

Super Ultra Flat Torque Converter with Multi Plate Lock-up Clutch

Hiroya ABE*

Tooru TAKAHASHI*

Masaaki TSURUOKA*

Hiroshi TAKANO*

ABSTRACT

Three-dimensional CFD was used to optimize the torus section and stator blade shape, and newly developed stator blades were also employed to develop the fluid flow channels for a thin type torque converter with a flattening ratio of 50%, while maintaining torque converter performance. A multi-plate lock-up clutch with heat-resistant performance approximately twice that of a conventional single-plate lock-up clutch has been positioned in the space created by the use of these new fluid flow channels. The developed Super Ultra Flat torque converter with multi-plate lock-up clutch enables all-area LC control without increasing the overall width compared to the previous torque converter, and can be fitted in an FF vehicle. As a result, in real-world driving, the new system increased fuel efficiency by approximately 3% in US06 mode, and enabled a more direct driving feeling by shortening the time from 0 to 100 km/h at 100% throttle acceleration by 0.2 s.

1. Introduction

Heightened awareness towards global warming in recent years has led to increased demands on torque converters, which are the launch device for automatic transmissions (AT). In particular, demands are increasing to simultaneously achieve both smooth torque transfer characteristics, which are important when the vehicle launches, and direct torque transfer characteristics with little slip, which contribute to increasing fuel efficiency. At the same time, from the viewpoint of securing collision safety, design restrictions on the overall torque converter width are also important and should be observed to help prevent the AT axial dimension from increasing.

The flattening ratio of fluid flow channels is generally in the 80% range, but Honda led the industry in mass-producing an Ultra Flat torque converter with a flattening ratio in the 60% range from 2001 year models. Now, a Super Ultra Flat torque converter with multi-plate lock-up clutch has been developed with the goal of further increasing fuel economy (Fig. 1). This new torque converter consists of a lock-up clutch (LC) system that enables all-area LC control and new fluid flow channels

with a flattening ratio of 50%, and can be fitted in an FF vehicle.

This paper describes the development goals, technical issues, and countermeasures for this Super Ultra Flat torque converter with multi-plate lock-up clutch, and reports the resulting enhanced performance.



Fig. 1 Side view of developed torque converter

* Automobile R&D Center

2. Development Goals

In order to simultaneously achieve both smooth and direct torque transfer characteristics, the following goals were set for development.

- (1) Enhanced LC performance
Comparison with previous model:
LC heat-resistant performance: Double
LC lock-up performance
Operating range: $0.5 < \text{speed ratio} < 1.5$
Response time: 0.5 s or less
- (2) Torque converter performance equal to that of the previous model
- (3) Overall torque converter width equal to that of the previous model

All-area LC control is employed to achieve direct torque transfer characteristics that contribute to increasing fuel efficiency. As shown in Fig. 2, the LC operates over a wider range than the previous model, from the high throttle range to the low vehicle velocity range.

The development goal of LC heat-resistant performance is needed to enable unhindered LC lock-up and release in the high throttle range and while shifting gears (area A in Fig. 2). In addition, the development goal of LC lock-up performance is needed to reliably operate the LC when decelerating in order to extend the fuel cut time that contributes to increasing fuel efficiency (area B in Fig. 2).

Furthermore, in order to shift to LC lock-up driving without placing an excessive thermal load on the LC facing material immediately after a smooth launch, the torque capacity factor, torque ratio and other torque converter performances should be the same level as that of the previous model.

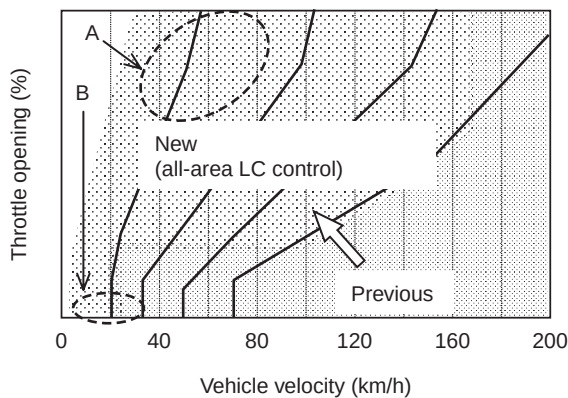


Fig. 2 Operating range of lock-up clutch

3. LC System

To achieve the LC performance development goals, LC systems were investigated from the viewpoints shown in Table 1. Single-plate LCs have a simple parts

Table 1 Comparison of LC systems

	Single-plate type (previous)	Multi-plate type
Typical layout		
LC operating pressure		
Comparison	○ : Good ⊙ : Very good	
(1) LC heat resistant-performance	○	⊙
(2) LC response time operating range	○	⊙
(3) Torque capacity	○	⊙
(4) Width	⊙	○

configuration, so they have good space efficiency and are employed in the torque converters of FF vehicles.

On the other hand, Table 1 shows that in contrast to single-plate LCs, the LC operating pressure in a multi-plate LC acts on the piston chamber, which is a closed space, so there is no need for the facing material to seal the working fluid pressure. This enables the establishment of lubrication grooves on the facing material surface, which increases the heat-resistant performance [Table 1 (1)]. In addition, the LC piston operation is not affected by the fluid flow inside the torque converter, which is advantageous in terms of LC operating range and operating time [Table 1 (2)]. Moreover, the multiple facing surfaces also provide a larger clutch capacity, which is advantageous for use in high displacement engines [Table 1 (3)].

Therefore, in consideration of the above performance comparisons and displacement of the target engines, a multi-plate LC system was selected. However, multi-plate LCs have many parts such as a piston chamber, multiple disc plates, and a clutch guide, so using the conventional fluid flow channel width would unavoidably increase the axial dimension of the torque converter. Therefore, the axial dimension of the fluid flow channels, which consist of the blades and the torus section, should be shortened to enable them to fit into an FF vehicle.

4. Development of Super Ultra Flat Fluid Flow Channels

Torque converter performance is represented by the torque capacity factor and torque ratio. The larger the torque capacity factor, the smaller the energy loss during

torque transmission, and the larger the torque ratio, the larger the driving force at launch. These torque converter performances are determined by the change in fluid momentum produced by turning the flow using the pump elements, turbine, and stator. To obtain high torque converter performance, the flow should be turned within a rotating three-dimensional space while minimizing both the secondary flow produced by imbalances between the centrifugal force and pressure gradient, and also separation flow and other flow loss factors.

4.1. Setting the Flattening Ratio and Aspect Ratio of the Torus Section

There are two approaches to shortening the axial dimension of the fluid flow channels as shown in Fig. 3. The torus section can be flattened without changing the inlet radius r_1 and outlet radius r_2 of each blade element, and the overall torus section can be reduced by keeping the flattening ratio the same and increasing the aspect ratio.

When the torus section is flattened, the curvature of the fluid flow channels becomes smaller, producing an increase in the flow loss inside the torque converter, and this tendency is particularly evident in the turbine, which generates torque by inverting the flow. On the other hand, when the aspect ratio of the torus section is increased, the radii ratio r_2/r_1 decreases as shown in Fig. 3. This makes it challenging to create a difference in flow momentum at the pump inlet and outlet, which tends to reduce the torque capacity factor.

The relationship between the axial dimension shortening effects and the ratio of change in torque converter performance of these two approaches was verified with the goal of reducing the axial dimension of

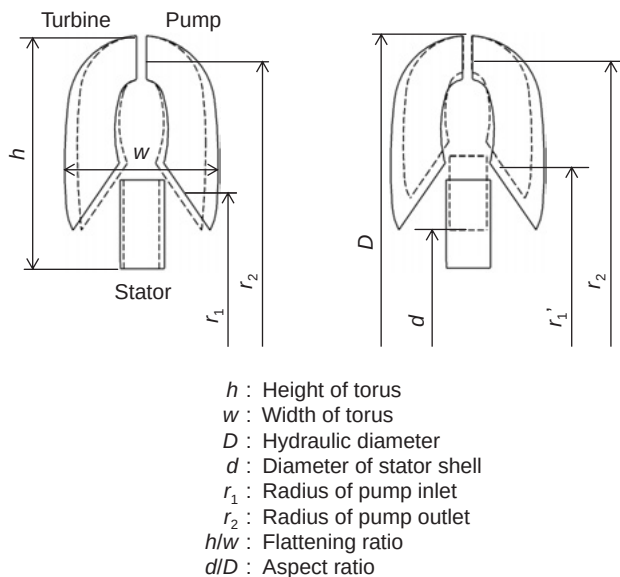


Fig. 3 Approaches to decrease axial length of torus

Table 2 Torque converter specifications and calculation conditions

Hydraulic diameter (mm)		252
Flattening ratio (%)		65
Number of blades	Pump	29
	Turbine	27
	Stator	15
Aspect ratio of torus		38
Rotation speed of input shaft (rpm)		2000
ATF temperature (°C)		85

the fluid flow channels. Table 2 shows the specifications used for this comparison. Figure 4 shows the results of calculating the torque capacity factor at a speed ratio of 0.8, which has a large influence on fuel efficiency, when the blade angle, wing form function, and number of blades are kept the same, and only the flattening ratio or the aspect ratio of the torus section is changed.

The torque converter performance was calculated from three-dimensional CFD by general-purpose software that uses the finite volume method for the separation flow. The turbulence kinematic model was a standard κ - ϵ model⁽¹⁾, and the SIMPLE method⁽²⁾ was used as the analysis algorithm.

The verification results confirmed that to obtain the same axial dimension shortening effects, reducing the flattening ratio produced a smaller ratio of decrease in torque converter performance than increasing the aspect ratio.

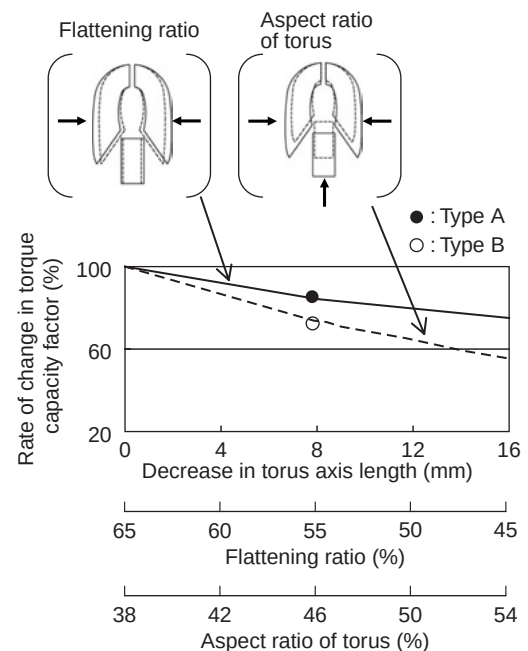


Fig. 4 Influence of flattening ratio and aspect ratio of torus

In addition, Fig. 5 shows the results of calculating the turbulence kinematic energy for Type A and Type B shown in Fig. 4. This turbulence kinematic energy κ is obtained by solving the κ - ε model, and shows that the flow loss increases as κ becomes larger.

Figure 5 shows that compared to Type A, the turbulence kinematic energy tends to increase together with the internal flow speed for Type B. Based on this and the aforementioned verification results, it was decided to keep the same aspect ratio and reduce the flattening ratio of the fluid flow channels compared to the previous torus section.

After the aspect ratio and flattening ratio of the torus section were set as described above, efforts were made to further reduce flow loss due to the core shape of the torus section, the blade shape, and the stator blades.

4.2. Optimization of the Core Shape of the Torus Section and Blade Shape

To optimize the core shape of the torus section and the blade shape, it is necessary to verify an immense number of combinations of design parameters, such as the torus section shape, the fluid flow channel area setting of each blade at the inlet, the blade angle, blade output and inlet radii, wing form function, bias angle, number of blades, and the like.

Therefore, a performance prediction method⁽³⁾, developed by Honda, based on one-dimensional angular momentum theory was used. The features of this calculation prediction method are as follows.

- (1) Loss within the fluid flow channels due to flattening is expressed using a virtual curved tube model.
- (2) The effects of stator loss on torque capacity characteristics are expressed using the outlet flow angle of the stator as the parameter.

This calculation prediction method was used to determine the base combination of design parameters, such as the fluid flow channel area at the pump outlet, the

flattening ratio, blade angle, blade outlet and inlet radii, and other reference parameters. Then, three-dimensional CFD was used to set the wing form function, bias angle, and number of blades from the viewpoint of optimizing the pressure gradient inside the turbine fluid flow channels.

Figure 6 compares the results for the fluid flow channel section, which has the largest calculated turbulence kinematic energy value, in order to illustrate the change before and after optimization in the turbulence kinematic energy inside the turbine fluid flow channels in the stall state. As shown in Fig. 6, the reduction effects on the flow loss are particularly large on the suction side near the turbine inlet, and the average reduction in flow loss within the fluid flow channel space was confirmed to be approximately 13%.

4.3. Development of New Stator Blades

The conventional blade shape that has been used for the stator of Ultra Flat torque converters has a bulbous protrusion in the part where the coring and the pressure surfaces of the stator blades contact. This bulbous blade shape was further developed, and the blade shape, fluid flow channel area, and number of blades were newly set from the viewpoint of reducing flow loss, produced by the separation flow phenomenon⁽⁴⁾, that occurs on the suction side (Fig. 7). This bulbous shape is able to reduce the flow loss that occurs around the stator coring without complicating the die-cast mold division plans, which is the method used to manufacture the stator. This effectively increases the torque ratio by approximately 5% in the stall state that has a fast internal flow speed.

Figure 8 compares the calculated turbulence kinematic energy at the stator blade center section in the stall state before and after optimization. These results show that the turbulence kinematic energy at the front and rear edges of the stator blade decreases [Fig. 8(1)].

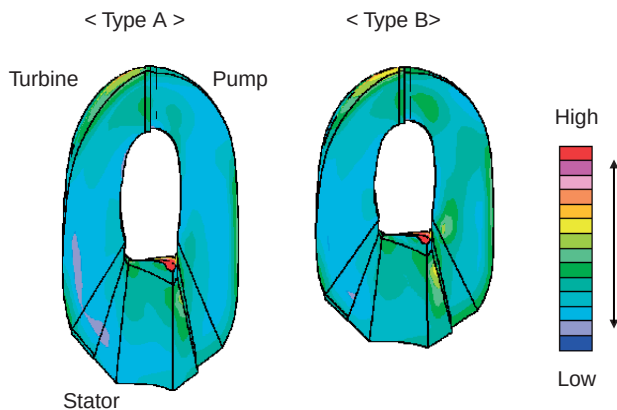


Fig. 5 Calculation results of turbulence kinematic energy

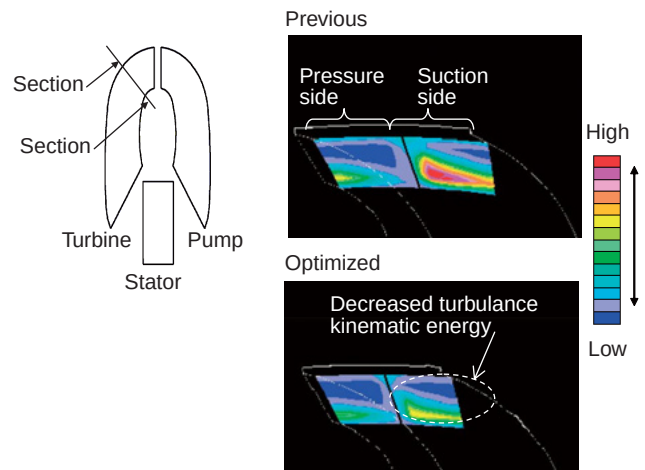
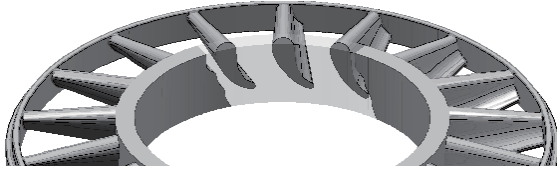


Fig. 6 Calculation results of turbulence kinematic energy at turbine inlet

Previous



Optimized

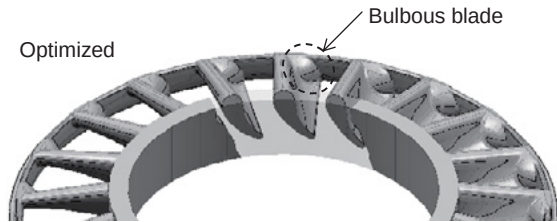


Fig. 7 Comparison of conventional and optimized stator blades

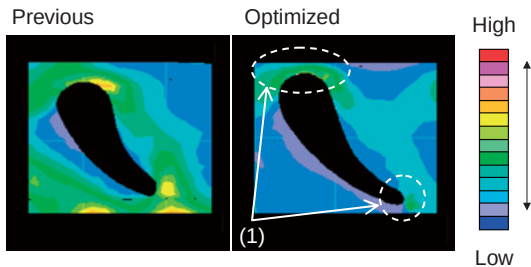


Fig. 8 Calculation results of turbulence kinematic energy at stator blades

5. Confirmation of Performance and Effects

5.1. LC Performance

A multi-plate LC with the structural merits shown in Table 1, aforementioned, was positioned in the space created by employing the Super Ultra Flat fluid flow channel developed by the above process. The LC size, facing surface inner and outer diameters, and number of clutch plates were set based on the allowable axial dimension and required clutch capacity, and the number and shape of the lubrication grooves on the facing material surface were set in consideration of the LC heat-resistant performance and clutch drag torque.

Figures 9 and 10 show the results of comparing LC lock-up performance and LC heat-resistant performance, respectively, for the previous and new torque converters. Figure 9 shows that the LC operating range is wider and the LC response time is also shorter and more stable compared to the previous torque converter.

Figure 10 shows the results obtained by measuring the facing surface temperature during LC slip control in the assembled torque converter state under the test conditions

Table 3 Test conditions

Measuring point: ●	
Single-plate type (previous)	Multi-plate type
ATF temperature (°C)	100
LC transmitted power (W)	3100
Cooling flow rate (L/min)	4

given in Table 3. This shows that during LC slip control, the facing surface temperature of the previous single plate LC exceeds 200°C at 3 100 W in the high load range. In contrast, the temperature for the new torque converter at this time is approximately 160°C, which is within the tolerance range.

In addition, the confirmation results showed that the

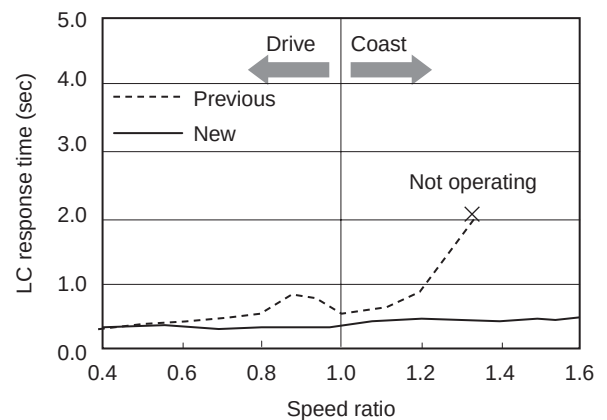


Fig. 9 Test results of LC response time

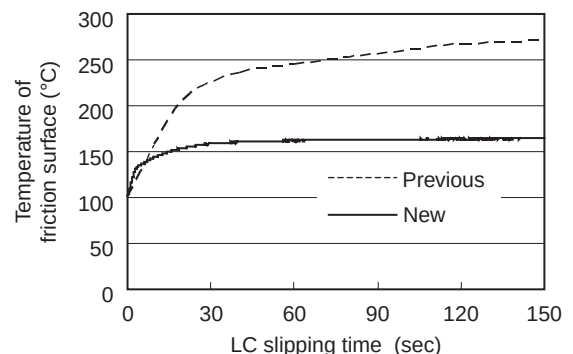


Fig. 10 Test results of facing temperature

Table 4 Comparison of torque converter specifications

		Previous	New
Hydraulic diameter (mm)		252	260
Flattening ratio (%)		65	50
Number of blades	Pump	29	31
	Turbine	27	29
	Stator	15	21

amount of LC work needed to reach a facing surface temperature of 160°C was approximately 1 330 kW for the single-plate LC. This confirmed that the new LC has LC heat-resistant performance almost double that of the previous LC.

These enhancements in both LC lock-up performance and LC heat-resistant performance enabled LC operation from the high throttle range to the low vehicle velocity range in which LC lock-up was not possible for the previous torque converter, and increased the LC lock-up driving frequency by approximately 1.5 times in real-world driving. When applied in an actual vehicle, the effects of this all-area LC control increased fuel efficiency in US06 mode by approximately 3%, and enabled the time from 0 to 100 km/h at 100% throttle acceleration to be shortened by 0.2 s.

5.2. Torque Converter Performance

Table 4 compares the main specifications of the new and previous torque converters. Figure 11 shows the torque converter performance for a 3.5-liter engine. This shows that even though the flattening ratio was changed from 65% to 50%, the new torque converter achieved the equivalent torque capacity factor and torque ratio to those of the previous torque converter.

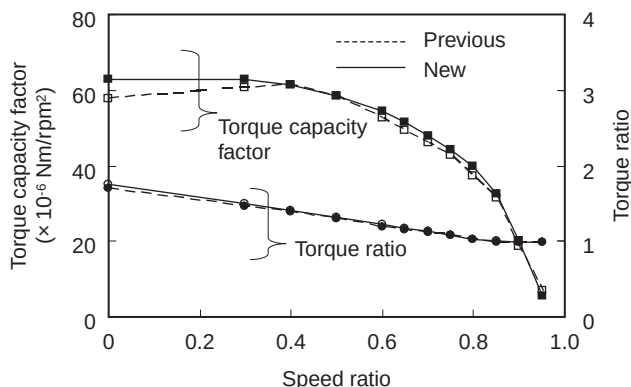


Fig. 11 Torque converter performance

6. Conclusion

This development simultaneously achieved both smooth torque transfer characteristics, which are important when the vehicle launches, and direct torque transfer characteristics with little slip, which contribute to increasing fuel efficiency, within the design restrictions on the overall torque converter width.

All-area lock-up control was enabled by employing thin-type fluid flow channels with a flattening ratio of 50% and a multi-plate lock-up clutch that has heat-resistant performance approximately double that of the previous single-plate lock-up clutch. As a result, the new system increased fuel efficiency by approximately 3% in US06 mode, and enabled a more direct driving feeling by shortening the time from 0 to 100 km/h at 100% throttle acceleration by 0.2 s, and the like.

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■ Author ■



Hiroya ABE



Tooru TAKAHASHI



Masaaki TSURUOKA



Hiroshi TAKANO