A Study on a Stepped Traction Drive Transmission*

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Abstract
This paper describes a new traction drive transmission which features a self-loading mechanism to achieve high efficiency and a simple ratio-change system without synchronizers. A cam incorporated in the roller support provides loading force in proportion to the force being transmitted, and the speed ratio is selected by changing the distance between the shafts. Tests conducted to evaluate the loading force, transmission efficiency and ratio changes have confirmed that this transmission achieves high efficiency equal to that of gears and quick ratio changes without any shift shock. This mechanism is expected to be a next-generation transmission for automobiles, achieving low cost, small size and high levels of performance. The study results show its fundamental performance and promising future.

Key words: Transmission, Traction Drive, Robotized, Automated, Tribology, Efficiency, Ratio Change

1. Introduction

While the term traction drive is generally associated with continuously variable transmissions (CVTs), many different kinds of fixed ratio transmissions have also been proposed which have their input and output shafts arranged in parallel (1). Because it is not easy to apply loading force to the rotating elements of the parallel shafts in proportion to the force being transmitted, these transmissions achieve a constant loading force by means of bolt tension or some other method (2). Accordingly, their power transmission capacity and efficiency are low, making it difficult to apply them to vehicles. Another requirement for
transmissions that has become increasingly important in recent years is for a more compact size, especially a shorter axial length.

In view of this situation, a new traction drive transmission has been developed, which features a self-loading mechanism for achieving high efficiency and large capacity, and a simple ratio-change system for shortening the axial length substantially. This paper describes the fundamental performance of this new transmission.

2. Structure and features of the transmission

Figure 1 is a schematic diagram of the self-loading mechanism. The rotating shaft of either the input or output roller is supported by a loading cam that is angled in the direction of the transmitted force. The transmitted force $F_t$ acting on the roller is supported by rolling bearings. However, because the outer race of the bearings can roll on the cam face, only the normal force $F_c$ acts on their contact point. Letting $\alpha$ denote the angle of the cam face, the sine of $F_c$ becomes $F_t$, and the cosine of $F_c$ becomes the loading force $F_r$. Hence,

$$F_t = F_r \tan \alpha \quad (1)$$

Therefore, the loading cam produces loading force in proportion to the transmitted force. Compared with a previously proposed transmission system that uses a wedge roller (3), the system in this study is much smaller in size and reduces power loss by half because it has only two shafts and one power transmission unit.

The ratio-change mechanism is shown schematically in Fig. 2. Several pairs of rollers are arranged on the same shaft. All the ratio steps are integrated on either the input or output shaft. On the other shaft, the ratio steps are separated and supported by the crankshaft via roller bearings. The rollers on the crankshaft do not restrict each other in the radial direction.
direction; however, they are fixed in the rotational direction by couplings and thus rotate together. The upper diagram(a) shows the 1st. of low speed ratio. When the angle of the crankshaft changes, the distance between each pair of shafts changes as well, and the pair of rollers transmitting power is selectable to make the 3rd. of high speed ratio as shown in the lower diagram(b). In a conventional manual transmission, all the gears must always mesh, and the speed ratio is changed by means of synchronizers that coordinate the rotational speeds of the gears and the shaft. The transmission described here takes advantage of the features of a traction drive, which can be connected or disconnected during operation. This makes it possible to integrate the functions of power transmission and ratio change, thereby achieving a shorter shaft length.

3. Evaluation of fundamental performance

The loading force, transmission efficiency and ratio-change performance were evaluated on the basis of calculations and experiments performed with a prototype variator test machine.

3.1. Loading force

Fig. 3 shows a cross section of the test machine. The loading cams, shafts, rollers and coupling were made of hardening steel. Traction oil was provided with all rolling and sliding portion to lubricate. Strain gages were attached to the loading cam of to measure the loading force in relation to varying levels of input torque. The results in Fig. 4 show that the measured loading force was proportional to the torque level; it nearly coincided with the designed value and displayed no hysteresis. Providing suitable loading force is essential for improving the performance of a traction drive transmission. The loading cam examined in this study meets that requirement.

![Fig. 3 Fixed-ratio prototype transmission](image)

![Fig. 4 Performance of loading cam](image)
3. 2. Transmission efficiency

The measured and calculated transmission efficiencies of the test machine are shown in Fig. 5. These results include the bearings supporting the rollers and the Oldham coupling in addition to the power transmission unit. It is seen that high efficiency was obtained from the low torque region, with maximum efficiency reaching 98%. The measured values show good agreement with the calculated efficiency obtained by applying a viscoelastic-plastic traction model (5) and a method of calculating the friction torque on a rolling bearing (6). From these results, power transmission efficiency can be estimated with good accuracy. It was found that this transmission achieves high efficiency equal to that of gears.

3. 3. Ratio-change performance

3. 3. 1. Crankshaft angle and transfer of forces

When the crankshaft is rotated for executing a ratio change, the distance between the roller pairs that have been transmitting power until that point increases and the rollers of the next ratio step approach each other (Fig. 6). If the input torque is constant at this time, the loading force produced by the loading cam also remains constant. As a result, the total force acting on both roller pairs is constant as well. In other words, the force acting on the rollers before the ratio change decreases and the force of next step increases to a similar extent, keeping the total force constant. Figure 7 shows the calculation results for the load distribution on each roller pair, which was estimated from the rigidity of the components and the change in the distance between the shafts of each roller pair. In conventional transmissions with clutches for each gear ratio, two clutches have to be controlled to change the ratio. The transmission described here can control the force on both rollers at the same
time by operating only one element, i.e., the crankshaft. Accordingly, it is easy to control this system.

3.3.2. Ratio-change test

A 2-speed prototype transmission (Fig. 8) was used to conduct a ratio-change test. Materials and lubrication were same with the fixed ratio prototype in Fig. 3. The output shaft was rotated by an electric motor, and a ratio change was executed without applying any load to the input shaft. Figure 9 shows the measured rotational speed of the input shaft and the crankshaft angle. Reduction of the input speed was completed in 0.1 s, enabling the transmission to execute the ratio change quickly.
3.3. Cooperative control with the clutch

The preceding section showed that the prototype transmission is capable of executing quick ratio changes. However, smooth ratio changes without any shift shock require cooperative control between the engine and the clutch. A ratio-change simulation was run using the model shown in Fig. 10. The calculated rotational speeds are shown in Fig. 11. The moment of inertia was low because the clutch was disconnected. Accordingly, the rotational speed of the input roller decreased in a short period of time. A ratio change was
completed in 0.2 s, even including the time required to reduce the rotational speed of the engine by half-clutching. Figure 12 shows the calculated transmitted torque and also plots one example of the torque level without any clutch operation for comparison. Suitable clutch operation achieves smooth ratio changes without a large drop in torque. Accordingly, this transmission has the potential to obtain ratio-change performance equal to or higher than twin-clutch robotized manual transmissions.

4. Conclusion

This paper has described the fundamental performance of a newly-invented traction drive transmission based on simulations and tests conducted with a prototype unit. The following results were obtained.

(1) It was shown that the loading cam incorporated in the new transmission can provide suitable loading force in spite of its simple mechanism, thereby achieving high power transmission efficiency equal to that of gears.

(2) This transmission operates smoothly and provides quick ratio changes to satisfy the requirements for automotive transmissions.

The new transmission has a significantly shorter axial length because no synchronizers are needed. Its simple mechanism results in lower cost. Therefore, this mechanism is expected to be used as a next-generation transmission featuring a compact size, low cost and high performance.

References


