Investigation of flattened torque converter performance at low speed ratio

Yuki Ota*1, Shouichiro Iio*1, Yoshihide Mori*2, Shinji Kondo*2

*1Faculty of Engineering, Shinshu University
4-17-1 Wakasato, Nagano, Nagano, 380-8553, Japan
*2Aisin AW Co.,LTD
10 Takane, Fujii-cho, Anjo, Aichi, 444-1192, Japan

Abstract. This study is aimed to investigate flow phenomena in a torque converter by CFD analysis. The converter performance was compared between different shape converters; traditional circular torus and flattened torus. Influence of aspect ratio on these converter characteristics was discussed. Converter flattening should be needed for requirement of size reduction to mount other drive components on the space. In the flattened torus, drastic flow separation near the core region just downstream the turbine element was easily occurred. The separation volume decreases with increase of the converter speed ratio. Suppression of the separation is useful for converter performance improvement especially in low speed ratio condition. Flattening causes three-dimensional complex flow patterns and its suppression and control is important.

1. Introduction

A torque converter, which is a type of fluid coupling, is one of the important elements in an automobile transmission. The converter works as a reduction gear, it can change transferring power to the drive-train by change the oil flow pattern in a torus of the converter, and it can also separate an engine and transmission. The driving characteristics including fuel consumption ratio is strongly depended on the converter performance.

The converter is consisted of three elements; pump, turbine, stator. The pump element is directory connected with an engine shaft and always rotating. The main role is to circulate the oil in the torus casing. The turbine element is rotated by deflecting the oil flow from the pump element. The oil flow issuing from the turbine element enters a stator element. The stator is necessary to multiply torque acting on a drivetrain. These elements are in a torus casing. The converter characteristic had been able to be predicted based on the one-dimensional angular momentum theory proposed by Ishihara et al. (1955) The predicted converter performance by the theory showed good agreement with actual performance for a circular torus. Recently, size reduction of the converter for enlargement of other drive components has been required. So, the size of converter torus has been shortened in the shaft direction. In the flattened torus, one-dimensional theory cannot be applied because of appearance of complicated three-dimensional flow field with large separation. Ejiri et al. (1998) reported that the converter performance and flow field in a flattened torus for the regular operation speed ratio of $e=0.8$. To meet high demand of reducing fuel consumption, the converter performance at lower speed ratio of $e<0.8$ like as starting and accelerating condition should be revealed but the detail is unknown. So, this study is focused on the performance and flow phenomena in the flattening converter for $e \leq 0.8$. The authors compared flow fields in two models with different flatness ratios.
2. Calculation Condition and Procedure

A cut image of a torque converter is displayed in Figure 1. Three elements, a pump, a turbine and a stator, are placed in the torus shape casing. The working oil circulates in counter clockwise in this image. Two converter models of Type 1 and Type 2 were used. The flatness ratio of each type, $W/H$ in the figure, is 0.77 and 0.64. Blade number of pump and turbine is 39 and 37, respectively for both types. Number of stator blade is different of 31 and 34 for Types 1 and 2.

Figure 2 shows meridional plane of one-pitch model of Types 1 and 2 which used in CFD simulation. It is easily recognized that the torus width of Type 2 is thinner than that of Type 1. Shape and size of torus core was also changed from Type 1 to Type 2.

ANSYS CFX Ver. 18.2 was used to simulate the flow in the torus in steady state. Computational domain and mesh is shown in Figure 3. The periodic condition was adopted as the boundary condition in the rotation direction. The general connection mode was used on the interfaces of each element. The non-slip condition was adopted on all elements surfaces including torus wall. Total mesh number was approximately 270000. Mesh number and size were determined considering the calculation accuracy by comparing with experimental result and calculation time. The maximum error of simulation result was bigger of 8% than the experimental result by comparing the value of capacity factor, and the capacity factor variation trend showed good agreement with the both results. Shear Stress Transport (SST) model was used to predict the turbulence flow. Rotation speed of the pump was kept constant at $N_1=2000$ rpm. The turbine rotation speed $N_2$ was set from 0 to 1600 rpm at 400 rpm intervals. In this simulation, the speed ratio was $e=0.0, 0.2, 0.4, 0.6, \text{ and } 0.8$ which was defined as the ratio of pump speed to turbine speed.

![Figure 1. Cut image of a torque converter](image1)

![Figure 2. Meridional plane of one-pitch model for CFD simulation](image2)
3. Results and Discussion

The calculation results were shown in Figures 4, 5, and 6. Figure 4 shows streamlines colored by normalized velocity magnitude for \( e = 0.0, 0.4 \) and \( 0.8 \). The left- and right-handed figures are the result of Types 1 and 2, respectively. The characters attached after element name, s and p, means the suction and pressure side of blade surface. In these figures, oil was circulated in counterclockwise direction. Flow velocity is enhanced by the pump element. It is recognized flow velocity through the turbine is highest and that is gradually decreased. At the turbine suction side, flow separates from the torus core. The separation area of Type 2 is larger than that of Type 1 for all velocity ratio. For \( e = 0.0 \) of Type 2, the area reaches the stator inlet. The flow into the stator element is deflected for \( e = 0.0 \) and 0.4 due to the separation occurs in the turbine. Especially in Type 2, the flow at the stator core side shows complex behavior. It may occur energy loss and reduction of torque multiplying effect of the converter. Streamwise vortex is observed at pump pressure side for \( e = 0.0 \). Trigger of this vortex is the separation in the turbine element. The separation reduces flow passage area, then flow circulation in the torus is decreases. These phenomena are one of the major reason of degradation of converter performance.

Figure 5 shows normalized total pressure distribution and streamline pattern around the stator blade at the different radial position for \( e = 0.0 \). White color region is cross section of the stator blade. In these figures, the oil flow goes from downward and through the gap between stator blade row. In the core side (span 0.2), separation area can be observed on the suction surface of Type 1, but it cannot be observed in Type 2. Focusing on the streamline of Type 2, it seems that the flow collides at blade pressure side. This is a radial flow from shell side to core side. Figure 5. (c) to (f) show flow at middle span and shell side, respectively. In streamlines, both models flow into the blade pressure surface at a high attack angle, and a separation area is formed on the suction side. It can be seen that this separation area overlap with having total pressure loss region. Author’s defined total pressure is 0 Pa or less as total pressure loss area. This total pressure loss area was defined as a separation area, and tried to grasp the three-dimensional distribution by calculating for each radial position. Figure 6 shows the relationship between the radial position and total pressure loss area ratio at \( e = 0.0 \). Total pressure loss area ratio is calculated from total pressure loss area divided by flow passage area in stator blade. In the figure, the vertical axis is total pressure loss area, and the horizontal axis is radial position. 0 is core side and 1 is shell side on the radial direction. Focusing on the graph of Type 1, there is no large change in total pressure loss area ratio due to the radial position, and it becomes higher toward shell side. In Type 2, the total pressure loss area ratio decreases with span 0.2 to 0.4, and increases in span 0.5 to 0.8. It is considered that the longitudinal vortex seen in figure 4 is influenced in this span 0.2 to 0.4. From this result, the distribution of separation region in the stator is changed by flattening, and in particular, the torque amplification action cannot be obtained on the stator core side.
Figure 4. Velocity distribution and streamline patterns between blade gap for Type1 and Type2.
Figure 5. Velocity and total pressure distribution in stator blade at \( \epsilon = 0.0 \)
4. Conclusions
This study focused on the influence of aspect ratio of the torus shape of torque converter on the flow field by CFD simulation. Flow fields were investigated based on the mean velocity, the streamlines and the total pressure distribution. As a result, it was revealed that reducing the aspect ratio enhances flow separation at the turbine element core. The separation blocked flow passage area, and then flow velocity is decreased. After that torque applying effect of the converter is degraded. This tendency is the most remarkable for the stall condition for $e=0.0$. The authors can clarify the major reason of the converter performance degradation. The authors are trying to performance improvement based on the results in this study.

References
[1] Ejiri E and Kubo M 1998 Influence of the Flatness Ratio of a Torque Converter on Hydrodynamic Performance, Transactions of The Japan Society of Mechanical Engineers, Series B Vol.64 No.623, pp 2109-2114
[2] Ishihara T 1955 Torque Converter, Report of Institute of Industrial Science Vol. 7 No.5 (University of Tokyo) pp 85-86