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Study on Continuously Variable System Using to Centrifugal Belt Pulley

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Abstract

In the case of a belt-pulley type CVT that transmits a driving force by using a variable pulley and a metal belt, slippage occurs due to transmission of power by using a belt, which results in a decrease in efficiency. Therefore, in this study, the rails were machined on the plate surface of the pulley to reduce the friction and slip between the belt and the pulley while applying the characteristics of the CVT. As the plate is rotated by the shape of the rail, a centrifugal belt pulley type continuously variable transmission system which shifts while varying the radius of rotation of the belt that transmits power is studied. Accordingly, the structure of the pulley was designed and the centrifugal belt pulley type continuously variable transmission was Manufactured. In addition, to verify the suitability of the manufactured transmission, the power transmission efficiency was monitored by establishing an interface with the controller. The structural analysis of the plate proved the suitability of the centrifugal belt pulley type continuously variable transmission.

Keywords: *Centrifugal belt pulley, Efficiency tester, FEM analysis, Plate, Gear ratio.*

1. Introduction

The transmission is a system intended to improve the driving force or to increase the speed of a vehicle according to driving conditions of the vehicle. This automotive transmission is divided into manual transmission, automatic transmission, and Continuously Variable Transmission(CVT) according to how it is operated and how it is driven. In the case of manual transmission, a person selects the transmission stage as they which according to the driving condition to secure the driving force of the vehicle, and transmission is implemented by a predetermined gear ratio of the multi-speed gear [1-3]. In the case of automatic transmission, transmission stage is selected by the control logic of Transmission Control Unit(TCU) according to the driving condition, and transmission is implemented by the predetermined gear ratio by fixing and rotating the planetary gear to transmit the output [4-7]. In the case of CVT, which is a continuously variable transmission, there is

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no gear ratio determined by the gear ratio and there is no resulting gear ratio, which enables flexible driving. In addition, since there is no output reduction or the deterioration of acceleration performance caused by the transmission ratio at the time of transmission, it improves fuel efficiency while maintaining the performance of vehicle. In automobiles, belt pulley type CVT, which transmits driving force using variable pulleys and metal belts, is commonly used. In the belt pulley type CVT, there are input shaft pulley and output shaft pulley and each pulley is connected by the belt. And the belt transmits the rotational force generated in the input shaft to the output shaft [8-10]. At this time, one side of the pulley is fixed and the other side becomes variable, changing the diameter of the pulley, and the belt, which is in contact with it, is driven. Therefore, there is no predetermined gear ratio, and optimal efficiency is achieved by varying transmission ratio according to the speed. However, when it is used for a real vehicle, slip occurs because the power is transmitted using the belt, which results in a decrease in efficiency. In addition, friction between the belt and the pulley during the process of power transmission results in significant mechanical load and frictional heat. Therefore, in this study, we conducted a study of the centrifugal belt pulley type continuously variable transmission by machining the rail of the plate surface of the pulley so as to reduce the friction and slip between the belt and the pulley while applying the characteristics of the CVT. The centrifugal belt pulley type continuously variable transmission is a system in which the rotation of the plate changes the rotational radius of the belt for transmitting power by the shape of the rail by the centrifugal force, not by the variable pulley moving to the X axis. Therefore, the transmission ratio is implemented by the rotation of the plate in a state in which the pulley is fixed. In this study, we designed the centrifugal belt pulley type structure by designing the rail shape appropriate for the plate and tested the efficiency of the developed centrifugal belt pulley type continuously variable to prove the conformance of the transmission.

2. Design of Centrifugal Belt Pulley CVT Structure

2.1 Design of centrifugal belt pulley

Figure 1 shows the shape of the conventional continuously variable transmission used in automobiles. As mentioned above, in the belt pulley type continuously variable transmission using variable pulleys, transmission is implemented by the friction between the belt and the pulley, which may result in problems such as slip or frictional heat. Therefore, in this study, we used a centrifugal belt pulley type continuously variable transmission system as shown in Figure 2.

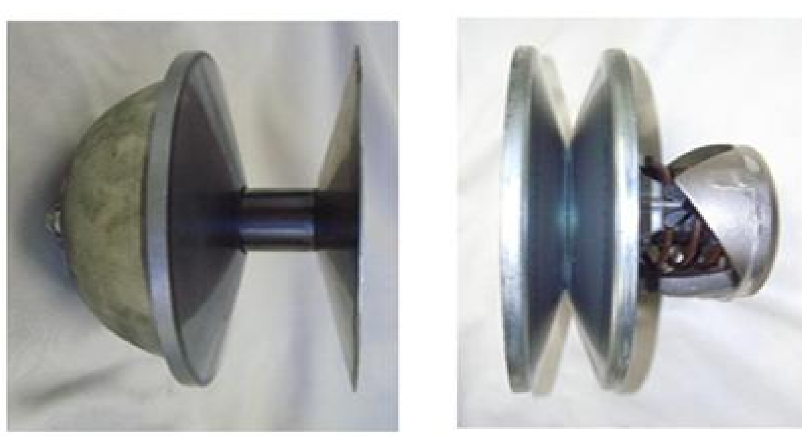
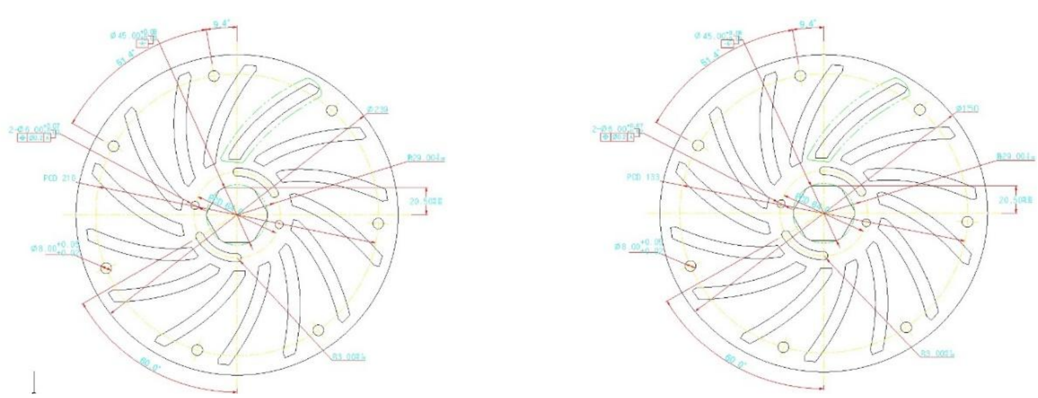


Figure 1. Structure of continuously variable transmission

In the centrifugal belt pulley type continuously variable transmission as shown in Figure 2, the gear ratio is selected by the shape of the rail groove machined on the plate of pulley and the transmission ratio is outputted through the change of the outer diameter in which the rubber belt is chafed.

Figure 2. Structure of centrifugal belt pulley CVT

Therefore, smooth transmission can be achieved according to the angle of the rail groove machined on the plate. In this study, we conducted a design based on an electric cart with a 5.5 horsepower(HP) motor. In the case of an electric cart, a decelerator of 10:1 is used to secure the driving force. Therefore, the transmission ratio was set to 2.8:1 to reduce the load on the motor, and the initial driving force was secured at a deceleration ratio of 28:1 in the initial driving. For the deceleration ratio, the gear ratio was basically obtained by calculating the ratio of the diameter at the time of maximum expansion in consideration of the variable width of the centrifugal belt pulley. And for the driving plate, the outer diameter, the hub PCD and the external fixed PCD and the number of the rail grooves for transmission in the driving plate were set to Ø239 mm, Ø64 mm, Ø210 mm, and 14, respectively. And for the driven plate, the outer diameter, the hub PCD, the external fixed PCD and the number of the rail grooves for transmission were set to Ø150 mm, Ø64 mm, Ø133 mm, and 14, respectively, for the transmission in the same manner as the plate of the driving pulley, and the plate for transmission was designed as shown in Figure 3. (a) and (b).



(**a**) (**b**)

Figure 3. (a) Design of centrifugal belt pulley CVT drive plate; (b) Design of centrifugal belt pulley CVT driven plate.

2.2 Design of centrifugal belt pulley CVT housing

The transmission housing for mounting the centrifugal belt pulley type continuously variable transmission was designed as shown in Figure 4.

The inter-axis distance between the drive pulley and the driven pulley was set to 290 mm, and the belt length was selected to be 1,120 mm considering the tension. And then drive PCD Ø210 mm and for fixing to the drive pulley and the driven pulley hub. In addition, the driving plate PCD Ø210 mm and the driven plate Ø150 mm were designed for plate fixing. To insert the motor shaft into the driving unit, the spline, which was the same as the motor shaft, was machined after Ø60 mm hole was machined.

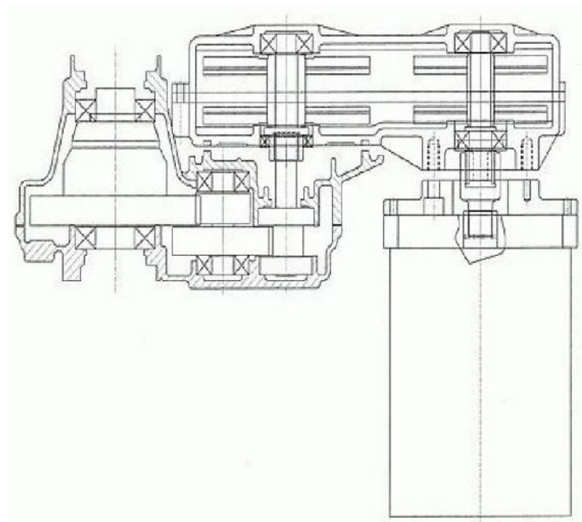


Figure 4. Design of centrifugal belt pulley CVT housing

Based on the design, a CVT with a centrifugal belt pulley structure integrated with a motor was manufactured as shown in Figure 5.

Figure 5. Manufacture of centrifugal belt pulley CVT

3. Centrifugal Belt Pulley Type CVT Test

3.1 Analysis of plate structure

The plate structure was analyzed for its application to centrifugal pulley belt type continuously variable transmission using Abaqus program. Since the shaft is inserted in the plate hub, constraints were set on the plate hub, and carbon steel was used as material because SM45C was used in preparation.

As a result, it was found that the stress was the highest at the hub part where the load was generated when the shaft rotated and the part where the distance between the hub part and the rail groove was the shortest as shown in Figure 6. However the maximum stress was 23.02 kgf / mm^2, indicating that the yield strength of SM45C selected as the plate material was about 50 kgf / mm^2 and the tensile strength was above 70 kgf / mm^2. Therefore it is deemed that there would be no problem in using it.

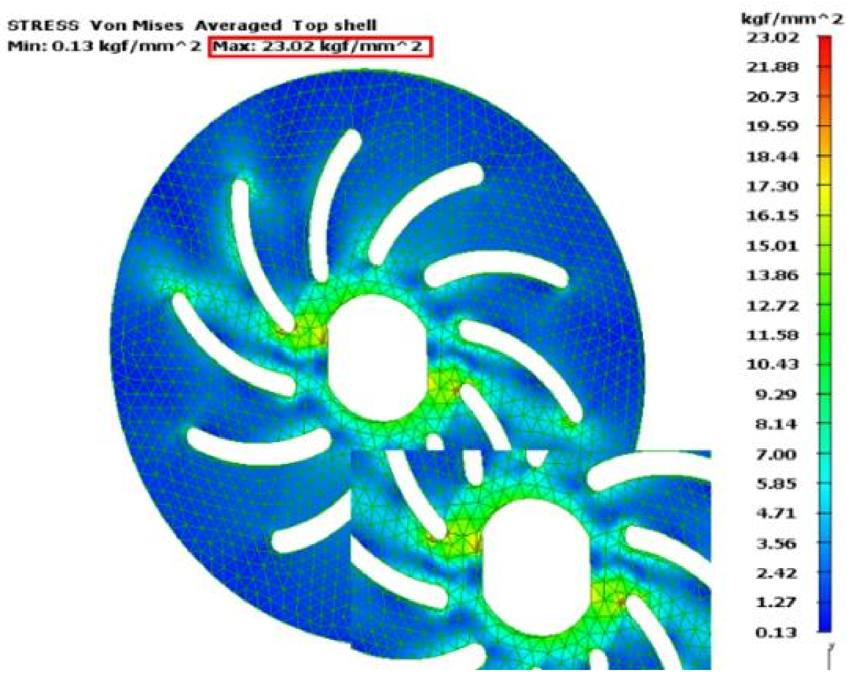


Figure 6. Analysis of plate

3.2 Configuration of CVT performance tester

To test the performance of the centrifugal belt pulley type continuously variable transmission prepared on the basis of the design, the structure of the performance tester was set as shown in Figure 7.

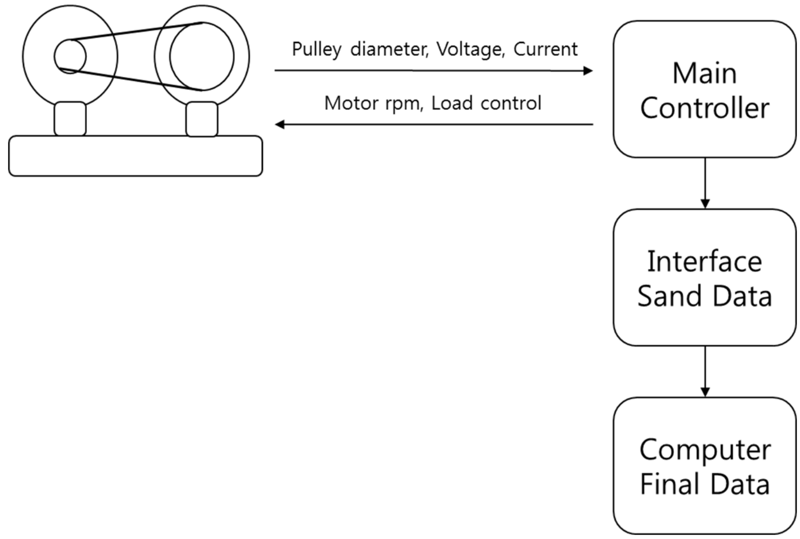


Figure 7. Diagram of centrifugal belt pulley CVT tester

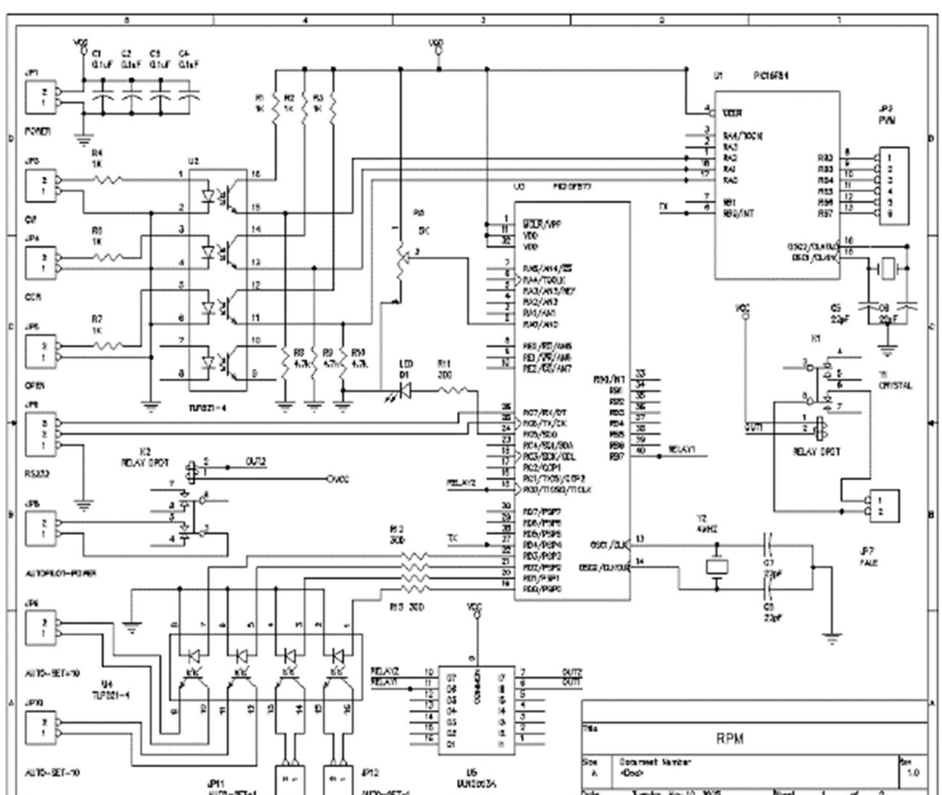


Figure 8. Circuit diagram of main controller

Regarding the basic concept of the tester, a main controller of the circuit configured control the speed and load of the motor when operating the continuously variable transmission, and the values, such as voltage and current, and the change and the rpm of the pulley, are obtained and transmitted to the interface. And then, the microcomputer-based RS-232C interface configured with the circuits shown in Figure8 generates signals to be recognized by the PC, and finally derives data result values [11, 12]. For the control by the computer by installing a mechanical system after configuring a test bed and connecting a main controller and a circuits configuring the interface, the finally assembled CVT performance tester was prepared as shown in Figure 9.

Figure 9. Structure of efficiency tester

The performance of the centrifugal belt pulley continuously variable transmission prepared based on the design was tested using the developed tester. In the test method, the driving motor was driven at a speed of 300 rpm at the initial driving, and the speed was inputted to the driving pulley was adjusted at a rate of 100 rpm by varying the load, and the measurement was made to 3,000 rpm. Based on the rotational speed detected in the driven pulley, the transmission ratio of the driven pulley vs. the driving pulley were derived as shown in Table 1. The gear ratio is lower than the gear ratio of 2.8:1 initially set at 300 rpm. However, since this is due to the slip and load generated during the initial drive and does not show a significant error, the power transmission efficiency has not been reduced and there will be no problem at the time of driving. And the gear ratio was 1:1 at 2,200 rpm, the 20th measurement section, and the gear ratio slightly changed thereafter. This is the final deceleration based on 2,200 rpm and the values thereafter are due to the change by the rotational inertia. Therefore, as a result of testing the performance of centrifugal belt pulley type continuously variable transmission, the gear ratio of 1: 1 was satisfied at 2.8:1, indicating the conformance of the tester.

Table 1. Ratio according to rpm.

No	RPM		Ratio
	Driver pulley	Driven pulley	
1	300	108	2.778
2	397	148	2.682
3	496	193	2.570
4	596	243	2.453
5	696	299	2.328

6	805	355	2.268
7	903	423	2.135
8	998	518	1.927
9	1103	683	1.615
10	1201	812	1.479
11	1297	993	1.306
12	1401	1161	1.207
13	1505	1301	1.157
14	1603	1462	1.096
15	1708	1598	1.069
16	1797	1702	1.056
17	1907	1873	1.018
18	2005	1987	1.009
19	2105	2098	1.003
20	2200	2200	1.000
21	2307	2327	0.991
22	2397	2425	0.988
23	2506	2559	0.979
24	2599	2672	0.973
25	2698	2773	0.973
26	2802	2879	0.973
27	2905	2986	0.973
28	2964	3045	0.973

4. Conclusion

In this study, we conducted a study of the centrifugal belt pulley type continuously variable transmission based on the concept of a continuously variable transmission which is excellent in acceleration and efficiency. To minimize the slip occurring in the conventional belt pulley type continuously variable transmission, we machined rail groove on the plate surface, not on the variable pulley, and developed a centrifugal belt pulley type continuously variable transmission in which the gear ratio is shifted by the difference in the diameter of the belt due to centrifugal force.

The results of this study can be summarized as follows:

1) Deceleration ratio of 2.8:1 was set in a small electric cart with a 10:1 decelerator to secure initial driving force.

2) For the design and preparation of a centrifugal belt pulley type continuously variable transmission in consideration of the inter-axis distance, the shape and structure of the plate were designed based on the basic concept of small size and light weight in consideration of the millage, and a housing was designed to protect it from external impacts.

3) To test the conformity of the developed plate, structural analysis was conducted to derive the yield strength of 23.02 kgf $/ mm^2$, half the value of SM45C, the material used. This result confirmed the conformance of the plate.

4) To test the power transmission efficiency of the finally prepared centrifugal belt pulley type continuously variable transmission, a performance tester with a driving motor was prepared and a control circuit was configured in the main controller intended to confirm rotational speed variability and output values.

5) In the performance test in which the rotational speed in the output values vs. input values and the resulting gear ratio were tested, the efficiency was confirmed.

It is deemed that there is the necessity for further studies to reduce errors of the performance tester and further studies on heat generation and cooling.

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