Design, development & testing of half toroidal continuous variable transmission system


Abstract — A continuously variable transmission, however, is a type of transmission that allows an infinitely variable ratio change within a finite range, thereby allowing the engine to continuously operate in its most efficient or highest performance range. The Half Toroidal CVT is an innovative transmission that executes smooth, continuous gear ratio changes by changing the angle of the power rollers between the input disk and output disk. This paper describes the working principle of Half Toroidal CVT and measurement of power transmitting capacity along with efficiency of the drive. This work documents a successfully developed experimental model of a ‘Toroidal’ continuously variable transmission (CVT) by adjusting its geometrical configuration of CVT and plotted the experimental results of speed, torque and power delivered at the output disc.

Index Terms—Half Toroidal, CVT, Infinite Speed Stages, Elliptical Contact, Traction

I. INTRODUCTION

As we know there are various problems with conventional transmission system in automobile industry. Also the efficiency of the system is max 70% and operation is not smooth due to engagement and disengagement of clutch while shifting the gears[1]. Hence there is a need of automated transmission system with better efficiency, smooth and simple changing of gear ratio, we are going to use a Continuous Variable Transmission System. From environment saving point of view the analysis performed seems to indicate that CVT adoption could produce a certain reduction in pollution emissions and a lower level of noise. All these features can be got because of the possibility offered by the CVT of changing the speed ratio in a continuous way under load conditions [2].

The Half Toroidal is one of the major types of Continuous Variable Transmission System. The first toroidal drive is patented in 1877 by C. W. Hunt [3]. In last 30 years there is a significant improvement in the fields of material, lubrication fluids, tribology and control.

II. THEORY

A continuously variable transmission (CVT) is a transmission which may change step less by way of an infinite variety of effective gear ratios between maximum and minimum values. This contrasts with different mechanical transmissions that solely permit just a few different distinct gear ratios to be selected. Continuously variable transmissions (CVTs) are mechanical devices that allow a continuous variation of the output velocity by adjusting its geometrical configuration. This offers several advantages over traditional transmissions such as better fuel efficiency [4], quieter operation, and a lower mass. Current efforts to reduce the vehicle fuel consumption in order to protect the environment and save fuel have seen a recent resurgence in CVT research, especially in the automotive industry. The torque of the continuously variable transmission system with friction drive mechanism is transmitted by contacting roller with input and output disks. For the higher transmitted torque, it is necessary to apply large load in order to get higher friction force, which in turn generates severe high stress on the contact surfaces of roller and disks. The ‘Toroidal’ type CVT system has simple component arrays that have three contact points between roller and each input or output disk to get the torque transmitted.

III. PROPOSED WORK

The Half Toroidal CVT is an innovative transmission that executes smooth, continuous gear ratio changes by changing the angle of the power rollers between the input disk and output disk. One disc connects to the engine. This is equivalent to the driving pulley. Another disc connects to the drive shaft. This is equivalent to the driven pulley. Rollers, or wheels, located between the discs act like the belt, transmitting power from one disc to the other.

The wheels can rotate along two axes. They spin around the horizontal axis and tilt in or out around the vertical axis, which allows the wheels to touch the discs in different areas. When the wheels are in contact with the driving disc near the center, they must contact the driven disc near the rim, resulting in a reduction in speed and an increase in torque (i.e., overdrive gear). When the wheels touch the driving disc near the rim, they must contact the driven disc near the center, resulting in an increase in speed and a decrease in torque (i.e., overdrive gear). A simple tilt of the wheels, then, incrementally changes the gear ratio, providing for smooth, nearly instantaneous ratio changes.

IV. LAYOUT OF HALF TOROIDAL CVT

![Fig.1. CAD Model of Half Toroidal CVT](image-url)
Fig. 2. Actual Setup Photograph

Table 1: Part list

<table>
<thead>
<tr>
<th>Part</th>
<th>Code</th>
<th>Qty</th>
</tr>
</thead>
<tbody>
<tr>
<td>22. LOCK NUT</td>
<td>STL</td>
<td>01</td>
</tr>
<tr>
<td>21. BALL BRGS</td>
<td>STL</td>
<td>02</td>
</tr>
<tr>
<td>20. SPRINGS</td>
<td>STL</td>
<td>02</td>
</tr>
<tr>
<td>19. BELL</td>
<td>STL</td>
<td>01</td>
</tr>
<tr>
<td>18. EXT FORK PIN</td>
<td>EN9</td>
<td>02</td>
</tr>
<tr>
<td>17. ROLLER PINS</td>
<td>EN24</td>
<td>02</td>
</tr>
<tr>
<td>16. CEN GEAR_PIN</td>
<td>EN24</td>
<td>01</td>
</tr>
<tr>
<td>15. FORK GEAR_1</td>
<td>EN9</td>
<td>01</td>
</tr>
<tr>
<td>14. FORK GEAR_1</td>
<td>EN9</td>
<td>01</td>
</tr>
<tr>
<td>13. BACK PLATE</td>
<td>EN9</td>
<td>01</td>
</tr>
<tr>
<td>12. CENTRAL GEAR</td>
<td>EN9</td>
<td>01</td>
</tr>
<tr>
<td>11. EXT FORK</td>
<td>EN9</td>
<td>02</td>
</tr>
<tr>
<td>10. ROLLER FORK</td>
<td>9</td>
<td>02</td>
</tr>
<tr>
<td>9. ROLLER</td>
<td>8</td>
<td>02</td>
</tr>
<tr>
<td>8. BRG HSG</td>
<td>EN9</td>
<td>01</td>
</tr>
<tr>
<td>7. FRICTION BOWL</td>
<td>EN24</td>
<td>02</td>
</tr>
<tr>
<td>6.IP SHAFT</td>
<td>EN24</td>
<td>01</td>
</tr>
<tr>
<td>5. IP SHAFT</td>
<td>EN24</td>
<td>01</td>
</tr>
<tr>
<td>4. SPACER</td>
<td>EN9</td>
<td>02</td>
</tr>
<tr>
<td>3. IP SHAFTPULLEY</td>
<td>EN24</td>
<td>01</td>
</tr>
<tr>
<td>2. MOTOR</td>
<td>STD</td>
<td>01</td>
</tr>
<tr>
<td>1. FRAME</td>
<td>MS</td>
<td>01</td>
</tr>
<tr>
<td>SR</td>
<td>PART NAME</td>
<td>MTRL</td>
</tr>
</tbody>
</table>

V. SPECIFICATION OF THE 2 POWER-ROLLER VARIATOR

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toroidal Diameter $D$ [mm]</td>
<td>25</td>
</tr>
<tr>
<td>Cavity Radius $r_0$ [mm]</td>
<td>36.5</td>
</tr>
<tr>
<td>Contact cone angle $\theta_0$ [deg.]</td>
<td>62.5</td>
</tr>
<tr>
<td>Number of power rollers $n$</td>
<td>2</td>
</tr>
<tr>
<td>Swing angle of power roller $\varphi$ [deg.]</td>
<td>27.5° to 97.5°</td>
</tr>
<tr>
<td>Speed ratio</td>
<td>0.427 to 2.344</td>
</tr>
<tr>
<td>Ratio range</td>
<td>5.49</td>
</tr>
<tr>
<td>Maximum input torque $T_{imax}$ [Nm]</td>
<td>140</td>
</tr>
<tr>
<td>Maximum input speed $N_{imax}$ [rpm]</td>
<td>6000</td>
</tr>
</tbody>
</table>

VI. RANGE OF HALF TOROIDAL CVT

A) Input speed = 1000 rpm
B) Min output speed = 1000 x 0.427 = 427 rpm
C) Max output speed = 1000 x 2.344 = 2344 rpm
D) Range = 430 to 2300 rpm (approximately)
E) Gear ratios possible = 200
D) Theoretical efficiency = 90 to 92 %

VII. TESTING ON TOROIDAL CVT

A] AIM: - To conduct trial to determine
1. TORQUE Vs SPEED CHARACTERISTICS
2. POWER Vs SPEED CHARACTERISTICS

In order to conduct trial on dynobrake pulley cord, weight pan are provided on the output shaft.

B] INPUT DATA:-

- Drive Motor AC230 Volt
  - 0.5 Amp, 50 watt
  - 50 Hz, 200 to 4500 rpm
  - TEFC Commutator Motor

Effective Diameter of Dynobrake pulley = 25 mm.

C] PROCEDURE:-

a) Start motor by turning electronic speed variator knob.
b) Let mechanism run & stabilize at certain speed (say 1300 rpm)
c) Place the pulley cord on dynobrake pulley and add 100 gm weight into the pan, note down the output speed for this load by means of tachometer.
d) Add another 100 gm cut & take reading.
e) Tabulate the readings in the observation table
f) Plot Torque Vs speed characteristic
   Power Vs speed characteristic

D] Specimen method:- (AT 0.6 kg Load)

1. Average Speed:-
   \[
   \frac{N_1 + N_2}{2} = \frac{850 + 850}{2} = 850 \text{ rpm}
   \]
2. Output Torque:-
   \[
   T_{dp} = \text{Weight in pan x Rad. of Pulley} \\
   = (0.6 \times 9.81) \times 12.5 \\
   = 73.575 \text{ N.mm}
   \]
   \[
   T_{dp} = 0.0737575 \text{ N.m}
   \]
3. Input Power :- \( P_{i/p} \)
   \[
   P_{i/p} = \frac{2 \times \Pi \times T_{dp}}{60} \\
   = \frac{2 \times \Pi \times 850 \times 0.10}{60}
   \]
   \[
   P_{i/p} = 8.90 \text{ watt}
   \]
4. Output Power :- \( P_{o/p} \)
   \[
   P_{o/p} = \frac{2 \times \Pi \times T_{dp}}{60} \\
   = \frac{2 \times \Pi \times 850 \times 0.0737575}{60}
   \]
   \[
   P_{o/p} = 3.70 \text{ watt}
   \]
5. Efficiency:
\[
\eta = \frac{\text{Output power}}{\text{Input power}} = \frac{6.565 \times 100}{8.90} = 73.76\%
\]

**VIII. ADVANTAGES**

1. Dual friction drive; i.e., two friction surfaces in contact which increases the torque transmitting capacity.
2. Even wear of rollers; thereby properly balanced power transmission.
3. Easy to maintain proper pressure between the contact surfaces thereby resulting in trouble-free operation.
4. Multiple speeds can be obtained; whereas regular clutches are of ON-OFF type where only one speed is available.
5. Infinitely variable speed available over a given range.
6. Ease of operation; the speed changes are gradual, without any shock.
7. Singular control:-

Entire range of speeds is covered by a single hand wheel control.

**IX. APPLICATIONS**

1. **Speed drives for machine tool spindles** Machine tool spindles are required to be driven at various speeds depending upon the size of work and material to be cut in such cases the gear less variable speed reducer can be used along with all geared head stock to give an infinitely variable speed condition.

2. By combination the duplex friction drive and a three stage all gear head stock a still wide range of speeds can be obtained for the main spindle of lathe.

3. Feed drives for machine tool slides. Machine tool slides can be moved at different speeds to impart feeding motion to the cutting tool.

4. Variable speed drives for conveyors in assembly line and automatic assembly plants.

5. Variable speed drives in automatic transfer lines and pick and place robotic devices.

6. Mr. Cheris Brocbank, and Mr. Cheris Greenwood already explained the applications of full toroidal continuous variable transmission in the formula 1 racing cars along with kinetic energy Recovery System. Torotrack is participating in the development of a mechanical Kinetic Energy Recovery System (KERS) which utilize full- toroidal fraction drive variator connected to a high speed flywheel.

**X. LIMITATIONS**

1. Duplex friction drive is actually a friction type drives which automatically limits the torque that can be transmitted by the drive hence it can be used satisfactorily for light to medium duty application.

2. The amount of slip becomes significant of high torque conditions, which reduces the velocity ratio making in-accuracies in power and motion. The minimum contact life appears at the maximum speed ratio [5].

3. Friction surfaces generate a lot of heat, being a dry friction drive; proper ventilation preferably forced ventilation must be provided for satisfaction application at any loads.

4. In case of full toroidal and half toroidal system; due to limitation of spin and slip effect, there is restriction on maximum speed ratio range [6].

**XI. CONCLUSION**

This paper shows test results of efficiency and power output capacity of 2 power-roller half-toroidal CVT for transmitting 0.073 Nm torque by \( r_0 = 36.5 \) mm cavity-radius discs. The measured power-transmission efficiency is nearly about 73% which shows this kind of drive is applicable in automobile by avoiding the slip rate in the belt drive.

**XII. FUTURE SCOPE**

1) The speed changing mechanism presently is manually operated which can be further modified by connecting it to be servo motor to make it microprocessor baud control. This will enable to have a truly infinite variable speed and speed can be minutely changed i.e. \( \pm 0.5 \) rpm etc.

2) This could also be convert into a wet friction type clutch by modifying the liner material and an oil tight casing with proper heat dissipation facility.

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REFERENCES


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