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Design Linkage Mechanism for Electromechanical Continuously Variable Transmission Ratio Controller Used in Motor Cycle

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Abstract. Good ride performance is one of the most important key attribute of a passenger vehicle. One of the methods to achieve this is by using continuously variable transmission (CVT). This is because a CVT has the capability of providing an almost infinite ratio within its limits smoothly and continuously. Motor with automatic transmission known as motor matic is now become widely used as main transportation. Easy to drive is the main reason to choose this type motor cycle. The mechanism of pulley axially movement controller based on centrifugal concept where the ratio of pulley totally depend on speed rotation of input shaft which is in line with the engine shaft. The effect of this system is there is no engine break during decline road condition. So that actually this motor cycle is not suitable for road with extreme decline condition. The purpose of the research is to design mechanism where the pulley movement can be controlled by the driver with the aid of electromechanical system. The design electromechanical of Single Acting Pulley Actuator (EmSAPA) Continuously Variable Transmission (CVT) utilizes combinations of DC motor system, gear reducers and power cam mechanisms to actuate primary movable pulley sheaves on the transmission shaft. The secondary pulley supported by spring provides a belt clamping force to prevent slips, while the secondary controls the rubber v-belt from slipping. This paper is also present comparison on mechanical linkage system which will actuate pulley to move axially.

1. Introduction

The first transmission made is a transmission belt or Continuously Variable Transmission (CVT) when the first combustion engine is found. Because of its large shape and low torque capabilities it is abandoned. CVT has been found in automotive and industrial applications such as machinery since the beginning of the 20th century. CVT is a power transmission device, where the speed ratio can be varied continuously between two constraints [1]. There are many types of CVT designs, each design has its own characteristics, such as CVT Belt, Spherical CVT [2], Hydrostatic CVT [3], E-CVT [4], Toroidal CVT [5], Power-Split CVT [6], CVT Chain, Milner CVT [7], Ball-Type Toroidal CVT [8], and so on. However, of all these, the type of chain and belt that is most widely used in CVT in automotive applications [9]. Therefore the CVT concept is more widely used in machinery such as milling machines to adjust spindle speed.



The continuously variable Transmission (CVT) is a transmission system that can change the transmission ratio with infinite steps to the number of effective transmission ratios between maximum and minimum values. This differs from other mechanical transmissions which only allow different discrete gear ratios. Thanks to CVT flexibility, the drive shaft can maintain a continuous angle speed at different output speeds. With the arrival of sustainable materials, early production systems, advanced electronic controls and better lubricants, CVT driveline systems with innovative ratio shift control strategies are more feasible. Today, new developments in reducing acceleration and manufacturing have led to stronger CVTs, which in turn allows them to be used in more diverse automotive applications. Given the ongoing development of sustainable training, costs will decrease and performance will increase, which in turn will lead to the development and implementation of better CVT technology. This cycle of technology improvement will offer CVT a solid foundation in the world's automotive infrastructure.

The rubber V-belt continuously variable transmission (CVT) has been widely used in low-power vehicles such as snowmobiles and scooters because of its significant advantages over other transmissions, including its simple construction, smooth operation, easy drivability, low cost, easy maintenance, etc. CVTs allow the engine to operate near maximum power point by automatically varying speed, so theoretically, rubber V-belt CVTs have an economic efficiency advantage over other transmissions [10]. However, in spite of the several advantages proposed by a CVT system, the goals of higher fuel economy and better performance have not been realized significantly in a real production vehicle. In order to achieve lower emissions and better performance, it is necessary to capture and understand the detailed dynamic interactions in a CVT system so that efficient controllers could be designed to overcome the existing losses and enhance the fuel economy of a vehicle [11]. To overcome this energy loss, the electromechanical actuated CVT system becomes a viable solution, since this system only operates during changing the transmission ratio.

2. The Basic Teori of Rubber Belt CVT.

2.1. CVT Component and its function

Generally Figure 1 shows the principle of Rubber belt CVT used in motorcycle. It consists of a primary pulley, a secondary pulley and a rubber V-belt connecting these two pulleys. Each of driver and driven pulley consists of a fixed and a movable pulley is given in Fig. 1. The fixed pulleys are fixed on the shafts and the movable pulleys are able to move in the axial direction on the shafts. Continuously variable transmission can be achieved by control of the pulley axial distance between the fixed and the movable pulleys. If the movable pulley of the driver shaft is moved towards the fixed pulley, the V-belt is forced to be pushed in the radial outward direction, which causes the belt pitch diameter to increase. Since the belt length and the center distance between the shafts are fixed, the belt pitch diameter of the driven pulley decreases. Therefore, the speed ratio decreases in a continuous manner.

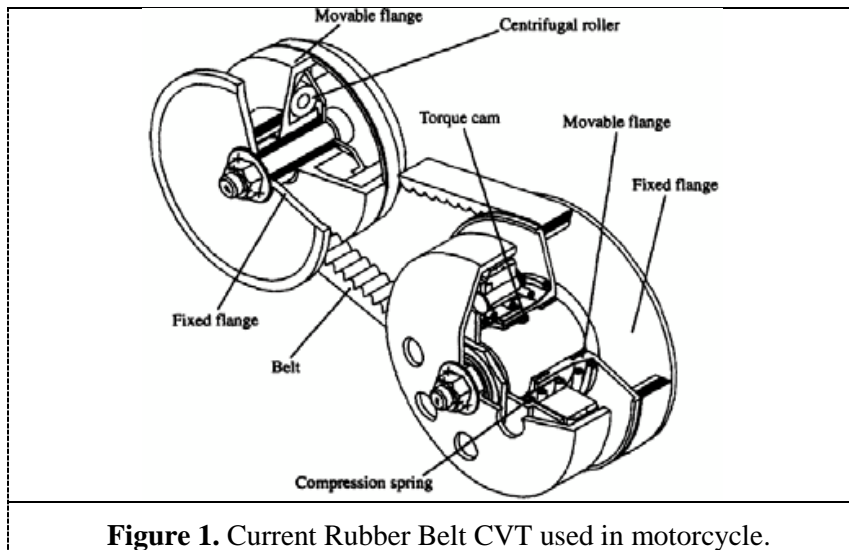


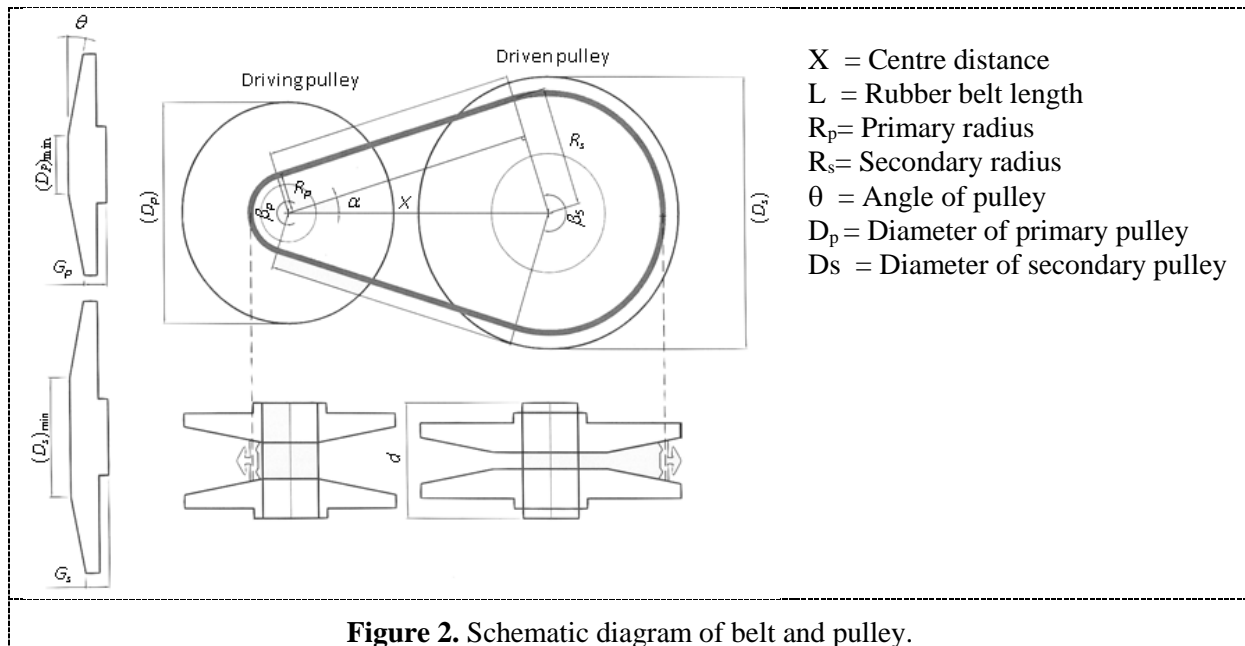
Figure 1. Current Rubber Belt CVT used in motorcycle.

In summary, the way CVT works is as follows:

- The input shaft is connected directly to the engine shaft so that when the engine rotates quickly it will have an impact on the centrifugal roller.
- This engine shaft rotation is forwarded to the output pulley through a rubber belt.
- In the output pulley there is a centrifugal clutch that works when the rotation is sufficient to rotate the shaft associated with the wheel.
- The change in ratio due to the centrifugal roller force will push the moveble flange to move axially and push the rubber belt so that the diameter increases. While the radius of the rubber belt on the output pulley decreases.
- While the torque cam functions when the vehicle goes up the hill. This cam will rotate so that it forces pushing the movable flange on the output pulley so that the radius of the belt that was small will enlarge.

2.2 CVT Ratio Calculation

In order to design a mechanism that is capable of replacing the current CVT mechanism system used in motorcycle, basic CVT ratio calculation based on belt theory is compulsory required. Figure 2 shows the schematic pulley diagram and belt to calculate its ratio.



From Figure 2 the length of belt L can be calculated:

$$L = R_p \beta_p + R_s \beta_s + 2\sqrt{X^2 - (R_s - R_p)^2} \quad \text{Where } \beta_p = \pi - 2\alpha \text{ and } \beta_s = \pi + 2\alpha$$

These equations assumed that:

- The belt is inextensible.
- The segments are in uniform size.

While the ratio is calculated based on the difference between R_p and R_s .

Transmission ratio = R_p / R_s

From the above equation shows that the change in ratio to changes in radius is not linear.

Whereas the pulley angle θ is used to calculate movable flange shift distance in certain R_p . The distance of the movable flange shift (X_p) is obtained $R_p * \tan \theta$. The equation shows that every distance ΔX_p moveable flanges moves axially toward or backward along its shaft will result the change in the radius of primary pulley hence gives difference ratio. Figure 3 shows nonlinear line the relation between X_p and ratio of transmission.

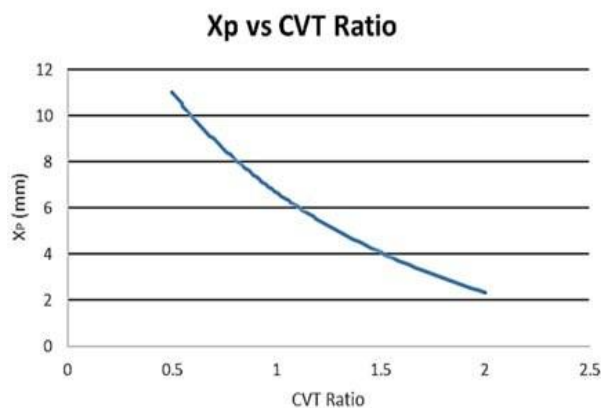


Figure 3. Graph of the relation between X_p and transmission ratio.

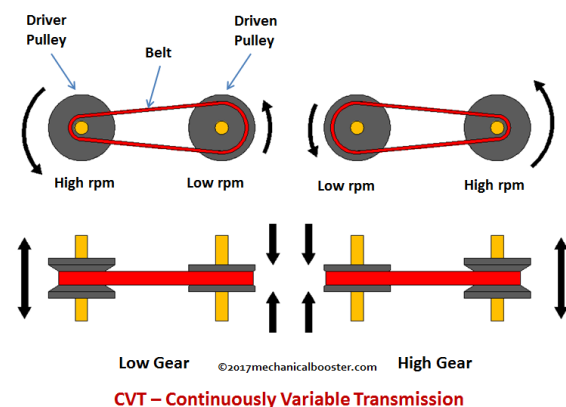


Figure 4. Rubber Belt CVT system

2.3. Linkage Mechanism Design for Electro mechanic CVT.

In accordance with its function that the transmission is used to transmit the rotational speed as well as the torque from the engine to the wheel. The transmission must be able to change the ratio from the low ratio/under drive to the higher ratio (over drive). Figure 4 shows the belt transmission system from a low position (low gear / under drive) to a high position (high gear / over drive). The input pulley of rubber belt transmission is controlled to change its radius while the output will follow because of compression spring in the secondary movable flange side. The linkage mechanism should be able to change the ratio by converting rotation motion to linear motion and one method to do so by using cam mechanism.

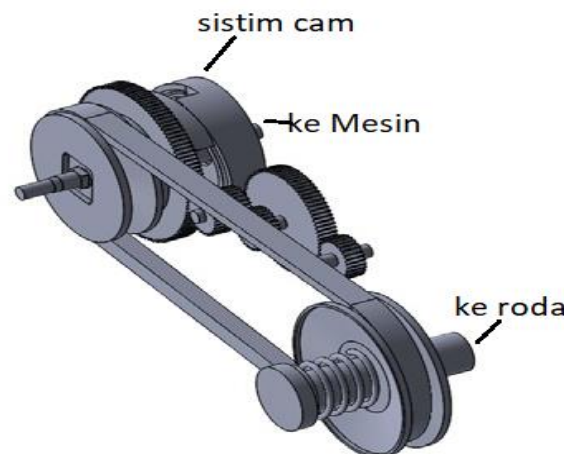


Figure 5. Basic concept of EMSAPA-CVT

The Single Acting Pulley Actuator Continuously Variable Transmission (SAPA CVT) system utilizes servomotor as actuators as shown in Figure 5. The system consists of two sets of pulleys, namely primary pulley placed on input fixed shaft, and secondary pulley placed on secondary fixed shaft. Each set of pulley has two movable sheaves that can be shifted axially along the shaft. The primary motor actuates the primary pulley movement for transmission ratio change, while the spring mechanism actuates the secondary pulley movement for clamping force [12]. A spring disc is inserted in the back of each secondary pulley sheave to provide continuous clamping force to the belt, and to reduce excessive slip during transmission ratio change.

3. Result and Discussion

The actuator used in Figure 5 has the disadvantages that point to point contact will occur when cam rotated. When cam in close position the surface fully contact each other, but when cam is rotated point to point contact occurs instead of surface as predicted before, Figure 6. To avoid this problem, surface cam should be redesigned is shown in Figure 7. The Figure shows that every angle when the cam rotates the surface of the cam always contact each other.

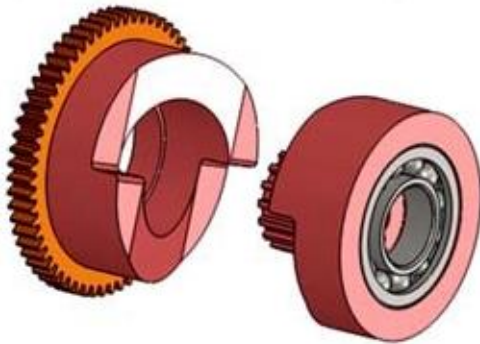


Figure 6. First Cam Design

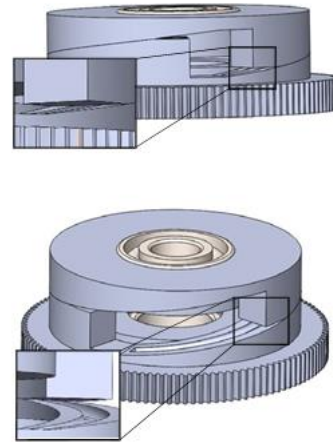


Figure 7. Redesign Cam

In general, this latest concept is able to change the ratio by loading on the cam surface evenly. Simulation using solidwork software for loading as big as 1 kN is also quite safe and does not reach the plastic point even with aluminum-class material. Analyze the cam by giving a load of 1 kN or as much as the tension of the rubber belt, because in the previous analysis at a load of 20 kN the cam entered the plastic area. The results of the test at a load of 20 kN can be seen in Figure 8.

Figure 8 (a) shows that the maximum voltage is $2.82 \times 10^8 \text{ N / m}^2$, so it is still safe because it is below the yield voltage limit of $3.51 \times 10^8 \text{ N / m}^2$. In Figure 8 (b) the maximum voltage is $6.5 \times 10^8 \text{ N / m}^2$ and Figure 8 (c) shows a maximum voltage of $7.47 \times 10^8 \text{ N / m}^2$ so that it exceeds the yield voltage, the cam is unable to accept a load of 20 kN. This force is applied to clamp the pulley to prevent slip when the CVT used metal belt. Hence the size of the cam should be larger if it used for metal belt.

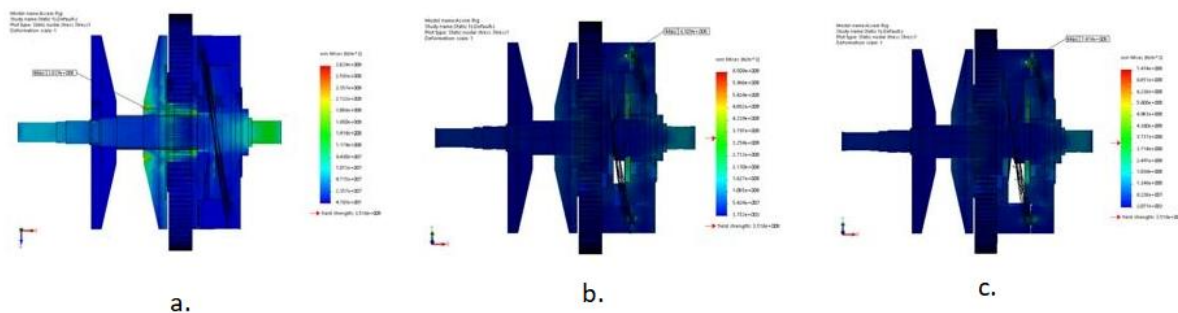


Figure 8. Simulation results with 20 kN force, where X_p in the difference position a. 0 mm, b. 3 mm and c. 6 mm.

The system is also analyzed its force flow to determine the critical area before it fabricated. Analysis of force flow can be obtained by lowering the scale to $1,500,000 \text{ N / m}^2$. The results of the analysis can be seen in Figure 9.

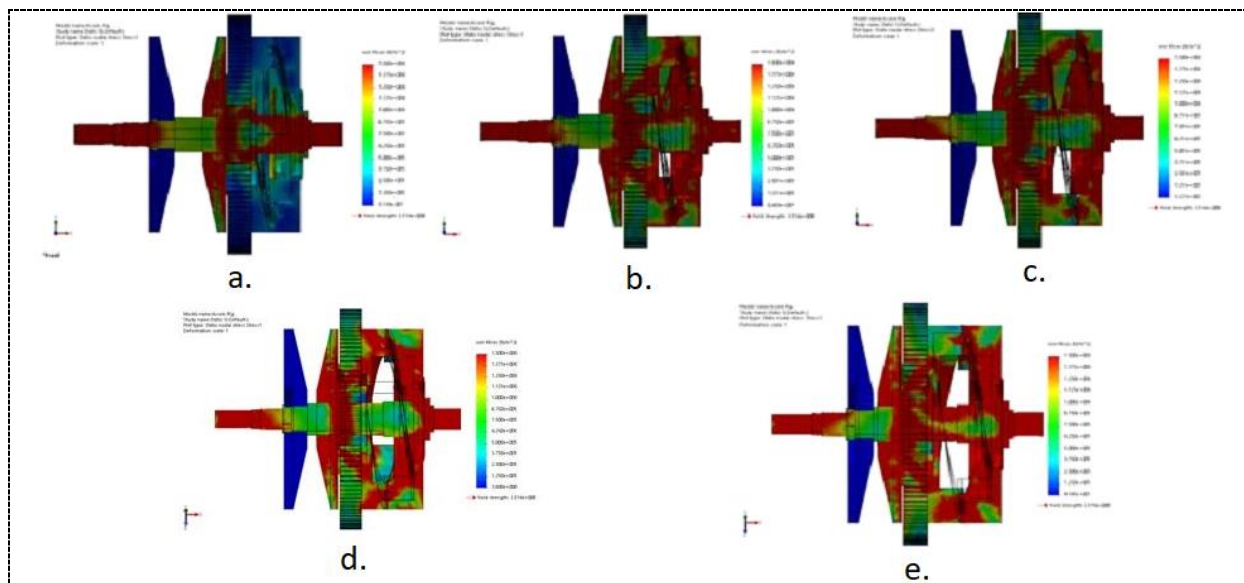


Figure 9. Simulation result with 4kN load and $1,500,000 \text{ N/m}^2$, movable flange moves (a) 0 mm (b) 3 mm (c) 6 mm (d) 9 mm (e) 12 mm

Figure 9 shows the result of simulation to analyse force flow in mechanical linkage. Figure 9 (a) the force flow is flowing through the input shaft because the main pulley displacement is still 0 mm. In Figure 9 (b) it can be seen that the force flow starts from the movable pulley to the top cam and then flows to the lower cam, then finally to the input shaft. In Figure 9 (c) shows similar behaviour to the previous displacement such as in the Figure 9 (b). Likewise in position (d) and (e), it's just that the bigger the radius of the belt as in position (e) the greater the force received by the cam and shaft, yet it still save because the most critical component is still under yield stress.

4. Conclusion

The new design of the surface cam is able to enlarge the contact area when the cam is rotated, which increases the force to force the pulley to move axially.

The new cam design on the EMSAPA-CVT system can also be controlled by several control methods. The analysis shows that the cam can accept loads up to about 4 kN so that it is still safe to use on rubber belts. Cam can still receive a load of 5 kN if a material changes to the ball bearing.

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