

# Design and Analysis of System Components of Alternative Fixed Pitch CVT Cone



#<sup>1</sup>S. A. Kale, #<sup>2</sup>N. S. Biradar

<sup>1</sup>kalesagar26@gmail.com

<sup>2</sup>nsbiradar123@gmail.com

#<sup>12</sup>Mechanical Department, JSPM's Imperial College of Engineering and Research, Wagholi, Pune

## ABSTRACT

Continuously Variable Transmission (CVT) is a type of transmission, which allows an endless variable ratio change within a limited range. Anderson CVT is one of its types. In Anderson CVT, two cones having variable diameter kept parallel having 'floating sprocket bars' mounted in linear grooves around the perimeter of every cone. A non-standard chain engaged with the floating sprocket bars, and it can move with length of cones, with in change in gear ratio. The bars make the system positive drive, non-friction dependent. The sprocket bars made of rubber and mounted with help of conventional spring, which gets wear and tear, have to change frequently, so manufacturing cost of full system increases and the weight of system are also high due its solid cover over cone. The following study is dedicated to the modifying the existing design in order to use the alternative materials for cone, floating sprocket bars changing to steel bars and non-standard belt to standard timing belt, other variable as vibration analysis of floating bars, as bars are kept floating on one side. So in this paper we designed a Alternative Fixed Pitch CVT by using empirical formulae. By using CATIA V5 we have created a model of Alternative Fixed Pitch CVT and then imported in ANSYS workbench for Automobile Applications. We have conducted static structural analysis of input shaft, LH Cone Ring, Sprocket Bars. The results are compared for the maximum deformation and stresses.

**Keywords**— Alternative Fixed Pitch CVT, Variable Diameter Cone, Floating Sprocket Bars, Gear Ratio, ANSYS.

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## I. INTRODUCTION

Continuously Variable Transmission (CVT) is a type of transmission, which allows an endless variable ratio change within a limited range. Variable speed drive is a type of automatic transmission that can change the gear ratio to any possible setting within the range. The CVT is not restricted to small gear ratios, such as the 4 to 6 forward ratios in typical automotive transmissions. CVT computer controlled often try to excel the traditional sudden gear changes, especially at minimum speeds, because most of drivers expect the sudden jerks and will reject a perfect smooth transmission as lacking in apparent power. In CVT two variable diameter pulleys are kept at a distance which is

fixed and connected by drive which is a power transmitting device like belt or chain. The belt or chain can move in radial and tangential direction depending on the torque loading condition and axial forces on the pulleys. In belt CVT torque is transmitted from the driver pulley to the driven pulley by the pushing action of belt elements. The flat rubber belts also participate in torque transmission. Hence, there is a combined push-pull action in the belt that enables torque transmission in a metal V-belt CVT system [3].

Hawthorn studied that a CVT capable staying positively engaged to transmit power while allowing for continuous change in ratio. The CVT design allows for automatic ratio selection based on the difference between power and load

based on the mechanical specification used in the design of the CVT, required no outside control input. The CVT consists of one or more Fixed Pitch Continuously Variable Transmission (FPCVT) units each having one spindle for Power input and one spindle connected to the output i.e. load. The two spindles are mounted so one may rotate freely

around the other and share the axis of rotation. Both spindles have same number of slots. One of the two has these slots so cut at a different angle or curvature than the other. One pin intersects each set of slots and has mounted on it a combination of either all idler pulleys or idler pulleys and a sprocket to transmit the power to a chain. Rotating either spindle relative to the other will cause the pins to force a pitch diameter change of the CVT assembly and the chains mounted on each pitch line. Only one sprocket is mounted on any one pitch line on any one FPCVT, thus allowing for a ratio changes while the CVT stays engaged [4].

## II. ANDERSON -CONTINUOUSLY VARIABLE TRANSMISSION

Anderson CVT- It is a technology invented by Lawrence L. Anderson, under US patents. Two cones having variable diameter kept parallel having 'floating sprocket bars' mounted in linear grooves around the perimeter of every cone. A non-standard chain engaged with the 'floating sprocket bars', and it can move with length of cones, with in change in gear ratio. A specially-designed chain or belt meshes with the floating Sprocket bars, and is free to slide along the length of cones, changing the gear ratio at each point.

The power input to the system will be through driving cone (RH-cone) to a driven cone (LH-cone) with the help of drive belt. The conical shape of pulley or cone has grooves on its perimeter of cone. The grooves are like channels, with Sprocket bars located in it. The Channels are circumferentially larger than the sprocket bars because to allow the movement of the sprocket bars. The bars have one or more compression springs or any our elastic material, attached between sprocket bar and channel groove. The floating sprocket bars make the Anderson CVT positive-drive, non-friction-dependent. Another advantage of the Anderson CVT is the simplicity of its design, as it consists of far fewer components than other transmissions. The technology is also adaptable to a variable diameter pulley-type CVT, by mounting the floating sprocket bars on the inner face of the pulley sheaves [1]. The above design uses conventional spring loaded rubber sprocket bars, made from poly nit rile rubber. These sprocket bars are kept floating in the radial grooves along the generators of the cones mentioned above. These sprocket bars at their lower end carry a spring that keeps them floating where as the top profile engages in a special roller chain which acts as the transmission element. These sprocket bars are subjected to heavy wear and tear while in running condition, hence may have to be replaced frequently. Due to the floating nature of the sprocket bars the drive has inherent vibrations. Chain required for transmission is an special roller chain, required to be manufactured specially hence higher cost. Cone cover is made full of solid material due it, weigh increases. So also the manufacturing cost of the above device is slightly on the

higher side. Material used for IP-Shaft, Cone and Floating Sprocket Bars is EN9, Aluminum and Rubber-Polybutylene

The study is dedicated to the modifying the existing designs in order to design new, reliable, less weighed and minimizing cost of full system by using the alternative material for both the cones, replacing floating sprocket bars by alloy steel bars, changing the material of input and output shafts of both the cones and drive system specially design (non-standard) belt to standard timing belt, fig.1. The sprocket bars are made round in shape and are made integral with the cone, this reduces the problem of vibration and chatter. The simple round shape of the sprocket bars make engagement and disengagement of the transmission belt easy, and vibration free so also offering a positive engagement, unlikely of any slip. The simple shape of the sprocket bars makes the manufacturing process easy and at low cost, as shown in fig.2, below.

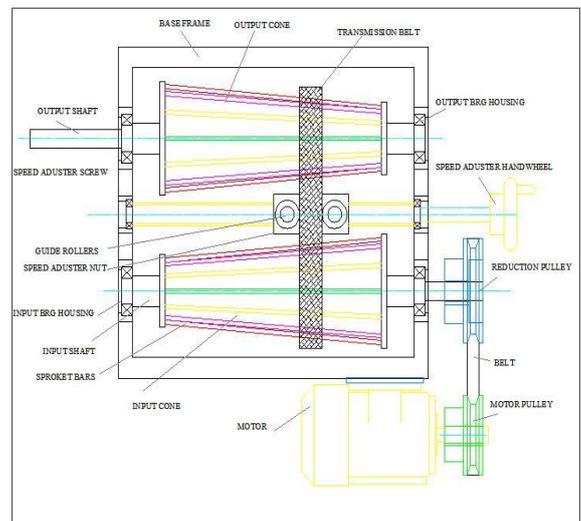


Fig.1.Design of Alternative Fixed Pitch CVT

## III. (A). MATERIAL USED FOR INPUT SHAFT

Material used in system for input shaft of cone and LH Cone Ring is alloy steel with grade EN24. Material Selection is done with reference of PSG Design Data Book. EN24 is a popular through hardening alloy steel due its excellent machinability. It is used in components such as gears, shafts, studs, bolts, etc. EN24 steel is a high tensile alloy steel known for its wear resistance properties and also where high strength properties are required. Ultimate Tensile Strength of EN24 is 850-1000 N/mm<sup>2</sup> and Yield Strength is 650-700 N/mm<sup>2</sup>.

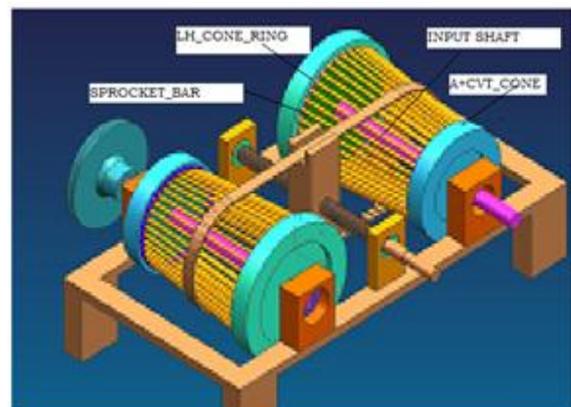


Fig.2.Design of Alternative Fixed Pitch CVT

**III. (B). MATERIAL USED FOR SPROCKET BARS**

Material used in system for Sprocket Bars is alloy steel with grade EN9. Material Selection is done with reference of PSG Design Data Book. It is used in components such as gears, shafts, axle, studs, etc. Ultimate Tensile Strength of EN9 is 600 N/mm<sup>2</sup> and Yield Strength is 480-500 N/mm<sup>2</sup>.

**IV. DESIGN AND ANALYSIS OF COMPONENTS**

**1. A. THEORETICAL DESIGN OF INPUT SHAFT.**

Material Selection is done from PSG Design data book; material used for input shaft is EN24. EN24 have Ultimate Tensile Strength 850-1000 N/mm<sup>2</sup> and Yield Strength is 650-700 N/mm<sup>2</sup>.

As per ASME Code,  
 $fs_{all} = 121.5 \text{ N/mm}^2$

*TO CALCULATE INPUT TORQUE*

$$T_{design} = 1.19 \times 10^3 \text{ N.mm.}$$

*CHECK FOR TORSIONAL SHEAR FAILURE OF SHAFT.*

Assuming minimum section diameter on input shaft = 16 mm

$$d = \sqrt[3]{\frac{16 \times fs_{act} \times Td}{\pi}}$$

$$fs_{act} = \frac{(16 \times Td)}{(\pi \times d^3)}$$

$$= \frac{[16 \times 1.19 \times 10^3]}{[\pi \times (16)^3]}$$

$$fs_{act} = 1.47 \text{ N/mm}^2$$

$$As, fs_{act} < fs_{all}$$

Where,  $fs_{act}$  – Actual Shear Stress,  $T_{design}$ - Designed Torque,  $fs_{all}$ – Allowable Shear Stress.

I/P shaft are safe under torsional load.

**1. B. STRUCTURAL ANALYSIS OF INPUT SHAFT.**

By using CATIA V5 design software, created a model of Alternative Fixed Pitch CVT as shown in Fig.2 and then imported components in ANSYS workbench, to make analysis of input shaft fig.3- fig.8.

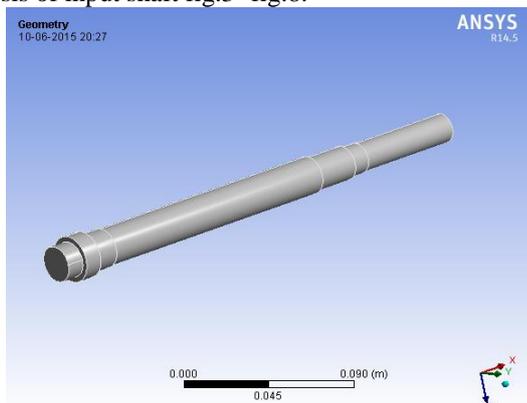


Fig.3. Importing of INPUT SHAFT into ANSYS WORKBENCH

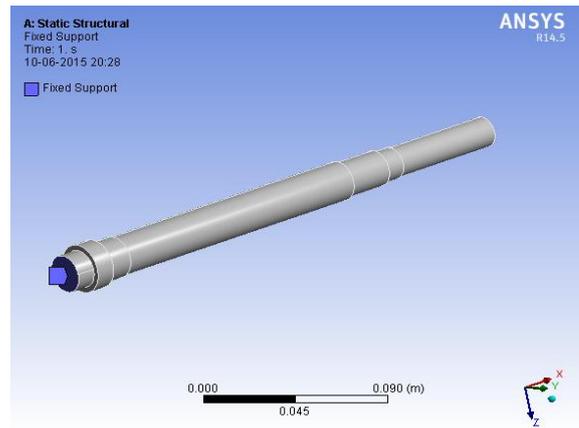


Fig.4. Fixed Support for INPUT SHAFT

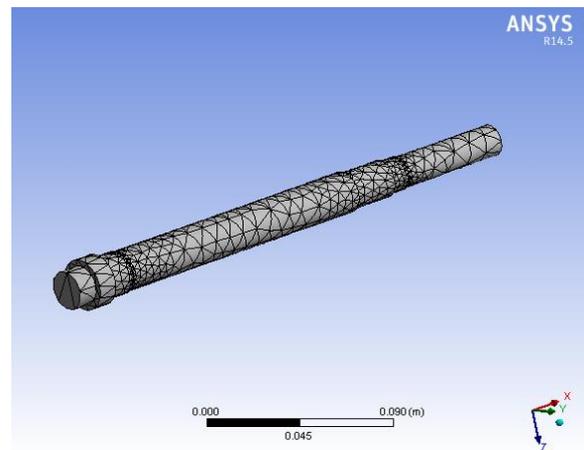


Fig.5. Meshing of INPUT SHAFT

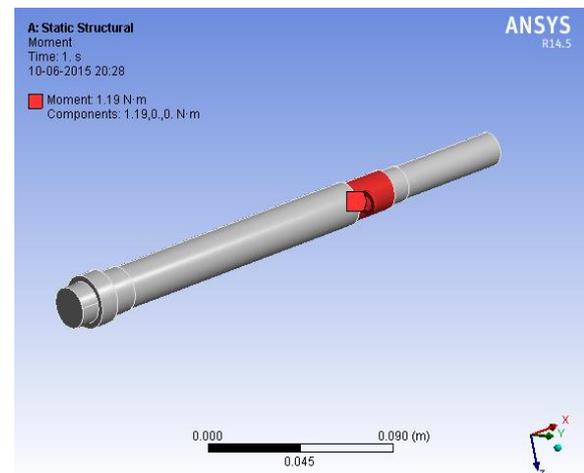


Fig.6 Application of Torque on INPUT SHAFT (Torque = 1.19 N-m)

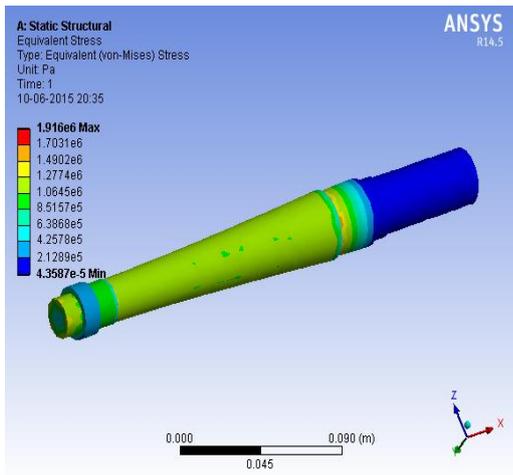


Fig.7. Equivalent Stress (von-Mises) in INPUT SHAFT

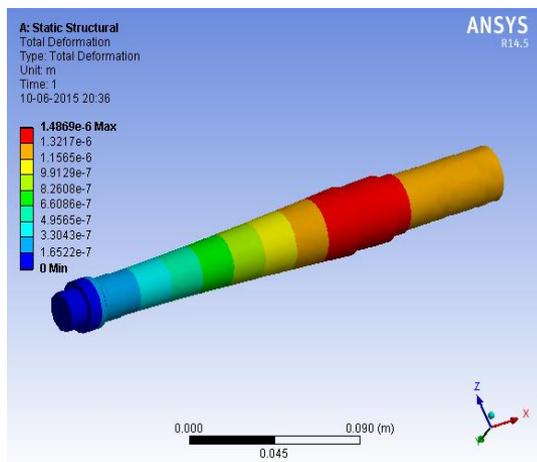


Fig.8. Total Deformation in INPUT SHAFT

2. B. STRUCTURAL ANALYSIS OF LH-CONE RING.

By using CATIA V5 design software, created a model of Alternative Fixed Pitch CVT as shown in Fig.2 and then imported components in ANSYS workbench, to make analysis of LH-Cone Ring, fig.9- fig.14.

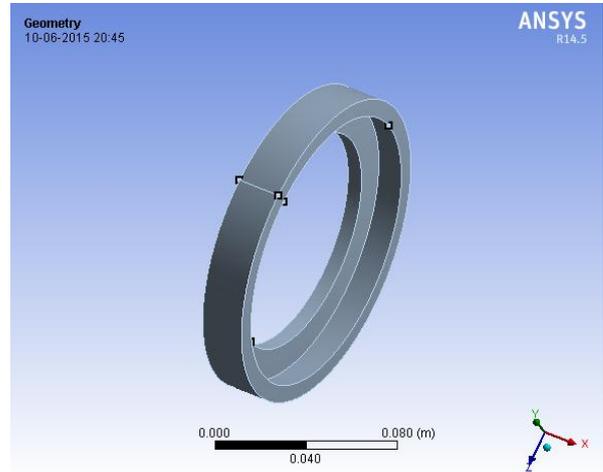


Fig.9. Importing of LH-Cone Ring into ANSYS WORKBENCH

3. A. THEORTICAL DESIGN OF SPROCKET BARS.

Sprocket Bars are located in holder ring on driver disk at a PCD of 122 mm. These bars engage in the belt placed as the transmission link and act as transmission elements. Material Selection is done from PSG Design data book; material used for lh cone ring is EN9. EN9 have Ultimate Tensile Strength 600 N/mm<sup>2</sup> and Yield Strength is 480 N/mm<sup>2</sup>. They can be designed similar to the bush pins in the bush pin type flexible flange coupling.

'40 bars' transmit the entire torque;  
 These pins are located at PCD (D<sub>p</sub>) = 122mm  
 Tangential force on each bolt (F<sub>b</sub>) = [T/ (D<sub>p</sub> x n/2)]

2. A. THEORTICAL DESIGN OF LH-CONE RING.

Material Selection is done from PSG Design data book; material used for lh cone ring is EN24. EN24 have Ultimate Tensile Strength 850-1000 N/mm<sup>2</sup> and Yield Strength is 650-700 N/mm<sup>2</sup>.

Inner Diameter of Ring, Di =127.8 mm,  
 Outer Diameter of Ring, Do =140 mm,  
 As per ASME Code,

$$fs_{all} = 108 \text{ N/mm}^2$$

TO CALCULATE INPUT TORQUE

$$T_{design} = 1.19 \times 10^3 \text{ N.mm.}$$

CHECK FOR TORSIONAL SHEAR FAILURE OF CONE RING.

$$T = (\pi \times fs_{act} / 16) \times (Do^4 - Di^4 / Do)$$

$$1.19 \times 10^3 = (\pi \times fs_{act} / 16) \times (140^4 - 127.8^4 / 140)$$

$$fs_{act} = 7.23 \text{ N/mm}^2$$

$$As, fs_{act} < fs_{all}$$

Where, fs<sub>act</sub> – Actual Shear Stress, T<sub>design</sub>- Designed Torque, fs<sub>all</sub> – Allowable Shear Stress.

LH Cone Ring is safe under torsional load.

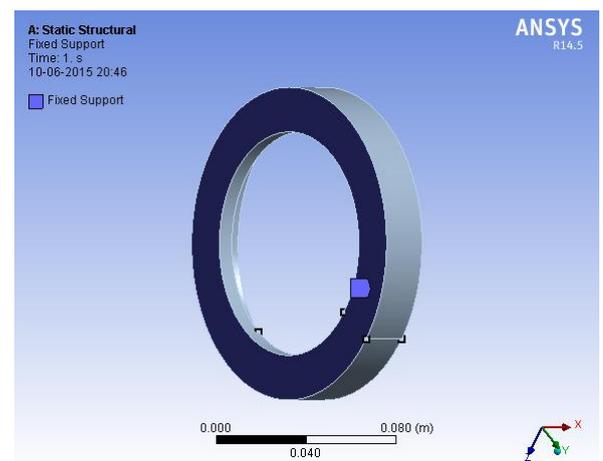


Fig.10. Fixed Support for LH-Cone Ring

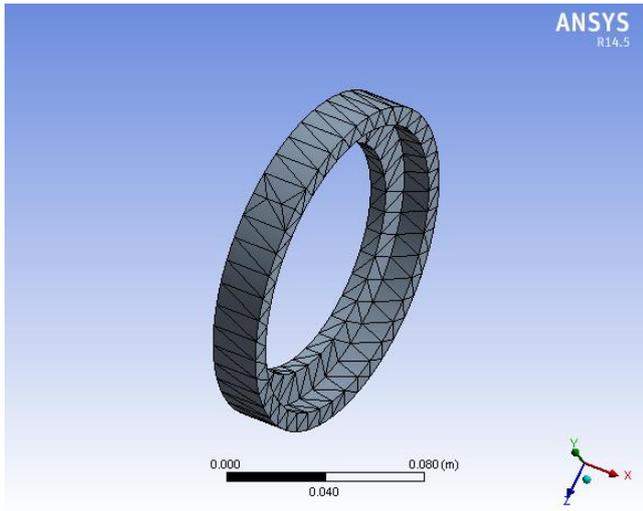


Fig.11. Meshing of LH-Cone Ring

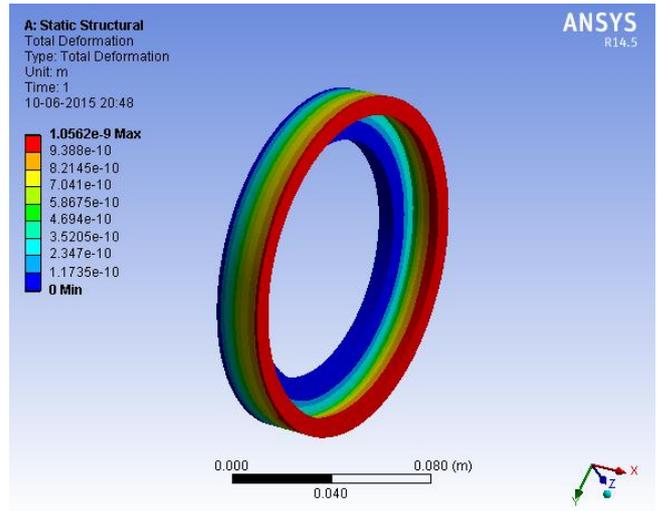


Fig.14. Total Deformation in LH-Cone Ring

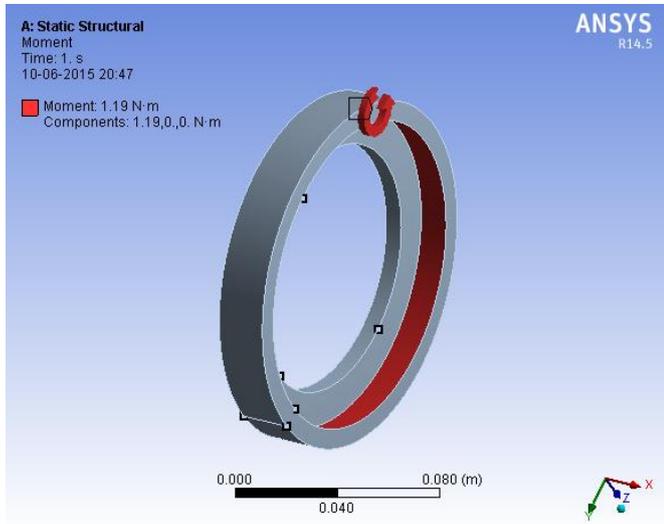


Fig.12. Application of Torque on LH-Cone Ring (Torque = 1.19 N-m)

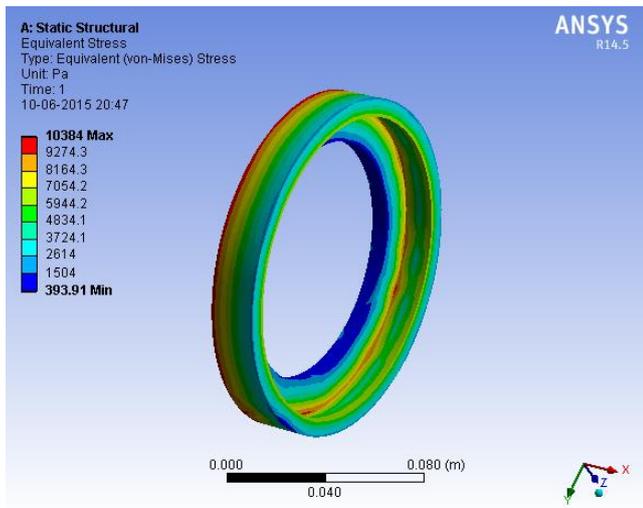


Fig.13. Equivalent Stress (von-Mises) in LH-Cone Ring

Now,  
 Shear Stress=Shear Force/Shear Area  
 Assuming Pin diameter = 4 mm

$$f_{act} = F_b / (\Pi/4 \times d^2)$$

$$F_b = fs_{act} \times \Pi/4 \times d^2$$

$$T = n \times (fs_{act} \times \Pi/4 \times d^2) \times D_p/2$$

$$1.19 \times 10^3 = 40 (fs_{act} \times \Pi/4 \times 4^2) \times 122/2$$

$$fs_{act} = 0.04 \text{ N/mm}^2$$

$$As, fs_{act} < fs_{all}$$

Where,  $fs_{act}$  – Actual Shear Stress, T design- Designed Torque,  $fs_{all}$  – Allowable Shear Stress.  
 Sprocket Bars are safe under torsional load.

### 3. B. STRUCTURAL ANALYSIS OF SPROCKET BARS.

By using CATIA V5 design software, created a model of Alternative Fixed Pitch CVT as shown in Fig.2 and then imported components in ANSYS workbench, to make analysis of Sprocket Bars, fig.15.- fig.20.

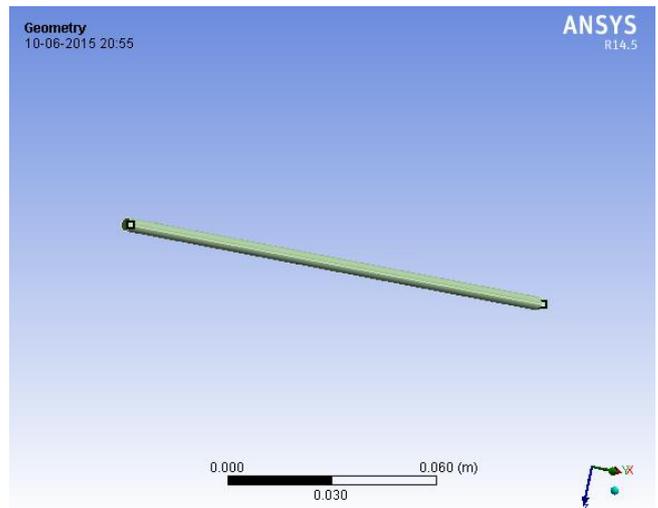


Fig.15. Importing of Sprocket Bars into ANSYS WORKBENCH

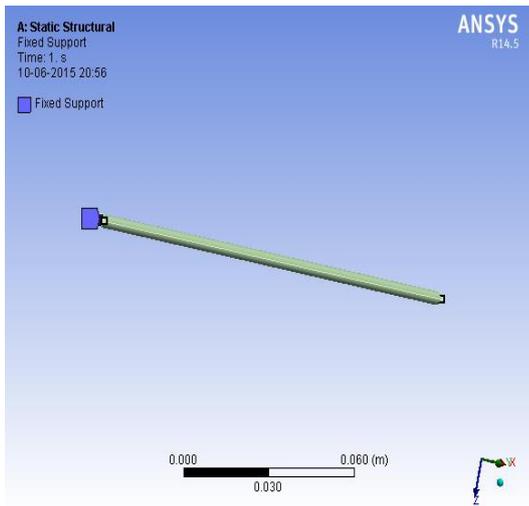


Fig.16. Fixed Support for Sprocket Bars

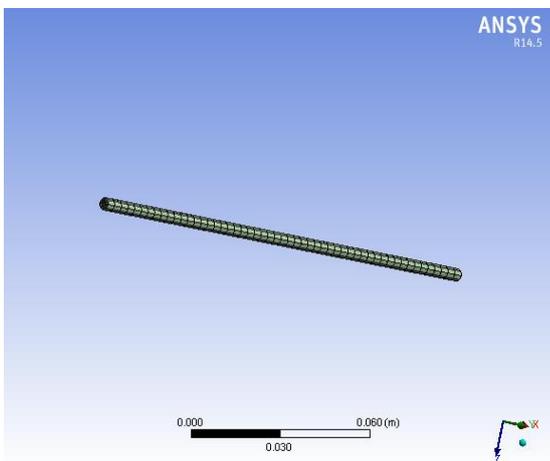


Fig.17. Meshing of Sprocket Bar.

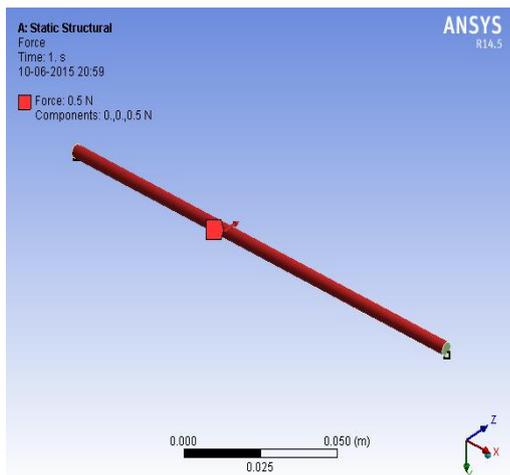


Fig.18. Application of Force on Sprocket Bars (Torque = 0.5 N)

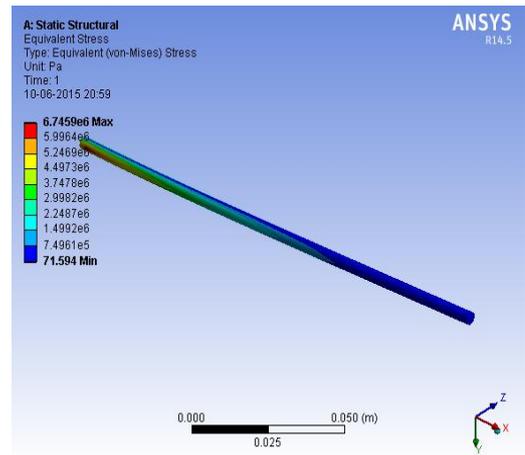


Fig.19. Equivalent Stress (von-Mises) in Sprocket Bars

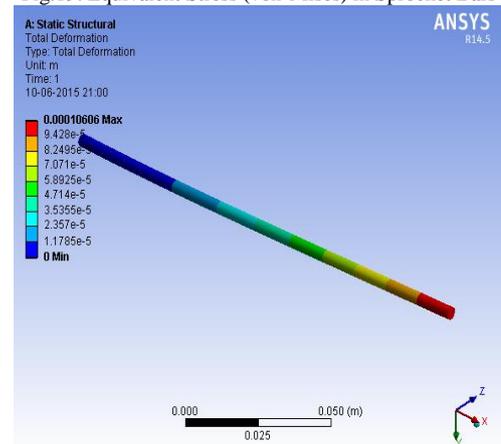


Fig.20. Total Deformation in Sprocket Bars

IV. CONCLUSION

In the above work we have design a Alternative Fixed Pitch CVT from theoretical calculation and the 3D model is design by using CATIA V5 software. The Input Shaft, LH Cone Ring and Sprocket Bars are analyzed through ANSYS, the material is taken as EN24, EN24 and EN9 respectively and it is found that

- 1) In old CVT, for IP\_SHAFT the EN9 grade material was used, where as in the new CVT EN24 grade material is used. Since for both material i.e. EN9 and EN24 maximum stress is below the allowable limit hence parts are safe.
- 2) In case of deformation, negligible deformation is seen in both the material under action of system forces, there by suitable for practical performance.
- 3) Weight of EN24 is slightly more than EN9 also the cost more for EN24 than EN9 for IP\_SHAFT.
- 4) In old CVT, for CONE aluminum material was used and in new CVT for LH-Cone Ring, EN24 steel alloy material is used. Since for both material i.e. Al and EN24 maximum stress is below the allowable limit hence parts are safe.
- 5) In case of deformation, negligible deformation is seen in LH-Cone Ring material under action of system forces, but in AL slightly more deformation than EN24 is seen, but are suitable for practical performance.
- 6) Weight of EN24 as a ring is much less than AL as AL is taken as full cone also the cost is much higher for Aluminum than EN9 for Cone Ring.
- 7) In old CVT, for FLOATING SPROCKET BARS the Polybutylene rubber grade material was used, where as in

the new CVT EN9 steel grade material is used. Since for both material i.e. Polybutylene and EN9 maximum stress is below the allowable limit hence parts are safe.

8) In case of deformation, negligible deformation is seen in new sprocket bar material under action of system forces, but in polybutylene slightly more deformation than EN9 is seen, EN9 is suitable for practical performance, as rubber material has to change frequently.

9) Weight of EN9 as a bar is much less than polybutylene as polybutylene is taken as solid rubber also the cost is much higher for polybutylene rubber material than EN9 for Sprocket Bars.

Except IP\_SHAFT, the weight and cost of material for LH-CONE and SPROCKET BARS are much less than existing CVT's material.

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