Development of Compact and High Efficient Linear Solenoid

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We JTEKT have developed and started the production of a proportional controlled solenoid valve (linear solenoid valve) for compact, highly efficient, and highly accurate automatic transmissions. The developed product is the first in the world to have a double-throttle valve structure on the hydraulic pressure adjustment part. By having a highly efficient magnetic circuit for the electromagnetic portion and by adopting a double-throttle valve structure on the hydraulic pressure adjusting part (first in the world), we were able to halve its size and mass compared to the conventional product, and were also able to reduce the flow volume loss at hydraulic pressure adjustment by approximately 30%. This contributes to improved vehicle fuel consumption. JTEKT plans to use the newly structured solenoid valve on a wider scale, and will implement design optimization, aiming at low fuel consumption vehicles.

***Key Words**: Linear Solenoid Valve, high fuel efficiency, flow rate consumption, downsizing, weight reduction*

1. Introduction

As our awareness of Earth's environmental problems grows, and in light of the sudden jump in the price of crude oil, efforts to reduce automobile CO_2 emissions and improve fuel consumption are becoming a necessity. From the field of vehicle drivetrains, continuously variable transmissions (CVT), idling stop, low fuel consumption flow pumps and hybrid technology with electric motors are gaining attention as countermeasure technologies.

Ever since JTEKT began the production of proportional control solenoid valves (linear solenoids) for automatic transmissions (AT) in 1981, we have also developed and mass produced solenoid valves for multiple uses, such as in pilot control, direct control and CVT sheave control. This time, we will introduce our compact, high-efficiency linear solenoid, developed for low fuel consumption vehicles in response to recent market demands.

2. Development Aims

Linear solenoids control the switching behavior of the clutch (gear control) by managing hydraulic pressure generated from the AT oil pump, ensuring a smooth, shockless gear shift depending on vehicle status.

In response to automakers' demands, we have established the following goals for the linear solenoid:

(1) Compactness: Reduced size and mass by 50% compared with the conventional
⇒ Improved mountability to vehicles, weight reduction of automobile (AT)

(2) High efficiency: Flow loss during hydraulic adjustment reduced by 20% compared with the conventional
⇒ Improved automobile fuel consumption

(3) High accuracy: Hydraulic hysteresis reduced by 20% compared with the conventional
⇒ Improved controllability due to reduced hydraulic dispersion

3. Outline of Development

3. 1 Structure of Developed Product and Main Development Points

The developed linear solenoid is shown in **Fig. 1**, its structure in **Fig. 2**, and the main development points in **Table 1**.

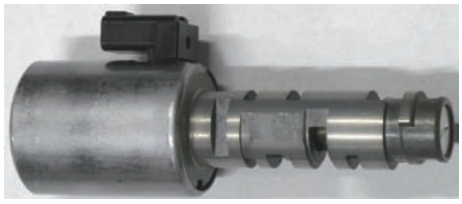
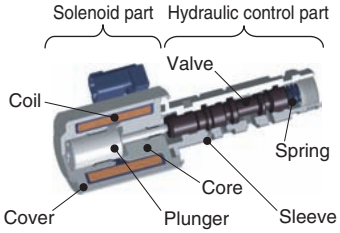


Fig. 1 Exterior of the developed linear solenoid valve



- Opens and closes the valve using electromagnets, controlling hydraulic pressure.
- Performs clutch switch by controlling line pressure within automatic transmissions (AT) and continuously variable transmissions (CVT)
- The JTEKT linear solenoid uses a structure superior in consumption flow/controllability to improve fuel efficiency and reduce gear switch shock.

Fig. 2 Structure and motion of linear solenoid valve

Table 1 Main development points of the linear solenoid valve

	Item	Development description	Aim
1	Optimization of magnetic circuit	Development of efficiency in magnetic circuits by central placement of magnet attractive force and air gap reduction, etc.	• Size reduction of electromagnet part • Shorten operation stroke ⇒ Reduce size of hydraulic control part
2	Valve throttle modified to 2 serial locations	Development of new structure doubling substance seal length for each stroke	• High efficiency due to reduced hydraulic flow loss
3	Change of bearing structure	Reduced bearing surface pressure through plunger support	• Improved hydraulic controllability

3. 2 Main Development Points

3. 2. 1 Optimization of the Magnetic Circuit

In order to reduce the size and weight of the linear solenoid electromagnetic part, a study was conducted on the reduction of the number of turns made by the electromagnetic coil, due to optimization of the magnetic circuit (highly efficient magnetic attractive force). This led to the employment of the below four elements, which resulted in a 60% reduction in flux leakage.

Concrete measures are in the three elements (I through III) focused on the magnetized section between the plunge and core center (which both hold great influence on attractive force), and one element (IV) that focuses on the magnetic circuit from the cover to the plunger.

The goal compactness was reached through the optimization of the magnetic circuit by these elements (**Fig. 3**).

I	Attraction position changed to the center of the coil
II	Shortened plunger stroke (30% reduction)
III	Radial clearance reduction between plunger and core (40% reduction)
IV	Changes to the magnetic circuit (yoke ⇒ yoke + end face)

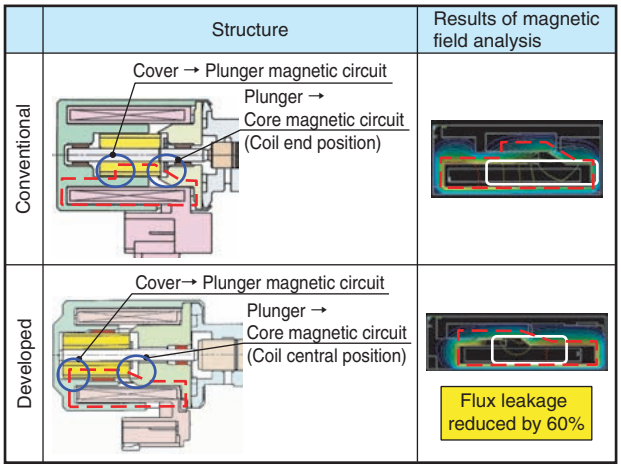


Fig. 3 Optimization of the magnetic circuit

3. 2. 2 Valve Throttle Modified to Two Serial Locations

With this development, the throttle (seal part) configured at the hydraulic control part valve port has been modified from the conventional one location, into two serial locations (**Fig. 4**). This has created a structure with twice the seal length for each stroke.

From this, we were able to change the relationship of

Seal length = Stroke (Conventional structure)

to

Seal length = Stroke × 2 (Developed structure)

In other words, the feature of this structure is a doubled seal length without increasing dimensions. This results in a 50% reduction in hydraulic flow loss from each stroke length.

The developed product also has a shortened hydraulic control part valve stroke due to the previously mentioned "shortened plunger stroke (30%)". As the conventional structure reduces seal length by 30%, the actual seal length can be increased by using the new structure, making both compactness and reduced flow loss possible (**Fig. 5**).

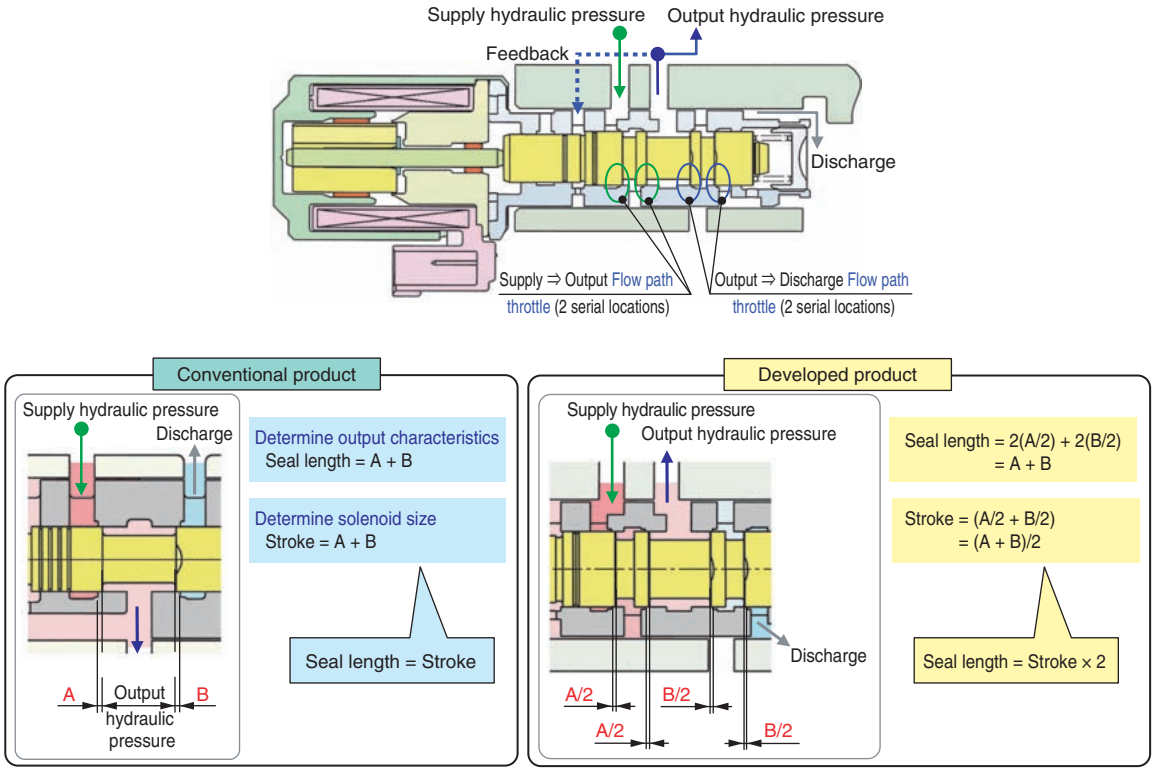


Fig. 4 Creating a valve with a series of two throttles

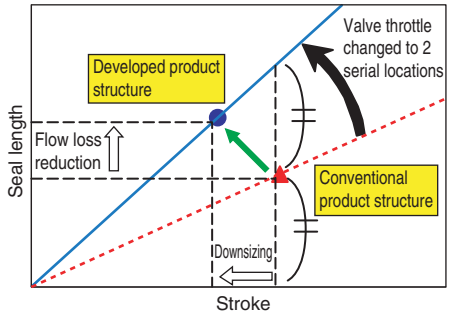


Fig. 5 Results of the double-throttle valve

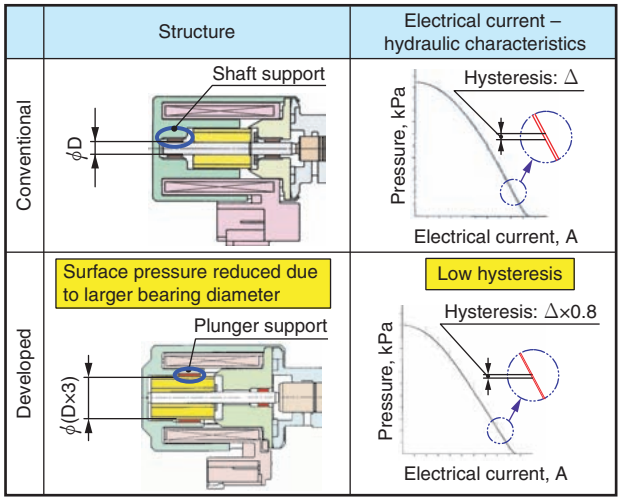


Fig. 6 Changes to the bearing structure

3. 2. 3 Change in Bearing Structure

We responded to the high accuracy of hydraulic pressure sought for linear solenoids by changing the bearing support structure for the plunger (the movable part that receives attractive power with the electromagnetic section) (**Fig. 6**).

In conventional products, the shaft is passed through the plunger for assembly, creating 2-point support using a bush (bearing component) on each of the upper and lower (total of 2) locations on the shaft. With the developed product, the bearing face pressure is reduced by changing one of the bush supports to the plunger with the larger outer-diameter (3 times that of the shaft). This reduces the sliding resistance (maximum value) on the bearing support by 35%, and reduces the hydraulic characteristic of hysteresis by 20%.

3. 3 Development Results

Linear solenoids incorporating these elements of development have reached the development goal values (**Fig. 7**). In particular, compactness/weight-saving does not only concern mountability to vehicles, but also contributes to improved vehicle fuel consumption and improved controllability for a refined gear switch feeling; this is recognized as an important item in advancement. This developed structure also contributes to a large reduction in cost.

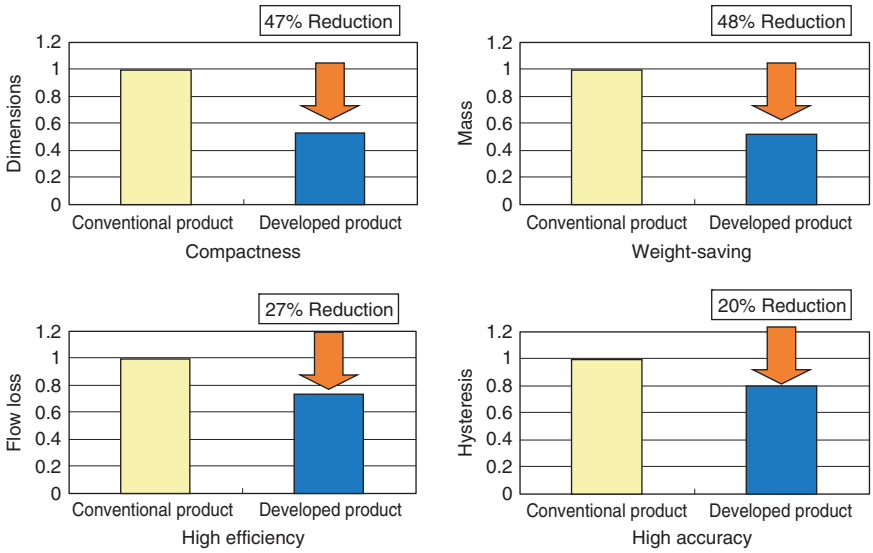


Fig. 7 Development results

4. Product Series

This report introduced development examples of linear solenoids for mid-size and large-size CVT sieve controls. These linear solenoids are already employed within medium-class vehicles and minivans, and are currently being mass-produced (**Fig. 8**). As the environments of use for direct-type linear solenoids are areas of high pressure, high responsiveness is required; low-pressure areas employ pilot-type linear solenoids sought for small-size vehicles due to their compactness and weight-saving qualities. Development for these solenoids has also been completed based on the technology in this report (**Fig. 9**).

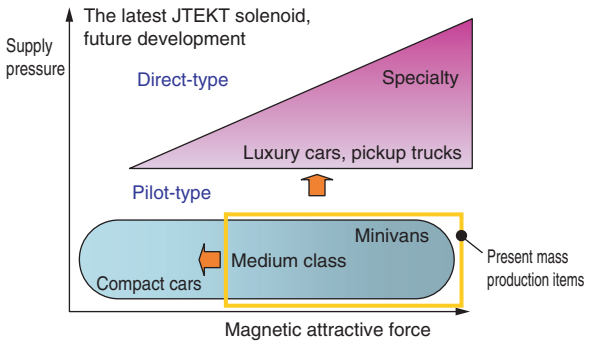


Fig. 8 Creating a product series

Fig. 9 Exterior of the direct type and compact pilot type

5. Conclusion

Compact/highly efficient linear solenoids for the AT were developed with the aim of improving vehicle fuel efficiency. We will continue our efforts to expand the application of these new linear solenoids and promote optimum design and expansion in line with low-fuel consumption automobiles.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