New high efficiency CVT for middle class FWD vehicle

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Abstract
Many kinds of transmissions have been developing and recently electrification is processing rapidly to reduce fuel consumption. Automatic transmission has been developing in multi-stages to improve fuel economy and power performance. CVT, kinds of transmissions, also need to increase the ratio spread to improve the two performances. Thus CVT has better fuel economy performance through the engine’s optimal operating. So, CVT would be a good solution for fuel economy among the conventional transmissions. The newly developed CVT for FWD vehicles has wider pulley ratio spread than any other competitors. And in spite of wide ratio coverage, CF28 has good competitiveness in the overall length by minimizing the length increase. In spite of reducing transmission length, we had achieved maximum torque capacity, minimum length, highest efficiency, and largest pulley ratio coverage compared to competitors’ middle-class CVTs.

Introduction
Recently many kinds of transmissions have been continuously developing to increase driving performance and reduce fuel consumption, And to achieve vehicle mount-ability, it necessary to miniaturize the transmission, because the room for transmission gets smaller and smaller. The newly Continuous Variable Transmission(CF28) for the front-wheel-drive vehicle which was recently developed, substantially enlarge the torque capacity based on the current Small-CVT(CF18). Nevertheless, the driving performance has greatly improved through the expansion of ratio span, the competitiveness of efficiency, weight and overall length is the best in the same class CVT.

The planetary gear was newly designed to reduce the overall length of the transmission and the clutch, hydraulic system, torque converter and oil pump were optimized to improve the efficiency. And the belt & pulley also had been newly designed for the wider ratio span, fewer components, and shorter overall length, lower the weight.

In this paper, the new planetary gear, new belt & pulley system, and newly optimized systems for marketability would be described.
TORQUE-UP, MINIMIZING AND WEIGHT REDUCTION

Figure 1 below shows that the CVT for front-wheel (CF18), which is currently in production, has one planetary gear set, one clutch set and one brake set. The newly developed CF28 has been increased only 8mm in overall length despite the fact that the torque capacity was increased by 53% compared to the current mass production CF18.

Fig. 1: Cross section of CF18

The following is a description of how we were able to minimize the increase of the overall length and weight.

1. Structure of Planetary gear and Brake
To reduce the overall length, it was necessary to change the structure of planetary gear and brake system. Regarding this changes, there are also changes in power flow. The hub of the brake was changed to integrate with carrier rather than the annulus gear. Therefore it was...
possible to remove the connecting plate of annulus gear and one thrust bearing, and the overall length could be reduced by 6.1mm. The input of power flow was changed from sun-gear to annulus-gear, and output of power flow was changed from carrier to sun gear.

2. Structure of Sheave Connection
To reduce the overall length, it was necessary to change the structure of the pulley system. Fixed sheave and movable sheave of CF18 were connected by rollers so that movable sheave can rotate together with fixed sheave and can move through the fixed sheave's axis. But fixed sheave and movable sheave of CF28 were changed to be connected by spline without rollers. Therefore the pulley length could be reduced by 4.2mm. In addition to the overall shortening effect, this change also has an effect on reducing the number of parts and simplification of the assembly process.
3. Optimize the Packaging Condition

To improve the packaging condition on vehicle, packaging analysis had been completed with various vehicles. So, it was necessary for CF28 to optimize external designs of transmission. Design of Housing parts and external devices had been more optimized to improve the mount ability on middle class vehicles. As a result CF28 has a good competitiveness compared to competitors’ middle class CVT (Fig. 5) According to In-Diff. distance, CF28 has two option to satisfy the mount-ability on various vehicles (189mm/204mm). Especially 189mm of In-Diff. distance is difficult condition for constructing internal parts in middle class CVT. This is about 8mm smaller than the competitor’s middle class CVT.

![Fig. 5: Package Layout](image1)

![Fig. 6: Comparison of Packaging Condition](image2)

**EFFICIENCY IMPROVEMENT**

Needless to say, the transmission efficiency is more important than ever in accordance with the recent fuel efficiency regulations.
The front-wheel CVT (CF18), which is currently in production, boasts the world's highest level of CVT efficiency. Likewise, CF28 has significantly improved efficiency compared to competitor's middle-class CVT.

1. Oil Pump

Oil pump was one of the biggest losses in the transmissions using hydraulic control and we could improve transmission efficiency through optimization of capacity and minimized drive losses. The oil pump of CF28 is vane type, which is able to reduce drive torque loss by maximum 9% in comparison to gear-type pump. It allowed an improvement of 0.4% in CVT efficiency.

![Comparison of Drive Torque](Fig. 7: Comparison of Drive Torque)

2. Chain Belt

Chain belt is also an important item to improve the efficiency dramatically. The chain was also applied to the CF18 and had been proved to be very efficient compared to the push belt. Chain belt of CF28 has better efficiency of 5% in under-drive area, 3% in over-drive area than push belt of CF28 in same CVT assembly. As a result, chain belt has better efficiency of 1.9% than push belt. It also appeared with a fuel economy difference of 1.2% on vehicle test. It is due to the fact that the chain has less friction loss than the belt.

![Variator of CVT Pulley](Fig. 8: Variator of CVT Pulley)
3. Separating Spring

Separating springs were applied to reverse brake system to improve the efficiency while driving forward. Because when CVT operates driving forward, the drag torque must be occurred on disk set of reverse brake. Forward clutch does not need separating spring because forward clutch is engaged in step “D” position and drag torque is not generated.

These springs are assembled between the disk set, and help the brake’s each disk to maintain same clearance. This prevents the drag torque loss from increasing because the disk is positioned to one side.
4. Wider Pulley Ratio Span

Ratio span is one of the important performance indicators of transmission. Wider ratio coverage improves fuel economy in the high ratio region and acceleration in the low ratio region. In the high ratio region, the engine speed is lowered to improve fuel efficiency. In the low ratio region, the engine torque is multiplied to improve the acceleration performance.

To increase the pulley ratio width, the distance between two pulleys’ axes was also increased by 5%. And system analysis had been done to secure stiffness under the worst use conditions, to optimize sheaves in terms of weight reduction.
COST REDUCTION

In modern times, the competition of the transmissions on the price and efficiency is getting overheated. The cost reduction technologies had also been applied to lower the material cost, and then to improve the marketability of CF28. The price competitiveness of CF28 also reached the world's highest level in the middle class vehicles' CVTs which is currently in production.

1. Single Pinion Planetary Gear

In the case of two-step CVT, simple compound planetary gear set is required, which increases the burden of material cost. But CF28 can shift only by Belt & Pulley; CF28 only needs one planetary gear set for step “forward” and “backward”.

To save the material cost and weight, single pinion planetary gear has been applied. The material cost of single pinion type could be reduced by about 27% compared to double pinion type, and also could be reduced by about 50% compared to simple compound type.
NVH

The CF28 has some noise sources. Planetary gear noise, transfer gear noise, differential gear noise, and chain belt noise are present. First of all, the local stiffness of the case was secured.

1. Noise improvement of Planetary Gear

In the NVH development, planetary gear’s noise and transfer gear’s noise were improved. In the case of planetary gears, the number of teeth was reduced and the bite rate was increased to improve the noise of the planetary gears when driving backward.

2. Noise improvement of Transfer Gear

For improving of transfer Gear’s noise, the internal clearance of the roller bearing supporting the secondary pulley was optimizied. As a result, there was a dramatic noise reduction effect than 5dB(A).
3. Noise improvement of Chain belt

In the development, two noises of chain belt were present. The one is impact noise between pulley and chain belt, the other is string vibration noise of chain belt. As string noise is due to the impact noise, the first improving sequence is to lower the impact noise.

The one method for lowering impact noise is to change the sequence arrangement of the chain’s two kinds of link plates. Chain has two kinds of link plate (long, short), which is able to avoid the concentration of vibrations at specific frequencies. The other method for lowering impact noise is to shorten the pitch (distance between prior pin and next pin) for lowering
impact energy. By reducing the pitch by 15% and optimizing the arrangement of the link plate, it was possible to find the optimal conditions for reducing the impact noise.

The second improving sequence is to lower the chain’s vibration noise. To lower the chain’s vibration noise, usually two guide-rail sets are added. CF28 also has two guide-rail sets. The shape of the parts was optimized for further noise improvement. In this process, it was also possible to derive the design parameters of the guide rail to reduce the vibration noise of the chain.

Fig. 19: Improving Noise of Chain belt
OPTIONAL DEVICES
The CF28 is available for various requirements of carmakers by applying various options.

1. ISG (Attached EOP)
ISG (Idle Stop & Go) is an inverter-integrated type that supports vehicle sailing and creep operation and is mounted outside the transmission. It is not necessary to make additional space for the motor controller and wiring between the motor and the controller.

2. Attached TCU
If the customer wants attached type, TCU can be equipped to side part of converter housing of transmission.

3. ATF Cooler/Warmer (Attached)
ATF cooler is equipped to outside the transmission. At low temperature when starting the engine, the ATF temperature of the automatic transmission is increased by using cooling fluid from engine, which can contribute to the improvement of fuel economy by reducing the friction loss due to viscosity reduction.

Fig. 20: Optional Devices
CONCLUSION

In order to reduce the overall length, the hub of brake is integrated with carrier, and the input of power flow was changed from sun-gear to annulus-gear, and output of power flow was changed from carrier to sun gear. The existing connecting plate and thrust bearing were eliminated by this change.

And connecting structure between fixed sheave and movable sheave were changed from roller type to spline type which is integrated with sheaves. In addition to the overall shortening effect, this change also has an effect on reducing the number of parts and simplification of the assembly process. As a result, the CF28 simultaneously achieved torque capacity of 28kgf.m and over length of 359 mm.

In terms of weight, CF28 had achieved 88kg, which is an amazing value of 3.14kg/kgf.m in terms of weight versus torque.

For efficiency of CVT, the pulley ratio span was extended, which was also advantage in acceleration performance. And in addition to, chain belt, vane type oil pump, separating spring had been applied. As a result, the newly developed CVT achieved efficiency of world highest level in the middle class CVT. CF28 achieved more than 2% efficiency compared to competitors' mid-sized cvt.

The new CVT has been designed to give the driver a feeling of shift quality similar to the automatic transmission under certain condition. But this function requires higher durability performance of the transmission. The CF28 meets this high level of durability.

The CF28 has various options available. It is possible to use the ISG integrated with the inverter and extended function to support the sailing and creep operation of the vehicle, the ATF cooler(warmer), and the attached type of TCU.

The newly developed CF28 has been introduced above. The CF28 not only improves marketability by increasing torque capacity of the transmission, but also improves the mount ability by minimizing the increase in the overall length due to the reinforcement torque capacity. And world's highest level is achieved in terms of torque capacity, efficiency, weight, mount ability. It is considered as the world's best mid-sized CVT in every aspect.
REFERENCE
