DESIGN AND DEVELOPMENT OF TOROIDAL CONTINUOUSLY VARIABLE TRANSMISSION DRIVE FOR MACHINE TOOL APPLICATIONS

Mohammed Afzal Ali[1], Dr. M.V. Satish Kumar[2], KK Guduru[3], Zafar Anwar[4]
[1]Asst Professor, Department of mechanical engineering, KITS(S), JNTUH, INDIA
[2]Professor, Department of mechanical engineering, KITS(S), JNTUH, INDIA
[3]Asst Professor, Department of mechanical engineering, KITS(S), JNTUH, INDIA
[4]Asst Professor, Department of mechanical engineering, KITS(S), JNTUH, INDIA

ABSTRACT
The selection of correct cutting parameter is important in lathe machine, cutting parameters are depth of cut, feed rate and spindle speed. As the conventional lathe headstock is equipped with a stepped pulley that can produces limited range of spindle speed, which causes low tool life and more power consumption. Therefore, this research focused on to tune toroidal CVT drive for a lathe head stock. The proposed model of Toroidal CVT was modelled by using Autodesk inventor software. And required calculations for designing the toroidal drive cone pulley has been done by using empirical formulae's.

Keywords: Toroidal, Continuously Variable Transmission (CVT),

I. INTRODUCTION

This study describes a method for analyzing and designing a continuously variable transmission system (CVT). The analysis process can be implemented in a software package that can be used to tune a CVT for a given application, such as for achieving variable speed of lathe spindle. The analysis can be accomplished through the use of kinematic principles as well as equations developed from basic energy principles. Although the theory developed can be applied to any CVT system still there is a necessity to implement CVT and analyze it for various applications. The work was motivated by the need for a reliable and inexpensive method of CVT tuning for a specific application. Previous approaches to CVT tuning were strictly empirical and involved mechanical component replacement in a slow and expensive trial-and error optimization loop. The software used for tuning the parameter is intended to be a first step in the process of properly implementing a CVT for a specific application. A Literature review is carried out for finding the importance of variations of spindle speed and to show the effect of spindle speed on lathe operations. Such as, cutting timing (production or manufacturing timing), tool wear, and power consumption. During this review it was also found that every engineering material has its own optimum cutting speed.

A. Cutting Time (Production or Manufacturing Time)

S. S. K. Deepak [1] has studied about production timing of turning process and result curves obtained between production time and cutting speed reveal that a smaller value of cutting speed results in high production time. It is due to the fact that a smaller cutting speed increases the production time of parts. Also, it will decrease the profit rate due to the production of a lesser number of parts. However, if the cutting speed is too high, it will also lead to a high production time due to excessive tool wear and increased machine downtime. The optimum cutting speed is somewhere between “too slow” and “too fast” which will yield the minimum production time.

B. Tool Wear

Viktor P. Astakhov [2] has find as a result, the influence of the cutting feed on the tool wear rate is different at different cutting speeds. The diameter of the hole being machined affects the cutting process significantly in boring operations. In the range of optimum cutting speeds, the smaller the diameter of the hole being machined, the smaller the optimum cutting speed, the greater the chip compression ratio and thus the work of plastic deformation, the greater the tool wear rate.

C. Power Consumption

Richard Geo, Jose SherilD'cotha [3] has conducted experiment work. which clearly reveals that the rpm is the main influencing factor for power consumption and tool feed rate has the lowest influencing parameter.

II. Gap Analysis

It is clear from the above literature review that the speed of the spindles in various machine tool applications, such as lathe, plays an important role for carrying out cost effective operations on it. And also, the gap analysis reveals that, the application of CVT system was limited to automobile, but somehow a proper tuning and designing of CVT system can be extended for various Engineering applications.

III. Methodology

a. Study of conventional lathe Power Transmission Drive

Fig 1: conventional lathe heat stock equipped with stepped pulley

Observations:

- Lathe head stock (belt drive) dimensions
- Fly wheel diameter: 240 mm
- Motor spindle circumference: 20 mm
- Motor wheel diameter: 60 mm

Table: 1 Dimensions of motor (driver) pulleys

Motor pulleys (Driver)	1st pulley diameter	50 mm
	2nd pulley diameter	70 mm
	3rd pulley diameter	100 mm
	4th pulley diameter	120 mm

Table: 2 Dimensions of spindle (driven) pulleys

Spindle pulley (Driven)	1st pulley diameter	60 mm
	2nd pulley diameter	90 mm
	3rd pulley diameter	110 mm
	4th pulley diameter	140 mm

IV. Speed ratio and Torque calculations

Circumference of the circle:

$$C = 2\pi r$$

Where, r =radius.

Based on the formula D2/D1 = N2/N1

where, D_2 = Major diameter of pulley

D_1 = minor diameter of pulley

N_2 = Major speed of pulley

N_1 = minor speed of pulley

Power:

$$P = \frac{2\pi n T}{60}$$

Where, n = speed, T = torque.

The rated power of the motor is 1.4 KW

According to the above formula the diameter is inversely proportional to the speed. As the diameter of the pulley increases the speed of the pulley decrease and the vice versa, to have a various speed on lathe machine tool based on the working conditions, cutting tool and work piece material the limited and desired speed is engaged by changing the position of the v belt position on the cone stepped pulley which is mounted on lathe head stock.

With the little consideration and from the reference to the above all formula, we get that

1) For 1st pulley on spindle side, were diameter of pulley is 140mm

Therefore:

$$\frac{D1}{D2} = \frac{N2}{N1}$$

=50/140=1440/N2;

=1440 x 50/140

N2=618rpm

2) For 2nd pulley on spindle side, where diameter of pulley is 110mm

$$\frac{D2}{D3} - \frac{N3}{N2}$$

70/110 =N3/618

N3 =70 x 618/110

N3=787rpm

3) For 3rd pulley on spindle side, where diameter of pulley is 90mm

Similarly,

100/90 =N4/787

N4=100 x 787/90

N4=1224rpm

4) For 4th pulley on spindle side, where diameter of pulley is 60mm

120/60=N5/1224

N5=120 x 1224/60

P=2 x 3.14 x NT/60, rated power of the lathe motor is 0.75Kw

Therefore, we get the amount of torque transmits by the stepped cone pulley drive on head stock of lathe.

$$T = \frac{P \times 60}{2 \quad 3.14 \; N}$$

1) Toque transmitted by the 1st pulley :(where D=140mm, N=618rpm)

T=0.75 x 60/2 x 3.14 x 618

T1=0.011 N-m

2) Toque transmitted by the 2nd pulley :(where D=110mm, N=787rpm)

T=0.75 x 60/2 x 3.14 x 787

Table no: 04 Torque transmitted with the respective pulley on spindle side

Spindle side	Diameter(mm)	Torque (N m)
1st pulley	140	0.011
2nd pulley	110	0.009
3rd pulley	90	0.005
4th pulley	60	0.003

V. Geometric modeling of the proposed toroidal CVT drive

The Toroidal CVT is designed based on the following assumptions:

- Rated required rpm
- This model consists of no friction.
- Constant pressure on the rollers.
- No dynamic forces are involved.
- To produce needed speed and torque.
- To have a smooth and soft start up.

We developed this model in software of 3D inventor with a referable diameter of conventional lathe stepped cone pulley. A torus cones consist with a larger and smaller diameter; these two diameters are joined with a 2° degree parabolic curve to have a torus shape. Suitable dimensions are assumed and drafted based on the required speed ratios. All the parts are designed and drafted in AUTO CAD and assembled together in software.

T2=0.009 N-m

3) Toque transmitted by the 3rd pulley :(where D=90mm, N=1224rpm)

T=0.75 x 60/2 x 3.14 x 1224

T3=0.005 N-m

4) Toque transmitted by the 4th pulley (where D=60mm, N=1836rpm)

=0.75 x 60/2 x 3.14 x 1836

T4=0.003 N-m

Table no: 03 Different speeds that can be obtained in convention

Spindle side	Diameter(mm)	Speed(rpm)
1st pulley	140	618
2nd pulley	110	787
3rd pulley	90	1224
4th pulley	60	1836

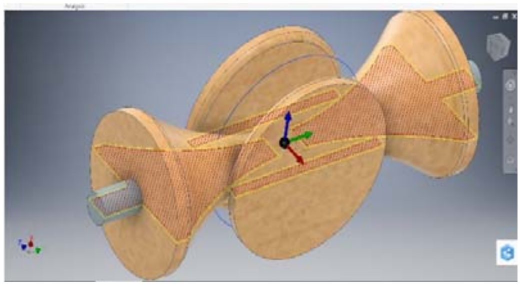

Fig:1 Toroidal drive 3D model.

VI. Mathematical Model of the proposed Drive:

Observations:

Length of the torus cone:	80 mm
Width of the torus cone:	150 mm
Maximum diameter of torus cone:	150 mm
Maximum diameter of torus cone:	30 mm

Power rollers:

length of power rollers:	150 mm
With of power rollers:	150mm
Thickness of power rollers:	30 mm

Calculations:

Based on the formula D2/D1 = N2/N1

where, D2 = Major diameter of pulley

D1 = minor diameter of pulley

N2 = Major speed of pulley

N1 = minor speed of pulley

POWER (P) = 2 x 3.14 x n t /60

where, n = speed, t = torque.

The rated power of the motor is 1.4 Kw

According to the above formula the diameter is inversely proportional to the speed. As the diameter of the pulley increases the speed of the pulley decrease and the vice versa, to have a various speed on lathe machine tool based on the working conditions, cutting tool and work piece material the limited and desired speed is engaged by changing the position of the v belt position on the cone stepped pulley which is mounted on lathe head stock.With the little consideration and from the reference to the above all formula, we get that

The speed ratio in Toroidal CVT is 5:1

1) N2/N1 =D1/D2

N2/1440 =30/150

N2=288rpm

2) N2/N1 =D1/D2

N3/N2 =150/30

N3 = 7200 rpm

3) N2/N1 =D1/D2

N2/1440= 60/60

N2 = 1440 rpm

The above calculations give the information about the speed of the model in low speed mechanism, equal speed mechanism and high-speed mechanism.

Generally, in practice we can achieve an infinite number of speed ratios as the rollers change the position from point to point on the torus cone

Torque T =P x 60/2 x 3.14 x N

Torque in Toroidal CVT

1) Torque transmitted at the low speed mechanism (where minimum diameter =30mm, maximum diameter = 150mm, speed =288rpm)

T = 0.75 x 60/2 x 3.14 x 288

T = 0.024 N- m

2) Torque transmitted at the high-speed mechanism (where minimum diameter =30mm, maximum diameter = 150mm, speed =7200rpm)

T = 0.75 x 60/2 x 3.14 x 7200

T =0.009 N- m

3) Torque transmitted at the equal speed mechanism (where equal diameter =60mm, speed =1440rpm)

T = 0.75 x 60/2 x 3.14 x 1440

T = 005 N-m

VII. **Results**

Table no: 03 Final speed of a Toroidal CVT

Torus cone	Diameter (mm)	Speed (rpm)
Minimum diameter	30mm	288
Equal diameter	60mm	1440
Maximum diameter	150mm	7200

Table.no:04 Torque generated in Toroidal CVT

Torus cone	Diameter (mm)	Torque N-m
Minimum diameter	30mm	0.024
Equal diameter	60mm	0.015
Maximum diameter	150mm	0.009

For the same rated rpm of the motor and the diameters of the pulley as steeped pulley the Toroidal CVT shows the better results in the aspects of the speed ratio and torque. As the speed is the major effecting parameter of the various factors like surface roughness, tool life, tool geometry and cutting timing.

Speed ratio in stepped cone pulley 3:1

Speed ratio in Toroidal CVT 5:1

Table: comparison of speed ratios

Maximum speed in steeped cone pulley	1836 rpm
Minimum speed I stepped cone pulley	618 rpm
Maximum speed in Toroidal CVT	7200 rpm
Minimum speed in Toroidal CVT	288 rpm

Torque:

Maximum torque in steeped cone pulley is	0.011 N-m
Minimum torque in steeped cone pulley is	0.003 N-m
Maximum torque in Toroidal CVT is	0.024 N-m
Minimum torque in Toroidal CVT is	0.009 N-m

Weight:

Weight of a steeped cone pulley	20 kg.
Weight of the Toroidal CVT model	12 kg

Space:

Space occupied by the stepped cone pulley drive is	35 x 45 inch
Space occupied by the Toroidal CVT is	24 x 12 inch

VIII. **Conclusion**

A toroidal CVT drive has been proposed for achieving optimum speed in a lathe head stock. As speed is most effecting factor on machine tool parameters as well as for the quality of the finished product. Therefore mathematically, a wide range of ratio can be achieved by using toroidal CVT drive has been shown. The following are the conclusion that can be draw

- The stepped pulley employed in conventional Lathe head stock for power transmission, cannot produces optimum speed for a given operation and tool material.
- Required calculations for designing a toroidal CVT drive has been done. Calculations work reveals that the maximum and minimum diameter of a cone pulley for a toroidal CVT is 150mm and 30mm.
- Mechanism used in a toroidal CVT drive, for changing the speed is found easier and consumes less time, when compared to the conventional stepped pulley drive.
- A software 3D model of the proposed toroidal CVT drive has been modeled.
- The velocity ratios in conventional stepped pulley drive were found 3:1, where as in toroidal CVT the velocity ratio were found 5:1.

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