Design, Analysis, and Optimization of Continuous Variable Transmission

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Abstract - *The Continuous Variable Transmission (CVT) system offers a solution that permits stepless gear ratio shifting regardless of the required speed and torque. Since its introduction a century ago, CVT technology has grown in popularity among luxury vehicles. However, CVTs are not widely used in machinery because of some limitations in the existing design. This study evaluates the CVT's design to identify its weakest point. Increasing the CVT's design efficiency to extend its operational life. The current design has several issues that should be minimized, including noisy operation, jerking while accelerating, and lack of awareness of speed changes, expensive production, low belt life, and belt sliding after a certain number of cycles. For that, a Solid Works CVT model has been made, and Ansys will be used for analysis. The CVT V-Belt, which is built of composite material, is the subject of this study. As one of the transmission's major components, the performance of the belt under extreme conditions may provide insight into its long-term durability and performance. This study was conducted in five steps: review of the existing design, analysis of the existing design, design optimization, analysis of the revised design, and result comparison. The belt's material was changed to achieve an optimized design.*

***Key Words*: Cvt, Solid Works, Ansys, V-belt**

1. INTRODUCTION

V-belt CVTs are popular due to their lightness and quietness, as well as their greater gearbox efficiency. They are commonly used in small automobile vehicles and have been studied for their mechanics and efficiency [1, 2]. Gerbert looked into the operation of V-belts and found that rubber CVT belt's durability is the most important issue. The specified lifetime is 25,000 km, so it is important to make recommendations for enhancing fatigue strength. However, since rubber CVT belts are made of composite material, it is difficult to explain the fatigue failure mechanism for these belts. CVT belts are subjected to high tension, bending deformation, and pulley friction forces, which can lead to fatigue failure [3]. The coed was harmed by cyclic bending around the pulley, collecting fatigue damage from the synchronous belts. To strengthen the rubber CVT belts, detailed observations and mechanical analysis are needed [5].

Wen-Fang Wu, Tyng Liu, and Chih-Hsien Wu conducted a failure analysis on the continuously variable transmission (CVT) system, which is one of the scooter's major components. They identified potential failure modes using fault tree analysis (FTA) and failure mode, effect, and criticality analysis (FMECA). The impacts of component failure on the CVT system are highlighted [6].

2. PROBLEM FORMULATION:

Hiroshi lizuka, Yoshikatsu Ohta, Akihiro Ueno, and Takeshi Murakam's research on CVT V-belt examination uses experiments and finite element analysis (FEA) to determine the failure initiation point. FEA results show that as tooth load increases, stress initiation shifts from the working flank's opposite side to the working flank side. The failure initiation site is primarily determined by tooth load distribution on the working stress on the working flank side, while the load near the tooth tip causes high stress on the opposite side. The belt underwent initial stress after looping around the pulley, the general model was used to analyze the contact area and tension distribution [6].

3. DESIGN AND CALCULATION

3.1 Calculation

- **Dimension of pulley**

The material of the pulley is mild steel. Pulley is made in 2 Disks.
The density if mild steel is 7860 kg/m^3.

Center distance between pulleys (C) = 214mm.
Driven pulley diameter (Assuming) = 195.5mm
Driving pulley diameter (d) =

$$D - \pi C + 2C\sqrt{\left(\frac{\pi}{2} - \frac{D}{2C}\right)^2 - \frac{1}{C}\left(\frac{\pi}{2}D + \frac{D^2}{4C} + 2C - L\right)}$$

Driving Pulley diameter (d) =152.5mm

Variation in diameter of a driving pulley (t)
= (138.5-46.5)

= 92mm

Variation in diameter of a driven pulley (T)

= (181.35-69.25)

= 112.1mm

Pulley Grove angle (α) =24°

Total Displacement of driven pulley = (t/2)*tan (α/2)

= (92/2) tan (12)

= 19.5mm

Total displacement of Driven Pulley = (T/2)*tan (α/2)

= (112/2) tan (12)

= 23.79mm

❖ Dimension of Belt:

The Dunlop industrial belts catalog provides the belt's specifications. Which is mentioned below:

Length of belt = 816mm

Belt Groove angle =24°

Mass of belt = 0.5kg/m

Main Cross Section = 33mm X 10mm

❖ Calculation of centrifugal force:

N_{Max}= 3800 RPM

R_{Max} = 65mm

Centrifugal force = mr□²

□Max = (2×π×N)/60 = (2×π×3800)/60

= 397.93 red/sec

Considering the mass of a smaller pulley 900 gm

Considering the mass of a bigger pulley 1800 gm

Centrifugal force of smaller pulley

= (0.9×65× (397.93) ^2)/1000

= 9263.374N

Centrifugal force of bigger pulley

= (1.8×65× (397.93) ^2)/1000

=18526.74 N

❖ Belt Tension:

Mass of Belt (m) = 0.5 kg/m

Coefficient of friction between belt and pulley (μ) = 0.2

Power transmitted (Power output from the engine)

$$= \frac{2\pi NT}{60}$$

$$= \frac{2*\pi*3800*10}{60}$$

= 3979.35 watt

Wrap angle of the driving pulley $\theta_s = 180 - \sin^{-1}(\frac{D-d}{2C})$

$= 180 - \sin^{-1}(\frac{195.35-152.5}{2\times214})$

= 168.50°

Wrap angle of the driven pulley $\theta_b = 180 + \sin^{-1}(\frac{D-d}{2C})$

$= 180 + \sin^{-1}(\frac{195.35-152.5}{2\times214})$

= 191.49°

Velocity of belt = $\frac{\pi DN}{60}$

= 38.86 m/s

Tension in slag side (T_2) = $MV^2 + \frac{\frac{P\times1000}{\mu\theta}}{v\times(e^{\sin(\frac{\theta}{2})}-1)}$ [6]

Tension in tight side (T_1) = T_2 + P×1000/v [6]

Tension in slack side = 755.04 N

Tension in tight side = 103.250 KN

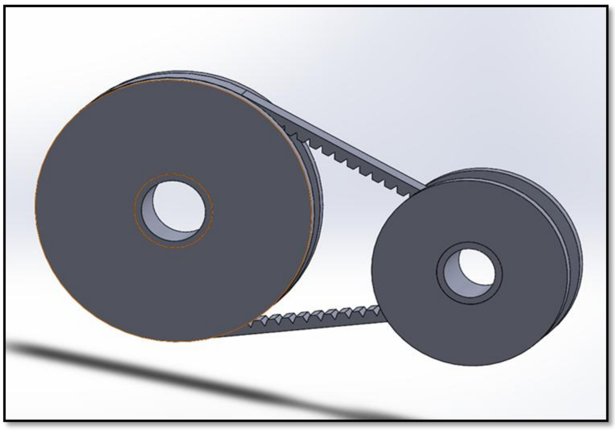

Fig – 1: Cad model of CVT

4. METHOD OF SOLUTION:

The impact of CVT operation at maximum torque on belt life and material stress and deformation will be studied using static structural analysis in Ansys. The fatigue tool gives information about the possible life cycles and safety factors. After analysis of the rubber belt's present material, new material, such as high-performance fibers, will be used to achieve low deformation.

The model simulates belt dishing in the pulley groove, using material constant from Table 1. The geometry of the belt and pulley is determined by the shape of the belt and pulley. The stress-strain curve of the adhesive robber was expressed using the Neo-Hookean coefficient, C_{10}. Reinforced rubber was handled like an anisotropic elastic substance. A truss element replaced the rope, and belt tension was applied to the end of the rope. The wedged force and friction were applied to the belt sides, resulting in a 0.7 friction coefficient on the side face. [6]

4.1 Solution Procedure

The method involves coupling a CVT with material attributes using ANSYS software, producing various outcomes listed in Table 1

Sr. no	Properties	Rubber	Kevlar
1.	Density(g/cm^3)	1.38	1.44
2.	Young's Modulus (MPa)	20000	70500
3.	Poisson's Ratio	0.3	0.44
4.	Tensile Strength (MPa)	370	3600

4.2 Simulation

In using the ANSYS software, the CVT system model has been developed and statically examined.

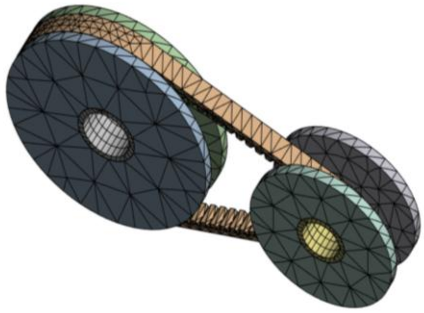

Fig – 2: Mesh Generated

5. RESULTS AND DISCUSSION

5.1 Results of Rubber Belt

1 Equivalent stress:

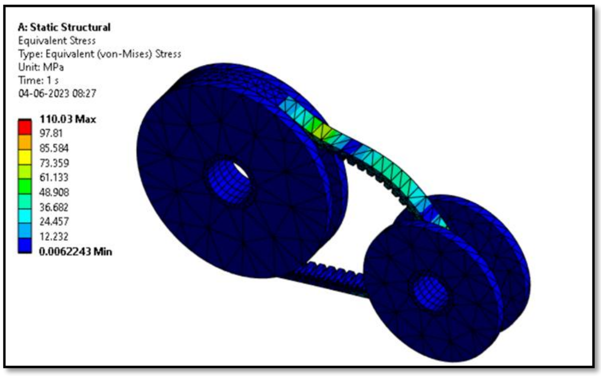

Fig – 3: Equivalent stress of rubber belt

Analysis results show maximum stress is 110 Mpa.

2 Total Deformation:

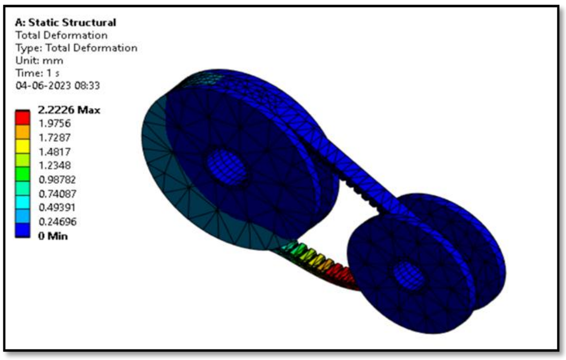

Fig – 4: Total Deformation of rubber belt

Analysis result show maximum Deformation is 2.22 mm.

3 Maximum Principal Stress:

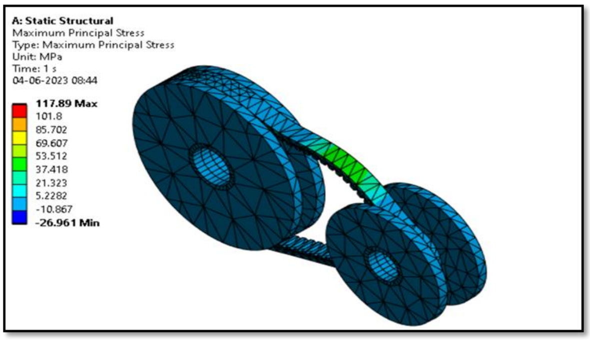

Fig – 5: Maximum Principal Stress of rubber belt

Analysis result show maximum Principal stress is 117.89 MPa

4 Factor of safety:

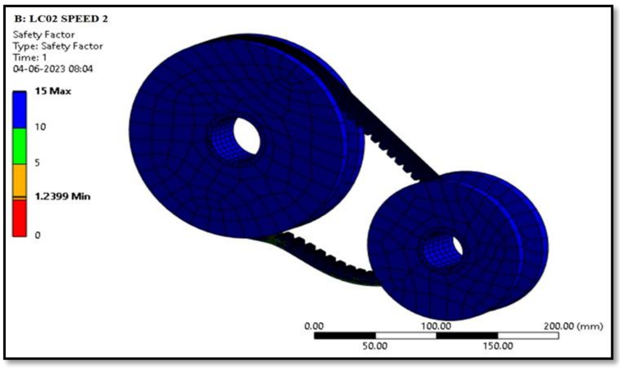

Fig – 6: Factor of safety of rubber belt

Analysis result show factor of Safety 1.23

5 Life Cycle:

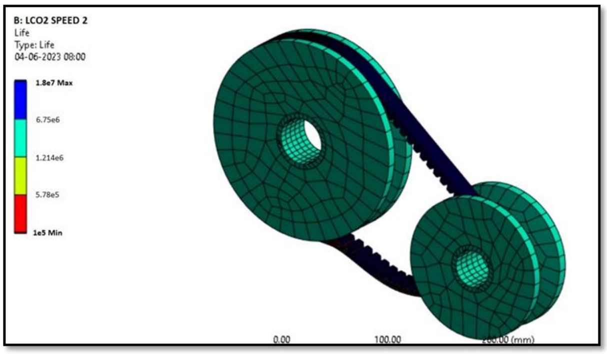

Fig –7: Life Cycle of rubber belt

Analysis result show maximum life cycle is 10^7

5.2 Results of Kevlar Belt

1 Equivalent stress:

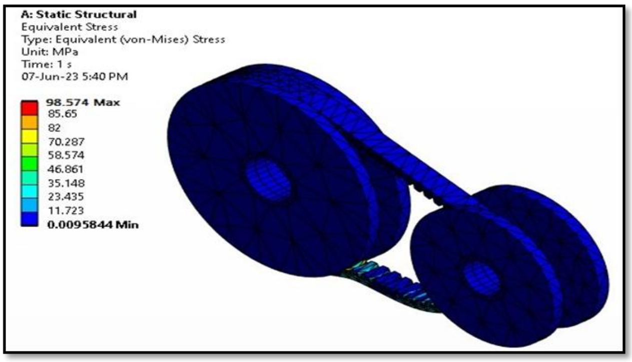

Fig – 8: Equivalent stress of Kevlar belt

Analysis result show maximum stress is 98.57 MPa.

2 Total Deformation:

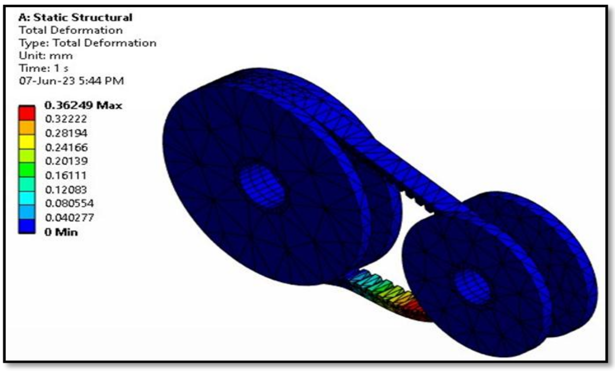

Fig – 9: Total Deformation of Kevlar belt

Analysis result show maximum Deformation is 0.362 mm.

3 Maximum Principal Stress:

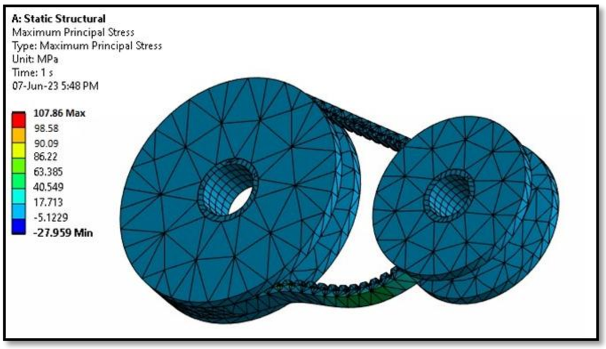

Fig – 10: Maximum Principal Stress of Kevlar belt

Analysis result show maximum Principal stress is 107.86 MPa

4 Factor Safety:

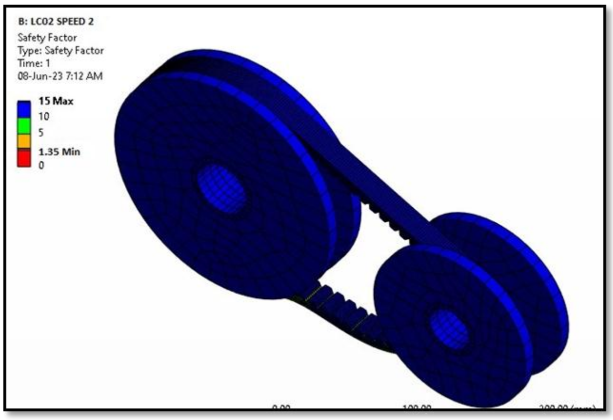

Fig –11: Factor of safety of Kevlar belt

Analysis result show factor of Safety 1.35

5 Life Cycle:

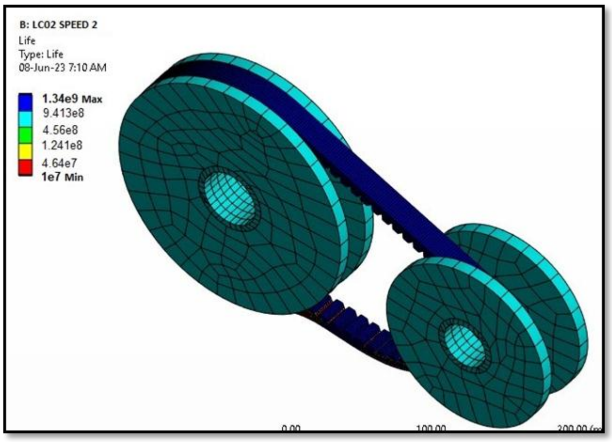

Fig –12: Life Cycle of rubber belt

Analysis result show maximum life cycle is 10^9

The deformation obtained for the 10 Nm torque condition accounts for the majority of the differences in these results. Whereas in the deformation is 0.362 mm for Kevlar and 2.22 mm for rubber. And Life cycle for Kevlar is 10^9 and for rubber is 10^7.

5.3 Comparison Table:

Material	Equivalent Stress	Deformation	Maximum Principle Stress	Factor of Safety	Life Cycle
Rubber	110 Mpa	2.22 mm	117 Mpa	1.23	10^7
Kevlar	98.57 Mpa	0.362 mm	107.86 Mpa	7.35	10^9

5.4 Comparison Graphs:

1 Equivalent Stress:

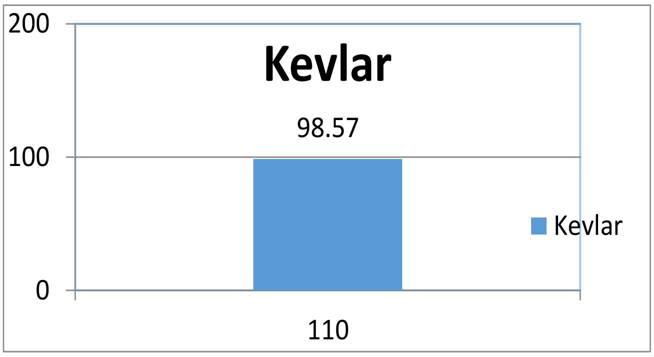

Chart -1: Equivalent Stress

2 Deformation:

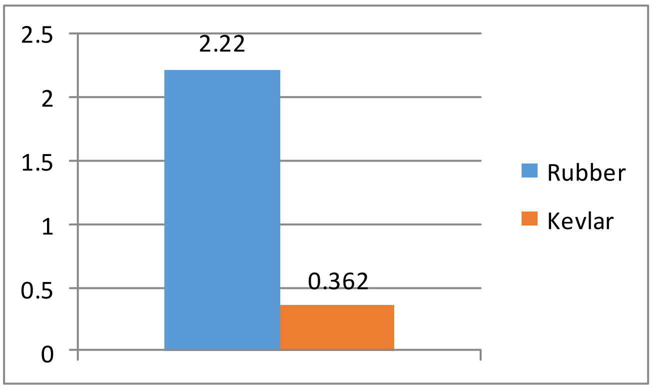

Chart -2: Deformation

3 Maximum Principle Stress:

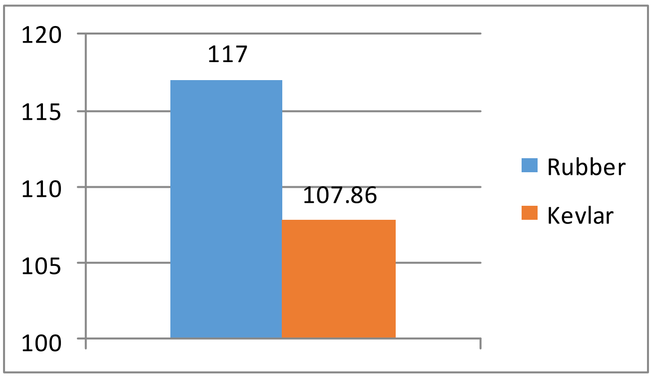

Chart -3: Maximum Principle Stress

4 Factor of Safety:

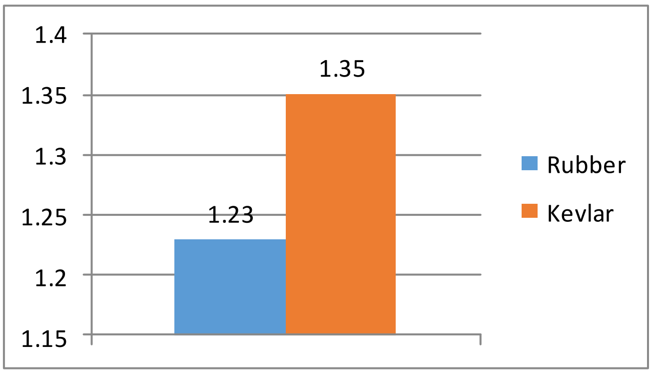

Chart -4: Factor of safety

5 Life cycle:

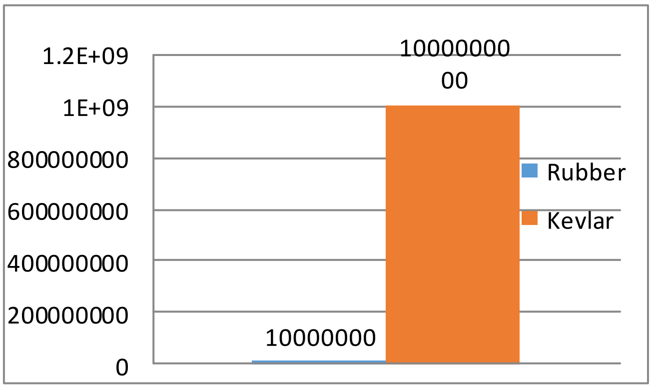

Chart -:5 Life cycle

6. CONCLUSION

From the information above, it can be inferred that using Kevlar for a CVT belt will result in smoother operation because the material's overall distortion is much smaller than that of a cord composed of normal steel. Because V belts have the propensity to lose their grip after a given number of cycles, Kevlar also has a low elastic strain, which further indicates that it will endure for longer without being further stretched. The Kevlar belt has a higher safety factor than steel cord, which also suggests that it will be stronger to handle heavy wear.

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