

Mechanism of Torque Capacity Change during Operation of AT with Focus on Friction Properties

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ABSTRACT

The project discussed in this paper focused on the frictional characteristics of clutch facing materials in order to elucidate the mechanism by which the torque capacity of the multiple-plate clutches used in automatic transmissions (ATs) varies with their mode of use. The frictional characteristics of the facing materials are affected by the temperature, contact pressure, and sliding velocity of the friction surfaces. The temperature of the clutch plate, sliding velocity of the friction surfaces, and degree of misalignment of the gears transmitting torque were therefore measured in an AT during torque transmission. Next, a dynamic behavior analysis model, able to simulate the flow of torque transmission in the AT, was constructed on the basis of these measurement results. The results showed that the torque capacity of an AT operating at a constant temperature is affected by radial components of the friction force vectors on the friction surfaces.

1. Introduction

Contemporary increases in engine power have led to a demand for automatic transmissions that display high torque capacity while remaining lightweight and compact⁽¹⁾. Honda ATs feature a compact design that positions a multiple plate clutch for each speed on three or four parallel shafts⁽²⁾. A smooth shift response with minimal shift shock is realized by direct control of the piston pressure of the clutches that are engaged when the gears are shifted. However, the parallel shaft configuration limits the diameter of the clutch; heat production per unit area of the disks is controlled in order to increase durability by maximizing the difference between the internal and external diameters of the disks⁽³⁾. Because of this, it is important to control disk contact pressure distribution and plate temperature distribution when the clutch is engaged. As has previously been reported⁽⁴⁾, a simulation technology has been developed that is able to quantify the disk contact pressure distribution and plate temperature distribution, enabling the wear history of the clutch to be predicted based on the wear properties of the facing material.

Torque capacity is increased by increasing the number of disks in the clutch. The clutch unit is generally

designed using a simple torque capacity equation. However, this equation was formulated for conditions of uniform contact pressure distribution on each disk and an identical coefficient of friction at all points on the surfaces of the disks during clutch engagement. As previously reported⁽⁴⁾, the disk contact pressure distribution in a clutch unit is not uniform. The friction properties are known from the results of SAE#2 performance tests and other results to be dependent upon the temperature, the contact pressure, and sliding velocity of the disk surfaces⁽⁵⁾. For these reasons, average values for the disk contact pressure and coefficient of friction are employed in the equation used to calculate torque capacity.

In addition, it is known from experience that a variety of factors, including the inclination of the drive gears and the flexibility of the shafts, affect the torque capacity of a clutch fitted in an AT. However, these effects vary depending on the layout, friction properties and operating conditions of the AT, among other factors, and it is therefore challenging to consider them using a clutch unit equation. For this reason, the torque capacity of ATs is evaluated exclusively by manufacturing test transmissions and conducting torque capacity tests.

The research discussed in this paper focused on the friction properties of the clutch facing materials. A

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dynamic behavior analysis technology that is able to simulate the torque flow to each clutch during AT operation using these friction properties was developed. This enabled the mechanism by which the direction of friction force on the friction surfaces of the clutches results in changes in torque capacity during AT operation to be clarified.

2. Development Goals

Figure 1 shows the main section of the AT with a 5th gear used in the analysis. As the figure shows, the clutches and gears for each speed are positioned on parallel shafts, and shifting from clutch to clutch in the shifting process is enabled by controlling the oil pressure in oil channels located inside the rotating shafts.

Figure 2 shows the results of measurement of the torque capacity of the clutch. During the measurements, a constant temperature, T_0 , was maintained in the interior of the transmission, including the lubricant oil and clutch plates, and the piston thrust was also constant. The horizontal axis of the graph shows the torque input to the clutch, and the vertical axis shows the rotational speed differential between the disks and the plates. Torque capacity was defined as the torque input when the rotational speed differential reached a specified value. It was necessary for this specified value to be sufficiently small for the cooling effect of the lubricant oil to help prevent the temperature of the plates from changing. As the graph indicates, torque transmission increases as the rotational speed differential increases. This phenomenon is conjectured to be influenced by the friction properties of the clutch facing materials themselves.

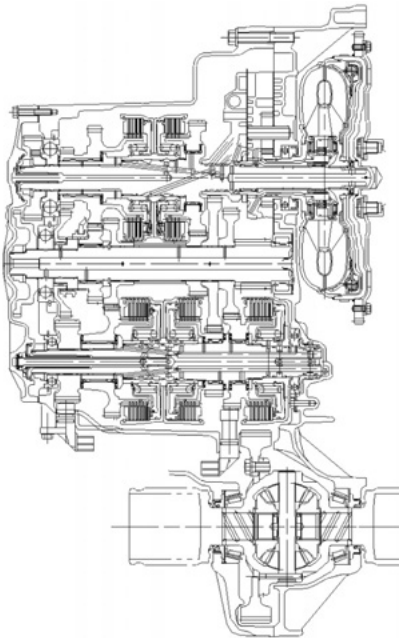


Fig. 1 Main section

Figure 3 shows the clutch configuration. The 4th and 5th clutches were identical clutches made up of four disks. The back surfaces of the guides of each clutch were welded together. The same facing material was used in both clutches. However, when the torque capacity of the clutches was measured, it was found that the torque capacity of the 4th clutch was higher. Given that there were no differences in the configurations of the individual clutch units, it was conjectured that this phenomenon was due to a difference in the torque flow in the transmission. If a clutch displays insufficient torque capacity, slipping occurs between the disks and the plates, and the rotational speed differential increases. If this rotational speed differential becomes too high, the configuration or layout of the clutch may need modification, and this can delay development.

Based on these considerations, the goal of the research project discussed in this paper was established as clarification of the mechanism by which torque capacity changes during AT operation.

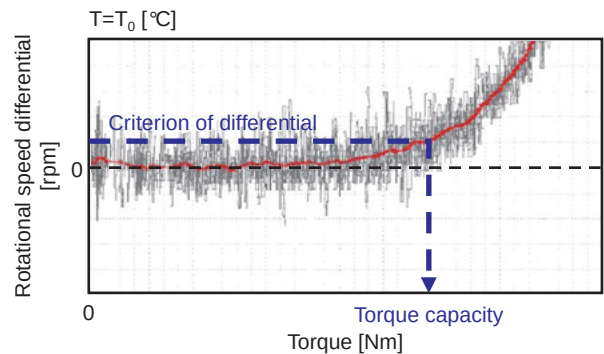


Fig. 2 Torque capacity measurement results

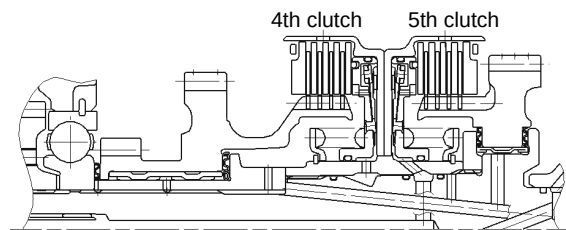


Fig. 3 Detail of clutch

3. Mechanism of Change in Torque Capacity

3.1. Differences in Torque Flow

This section will consider the mechanism causing torque capacity to change in the 4th and 5th clutches that formed the focus of this study during actual AT operation. The sectional shape of the gears and their method of mounting can be indicated as factors producing differences

in torque flow. The 4th gears are supported by long needle bearings, and this configuration makes them less prone to misalignment than the 5th gears when loads are being transmitted by the helical gear sections. The degree of misalignment of the 4th and 5th gears was therefore measured using a gap sensor positioned in an AT [Fig. 4(a)]. The degree of misalignment is clearly lower in the 4th clutch, in which torque capacity is higher [Fig. 4(b)].

3.2. Hypothesized Mechanism of Change in Torque Capacity

This section will consider the mechanism by which gear misalignment results in a decline in torque capacity. Plate temperature, disk contact pressure, and sliding velocity are assumed to be constant.

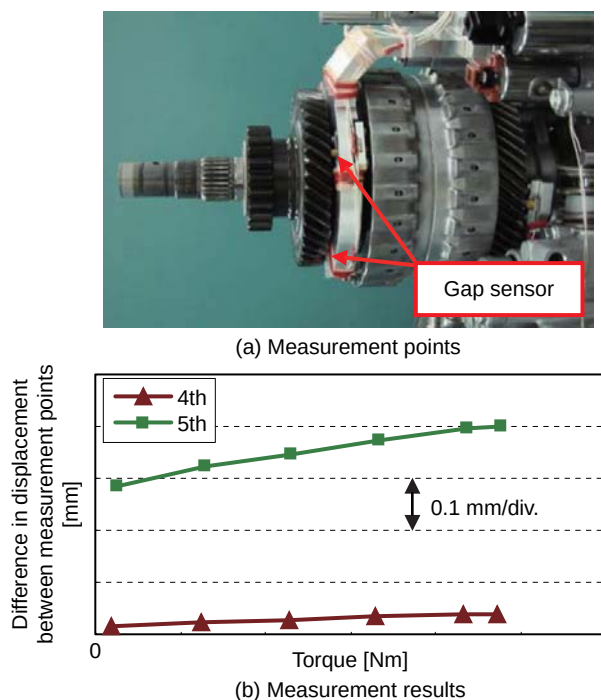


Fig. 4 Comparison of gear displacement

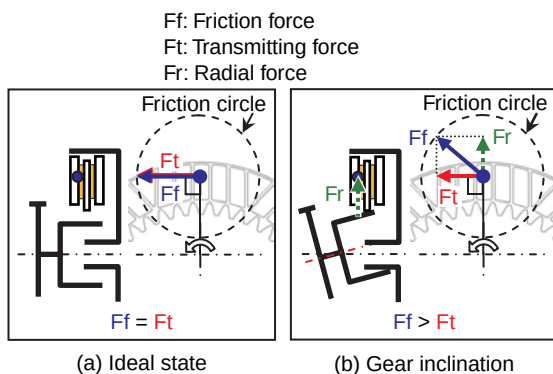


Fig. 5 Hypothesized mechanism of change in torque capacity

A friction circle drawn around one point on the friction surface of the clutch (Fig. 5) will be considered first. If the radius of this friction circle is considered as friction force, F_f , assuming that the coefficient of friction is constant, the size of the friction circle will not change irrespective of the direction of F_f . When the system is in an ideal state with no gear misalignment [Fig. 5(a)], the disks and the plates rotate on the same axis, and F_f acts in a tangential direction. The entire value of F_f can therefore be considered to contribute to torque transmission. Considering next the case of gear misalignment [Fig. 5(b)], when the gears are misaligned, a radial load, F_r , is generated where the gears and the disks mesh. This is transmitted to the friction surface, and depending on the magnitude of F_r , F_f can incline in a radial direction. When this happens, because the size of the friction circle does not change, the torque force, F_t , which is the component of F_f acting in the tangential direction, becomes lower than F_f . This is believed to be the mechanism by which the radial load on the disk increases and torque capacity declines as a result of misalignment of the gears.

4. Torque Capacity Simulations

The measurement of the magnitude and direction of the friction forces on the clutch friction surfaces during AT operation in order to prove the foregoing hypothesis would represent a challenge. Dynamic behavior analysis models, which modeled the flow of torque transmission in a clutch in an ideal state with no gear misalignment and the 5th clutch were therefore constructed, and results were compared.

4.1. Construction of AT Clutch Torque Capacity Analysis Models

Figure 6 shows the dynamic behavior analysis model constructed to simulate the torque flow in the 5th clutch of the AT. Care was taken to reproduce the actual clearance of the needle bearings that support the gears. With regard to load conditions, because the clutch is positioned on the M shaft, the right extremity of the M

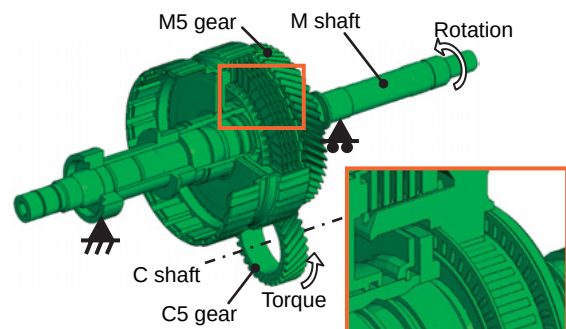


Fig. 6 Torque capacity prediction model for 5th clutch

shaft was forced to rotate, gradually increasing the torque load on the 5th driven gear, C5, positioned on the C shaft. During this process, the piston thrust was held constant. As the torque load increased, a sliding speed differential began to develop between the disks and the plates.

4.2. Friction Properties of Clutch Facing Materials

SAE#2 test equipment and LVFA test equipment can be used to measure the friction properties of the clutch facing material. However, the facing material is immersed in lubricant oil for measurement by these test equipments, preventing measurement of the effect of the amount of lubricant oil; it is also challenging to heat the entire facing material to a high temperature and to maintain a constant temperature. The torque transmission characteristic test apparatus, shown in Fig. 7, was therefore newly developed. The design of the apparatus incorporates uniform disk contact pressure, a lubricating system that supplies oil via the shaft, as used in an AT, and a configuration that enables simple control of temperature. This enables the torque transmission characteristics to be measured while holding the temperature and contact pressure of the disk surfaces and the rotational speed differential constant.

Figure 8(a) shows the clutch facing material friction properties obtained using this test apparatus with the

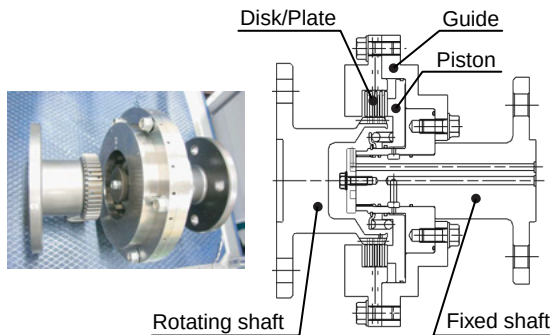


Fig. 7 Test apparatus for torque transmission characteristics

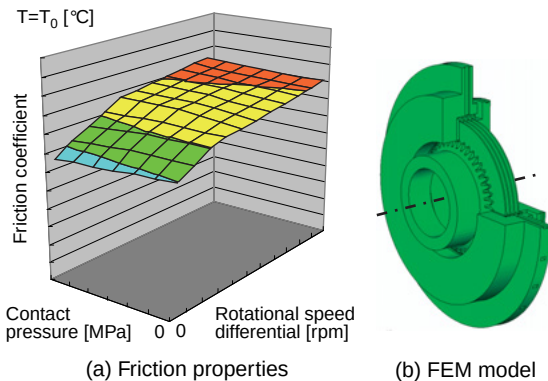


Fig. 8 Identification of friction properties

temperature held constant at T_0 . The vertical axis shows the coefficient of friction, and the horizontal axis shows the disk contact pressure and sliding velocity. The coefficient of friction during the test was identified using a structural analysis model [Fig. 8(b)] which modeled the test apparatus. The friction properties of the facing material discussed here were not significantly affected by changes in contact pressure, but a positive correlation with sliding velocity was obtained.

Figure 9 shows the results of simulation and measurement of the torque capacity of the 5th clutch, using these friction characteristics. The results show that the simulation was able to reproduce the qualitative tendency, in which rotational speed differential increased as the torque load increased.

The plate temperature for these results is the constant temperature T_0 .

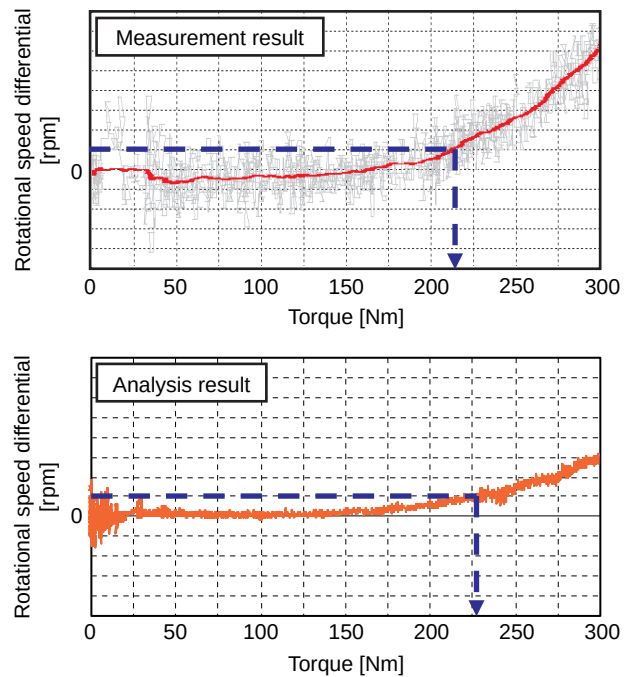


Fig. 9 Comparison of torque transmission by 5th clutch

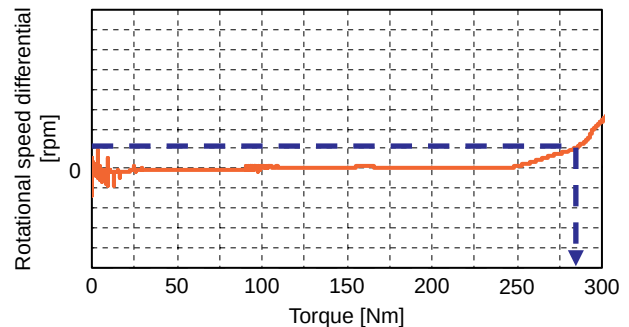


Fig. 10 Torque capacity of clutch without gear misalignment

4.3. Torque Capacity of Clutch with No Gear Misalignment

Next, the clutch in an ideal state with no gear misalignment was analyzed. In this analysis, the 5th driven gear, C5, was removed from the 5th clutch dynamic behavior analysis model, with the torque load applied directly to the 5th drive gear, M5. Figure 10 shows the results for the rotational speed differential. The results clearly show that torque capacity was higher in the clutch without gear misalignment than in the 5th clutch.

4.4. Friction Force Vectors on Surface of Disk

Figure 11 shows the friction force vectors acting on the surfaces of the disks of the 5th clutch and the clutch without gear misalignment when transmitting identical torque. In the clutch without gear misalignment, the friction force vectors all act in the direction of rotation, while in the 5th clutch there are also friction force components acting simultaneously in the radial direction. Because both clutches are transmitting the same amount of torque, the friction force components acting in the direction of rotation are identical, but the total friction force is higher in the 5th clutch because of the radial components. As a result, the increase in the rotational speed differential is higher in the 5th clutch than in the clutch without gear misalignment, and thus transmits torque at a higher coefficient of friction.

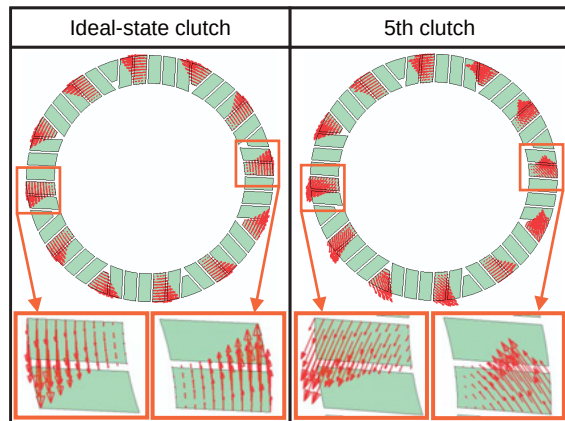


Fig. 11 Direction of friction force on disk surface

5. Torque Capacity during AT Operation

This section will consider the degree of gear misalignment and the friction force vectors for the 4th and 5th clutches. As Fig. 12 shows, the degree of misalignment of the drive gears is lower in the 4th than in the 5th clutch. This means that the radial load transmitted by the drive gears via contact with the disk teeth is also lower in the 4th clutch (Fig. 13). As a result, the radial components of the friction force vectors of the

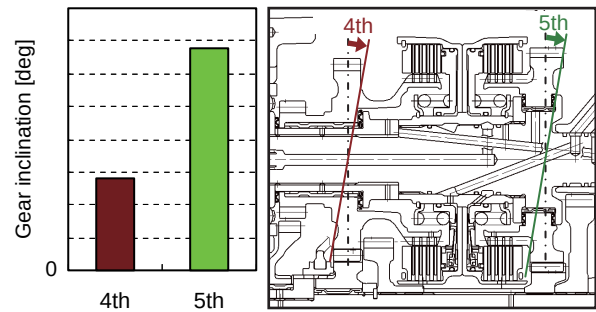


Fig. 12 Comparison of degree of gear misalignment in 4th and 5th clutches

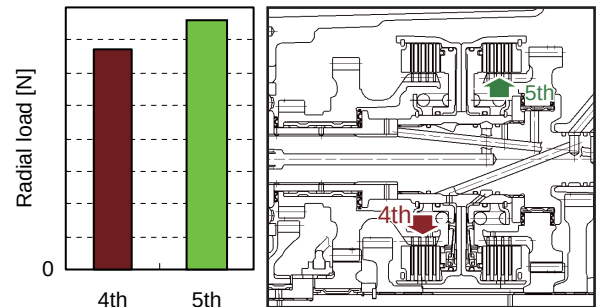


Fig. 13 Comparison of radial load in 4th and 5th clutches

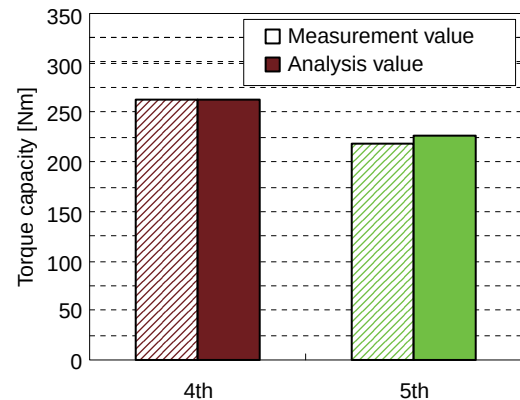


Fig. 14 Torque capacity of 4th and 5th clutches

4th clutch are smaller, and its torque capacity is therefore higher than the 5th clutch. Figure 14 shows simulation results and measurement results for torque capacity in the 4th and 5th clutches during AT operation.

6. Conclusion

Measurements of gear misalignment and dynamic behavior analysis models that reproduce the flow of torque transmission have been used to enable clarification of the mechanism of changes in torque capacity in an operating AT. The following results were obtained:

- (1) Study of clutch friction vectors showed that the torque capacity of an AT at a constant temperature is not only affected by friction force components acting in the direction of rotation, but by simultaneously occurring friction force components acting in the radial direction, and that as these friction force components become higher, torque capacity declines.
- (2) Reproduction of misalignment in the clutch drive gears, treating the friction properties of the clutch facing material as dependent on the temperature, contact pressure, and sliding velocity of the friction surfaces, enables prediction of torque capacity during AT operation.

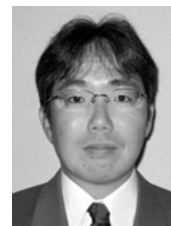
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