Development of a new CVT featuring high efficiency and wide ratio coverage

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Summary

Higher efficiency and wider ratio coverage are demanded of continuously variable transmissions (CVTs) today in this transitional period toward electrification as a continuous environmental response. JATCO has developed a new high-efficiency CVT by adopting a twin oil pump system incorporating a high-output electric oil pump and simultaneously evolving existing technologies of the torque converter, chain, control valve and other components.

1. Introduction

The shift to electrification is accelerating toward the attainment of carbon neutrality. However, there are still many issues, including infrastructure aspects, that must be overcome in order for electrified vehicles without an internal combustion engine (ICE) to become popular throughout the world. Since ICE-powered vehicles will remain the mainstream for some time to come, it is absolutely essential to improve their efficiency. This article describes the technologies adopted for the new Jatco CVT-X (CVT-X), featuring wide ratio coverage, high efficiency and excellent compatibility with downsized turbocharged (DST) engines.

2. Overview of CVT-X

2.1 Development concept

Vehicle manufacturers are switching from naturally aspirated engines to DST engines as a measure for complying with global environmental requirements. The ratio coverage for the CVT-X pulley system was set at 8.2 in order to improve the acceleration response of DST engines before turbocharging provides boost and to lower the engine speed during cruising. A chain-driven variator system with high torque transmission efficiency was adopted to improve vehicle fuel economy. In addition, various measures were employed to reduce friction along with adopting a twin oil pump system that combines an electric oil pump (ELOP) with a mechanical oil pump (MOP), enabling the MOP to be downsized for reducing mechanical losses.

2.2 Specifications and major technologies

The specifications of the CVT-X and the existing Jatco CVT8 (CVT8) model are compared in Table 1. As shown in Fig. 1, the CVT-X has a standard CVT mechanism without an auxiliary transmission. It consists of a torque converter, forward-reverse clutch system, planetary gear set, pulley/chain assembly and 2 stage reduction gear pairs. As indicated in Fig. 2, the major technologies shown in Fig. 1 effectively reduce mechanical losses by 30% and achieve transmission efficiency of over 90%, thereby enabling the CVT-X to contribute to an 8% improvement in vehicle fuel economy under the U.S. city/highway combined driving mode. Among the major technologies adopted, the following section describes the attainment of ratio coverage of 8.2, twin oil pump system, control valve, torque converter, and resin baffle plates with a rubber seal.

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Table 1 Major specifications

Item		CVT-X (New CVT)		CVT8 (Current CVT)	
Torque capacity [Nm]		330		250 (mounted on previous car model)	380
Torque converter	Clutch / Oil flow route	Multiplate / 3-way		Single plate / 2-way	←
	Vibration damper	With pendulum damper	Long torsional damper	Long torsional damper	←
Variator system		Chain (3307 pitch)		Belt (28-10 layers)	Chain (3008 pitch)
	Ratio coverage	8.2 (2.95 - 0.36)		7.0 (2.64 - 0.38)	6.3 (2.43 - 0.38)
Gear ratios	Final gear	5.7 - 6.0		4.8 - 6.4	4.7 - 5.8
	Reverse gear	0.75		0.75	0.75
Size [mm]	Overall length	381	408	345	356
	Distance between prim.-sec. pulley shafts	180		173	173
Oil pressure control	Mechanical oil pump	12.7 cc/rev		14 cc/rev	18 cc/rev
	Electric oil pump	400 W		30 W (for stop-start)	-
Other	Shift-by-wire	○		○	-
	AT-CU	Integrated with case		Separately mounted (engine compartment)	←

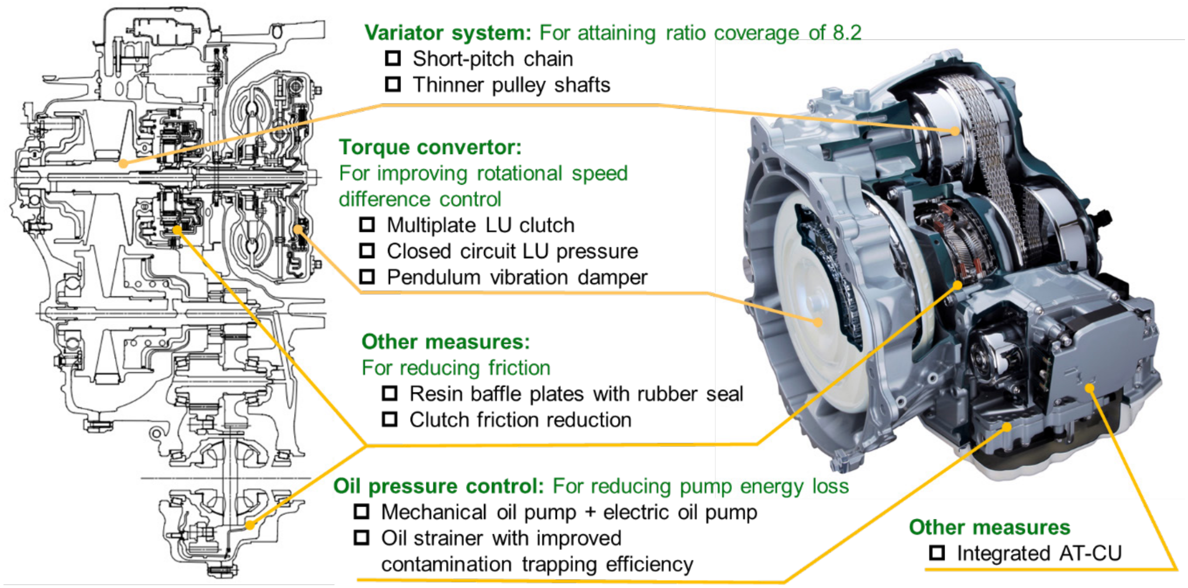

Fig. 1 Cross-sectional view and major technologies

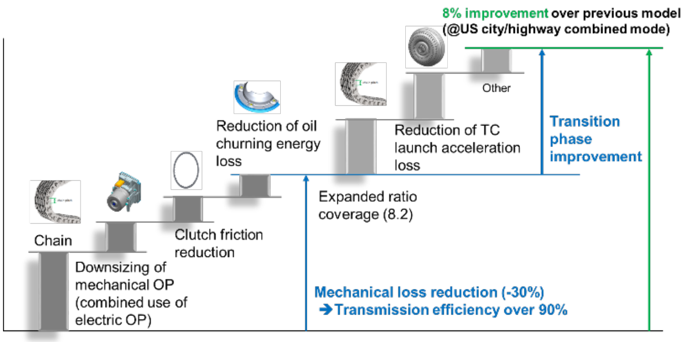

Fig. 2 Breakdown of 8% fuel economy improvement

3. Major technologies

3.1 Attainment of ratio coverage of 8.2

In order to expand ratio coverage, the radius ratio between the large and small wrap-around diameters of the chain must be increased on both the primary and secondary pulleys. It was desired to achieve ratio coverage of 8.2 while designing the CVT-X with the same minimum wrap-around radius on the small diameter side as that of the CVT8. To accomplish that, as shown in Fig. 3, the pulley outer diameter of the CVT-X had to be enlarged by 21% over that of the CVT8; in addition, the distance between the pulley shafts had to be increased by 37 mm from 173 mm for the CVT8 to 210 mm for the CVT-X. As shown in Fig. 4, the chain wrap-around radius on the small diameter side of the CVT-X was reduced by 15% from that of the CVT8 by adopting a short-pitch chain. Moreover, on the large diameter side, a chain wrap-around radius closer to the pulley outer diameter was achieved, thanks to the amount of chain stretch and management of the dimensional tolerances of the parts. That obtained a chain wrap-around radius ratio that effectively uses up to 98% of the pulley outer diameter. Consequently, the increase in the pulley outer diameter was kept to 4% and the increase in the center distance between pulley shafts was kept to 7 mm, increasing only from 173 mm for the CVT8 to 180 mm for the CVT-X. As a result, ratio coverage of 8.2 was achieved with good space efficiency.

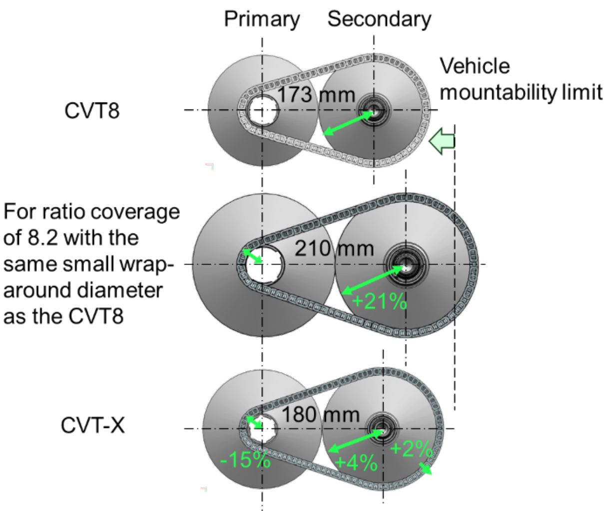

Fig. 3 Comparison of distance between pulley shafts based on wrap-around diameter

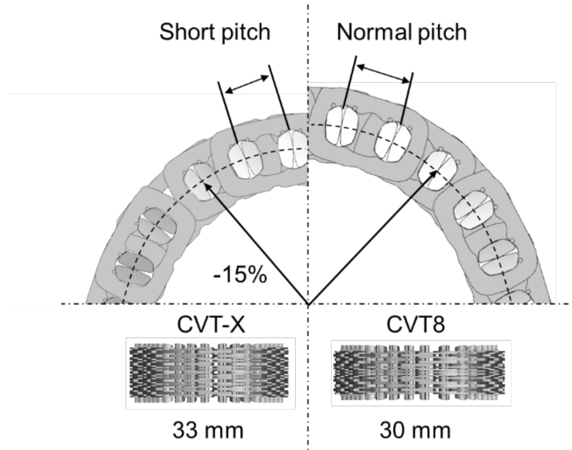

Fig. 4 Pitch comparison for previous and new chains

3.2 Twin oil pump system

As shown in Fig. 5, only the downsized MOP is used when driving with the flow of traffic in town; the ELOP is activated in situations where a large flow rate is needed to execute various quick shifts such as for kick-down acceleration or for sudden deceleration. It is also operated in other regions such as for stop-start driving and for stop-start coasting with the engine turned off. This system concept has made it possible to reduce mechanical losses by downsizing the MOP that is used in ordinary driving situations. For the CVT-X, the MOP was downsized by approximately 30% to reduce mechanical losses by 5.4% in driving situations where it alone supplies all the required flow rate.

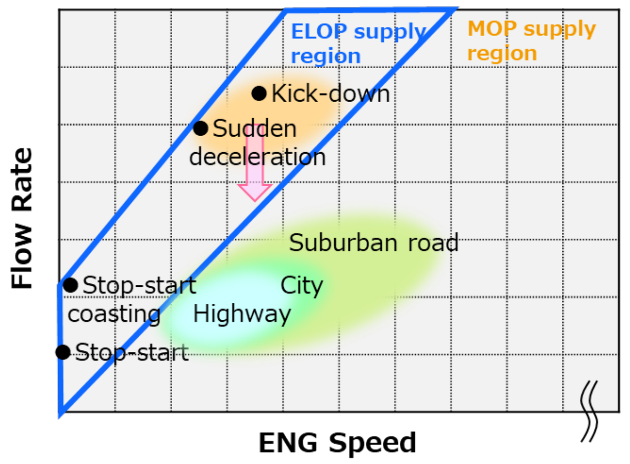

Fig. 5 Twin oil pump system concept

Both oil pumps are located inside the CVT case. As shown in Fig. 6, they suck up oil through a common oil strainer from a shared oil pan and supply it to various parts via the control valve. In situations where the driver presses the accelerator pedal hard with the intention to accelerate, the ELOP is activated to supply the flow rate to the pulleys that is needed to execute a quick shift, thereby achieving a highly responsive downshift. In deceleration situations due to sudden braking, the ELOP is also activated to complete the downshift in a short interval before the vehicle comes to a stop so as to ensure driving force for re-acceleration after the vehicle stops. This operation of the ELOP is shown in the time chart in Fig. 7. The system judges the flow rate needed from the ELOP based on the accelerator pedal position, vehicle speed, rate of deceleration and other factors. At the point where the system judges that the MOP alone can provide the required flow rate, it stops the ELOP to minimize the consumption of electric power.

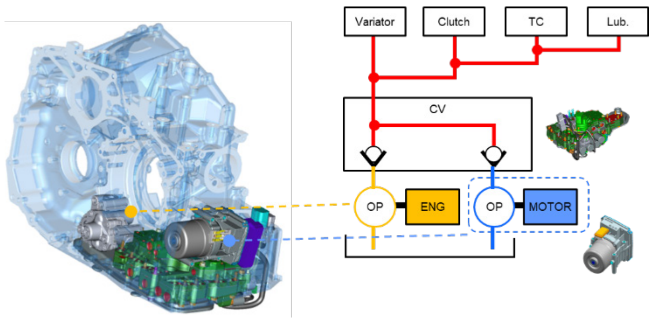

Fig. 6 Twin oil pump system layout

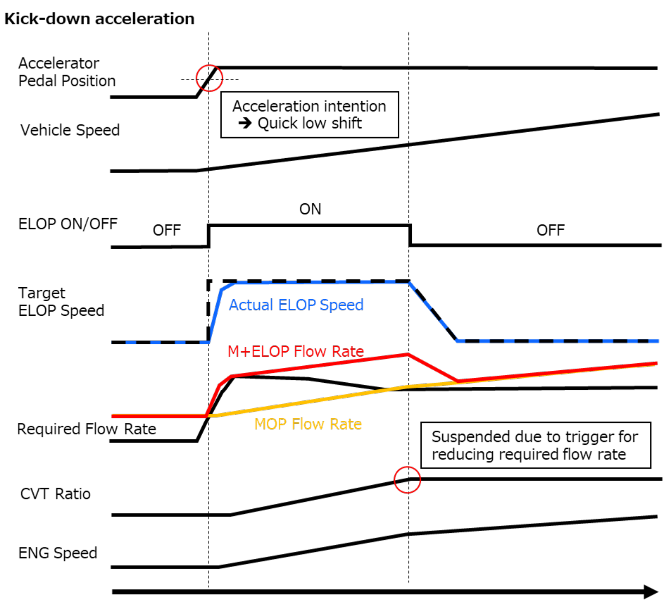

Fig. 7 ELOP time chart

3.3 Control valve

Control valve leakage and flow rate consumption must be reduced in order to improve fuel economy and ensure hydraulic pressure stability. For the CVT-X, the amount of leakage was reduced by 10% at representative operating points by optimizing the specifications of the valve body and spool. In addition, as shown in Fig. 8, a boring process was applied to the port involved in regulating the pressure, making it easy to control variation in the amount of lapping of the valve body and spool, thus enabling a design for suppressing hydrodynamic force. Moreover, wear resistance was improved by applying a high-consistency silicone to the valve body, thereby suppressing variation in the spool opening area characteristic and enhancing simulation accuracy of hydraulic pressure characteristics. As a result, it also became possible to simulate in advance the trade-off between stability and responsiveness, which was effective in improving pressure controllability as well.

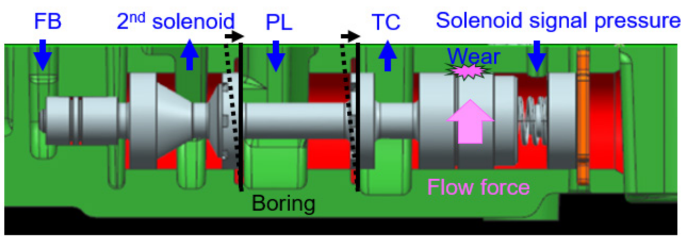

Fig. 8 Control valve (pressure regulator valve)

3.4 Torque converter

The torque converter transmits the driving force produced by the engine by means of the transmission fluid and engagement of the lock-up (LU) clutch. In order to obtain high levels of both driving force and fuel economy, the torque split between the fluid and LU clutch must be properly balanced. For the CVT-X, as shown in Fig. 9, a dedicated oil circuit was provided for the LU clutch as a means of improving the degrees of freedom for controlling torque transmission by the clutch. This made it possible to reduce the volume of the hydraulic pressure chamber by 58% to improve controllability of rotational speed differences between the engine and the turbine owing to LU clutch engagement. In addition, the LU clutch requires a thermal design because of the heat generated by sliding contact during rotational speed difference control. Accordingly, as shown in Fig. 9, a multiplate clutch was adopted that reduces contact pressure on the LU clutch friction material by 56%. Suppressing the temperature rise at the sliding surface of the facing friction material has made it possible to use acceleration slip control in all speed ranges, as shown in Fig. 10. Previously, this control feature was applied only in the region of a small throttle valve opening. This change in the acceleration slip control system achieves a 1.3% improvement in fuel economy.

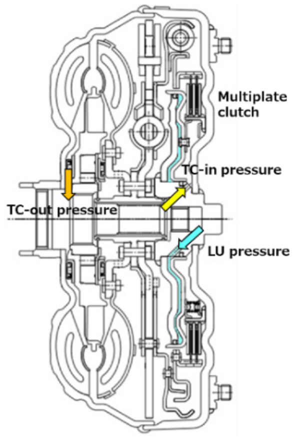

Fig. 9 3-way oil flow route of torque converter

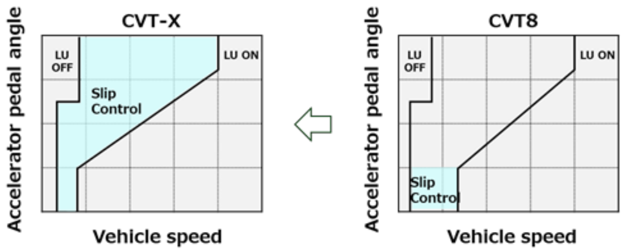

Fig. 10 Slip control region at vehicle launch

The CVT-X lineup is also intended to be combined with 3-cylinder DST engines, which experience greater torque fluctuation due to the reduced number of cylinders. As a countermeasure for this, a pendulum vibration damper was adopted as shown in Fig. 11. This type of damper provides damping force by activating the pendulum mass in the opposite phase of the input torque fluctuation frequency. In order to suppress any increase in the layout caused by the addition of the pendulum damper, it was combined with the main damper on the outer circumference side while the torque converter diameter was reduced by adopting the multiplate clutch. This created a compact layout that ensures sufficient torque transmission capacity without sacrificing performance.

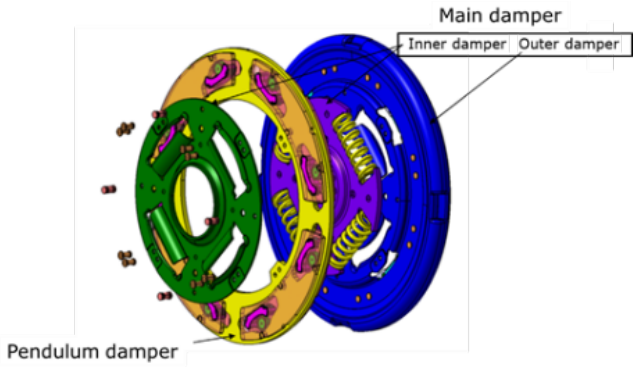

Fig. 11 Pendulum vibration damper

3.5 Resin baffle plates with rubber seal

The differential gear located in the bottom part of the CVT is its largest component and is a factor that worsens mechanical losses by causing oil churning. For that reason, baffle plates have previously been applied to suppress the inflow of oil to the differential gear chamber. To further reduce mechanical losses for the CVT-X, a rubber seal has been added to the baffle plates as shown in Fig. 12. The seal eliminates any gap to suppress the inflow of oil for reducing churning resistance, which achieves a 5.1% reduction in mechanical losses. In addition, molding the baffle plates of resin lightens their weight by approximately 300 g.

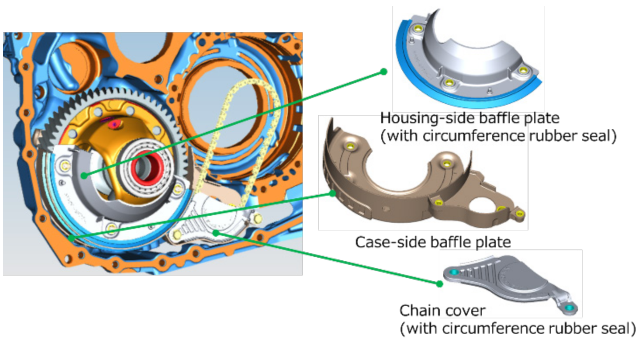

Fig. 12 Baffle plate

4. Conclusion

The new CVT-X achieves ratio coverage of 8.2 without adopting any auxiliary transmission or direct coupling device. Moreover, it reduces unit friction by 30% and achieves transmission efficiency surpassing the 90% barrier at representative management points of the U.S. city/highway combined driving mode to contribute to an 8% improvement in vehicle fuel economy. As such, it represents the ultimate CVT that has attained the final stage of evolution of mass-produced CVTs.

5. References

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