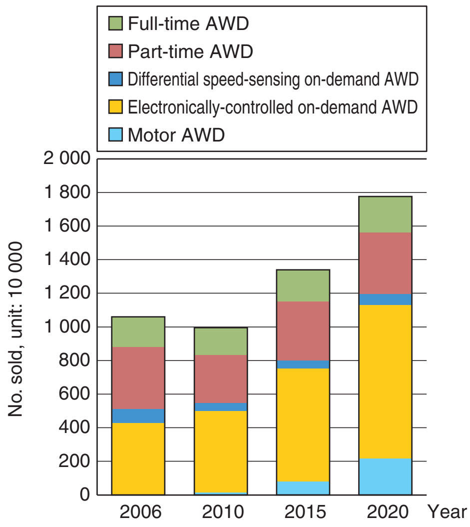
Name	Sketch	Features
Full-time AWD	 Center differential	• Torque to front/rear wheels is distributed by center differential • High traction performance and excellent vehicle dynamics • Large and high-cost drive components due to high torque transmission
Part-time AWD	 2WD⇔AWD Shift mechanism	• Manual shift between 2WD and AWD • High traction performance can be expected when front and rear wheels are directly locked; however a tight corner braking phenomenon occurs
On-demand AWD	 Differential, On-demand coupling	• Torque to front/rear wheels is distributed by the coupling • Differential speed-sensing type which senses the difference in speed between the front and rear wheels, and an electronically-controlled type which can actively change torque distribution
Motor AWD	 Differential, Motor	• Motor to drive the driven wheels (rear wheels) • Suitable for vehicles with high voltage sources such as EVs and HVs

Fig. 1 AWD systems



Source: Investigation by JTEKT, 2006/2010 figures from Global Information, Inc.

Fig. 2 Trends of AWD systems

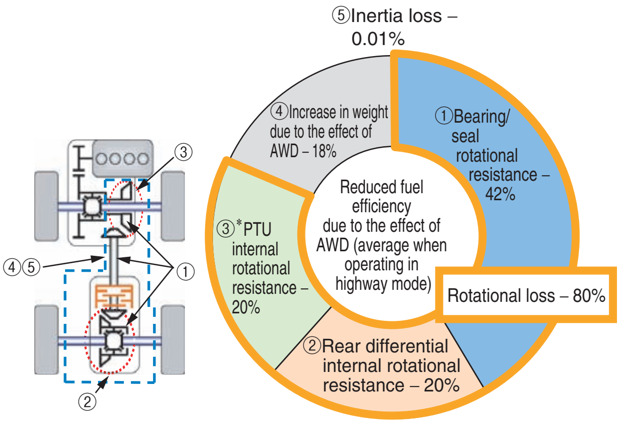
popularity of electronically-controlled on-demand AWD will continue to rise as it allows vehicle operation in 2WD during normal conditions, and in AWD, which offers higher safety, when driving on snow-covered or frozen roads.

2. 2 Increase in disconnect systems

Interest in the prevention of global warming and improvement of the atmospheric environment is increasing on a global basis and all countries are reinforcing their exhaust gas regulations. In response, automobile manufacturers are accelerating their initiatives to improve fuel economy and AWD vehicles are no exception.

As **Fig. 3** shows, of all the factors which increase fuel consumption of on-demand AWD in comparison to 2WD, rotational loss accounts for approximately 80%. Although electronically-controlled on-demand AWD improves fuel efficiency by lowering the torque distribution to driven wheels during constant driving on paved roads, it is not possible to stop rotation, and therefore poorer fuel efficiency due to rotational loss compared with 2WD is unavoidable. As a consequence, recent years have seen a stir in interest regarding disconnect systems which stop rotation of the propeller shaft and hypoid gears during 2WD operation and further improve fuel efficiency.

Figure 4 gives an example of a disconnect system on an electronically-controlled on-demand AWD based on front-engine, front-drive (FF) layout. On this system, in order to stop rotation of the power transfer unit (PTU) through propeller shaft to rear differential, the coupling which disconnects torque distribution and rotation to the rear is mounted on the rear drive shaft rather than the



*PTU：Power Transfer Unit

Fig. 3 Effect of AWD on mileage

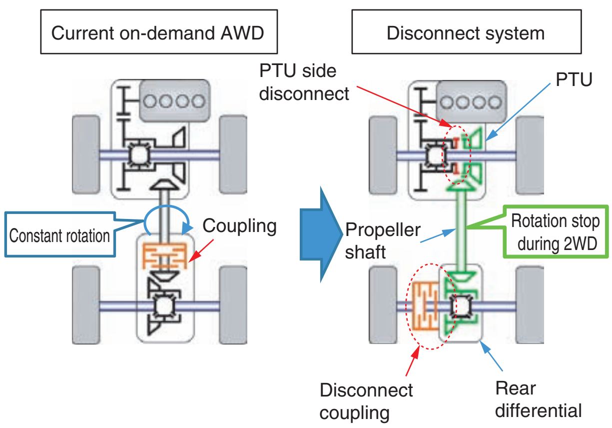


Fig. 4 Example of disconnect system

propeller shaft and a disconnect mechanism has also been added to the PTU side.

By disconnecting at the PTU and the coupling during 2WD operation it is possible to stop rotation of the components between the PTU, propeller shaft and rear differential, thus reducing loss in drag torque, etc. and improving fuel efficiency. When AWD is determined as necessary, the coupling and PTU can be reconnected, creating a normal on-demand AWD condition. By changing between operation modes instantaneously depending on the vehicle's driving condition, it is possible to improve fuel efficiency in disconnect operation as well as achieve traction performance and driving stability with AWD.

The cost of disconnect systems is high compared to that of normal on-demand AWD as a disconnect mechanism must be added to the PTU side. Despite this, the systems are predicted to increase in popularity due to the reinforcement of exhaust gas regulations in countries around the world.

2. 3 Increase in motor AWD

From the forecast of global AWD sales shown in **Fig. 2**, it can be ascertained that the number of vehicles with motor AWD, which did not exist in 2006, is increasing. As **Fig. 1** demonstrates, the motor AWD systems do not have a propeller shaft, but rather drive the driven wheels (rear wheels) using a motor. Although the motor AWD requires a high output motor and high voltage source, vehicles with high voltage sources such as hybrid vehicles have grown in number in recent years, and the motor AWD is often adopted for the AWD conversion of those vehicles.

Due to issues such as motor output and power capacity, high traction performance cannot be expected of the motor AWD systems. However, it is believed they will increase with the popularization of HVs and EVs due to their ability to provide smooth launch and driving stability on snow-covered and frozen roads through electronic controls.

2. 4 Increase in torque vectoring

Conventional AWD systems, as represented by full-time AWD and on-demand AWD, improved turning performance by controlling torque distribution to the front and rear wheels. In an effort to achieve even higher turning performance, torque vectoring systems have been developed and launched on the market in recent years to allow not only front and rear wheel distribution, but also independent control of torque to the left and right wheels (**Fig. 5**).

This system is based on an FF-based AWD and there is one torque control device each on the left and right wheel side of the rear differential. During normal driving, the vehicle operates in FF mode with the torque control devices in a free state, but when a condition in which the front wheels are likely to slip is detected, the torque control devices of the rear left and right wheels transfer torque and the vehicle enters AWD mode.

While the vehicle is turning, understeer occurs if the front wheels slip during FF mode. However, in normal on-demand AWD, it is possible to recover the grip of the front wheels and reduce understeer by transferring torque to the rear wheels. By making the torque to the outer rear wheel greater than that to the inner rear wheel, the torque vectoring systems make it possible to generate yaw moment on the vehicle in a direction which cancels out understeer (**Fig. 6**). Through this, not only does the

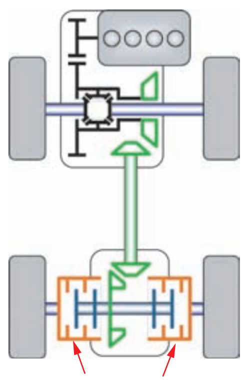


Fig. 5 Example of torque vectoring system structure

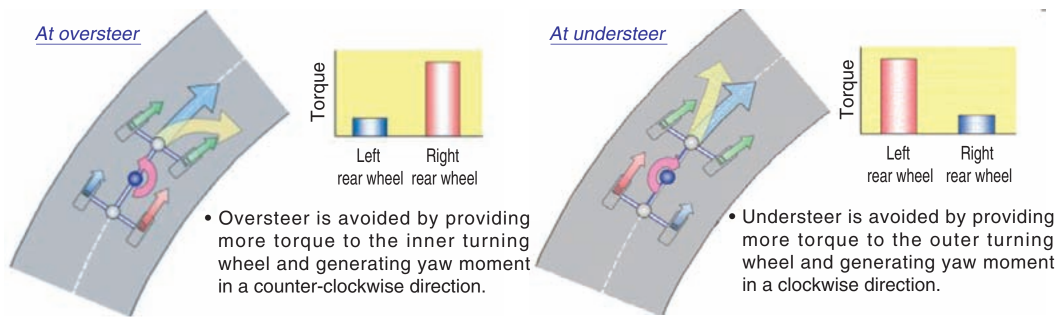


Fig. 6 Torque vectoring system

controllable vehicle yaw moment range become greater than that of normal on-demand AWD thereby achieving safer turning performance, but it is also possible to operate the vehicle freely and enjoy enhanced driving pleasure by proactively controlling torque.

It is believed that the number of vehicles equipped with torque vectoring systems will grow with the aim of enhancing vehicle dynamics even further.

2. 5 Development technologies related to JTEKT's AWD

2. 5. 1 Advancement of ITCC

As we touched upon earlier, due to the emphasis on protecting the global environment, there is a demand for driveline components which enhance driving stability and safety at the same time as leading to lower fuel consumption. AWD systems are no exception, and they are expected to contribute to lower fuel consumption through weight reduction and enhanced efficiency of components.

JTEKT's ITCC is an electronically-controlled on-demand AWD which uses electronic controls to distribute optimal torque when necessary, therefore achieving not only superior AWD performance but also high-level compatibility with other control systems such as brake control and anti-skid control. Moreover, it can also regulate torque, ultimately contributing to the weight reduction of driveline components.

ITCC is structured from a wet multi-plate clutch as shown in **Fig. 7**. The friction torque generated by an electromagnetic clutch is converted by the cam mechanism into thrust force which pushes the main clutch, then amplified, thus generating transmission torque. There are no changes to the basic structure from the 1st generation (Gen1); however, performance has been improved by adding various technologies, as shown in **Fig. 8**.

For the 2nd generation (Gen2) ITCC, we adopted diamond like carbon (DLC) coating for the surface treatment of the electromagnetic clutch and, at the same time, developed special-purpose lubricant to significantly improve durability and reduce clutch drag torque at low temperatures.

Moreover, for the 3rd generation (Gen3) which has been mass produced since 2013, we newly developed the electromagnetic clutch to further reduce clutch drag torque at low temperatures and improve torque temperature dependency, thus improving control performance with the brake and further reducing the weight of the driveline.

As **Fig. 9** shows, Gen3 has several dozen μm of crowning on the inner plate surface land portion and proactively uses the dynamic pressure between clutches in areas where lubricant viscosity increases at low temperatures. Thus, it widens clutch clearance (**Fig. 10**) and suppresses excessive torque increase.

Figure 11 shows a comparison of drag torque in each temperature range of Gen2 and Gen3. Particularly at 0 ℃ or less it has been possible to reduce drag torque by a maximum of approximately 50%.

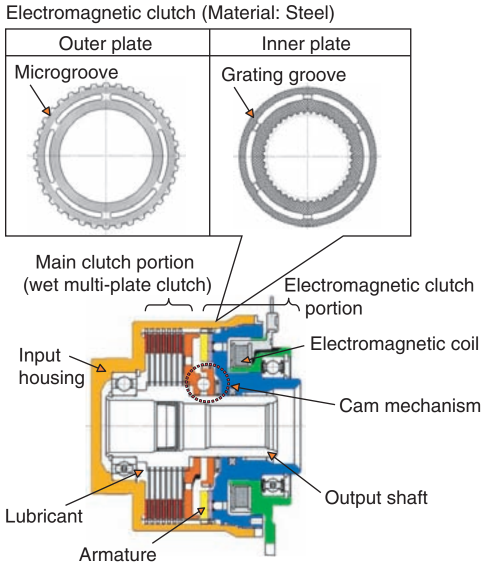


Fig. 7 Structure of ITCC

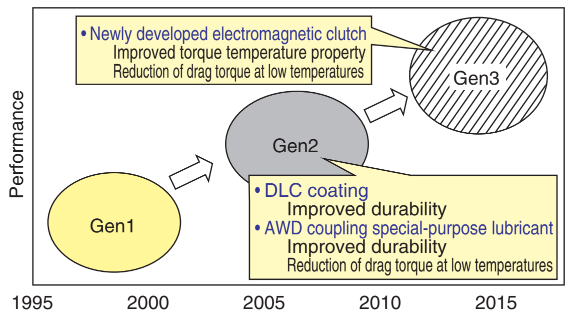


Fig. 8 History of ITCC

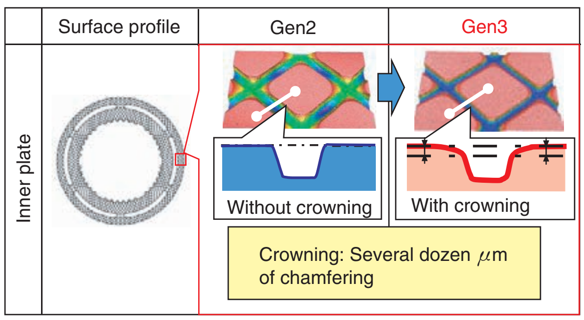


Fig. 9 Comparison of surface profiles of second and third generation electromagnetic clutches

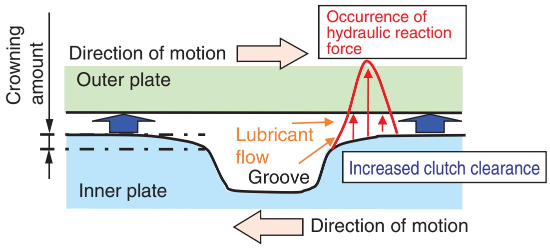


Fig. 10 Mechanism of drag torque reduction at low temperature due to crowning

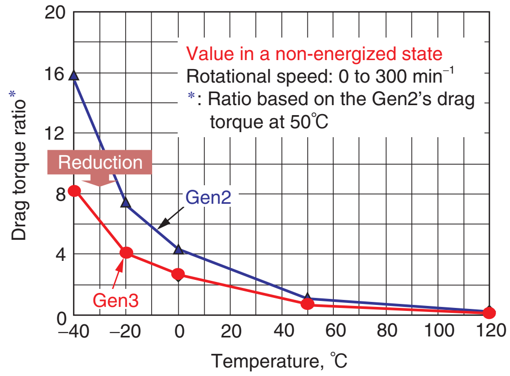


Fig. 11 Temperature dependence of ratio of drag torque in actual ITCC units

2. 5. 2 Twin ITCC

In response to the demand for a torque vectoring system discussed earlier which can independently control torque to the left and right wheels, JTEKT developed a small, lightweight twin ITCC which can be placed on the left and right of the rear differential, and launched it on the market in November of 2010.

The twin ITCC allows the differential rotation between the left and right wheels while having a function as a differential which transfers torque, therefore eliminating the need for a differential gear at the rear side.

Compared to a left/right torque transfer mechanism system which uses motor drive clutches and differential gears as shown in **Fig. 12**, the structure of the twin ITCC is simple and allows the overall system to be made smaller and lighter.

With high-performance, high-durability ITCCs as our core technology, JTEKT will continue to develop next-generation units which achieve downsizing and weight reduction including that of peripheral units such as differentials, as well as excellent vehicle dynamics and improved fuel efficiency.

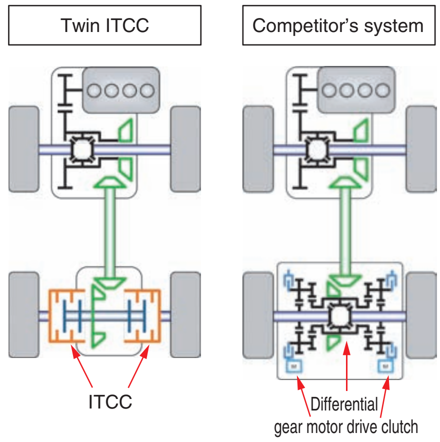


Fig. 12 Twin ITCC and system of other company

2. 5. 3 Tribology of a Torsen differential

JTEKT's flagship Torsen differential product for full-time AWD highly sought after for use in SUVs and high power engine vehicles is Type C (**Fig. 13**), which is a planetary gear type customized for the center differential of AWD.

The Torsen differential slides internally and transmits torque while allowing differential rotation, and is required to reduce stick-slip of the sliding portion and achieve smooth friction at the same time.

The quietness of vehicles has improved in recent years, and as such the Torsen differential is also required to achieve high-level quietness. It is a known fact that stick-slip occurs when the gradient of the dependency of friction coefficient (μ) on velocity (v) (μ–v characteristic) is negative. Therefore, to avoid stick-slip, it is effective to reduce the negative gradient of the μ–v characteristic and bring it closer to a positive gradient ($d\mu/dv \geqq 0$). Optimization of the sliding face profile and material as well as the various additives included in lubricant greatly impact the μ–v characteristic (**Fig. 14** and **15**).

The top land of Type C planetary gears must have an adequate concave/convex shape to mitigate vibration. However, doing so causes the local surface pressure of the sliding portion to rise, creating more friction and reducing durability. In other words, this design feature is a tradeoff between adequately controlling vibration (concave/convex shape) and durability (friction, seizing).

This contradiction is solved using magnetron sputtering, a type of physical vapor deposition (PVD), to apply a carbon coating. The concave/convex-shaped planetary gear outer peripheries, which slide together, are optimally designed at the micron level and maintained with carbon coating. Even on the gear, where the sliding environment is extremely harsh, we have secured durability using the advanced tribology technology.

We will open up new gear-type LSD markets by expanding the range of differential limiting force and promoting downsizing/weight reduction.

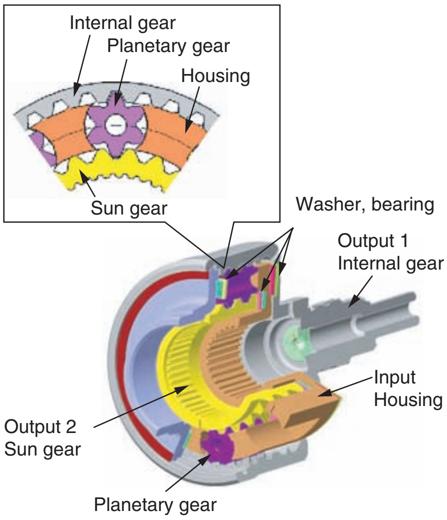


Fig. 13 Structure of Type C Torsen

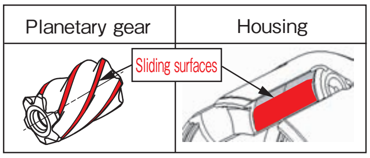


Fig. 14 Friction surfaces of Type C Torsen

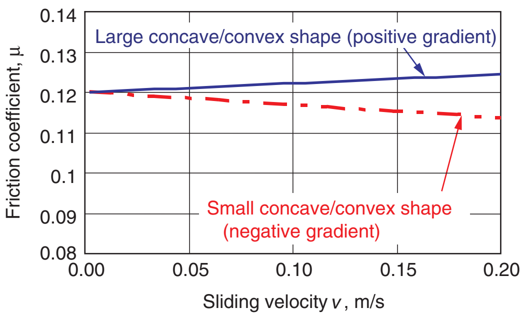


Fig. 15 Relationship between friction coefficient and sliding velocity

3. Driveshaft Trends

3. 1 Downsizing and weight reduction

Driveshafts are mainly used in independent suspension vehicles and transfer drive force from the differential to the wheels. **Figure 16** shows the mounting position of a driveshaft. The role of the driveshaft is to transfer drive force to the wheels and respond to steering maneuvers and suspension vertical displacement to ensure rotation is uniformly transferred at all intersection angles. **Figure 17** shows the configuration of the driveshaft. The driveshaft is configured from two constant velocity joints (CVJ) and an intermediate shaft which joins them together. Sliding CVJs are primarily used as the differential side CVJ, and they are required to enable expansion/contraction in the axial direction as well as smoothly transfer drive force. Fixed CVJs are primarily used as the tire side CVJ and are required to smoothly transfer drive force even at wide intersection angles.

As with other drive units, the demands on the driveshaft from the various automobile manufacturers are downsizing and weight reduction in order to improve fuel efficiency, as well as quietness. In response to these demands, suppliers have developed and launched a driveshaft which is smaller and lighter thanks to optimal design of the internal components and a double-roller, low-vibration type CVJ mounted on the differential side. Moreover, in recent years, some vehicle models are adopting CVJs which cancel out the internal force which is generated when torque is transferred and reduce friction loss which occurs between the cage and outer race, etc. by changing the ball groove profile of the tire side, thus achieving higher efficiency. It is likely that, in order to further improve vehicle fuel efficiency and in response to the demand to reduce environmental burden, suppliers will continue to exert efforts to make driveshafts even smaller and lighter and promote a shift to driveshafts with low-vibration to achieve lower joint loss and improve quietness.

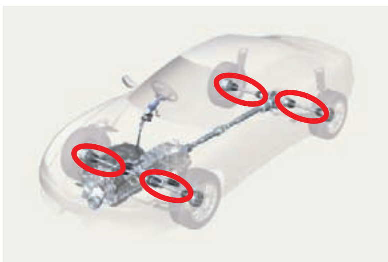


Fig. 16 Mounting position of driveshaft

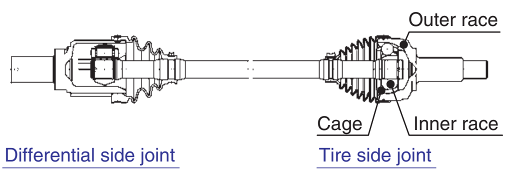


Fig. 17 Driveshaft

3. 2 Development technologies related to JTEKT's driveshaft

JTEKT also promoted downsizing and weight reduction, and launched a new model CVJ on the market in 2012. In order to achieve downsizing and weight reduction, it is necessary to optimally use any margin in the safety factor by diverting it for downsizing and weight reduction purposes. To achieve this, it is necessary to improve the accuracy in stress measurement during driveshaft operation, provide the acquired measurement results to CAE analysis and improve the accuracy of theoretical analysis. **Figure 18** shows the cross-check of FEM analysis results with the results of a stress measurement on the actual machine using infrared. By utilizing a measurement technology which applies the principles that a material generates heat when it is subjected to a compressive load and absorbs heat when subjected to a tensile load, it is possible to accurately measure maximum stress and its location, which was not previously measurable using conventional strain gauges, and this has enabled highly accurate theoretical calculations using FEM analysis. **Figure 19** gives an example of cage stress analysis. The CVJ mounted on the tire side has a large intersection angle to suit steering operation. The dispersion of stress within the joint at this time is complex and was previously difficult to assess. However, through coupled analysis of mechanism and stress, it became possible to accurately reproduce the stress fluctuation of the actual machine. By utilizing these technologies, we have optimized the safety factor and, as **Fig. 20** shows, created the smallest and lightest CVJ currently available on the market which is 4% smaller and 8% lighter than our conventional product.

Moreover, as discussed in the previous section regarding AWD system trends, there is an increase in the number of electronically-controlled on-demand AWD based on FF layout. This system optimally controls the torque transferred to the rear wheels based on the inputs from various sensors and aims to achieve high AWD performance and improve fuel efficiency. Also, by controlling the maximum torque distributed to the rear wheels, the electronically-controlled on-demand AWD makes it possible to lower the strength required of the drive unit on the rear wheel side. Therefore, as the functions demanded of driveshafts for rear tires in the electronically-controlled on-demand AWD are the ability to transfer relatively low torque and to provide

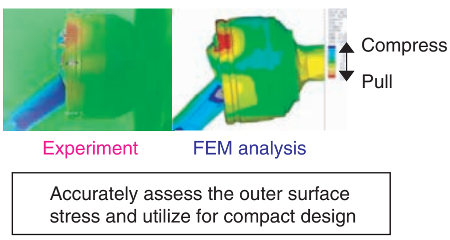


Fig. 18 Cross-check of FEM analysis results with infrared stress measurement

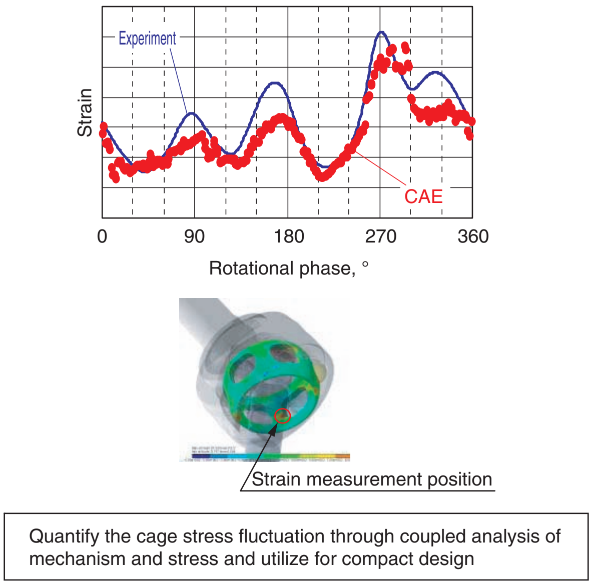


Fig. 19 Dynamic cage stress analysis

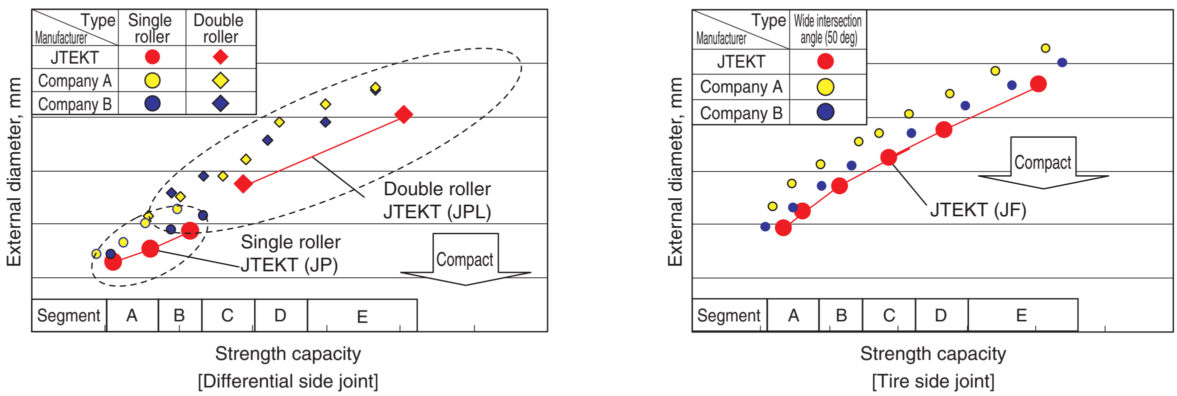


Fig. 20 Static torsional strength and outer race outer diameter

an operating angle capable of responding to the vertical movement of the tires. Focusing on this point, we developed a compact, lightweight driveshaft with limited functions specifically for rear tires. The main feature of this new driveshaft is that the outer race has been made smaller by limiting the maximum operating angle to 23 degrees, compared to 50 degrees for FF-based vehicles. This made it possible to reduce the weight of the driveshaft by 10% compared with normal front tire driveshafts (**Fig. 21**).

JTEKT will continue to engage in product development aimed at commercializing new driveshafts which are even more compact and lightweight, as well as achieve high efficiency and low vibration.

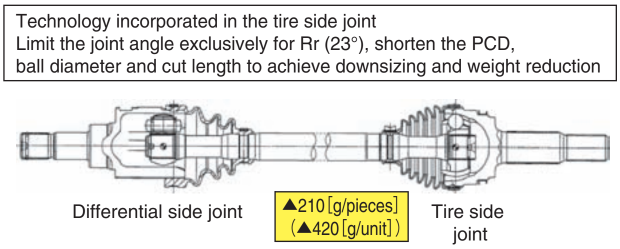


Fig. 21 Compact/lightweight driveshaft for rear axle

4. Propeller Shaft Trends

4. 1 Improving collision safety and reducing weight

Various measures are implemented on propeller shafts (**Fig. 22**) with the aim of mitigating risk (such as fire due to fuel leaks or injury to passengers) at the time of a collision. The tubes and CVJ for propeller shafts can absorb impact by having a crushable structure, and prevent the propeller shaft from penetrating the vehicle cabin by having a structure where the center bearing bracket drops from the vehicle underbody in the event of a collision.

Moreover, various items to reduce weight have been added from the perspective of improving fuel efficiency. Carbon fiber reinforced plastics (CFRP) and aluminum materials have been adopted on some premium sports cars, etc. since the 1990s, but their usage is limited to particular vehicles. This is because these materials have larger diameters than steel and have issues of difficulty of installation to vehicles and higher cost even though they are effective in reducing weight. If such issues can be resolved by achieving higher strength, it is believed adoption of these materials will increase.

Furthermore, for AWD based on FF layout, as discussed earlier, electronically-controlled on-demand AWD has become mainstream, and in this case, torque distribution to the rear wheels can be controlled, therefore offering the advantage of reducing propeller shaft weight even further and as such, each manufacturer is promoting weight reduction. In concrete terms, downsizing of the Hooke's joint and CVJ for propeller shafts makes a significant contribution.

4. 2 Development technologies related to JTEKT propeller shafts

4. 2. 1 CVJ for propeller shafts

In general, Hooke's joints are adopted on propeller shafts, but from the perspective of improving riding comfort, some propeller shafts adopt CVJs which do not create rotational fluctuation even at intersection angles.

Moreover, in the case of FF-based electronically-controlled on-demand AWD, movement of the engine and differential in the axial direction causes vibration; therefore, there is a need for a sliding CVJ.

JTEKT engaged in weight reduction for a sliding double offset joint (DOJ) (**Fig. 23**) and launched it on the market in 2013. The sliding DOJ structure is based on that of DOJ for driveshafts and has the combined features of smaller input torque and high-speed rotation. For the sake of strength and bearing durability, the size and clearance of each component has been optimized for the propeller shaft.

Moreover, in order to suppress heat generation at high-speed rotation unique to propeller shafts, we reexamined the curvature ratio of the ball to ball groove and designed the DOJ so that the ball contact face does not overlap with the ball groove edge.

As a result, we succeeded in developing a DOJ which secures strength and durability on par with our conventional product (DOJ for driveshafts) while achieving downsizing of 12% and weight reduction of 28% (**Fig. 24**).

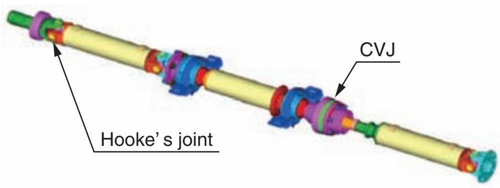


Fig. 22 Propeller shaft

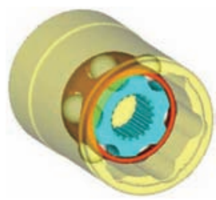


Fig. 23 DOJ

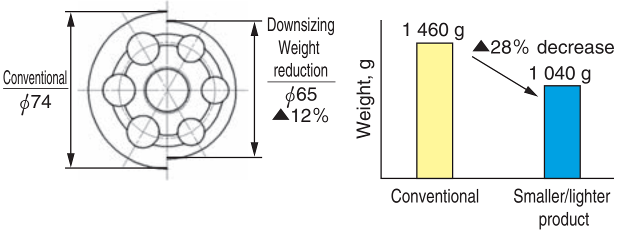


Fig. 24 Maximum outer diameter and results of weight saving

4. 2. 2 Downsizing of the Hooke's joint

Conventionally, it was common for propeller shaft Hooke's joints to comprise of a flange yoke and companion flange fixed with a bolt (**Fig. 25**). By converting to a center yoke structure with the bolt tightening eliminated (**Fig. 26**), however, we were able to reduce the number of components and reduce weight by approximately 48%. This product was launched on the market in April of 2015.

JTEKT possesses the elemental technology for Hooke's joints, center bearings, CVJ and other components which make up the propeller shaft and we will continue to evolve these so that we may further reduce propeller shaft weight.

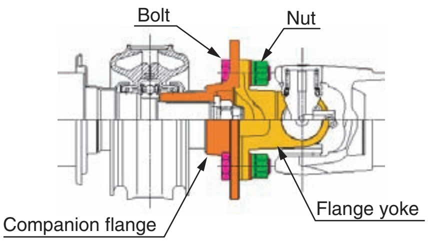


Fig. 25 Bolt tightening structure

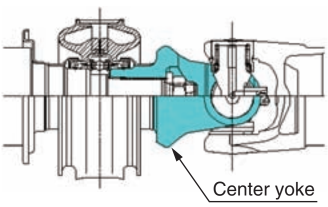


Fig. 26 Center yoke structure

5. Transmission trends

The performance expected of transmissions differs between markets depending on the driving style and road conditions, with various models such as MT, AT, CVT, AMT and DCT to be adopted depending on which of the following elements are prioritized; smooth driving, good start, good overtaking acceleration, swift gear-changing, and direct feel. In recent years, as a response to the demand for lower fuel consumption, multi-step AT (8-speed AT, 9-speed AT) to achieve optimal engine operation are increasing, and the gear ratio range such as CVT with sub transmissions, is expanding. Moreover, in order to minimize fuel consumption, there is a requirement for technologies which help to reduce fuel consumption upon deceleration and stop the engine when the vehicle is stopped.

5. 1 Oil pump trends

Hydraulics is used for AT clutch shift and CVT pulley position control, and as such, transmissions are mounted with oil pumps. Conventionally, oil pumps have adopted internal gear pumps (**Fig. 27**), were mainly installed on the engine output axis and supplied the necessary amount of oil using the engine drive force. Due to the demands for space-saving and higher efficiency that have emerged in recent years, the oil pump has been made smaller by mounting it on a different axis from the engine output axis and using chain drive. Also, vane pumps are becoming more popular with the aim of higher pressure, lower noise and so on (**Fig. 28**). Moreover, there are also emerging demands for variable capacity so that only the necessary amount of oil is supplied, and motorization so that HVs can be supported.

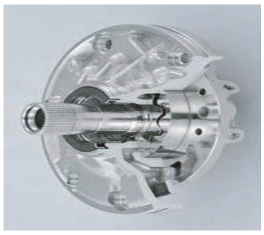


Fig. 27 Appearance of CVT internal gear pump

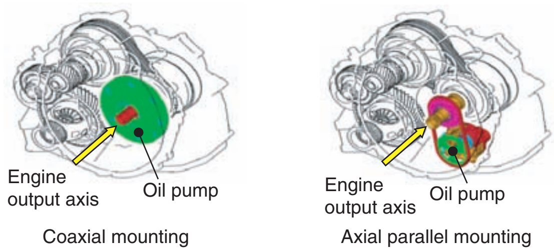


Fig. 28 Mounting example of CVT internal gear pump

5. 2 Electric oil pump trends

An increasing number of vehicles are equipped with a start-stop function as a technology for lower fuel consumption that stops the engine when a vehicle is in a stopped state, and it is believed this number will continue to increase (**Fig. 29**).

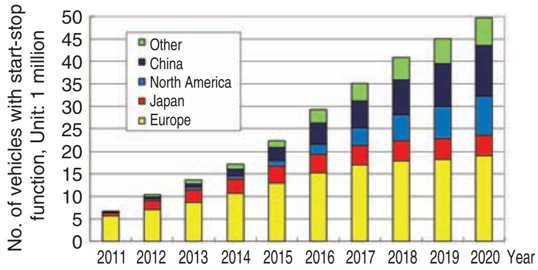


Fig. 29 Predicted demands for idle stop Source: IHS

Start-stop systems must be able to instantaneously engage the transmission clutch in order to promptly transfer drive torque to the wheels when the engine is restarted, and requires an electric oil pump (EOP) which only operates when the engine stops in order to maintain hydraulic oil for the clutch during engine stoppages. However, the EOPs have not been used in recent years, particularly on compact cars and "k-cars" which are Japan-specific small and light cars in an attempt to lower cost, and accumulators or electromagnetic pumps are used as alternatives in an increasing number of cases.

Meanwhile, in order to further improve fuel efficiency, there is also an increase in systems which stop the engine during deceleration immediately before the vehicle comes to a halt. There is also an increased possibility in the future that the engine is stopped during coasting when the vehicle is being driven at a high speed and the accelerator is not being used. Thus, it is believed that the scope of the start-stop approach will expand.

There is a need to make EOPs with higher pressure in order to also support engine restart from the above mentioned driving, and high output type EOPs need to be developed. Moreover, the size of HVs and EVs tends to be increasing, and as one of the technologies to cool the motors with higher output in those vehicles, EOP-based oil cooling is expected. The EOPs must be developed in order to respond to these needs (**Fig. 30**).

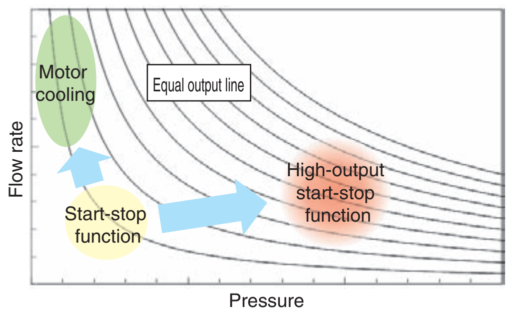


Fig. 30 Representation of output according to application

5. 3 Linear solenoid valve trends

In order to control the hydraulics generated from the oil pump and achieve smooth, shock-free gear change to suit the vehicle's condition, linear solenoid valves are used as hydraulic control parts in transmissions for clutch shift on ATs and to change the contact radius of the pulley and belt on CVTs (**Fig. 31**).

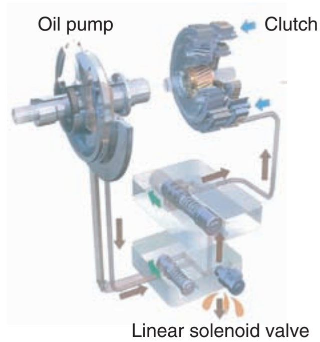


Fig. 31 Linear solenoid valve[7] during automatic transmission

In the case of the multi-step ATs that have emerged in recent years, between six to eight linear solenoid valves are used on one transmission. The more multi-step a transmission is, the greater the number of valves becomes, but direct control of clutch hydraulics through the high pressure and large flow rate of linear solenoid valves has made it possible to simplify the hydraulic circuit and eliminate reducing valves and regulating valves[8), 9)] (**Fig. 32**).

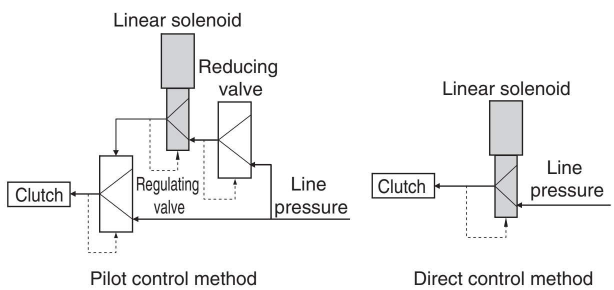


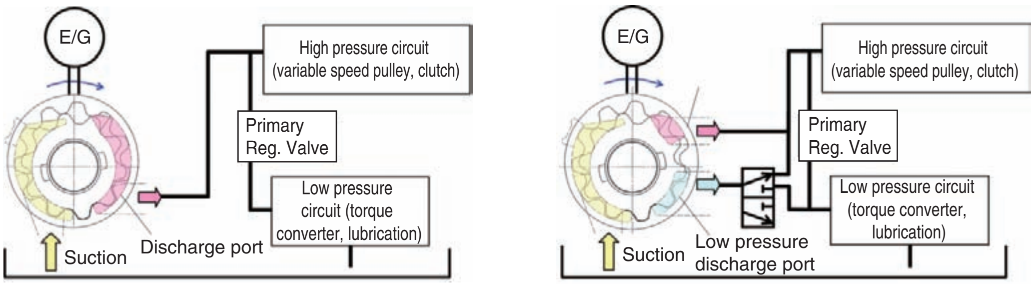
Fig. 32 Direct hydraulic control of clutch

Benefits of this direct control include the improvement in fuel efficiency achieved by combining an 8-speed AT practically the same size as the conventional 6-speed with reduced clutch, and achieving "the joy of driving" by obtaining both gear responsiveness and smoothness[10)].

Moreover, by reducing the amount of oil that leaks from linear solenoid valves, it is possible to reduce the flow rate required from the oil pump, which is the hydraulic source, thus enabling the oil pump to be downsized. We are also engaging in activities to reduce the amount of oil leak in order to improve fuel efficiency.

Internal gear pump with one discharge port (conventional model)   Internal gear pump with two discharge ports (developed model)

Fig. 33 Internal gear pump with two discharge ports



Hydraulic circuit with one discharge port   Hydraulic circuit with two discharge ports

Fig. 34 Difference between hydraulic circuit with one discharge port and hydraulic circuit with two discharge ports

It is believed that for transmissions, fuel efficiency will be further improved by shifting to multi-step ATs and expanding the ratio coverage of CVTs, and for linear solenoid valves, higher pressure, higher flow rate, reduced leakage and space-saving will be required.

5. 4 Development technologies related to JTEKT's transmissions

5. 4. 1 Oil pumps with two discharge ports

In 2013, JTEKT commercialized an internal gear pump with two discharge ports in contrast to the conventional pump which only had one. The pump has a high pressure discharge port and a low pressure discharge port in order to be energy-saving (**Fig. 33**). The high pressure port is used in the high pressure circuit for variable speed pulley and clutch control, etc., while the low pressure port is used in low pressure circuits such as torque convertor and lubrication.

For CVTs, the stroke of the pulley upon acceleration is long; therefore, a large amount of high pressure oil is required. However, during constant driving, a small amount of oil is sufficient as it is only necessary to maintain the force engaging the pulley to prevent the chain from slipping. Conventional pumps set all oil pump discharge flow rate to the highest pressure required by the system, and separate the flow in order to regulate the pressure for each circuit. Therefore, the process is inefficient as the flow rate used on low pressure circuits has to be regulated from high pressure to low pressure (**Fig. 34**). Efficiency could be improved if it were possible to reduce this task.

With two discharge ports, the oil used in low pressure circuits is supplied from the low pressure port, therefore achieving efficiency and eliminating the need to carry out that task. When the engine rotation is low and the flow rate from the high pressure port is insufficient, the required flow rate can be secured by merging the low pressure port and the high pressure port.

By switching between the two different types of discharge ports depending on the vehicle's operational status, pump drive torque has been reduced by approximately 25% compared with the conventional pump model and vehicle fuel efficiency has been improved by 0.5% (JC08 mode).

5. 4. 2 Compact, lightweight EOPs

In 2000, JTEKT developed and mass produced an EOP configured from a brush-type motor embedded with an internal gear pump and in 2004, integrated the pump, motor and controller to achieve downsizing, weight reduction and higher efficiency through the mounting of a brushless, sensorless motor. The EOPs are required to be smaller and have higher efficiency, therefore have undergone a transition regarding volume and efficiency, as shown in **Fig. 35**.

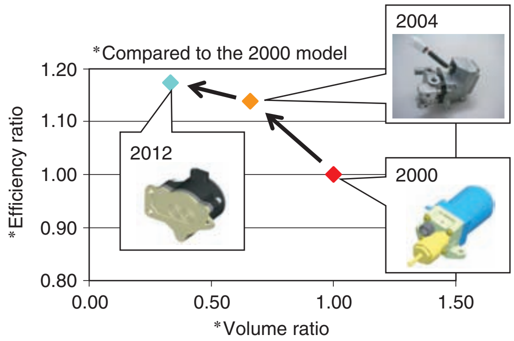


Fig. 35 Change and appearance of EOP

In 2012, JTEKT launched a model on the market which further achieved downsizing, weight reduction, and higher efficiency compared to the previous model, and was characterized by a shorter overall length and energy-saving controls by the adoption of a flat motor and new bearing arrangement (**Fig. 36**).

Moving forward, we will leverage our superior technologies for downsizing, weight reduction and high efficiency and promote product development to suit various applications.

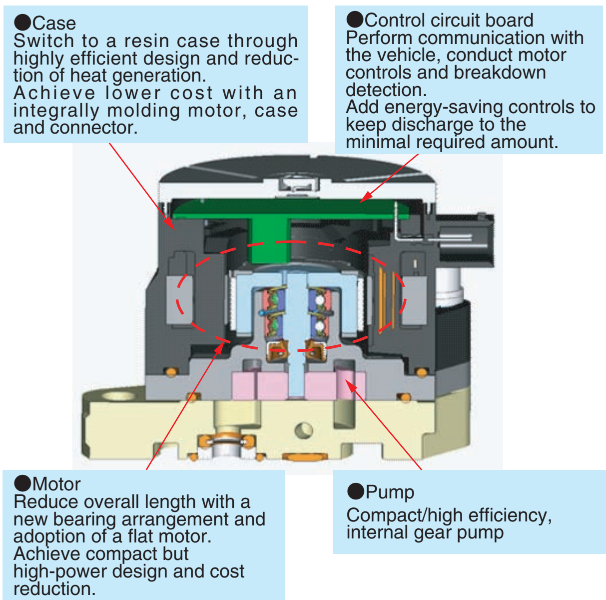


Fig. 36 Characteristics of latest model

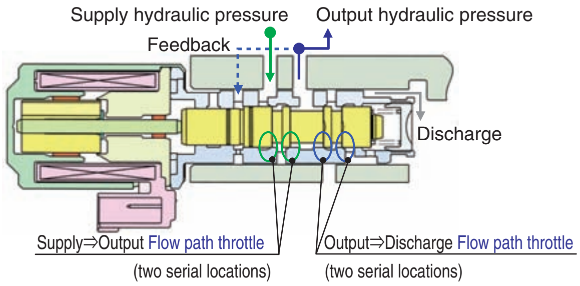


Fig. 37 Valve throttle modified to two serial locations

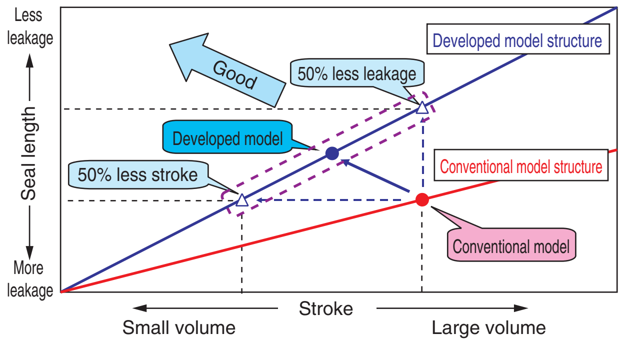


Fig. 38 Leak amount reduction along with compactness

5. 4. 3 Compact/lightweight linear solenoid valve

As mentioned earlier, reducing the amount of oil which leaks from linear solenoid valves enables the oil pump, which is the hydraulic source, to have a smaller capacity. If the oil pump capacity is made smaller, the load torque on the engine will decrease, improving fuel efficiency. JTEKT developed a compact and lightweight linear solenoid valve (**Fig. 37**) as a unique technology for low leakage which has valve throttles in two serial locations, rather than the conventional one location. This product was launched on the market in 2012[11].

This has made it possible to change the relationship from seal length = stroke (conventional structure) to seal length = two times the stroke (developed structure). In other words, the seal length doubles the stroke in this structure and, as a result, the amount of leakage decreases by half. Moreover, if the seal length is the same, the stroke is reduced by half, meaning that the magnetic portion can be made smaller as the air gap in the magnetic circuit can be narrowed.

As **Fig. 38** shows, the stroke, which was unmistakably determined by leak control conventionally, can be designed with a higher degree of freedom and both leak amount reduction and compactness can be achieved.

The developed linear solenoid valve has 27% less leakage compared with JTEKT's conventional product and a magnetic portion 47% smaller in volume.

We will continue developments to achieve higher pressure, lower leakage and better space-saving.

6. Conclusion

This paper has introduced the trends of technologies related to the automobile drive unit as one of JTEKT's major business areas, as well as the related JTEKT initiatives. It is believed that technological developments for preserving the global environment and improving safety will continue to be promoted in the drive unit sector. As this paper has introduced, JTEKT possesses many unit technologies in driveline and transmission areas. With these as our core technologies, we will achieve next-generation unit development which can be considered "No.1 & Only One" and lead on to new system proposals not previously possible, thus contributing to preservation of the global environment and improvement of safety.

*1 ITCC and Torsen are registered trademarks of JTEKT Corporation.

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