BORANG PENGESAHAN STATUS TESIS

JUDUL: **PRELIMINARY DESIGN OF SINGLE RUBBER BELT WITH ELECTRO-MECHANICAL CONTINUOUSLY VARIABLE TRANSMISSION (CVT)**

SESI PENGAJIAN; 2010/2011

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PRELIMINARY DESIGN OF SINGLE RUBBER BELT WITH ELECTRO-MECHANICAL CONTINUOUSLY VARIABLE TRANSMISSION (CVT)

THONG YEE HAN

Thesis submitted in fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering with Manufacturing Engineering

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BACHELOR OF ENGINEERING

UNIVERSITI MALAYSIA PAHANG

2010

EXAMINERS APPROVAL DOCUMENT

UNIVERSITI MALAYSIA PAHANG
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I certify that the thesis entitled "Preliminary Design for Single Rubber Belt with Electro-Mechanical Continuously Variable Transmission (CVT)" is written by Thong Yee Han. We have examined the final copy of this thesis and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. We herewith recommend that it be accepted in fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering.

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I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurently submitted for award of other degree.

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To my beloved father and mother

Mr. Thong Weng Sang

Mrs. Ching Sui Chin

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ABSTRACT

An internal combustion engine required transmission system to control or change the transmission ratio between the engine and the drive wheels, so that the vehicle can accelerate constantly. For small power engine such as shooter, the common transmission used is rubber belt continuous variable transmission (CVT). CVT is a kind of transmission that changes the infinite speed ratio between the engine and the drive wheel based on the speed of the engine's shaft and is known as centrifugal force CVT. Therefore driver cannot control the transmission according to the road profiles needs. To overcome this problem, the mechanism that responsible to change the transmission ratio had to be modified and electro-mechanical CVT is a promising new mechanism that can replace the centrifugal force CVT. In this paper, the new mechanism mixture of mechanical component with electric motor is introduced. Study and analysis are conducted on this mechanism to found out the possibility and potential of improving the current design of CVT. By using theoretical calculation and references from the current CVT design, the new design mechanism is analyzed and verifies the possibility for improvement of the current CVT by using electro-mechanical components to change the transmission ratio.

ABSTRAK

Enjin pembakaran dalaman yang memerlukan sistem penghantaran untuk mengawal atau menukar nisbah penghantaran antara mesin dan penggerak roda supaya kenderaan dapat memecut dengan lancar. Untuk engin berkuasa rendah seperti skuter, penghantaran umum digunakan adalah tali sawat getah penghantaran pembolehubah berterusan (CVT). CVT adalah jenis penghantaran yang perubahan nisbah penghantaran tak terbatas antara mesin dan roda drive berdasarkan kelajuan enjin dan CVT tersebut dikenali sebagai daya sentrifugal CVT. Oleh demikian, pemandu tidak boleh mengawal penghantaran yang sesuai dengan keperluan profil jalan. Untuk mengatasi masalah ini, mekanisme yang bertanggungjawab untuk menukar nisbah penghantaran harus lah di ubah suai dan CVT elektro-mekanikal adalah mekanisma baru yang menjanjikan potensi menggantikan CVT daya sentrifugal. Dalam kajian ini, campuran mekanisme baru dari komponen mekanikal dengan motor elektrik adalah memperkenalkan. Pengajian dan analisis akan melakukan pada mekanisme ini untuk mengetahui kemungkinan dan potensi peningkatan kualiti CVT yang ada dalam pasaran. Dengan menggunakan pengiraan teori dan rujukan dari CVT masa kini, mekanisme yang baru dianalisis dan disahkan kemungkinanya untuk perbaikan CVT masa kini dengan menggunakan komponen elektro-mekanik untuk menukar nisbah penghantaran.

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LIST OF SYMBOLS

α	Title
R	Radius
x, *y*	Distance
P	Power
D	Diameter
c	Center distance
τ	Torque
ω	Angular velocity
°	Degree
Fc	Clamping force
f	Friction
N	Newton

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF PROJECT TITLE

Many new snowmobiles and motor scooters use CVTs and virtually all snowmobile and motor scooter CVTs are rubber belt/variable pulley CVTs. Many small tractors for home and garden use have simple hydrostatic or rubber belt CVTs. The CVT is not constrained to a small number of gear ratios, such as the 4 to 6 forward ratios in typical automotive transmissions. CVT control computers often emulate the traditional abrupt gear changes, especially at low speeds, because most drivers expect the sudden jerks and will reject a perfectly smooth transmission as lacking in apparent power.

Lately, continuously variable transmissions (CVT) have aroused a great deal of interest in the automotive sector due to the potential of lower emissions and better performance. A CVT is an emerging automotive transmission technology that offers a continuum of gear ratios between high and low extremes with fewer moving parts. This consequently enhances the fuel economy and acceleration performance of a vehicle by allowing better matching of the engine operating conditions to the variable driving scenarios.

The first workable CVT, called Variomatic, was designed and built by the Dutchman Huub van Doorne, co-founder of DAF Trucks in the late 1950s, specifically to produce an automatic transmission for a small, affordable car.*(Nilabh Srivastava and Imtiaz Haque, 2008)*

1.2 PROBLEM STATEMENT

Rubber belt Continuous Variable Transmission (CVT) is well known as it's application in scooters and small cc engine drive vehicles. However, the application of a single belt energy transfer from engine to wheel has its limit. According to the CVT forum in the internet, review on the CVT application and the feedbacks are focused on the force that the rubber belt can withstand, most of them still doubt about the strength of the belting. Besides that, study found that, the weakness of CVT using centrifugal force to change the transmission and there are also doubted the system used in the CVT system. This scenario happen because of lack exposal to CVT system compared to manual transmission of four strokes engine. The flexibility of a CVT allows the driving shaft to maintain a constant angular velocity over a range of output velocities. Rubber belt CVT is now widely used in the motorcycle with most of them using single rubber belt. The engine with the capacity above 200cc needs more torque to deliver its power; hence it needs modification to overcome this problem.

1.3 OBJECTIVE OF THE RESEARCH

The aim of this project is to design and study the preliminary design for single rubber belt with electro mechanical continuous variable transmission (CVT) used in 250 cc engine.

1.4 SCOPE OF PROJECT

The approach in designing double rubber belt continuous vehicle transmission (CVT) will be as follows:

i. Design the conceptual of controller the movement of two sheave pulley
ii. Re-design / engineering drawing of concept CVT system by solid work
iii. Design and performance comparison. Documentation - Preparing a report for the project.
iv. Come out with a blue print

1.5 METHODOLOGY

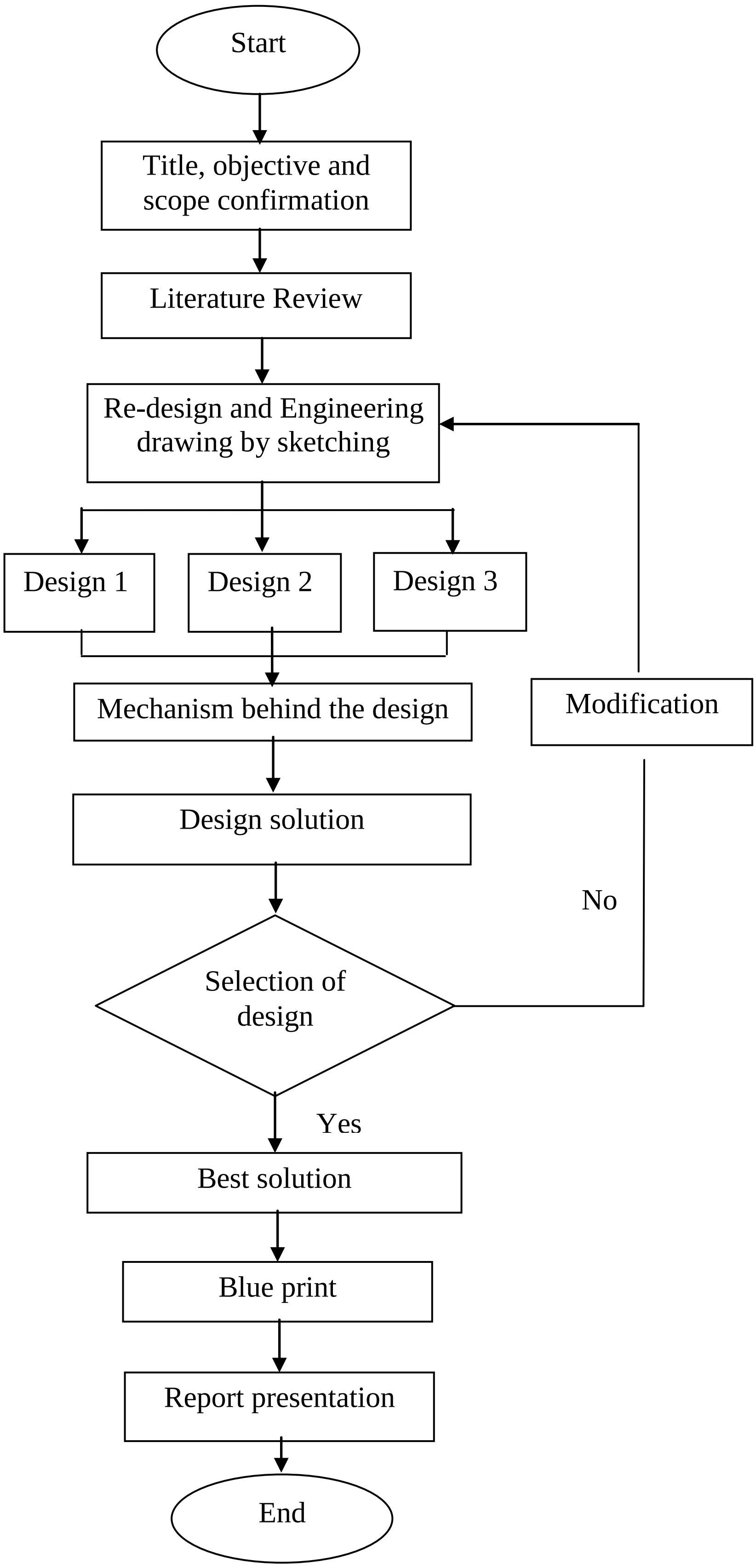

Figure 1.1: Project Flow Chart

1.6 THESIS STRUCTURE

i. Literature study
   - Make review on other model and focusing on how to make it simple and relevance to the project title

ii. Conceptual design
   - Sketching several type of design based on concept that being choose.
   - State the dimension for all part.

iii. Re-design / engineering drawing by solid work
   - Design the several model using sketching.

iv. Design Solution
   - Make a selection design using theoretical analysis (calculation).

v. Blue print
   - Come out detailed plan in drawing block.

vi. Documentation
   - Preparing a report for the project.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The aim of this chapter is to give some overview of what is continuously variable transmission (CVT) is all about. In this chapter, it consists of explanations and details of type of continuously variable transmission (CVT), the previous studies and the finding of research. It also will describe the basic design and analysis by using software to simulate the continuously variable transmission (CVT) system.

2.2 BACKGROUND OF CONTINUOUS VARIABLE TRANSMISSION (CVT)

Unlike traditional automatic transmissions, continuously variable transmissions don't have a gearbox with a set number of gears, which means they don't have interlocking toothed wheels. The most common type of CVT operates on an ingenious pulley system that allows an infinite variability between highest and lowest gears with no discrete steps or shifts. Although CVTs change this ratio without using a set of planetary gears, they are still described as having low and high "gears" for the sake of convention. *.(Nilabh Srivastava and Imtiaz Haque, 2008)*

A continuously variable transmission (**CVT**) is a transmission which can change sleeplessly through an infinite number of effective gear ratios between maximum and minimum values. This contrasts with other mechanical transmissions that only allow a few different distinct gear ratios to be selected. The flexibility of a CVT allows the driving shaft to maintain a constant angular velocity over a range of output velocities. This can provide better fuel economy than other transmissions by enabling the engine to run at its most efficient revolutions per minute (RPM) for a range of vehicle speeds.

2.3 HISTORY OF CONTINUOUS VARIABLE TRANSMISSION

Leonardo DaVinci sketched the first CVT in 1490. Dutch automaker DAF first started using CVTs in their cars in the late 1950s, but technology limitations made CVTs unsuitable for engines with more than around 100 horsepower. In the late 80s and early 90s, Subaru offered a CVT in their Justy mini-car, while Honda used one in the high-mileage Honda Civic HX of the late 90s. Improved CVTs capable of handling more powerful engines were developed in the late 90s and 2000s, and CVTs can now be found in cars from Nissan, Audi, Honda, Ford, GM, and other automakers. (*Nissanglobal.com.http://www.nissanglobal.com/EN/TECHNOLOGY/INTRODUCTION/DETAILS/CVT/. Retrieved 19 September 2009*).

2.4 COMPONENT IN CVT

The Continuously Variable Transmission (CVT) system consists of two parts: the variator (drive pulley), and the clutch (driven pulley). These are connected by the CVT belt.

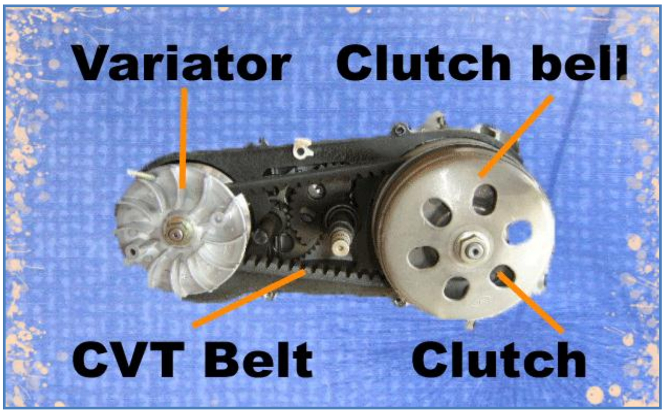

Figure 2.1: CVT System

Source: Buggypartsnw

The CVT system works through the changing of the distance between the plates on the two pulleys. The clutch pulley plate width increases, and vice versa. This creates an infinite number of possible gear ratios, as the transmission is altering itself on the fly to adapt to the current driving condition.

2.4.1 Variator

The variator is driven directly by the engine. Inside the variator are 6 rollers that are positioned in individual slots with ramps that they will move along outward when centrifugal force is applied. As the rollers move outward, they press against the ramp plate which causes the pulley plates of the variator to move toward one another, compressing the belt. This "V" shape created by the pulley plates pushes the belt outward, which draws the belt inward on the driven (clutch) side, increasing the gear ratio.

Figure 2.2: Ramp Plate
Source: Buggypartsnw

At idle, the rollers are at their innermost position, the variator pulley plates are at their farthest apart, and the CVT belt is low on the variator side and high on the clutch side. With increasing RPMs, the rollers move outward along their ramps applying pressure to the ramp plate, which compresses the variator pulley plates and squeezes the CVT belt outwards.

In the CVT transmission system, the rollers are actually working against the spring tension of the main torque spring on the clutch side. This is discussed in detail later in this report in the Clutch section.

Performance and racing aviators have specially engineered "ramps" for the rollers. Many have Teflon ramps and ramp cover plates for reduced roller friction. This means smoother transition between "gears".

2.4.2 Roller Weights

Rollers come in many different sizes and weights, depending on application. Roller weights that are at the lowest recommended end of the scale are often too light to fully push the aviator plate far enough out to achieve maximum speed. Similarly, the heavier weights quickly move you into a higher gear ratio at the expense of low end power. Please keep this in mind when choosing the right weights for your style of riding.

Rollers and sliders should be inspected annually (at minimum) for wear. Rollers are especially prone to developing flat spots that inhibit their ability to move smoothly. If this occurs, they should be replaced. This is one advantage of sliders, as they already have flat sides and are not affected by this wear as quickly as rollers. *(S. Akehurst, D. A. Parker, 2002)*

2.4.3 Clutch

The clutch in a CVT system engages when the centrifugal forces of the spinning clutch overcomes the tension of the clutch arm springs and allow the clutch pads to engage with the clutch bell, creating movement.

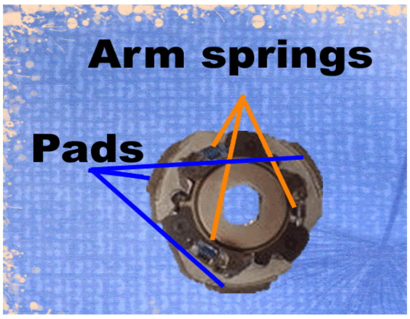

Figure 2.3: System Clutch
Source: Buggypartsnw

Racing and performance clutches are made of higher quality materials, such as metal composite or Kevlar clutch pads to reduce wear and heat damage. These clutches often have much larger clutch pads for better engagement with the clutch bell. Clutches can be altered with different rated arm springs to change their engagement RPMs.

The main clutch torque spring compresses the clutch pulley plates together, forcing the belt outward and acting against the variator. As the rollers compress the variator side pulley plates when RPMs increase, the belt is forced outward on the variator. Since the belt is a constant length, this causes the belt to be pulled inward on the clutch, overcoming the tension of the torque spring. *(Kobayashi, D., Mabuchi, Y, 1998)*

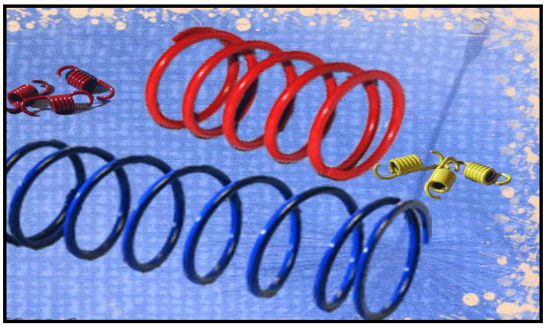

Figure 2.4: Compression Spring
Source: Buggypartsnw

2.4.5 Clutch Bell

The clutch bell is something that you should inspect annually at minimum and more often if you find that you are bogging down when climbing with the engine revving high and the wheels won't spin. This can be indicative of a "glazed" or smoothed clutch bell and/or clutch pads. An amount of frictional heat is created when pushing the climbing limits of your scooter, and this eventually leads to smoothing of the inside edge of the clutch bell. The heat (and smoke) can turn the bell a purplish color and result in a very smooth, glazed appearance. When this happens, it's time to replace the clutch bell.

2.4.6 V belt

The function of a V belt drive is to transmit rotational motion and torque from one pulley to another, smoothly, quietly and inexpensively. Belt provides overall combination of design flexibility, low cost and maintenance, ease of assembly and space savings. A V belt is made of fabric and cord, usually cotton, rayon, or nylon, and impregnated with rubber. In contrast with flat belts, v belt are used with similar sheaves and at shorter center distances. V belt are slightly less efficient than flat belts, but a number of them can be used on a single sheave, thus making a multiple drive. V belt are made only in certain lengths and have no joint. *(T. F. CHEN, D. W. LEE and C. K. SUNG, 1996).*

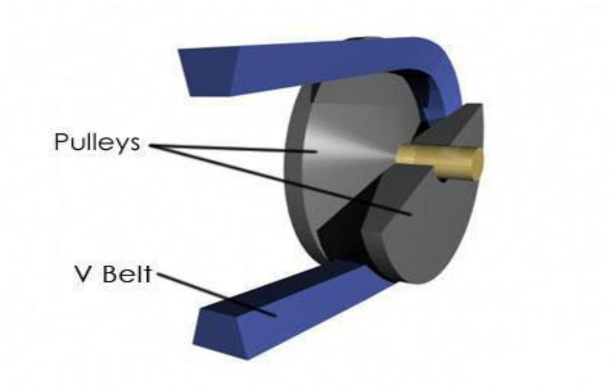

Figure 2.5: V Belt with Pulley

Source: Howstuffwork

2.4.7 Pulley

Pulleys, also referred to as sheaves, are the wheels that are connected to the shaft. The pulley has a groove around the outside, with a shape to match that of the belt. Scooter sheaves are machined from steel or cast iron, depending on diameter. Sheaves are classified with a pitch diameter, which is the diameter slightly smaller than the outside of the groove, corresponding to the location of the center of the belt. In CVT system that utilizes a belt drive need some feature that can compensate for the belt stretch, such as idler pulley. An idler pulley is used to maintain constant tension on the belt. It is usually place on the slack side of the belt and is preloaded, usually with springs, to keep the belt tight. (Ide, T. And Tanakan, H, 2002)

2.5 COMPARISON OF V BELT AND OTHER FORMS OF POWER TRANSMISSION

Compared to other forms of power transmission, belt drives have these advantages:

i. They are less expensive than gear or chain drives.
ii. They have flexible shaft center distances, where gear drives are restricted.
iii. They operate smoothly and with less noise at high speed.
iv. They can design to slip when an overload occurs in the machine.
v. They required no lubrication, as do chains and gears.
vi. They can be used in more than one plane.
vii. They are easy to assemble and install and have flexible tolerance.
viii. They required little maintenance.
ix. They do well in absorbing shock loading.

2.6 MECHANISM OF CVT

In system of CVT, when the engine is rotating, some roller in driving pulley is create the displacement of the drive pulley and change the CVT ratio by centrifugal force depend on how much speed from crankshaft. That roller will push the drive pulley to increase their diameter.

The distance between the centers of the pulleys to where the belt makes contact in the groove is known as the pitch radius. When the pulleys are far apart, the belt rides lower and the pitch radius decreases. When the pulleys are closes together, the belt rides higher and the pitch radius increases. The ratio of the pitch radius on the driving pulley to the pitch radius on the driven pulley determines the transmission gear ratio.

V belt is connected between drive pulleys to driven pulley to transmit the energy from the engine. In the driven pulley have weight set clutch to control the rotating of the rear tire. When engine on idle, the clutch set is not functioned till the rotation is increase. Clutch set is function to grab the cover clutch when reach a certain speed. In cover clutch consist a special spring to control the ratio of diameter. *(Brandsma, A., van Lith, Hendriks, E, 1999)*

2.6.1 How clutch springs work

The main torque spring makes it harder for the aviator to draw the belt inward on the clutch. This keeps the scooter in a lower gear ratio longer, and "downshifts" faster when decelerating so have more power when hit the gas again. This is especially helpful when climbing or coming out of a corner. A higher tension main torque spring downshifts more quickly than a lower tension spring, but be aware that high spring tensions can prevent very light roller weights from ever reaching the maximum position inside the aviator, sacrificing top speed.Clutch arm springs control when the clutch arms and pads engage with the clutch bell. These springs are rated at 1000, 1500, and 2000 RPMs. This means that the clutch has to be spinning at this RPM speed before the centrifugal force will overcome the spring tension and allow the clutch pads to engage. This is not the same as engine RPMs, as the engine will be idling at some rate and the engagement RPM is on top of this. *(Kobayashi, D., Mabuchi, Y, 1998).*

2.7 OPERATION OF CVT FOR SCOOTER

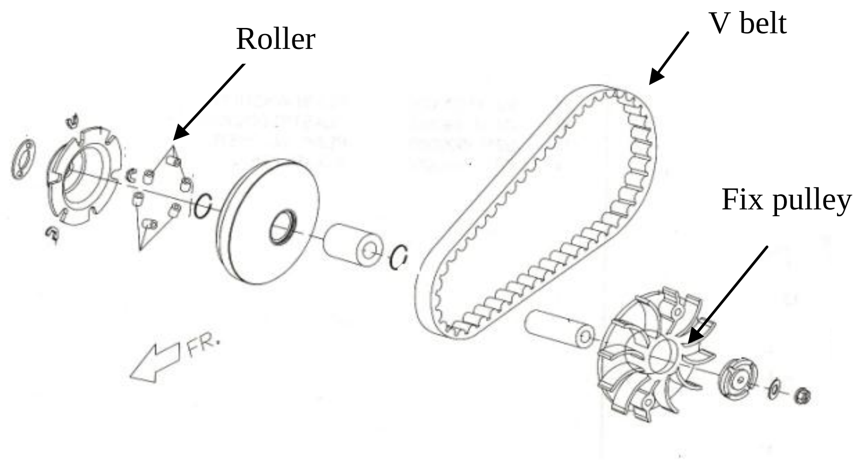

Figure 2.7: Front Set Driver Pulley

Source: Modenas User Manual

The variable-diameter pulleys are the heart of a CVT. Each pulley is made of two 20-degree cones facing each other. A belt rides in the groove between the two cones. Variable-diameter pulleys must always come in pairs. One of the pulleys, known as the drive pulley (or driving pulley), is connected to the crankshaft of the engine. The driving pulley is also called the input pulley because it's where the energy from the engine enters the transmission.

When the two cones of the pulley are far apart (when the diameter increases), the belt rides lower in the groove, and the radius of the belt loop going around the pulley gets smaller. When the cones are close together (when the diameter decreases), the belt rides higher in the groove, and the radius of the belt loop going around the pulley gets larger. For the front set driver pulley, roller is the main part to control the movement of pulley in X-direction to adjust the diameter depends on centrifugal force

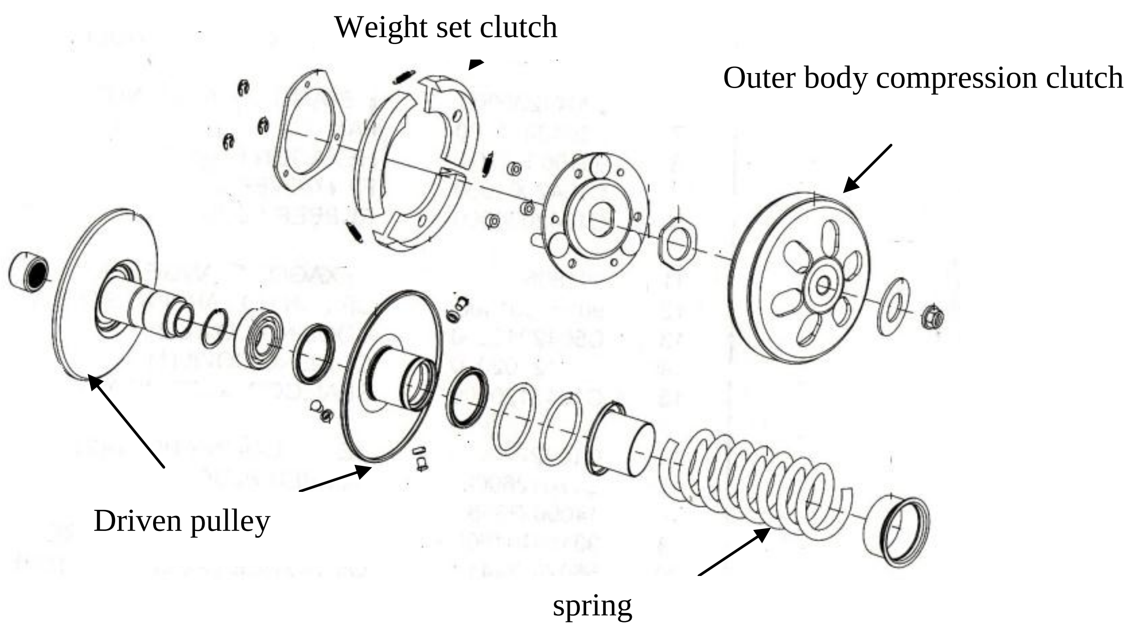

Figure 2.8: Rear Set Driven Pulley

Source: Modenas User Manual

The second pulley is called the driven pulley because the first pulley is turning it. When one pulley increases its radius, the other decreases its radius to keep the belt tight. As the two pulleys change their radii relative to one another, they create an infinite number of gear ratios, from low to high and everything in between. For the rear set driven pulley have a spring to create the force necessary to control the pulley halve. Spring also is the part which is to make sure the belt always tension. Thus, in theory, a CVT has an infinite number of "gears" that it can run through at any time, at any engine or vehicle speed.

2.8 PRINCIPLE OF IMPROVEMENTS IN FUEL ECONOMY AND PERFORMANCE WITH CVT

2.8.1 Principle of Improvement in Fuel Economy

The general concept of CVT is described as follows

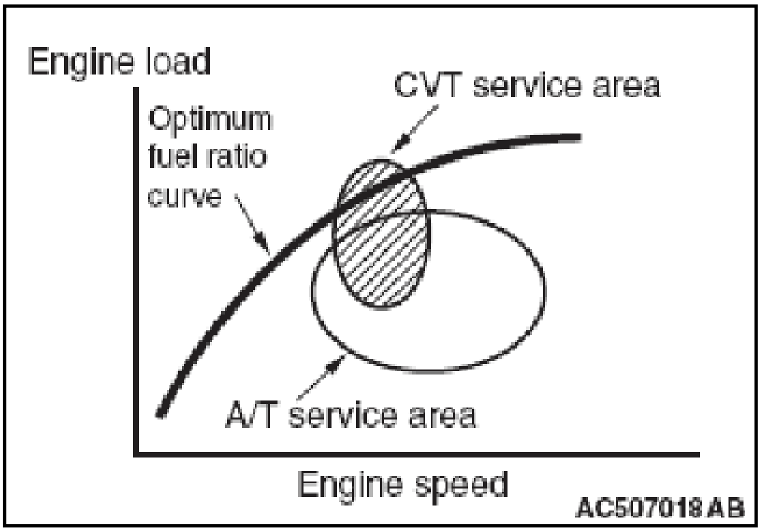

Figure 2.9: Engine Load Vs Engine Speed

Source: Buggypartsnw

CVT can continuously vary the pulley ratio, so the vehicle can be driven in the high engine fuel efficiency range all the time, resulting in excellent fuel economy. It means CVTs can compensate for changing vehicle speeds, allowing the engine speed to remain at its level of peak efficiency. For automatic transmission the change speed is depend on torque converter. Torque converter will change the gear ratio when enough the torque. For CVT system, the velocity of scooter depends on engine speed. That why the service operation for both transmission is different and from that can show the better fuel economy.

2.8.2 Principle of Improvement in Power Performance

The **(Figure2.10)** shows the maximum driving force diagram representing the power performance. The comparison with A/T shows that when the throttle is fully open, A/T causes a step change in driving force due to a step shift, but CVT changes driving force smoothly because it can accelerate with the engine kept in the high output range. Therefore, CVT provides more smooth and shockless driving without driving loss as much as the shaded area in the figure shown **(Figure2.10)**

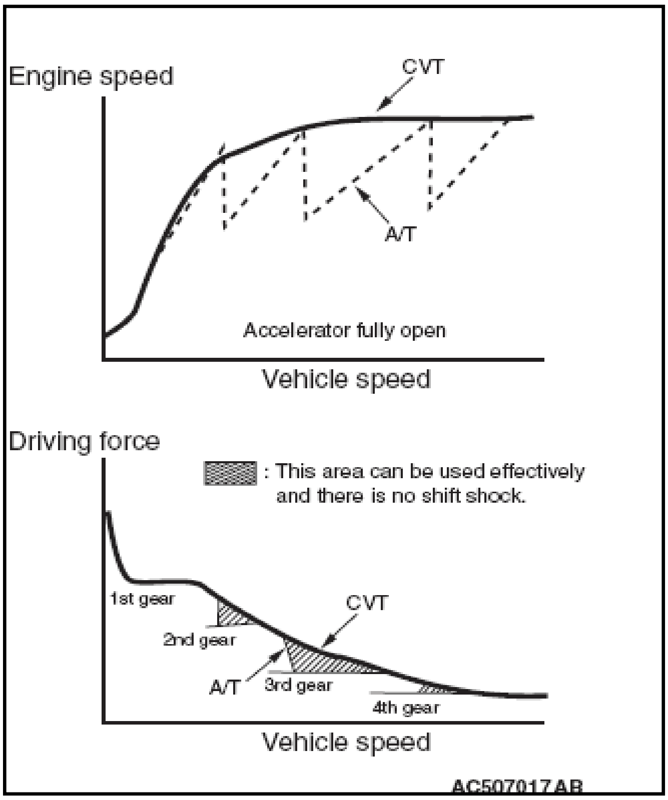

Figure 2.10: Driving Force Vs Vehicle Speed

Source: Buggypartsnw

2.8.3 Transmission Efficiency of a Rubber V-Belt CVT

Experimental study has been performed on the speed and torque-loss components of power loss of a rubber V-belt CVT. A dynamometer is constructed for measuring the input and output speed and torque, belt tensions, etc. The result illustrate that some of the phenomena of the rubber V-belt SVT are different from those of the V-belt drives. For instance, the speed-ratio change, the axial force and the total tension variation have significant effect on the efficiency of the CVT. Experimental result show that for the same installation condition(belt length and the center distance between driving and driven shaft), the efficiency reaches a maximum value as the speed ratio close to 1,0. This study may provide some concepts for the design of high efficient CVT systems. *(T. F. CHEN, D. W. LEE and C. K. SUNG, 1996)*

2.9 ADVANTAGES AND DISADVANTAGES

2.9.1 Advantages of CVT

Continuously variable transmissions are becoming more popular for good reason. They boast several advantages that make them appealing both to drivers and to environmentalists. The table below describes some of the key features and benefits of CVTs.

Table 2.1: Advantages of Continuous Variable Transmission

Advantages of CVT

Feature	Benefit
Constant, step less acceleration from a complete stop to cruising speed	Eliminates "shift shock" (jerk experience when the convention manual transmission shift it gear)

Table 2.1: Continued

Feature	Benefit
Works to keep the vehicle in its optimum power range regardless of how fast its traveling	Improved fuel efficiency
Responds better to changing conditions, Car such as changes in throttle and speed	Eliminates gear hunting as a decelerates, especially going up a hill.
Less power loss in a CVT than a typical automatic transmission	Better acceleration
Can incorporate automated versions of mechanical clutches	Replace inefficient fluid torque converters

2.9.2 Disadvantages of the CVT

The CVT's biggest problem has been user acceptance. Because the CVT allows the engine to rev at any speed, the noises coming from under the hood sound odd to ears accustomed to conventional manual and automatic transmissions. The gradual changes in engine note sound like a sliding transmission or a slipping clutch -- signs of trouble with a conventional transmission, but perfectly normal for a CVT. Flooring an automatic car brings a lurch and a sudden burst of power, whereas CVTs provide a smooth, rapid increase to maximum power. To some drivers this makes the car feel slower, when in fact a CVT will generally out-accelerate an automatic. Automakers have gone to great lengths to make the CVT feel more like a conventional transmission. Most CVTs are set up to creep forward when the driver takes his or her foot off the brake. This provides a similar feel to a conventional automatic, and serves as an indicator that the car is in gear. Other CVTs offer a "manual" mode that simulates manual gear changes. Because early automotive CVTs were limited as to how much horsepower they could handle, there has been some concern about the long-term reliability of the CVT. Advanced technology has made the CVT much more robust. Nissan has more than a million CVTs in service around the world and uses them in powerful cars such as the 290 horsepower Maxima, and says their long-term reliability is comparable to conventional transmissions.

2.10 TYPE OF CVT

2.10.1 Infinitely Variable Transmission (IVT)

A specific type of CVT is the infinitely variable transmission (IVT), in which the range of ratios of output shaft speed to input shaft speed includes a zero ratio that can be continuously approached from a defined "higher" ratio. A zero output speed (low gear) with a finite input speed implies an infinite input-to-output speed ratio, which can be continuously approached from a given finite input value with an IVT. *Low* gears are a reference to low ratios of output speed to input speed. This low ratio is taken to the extreme with IVTs, resulting in a "neutral", or non-driving "low" gear limit, in which the output speed is zero. Unlike neutral in a normal automotive transmission, IVT output rotation may be prevented because the backdriving (reverse IVT operation) ratio may be infinite, resulting in impossibly high backdriving torque; ratcheting IVT output may freely rotate forward, though.

2.10.2 Toroidal or roller-based CVT

Toroidal CVTs (Figure 2.11) are made up of discs and rollers that transmit power between the discs. The discs can be pictured as two almost conical parts, point to point, with the sides dished such that the two parts could fill the central hole of a torus. One disc is the input, and the other is the output (they do not quite touch). Power is transferred from one side to the other by rollers.

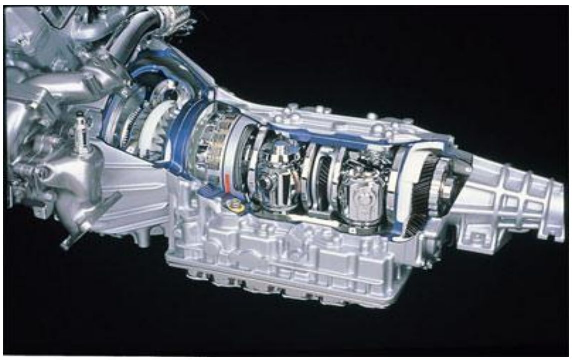

Figure 2.11: Nissan Extroid Toroidal CVT
Source: Buggypartsnw

When the roller's axis is perpendicular to the axis of the near-conical parts, it contacts the near-conical parts at same-diameter locations and thus gives a 1:1 gear ratio. The roller can be moved along the axis of the near-conical parts, changing angle as needed to maintain contact. This will cause the roller to contact the near-conical parts at varying and distinct diameters, giving a gear ratio of something other than 1:1. Systems may be partial or full toroidal. Full toroidal systems are the most efficient design while partial toroidals may still require a torque converter, and hence lose efficiency.

2.10.3 Variable-Diameter pulley (VDP) or Reeves drive

In this most common CVT system, there are two V-belt pulleys that are split perpendicular to their axes of rotation, with a V-belt running between them. The gear ratio is changed by moving the two sections of one pulley closer together and the two sections of the other pulley farther apart. Due to the V-shaped cross section of the belt, this causes the belt to ride higher on one pulley and lower on the other. Doing these changes the effective diameters of the pulleys, this changes the overall gear ratio. The distance between the pulleys does not change, and neither does the length of the belt, so changing the gear ratio means both pulleys must be adjusted (one bigger, the other smaller) simultaneously to maintain the proper amount of tension on the belt.

2.10.4 Hydrostatic CVTs

Hydrostatic transmissions use a variable displacement pump and a hydraulic motor (Figure 2.13). All power is transmitted by hydraulic fluid. These types can generally transmit more torque, but can be sensitive to contamination. Some designs are also very expensive. However, they have the advantage that the hydraulic motor can be mounted directly to the wheel hub, allowing a more flexible suspension system and eliminating efficiency losses from friction in the drive shaft and differential components. This type of transmission is relatively easy to use because all forward and reverse speeds can be accessed using a single lever.

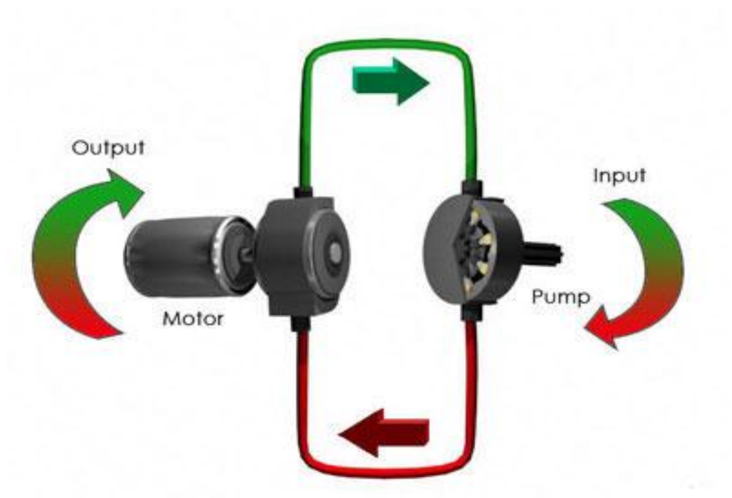

Figure 2.12: System of Hydrostatic CVTs

Source: Buggypartsnw

2.10.5 Variable Toothed Wheel Transmission

A variable toothed wheel transmission is not a true CVT that can alter its ratio in infinite increments but rather approaches CVT capability by having a large number of ratios, typically 49. This transmission relies on a toothed wheel positively engaged with a chain where the toothed wheel has the ability to add or subtract a tooth at a time in order to alter its ratio with relation to the chain it is driving. The "toothed wheel" can take on many configurations including ladder chains, drive bars and sprocket teeth. The huge advantage of this type of CVT is that it is a positive mechanical drive and thus does not have the frictional losses and limitations of the Roller based or VDP CVT's. The challenge in this type of CVT is to add or subtract a tooth from the toothed wheel in a very precise and controlled way in order to maintain synchronized engagement with the chain.

2.10.6 Cone CVTs

This category comprises all CVTs made up of one or more conical bodies that function together along their respective generatrices in order to achieve the variation. In the single-cone type, there is a revolving body (a wheel) that moves on the generatrix of the cone, thereby creating the variation between the inferior and the superior diameter of the cone. In a CVT with oscillating cones, the torque is transmitted via friction from a variable number of cones (according to the torque to be transmitted) to a central, barrel-shaped hub. The side surface of the hub is convex with a specified radius of curvature, smaller than the concavity radius of the cones. In this way, there will be only one (theoretical) contact point between each cone and the hub.

2.10.7 Electronically-Controlled CVT

This system is not a true CVT, having a fixed gear ratio, but behaves very similar to a true CVT. In this system, the transmission is an integral part of the hybrid power train and is actually a torque combiner. The gear train is a permanently-engaged, fixed-ratio, 3-way planetary gear. The engine is attached to one input, the driveshaft and the main electric motor to another, and then a smaller motor-generator controls the differential's third input to create a continuously-variable ratio between engine speed and wheel speed, with the variation taken by the electric motor and generator. At the extremes, the vehicle can move under electric power without the engine turning, or it can run the engine while stationary during engine warm-up or if needed to prevent discharge of the batteries.

The advantage of the system is its mechanical simplicity - no clutches, torque converters or shifting gears. A disadvantage is that continuous electrical power transmission between the two motor-generators is needed even during cruise, with resulting conversion losses, but the total effect is to increase the net efficiency through four methods:

i. The internal combustion engine may be completely shut down, rather than idle.
ii. The electric motor operates during high torque demands required to put the vehicle in motion.
iii. The internal combustion engine operates mostly at higher power demands, where it is more efficient.
iv. Energy may be recovered through the generation function when the vehicle is slowing or coasting downhill, with the energy (stored in the battery) applied to the initial acceleration of the vehicle and when high power demands require a that both the internal combustion engine and the electric motor operate.

2.11 SUMMARY

This project is begun by doing some research and survey on internet, journal, books and idea for design consideration to make decision the suitable concept and component to development in final project. Rubber belt CVT is now widely used in the motorcycle with most of them using single rubber belt system. Single rubber belt system is not suitable applied to engine with 250cc and above because need more torque to transmit high power from the engine. So, the engine with capacity more than 250cc using CVT system must need modification at their transmission system. To overcome this problem, alternative way is proposed by design rubber belt with electro-mechanical system to replace the current system. Further information, concept and the analysis of this system is show in the next chapter.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Based on literature review, modeling a double rubber belt CVT are planned follow up by the progress design. The project begins with some conceptual design with free sketches in plain paper before transforming it into 3D model with design dimension with CAD software. By comparing the all conceptual design, the best design is selected to do more analysis in this chapter.

3.2 DESIGN MAIN CRITERIA

i. Transmission : continuously Variable (CVT)
ii. Rates output : 47hp(35kW) @ 7,200rpm
iii. Maximum speed : 160 km/h (99 mph) verified accurate +/- 5 mph
iv. Maximum torque : 53 N·m at 6000 rpm
v. Final drive : 659 mm belt

3.3 CRITERIA FOR EACH CONCEPT

The major conceptual design is describe:

Driver pulley: have one pulley and control by electro- mechanical

Driven pulley: have one pulley and control by spring

Connection : belting (rubber belt)

Based on 250cc engine concept, the design are sketch out before turning it into 3D model. The designs are sketched and overall dimensions and parameter are determined.

After free sketches on paper, the design is drawn into solid model using CAD software. In this project, Solidworks is used to model the design. The model is drawn according to actual dimension. In this stage, the design is redesign into simplify form. It is important to ensure the design can easily to assemble.

The model will be creates part by part and then the part will be assemble together. This 3D software can show how the model is look like in real view.

3.4 SKETCHING MODEL

After getting conceptual design, model from free sketching is drawn in paper. Free sketching is more important thing in design for any system in mechanical part. From sketching, we can decide the dimension of part and the model. From sketching also we can see the real concept is what to do.

To draw the real concept in solidworks software, the detail of the sketching must be completed. This sketch is very important as reference to make the model in solidworks software.

3.5 ENGINEERING SOFTWARE

In this design and development of double rubber belt for CVT system, two engineering software are used to model the design and to analyze one of component structure. Solidworks 2007 is used to model the design while software is use to do analysis on structure.

3.5.1 Solidworks Software

Solidworks is a parasolid-based solid modeler, and utilizes a parametric feature based approach to create models and assemblies. Parameters refer to constraints whose values determine the shape or geometry of the model or assembly. Parameters can be either numeric parameters, such as line lengths or circle diameters, or geometric parameters, such as tangent, parallel, concentric, horizontal or vertical, and so on. Numeric parameters can be associated with each other through the use of relations, which allow them to capture design intent.

Building a model in Solidworks usually starts with a 2D sketch. Features refer to the building blocks of the part. They are the shapes and operations that construct the part. Shape-based features typically begin with a 2D or 3D sketch of shapes such as bosses, holes, slots, and other. This shape is then extruded or cut to add or remove material from the part. Operation-based features are not sketch-based, and include features such fillets, chamfers, shells, applying draft to the faces of a part, and extras.

3.6 ENGINEERING DRAWING BY SOLIDWORKS SOFTWARE

After the design phase and materials selection, this information then transform into engineering language- Technical Drawing. It is use to store the design information into hardcopy and this is the easier way to communicate with manufacturer.

3.6.1 Training of Advance Skill in Engineering Drawing

Engineering drawing is very important aspect in engineering. Without good engineering drawing, failure could happen during fabrication process and more worst than that is when the system is failure during operation cause in reading error in reading engineering drawing. Week engineering drawing also can cause losses to an organization because it can crate large error in manufacturing process.

Thus to avoid this from occur, a training in advance engineering drawing is held before real engineering drawing is drawn. It have several phase such as making good drawing blocks, drawn simple but compact, standardize font, arrows, and features in drawing.

3.6.2 Engineering Drawing Block

Function of this engineering block is for verify the drafter, the material, tolerance, scale and many more tat state the initial configuration of the drawing. All this detail must be state on a simple block. The most important factors about creating a good engineering block is to verify the drawing as an intellectual properties and to make sure initial configuration of the drawing is completely receive if the drawing hand to others. The detail engineering drawing block of this project is in Appendix B.

3.6.3 Complete Engineering Block

After training engineering drawing block, next process is completing all parts engineering drawing. In this process, the simplest part is drawn first and then followed by complex geometry parts..The drawing is use third angle view. It is consist front, side and top view, the drawing also include isometric view of the parts. All the part is carefully dimensional to make sure the drawing easy to read and all the info to fabricate the parts is stated. After done all part created, it will be assemble together. This will show how the model will come out. If there is any miss matching and poor looks, refinement on the model and part will be done.

3.7 DESCRIPTION OF THE DESIGN

3.7.1 Design 1

First concept as show in figure 3.1 can be exposed as follow:

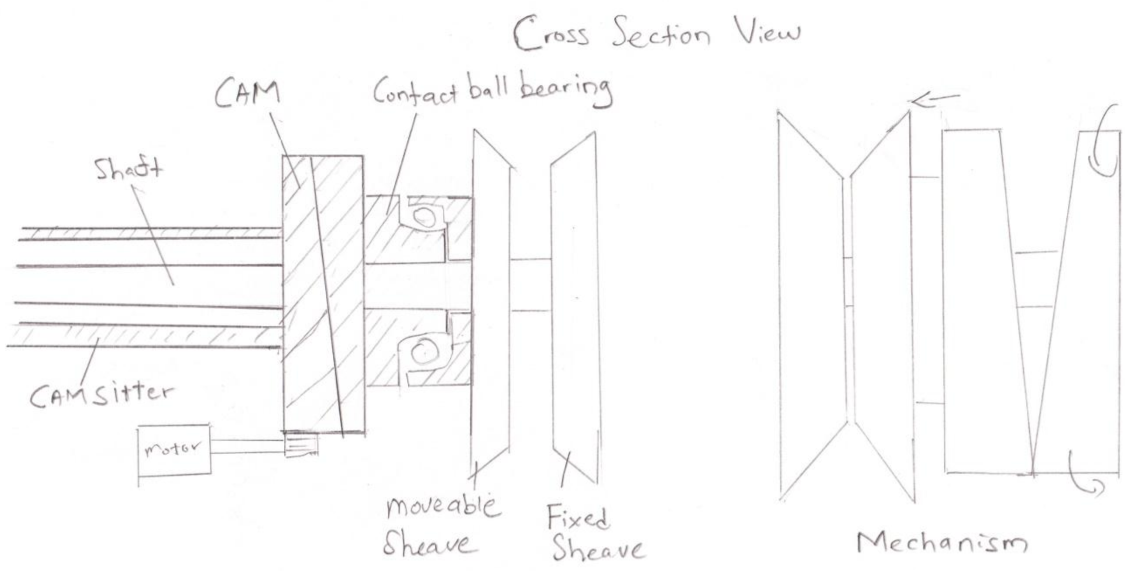

Figure 3.1: Complete Concept Criteria for Design 1

This system used mechanical CAM powered by DC motor to move the movable sheave. The CAM expand due to the incline surface profile that push both side of CAM apart creating motion in X axis as it rotate. The incline surface had a certain angle and by that angle of surface of inclination is the two surfaces will slip pushing each side backwards since the center of the cam is lock. The distance of the expansion depends on the angle of the incline surface as the CAM surface slide along the hypotenuse of the triangle.

3.7.2 Design 2

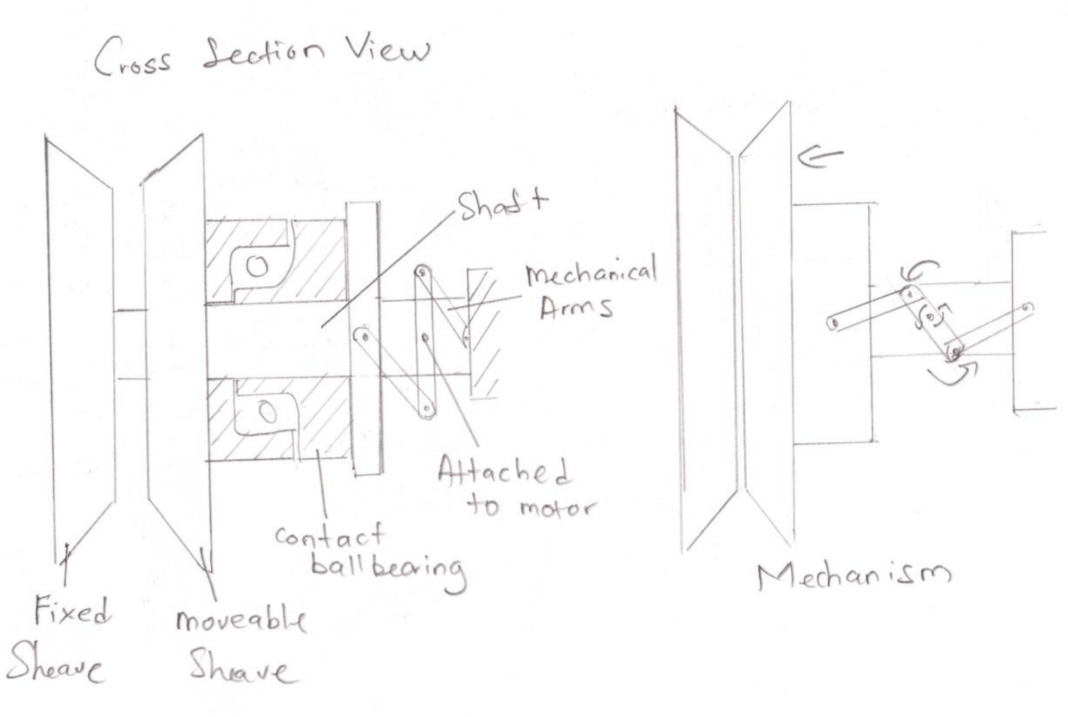

Figure 3.2: Complete Concept Criteria for Design 2

This system used mechanical arms to move the movable sheave of the pulley. It is equip with DC motor to turn the arms. The mechanical arms move the sheave forward as it turns anti clock wise direction and it can be reverse to move the sheave backward. The torque from the motor are transmitted through the mechanical arms to create force to push the moveable sheave to change the diameter of the belt at the driver pulley. The efficiency of torque transmitted is depend length of the arms as it as the amount of joints.

3.7.3 Design 3

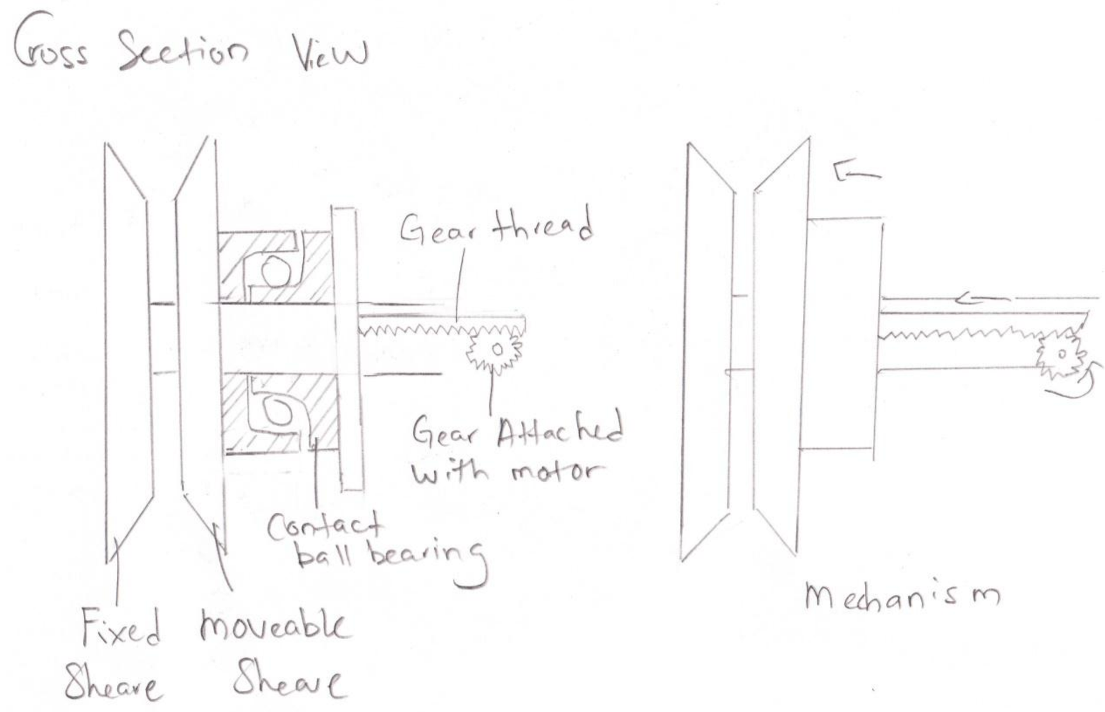

Figure 3.3: Complete Concept Criteria for Design 3

For this system is used gear tread attach on the moveable and it is move by DC motor to move forward and backwards. This is a simple and straight forward design where power from the gear is directly transmitted to the moveable sheave. The distance of the moveable sheave move is depends on the length of the track and also the limitation of the movement distance of the moveable sheave. The ratio of torque transmitted is 1:1 as the gear connected with only the gear track and gear attached to the motor. The direction of movement of the moveable sheave is depend on the of the rotation for the DC electric motor.

3.8 COMPARISON BETWEEN THREE DESIGNS

3.8.1 Comparison of Three Designs

Table 3.1: Comparison between Three Concept Designs

Conceptual design	Description	Advantages	Disadvantages
Design 1	Using CAM with electric DC motor mechanism as main control for the ratio change for the CVT	- Easy to assemble and dissemble for maintenance - Precise control for ratio change	- Bundle - Hard to fabricate - Heavy
Design 2	Using mechanical arms powered with DC electric motor with controller to change the ratio of the CVT	- Consist of simple parts and process - Easy to setup due to simple mechanism	- Hard to align with the controller due to numbers of joint which lead to vibration if it not firmly connected
Design 3	Using gear tread attached to the moveable side of diver pulley to provide control medium for the controller though DC electric motor	-Simplest mechanism to control ratio for the CVT - Provide direct control between movable pulley with controller	- gear guide tread is subjected to wear to time and part replacement cost for replacing wear part is costy

Table 3.2: Design Requirement Selection

Conceptual Design	Properties				
	Fabrication WF=25	**Costing** WF=30	**Maintenance** WF=25	**reliability** WF=20	**Total Score**
Design 1	15	23	20	18	76
Design 2	10	10	10	10	40
Design 3	20	18	5	15	58

* WF=Weight Factor

Table 3.1 shows the different between the three proposed concept design before select the best design and Table 3.2 shows the different of design requirement before make a best selection design. From the table 3.1 and 3.2 the third design show much better compare to other. Costing, maintenance fabrication and reliability is the main factor on the selection design. Costing related to manufacturer to make a mass production and maintenance is related to user choose the best motorcycle.

3.9 SELECTION OF DESIGN

Alter all the conceptual design are drawn out and the solution for each design are compared, all the design will be analysis in term of performance weather it meet the design criteria or not. If the design does meet the design criteria, the designs will need to undergo modification so that it meet or perform better then the fix standard.

If the design passes the require criteria the best solution will be selected to proceed with the analytics and performance testing of the design.

3.10 BLUE PRINT AND MECHANISM ANAYLSIS

3.10.1 Mechanism analysis

In this stage the every aspect of the mechanism are analyzed and it refer to the centrifugal CVT to produce an Electro-Mechanical CVT that can be used in the real application. After it is analyzed and redesign occur ding to real applications, and also fabrication capability, blue of the design is produced.

3.10.2 Blue Print

The selected design will be drawn in detail of parameters, and modification might needed to ensure the design can be fabricate and working, then the selected electro-mechanical design will be tested and documented.

3.11 REPORT PRESENTATION

The process for the entire project will be journal and all the design and solution will be compiled for future improvement reference. Will all the data compiled a conclusion are drawn stating whether the project meet it objective. This report will be the reference for feather improvement and research purpose.

3.12 SUMMARY

These methodologies are as the guideline for the project flow and to ensure that the project will be completed in time. If any problems appear at certain steps involved, the suitable solution must be taken quickly in case to prevent the other problems.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter covers in detail the selected conceptual design and the results that achieved by the analysis process that have been done. After doing a research about the existing system CVT and through the development process, the expected double rubber system now successful had been produced. The detail drawing and how the design does is work shown in this chapter.

4.2 SELECTED DESIGN

Figure 4.1 show the complete system of two rubber belt where is applied to CVT system of scooter with capacity engine above 200cc. The design is made by considering a couple of design consideration such as how to fabricated, costing to produce and reliability of the conceptual design. The figure 4.2 show the explode figure to show the all part is assemble in CVT system.

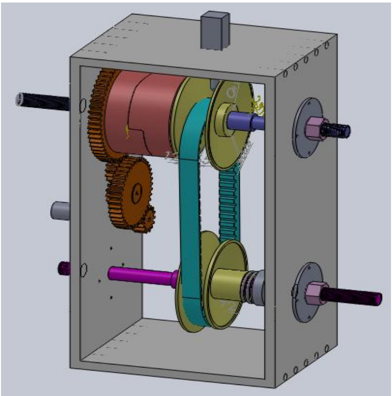

Figure 4.1: Complete Figure for Design 1

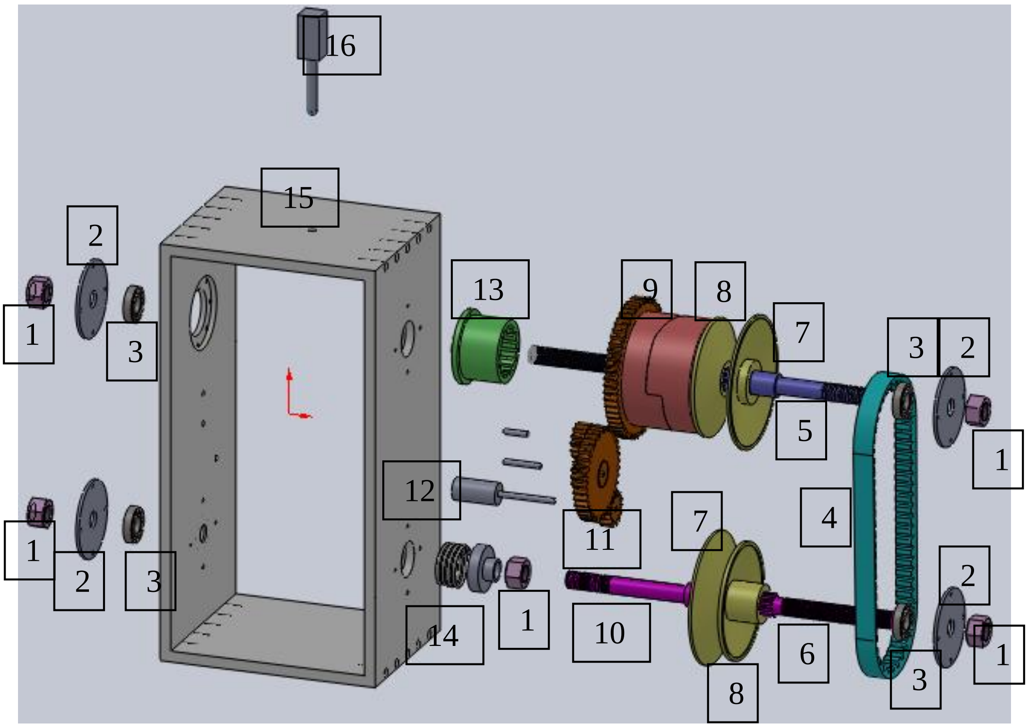

Figure 4.2: Explode View for Detail System Design 3

Table 4.1: Parts description and amount

No.	Description	Quantity
1	Hex Bolt Nut	5
2	Bearing Cover	4
3	Ball Bearing	4
4	CVT belt	1
5	Driver Shaft	1
6	Driven Shaft	1
7	Movable Pulley	2
8	Fix Pulley	2
9	CAM Set	1
10	Train Gear Set	1
11	Gear Shaft	2
12	DC electric Motor	1
13	CAM Sitter	1
14	Driven Pulley Spring and Holder	1
15	Casing	1
16	Belt displacement Sensor	1

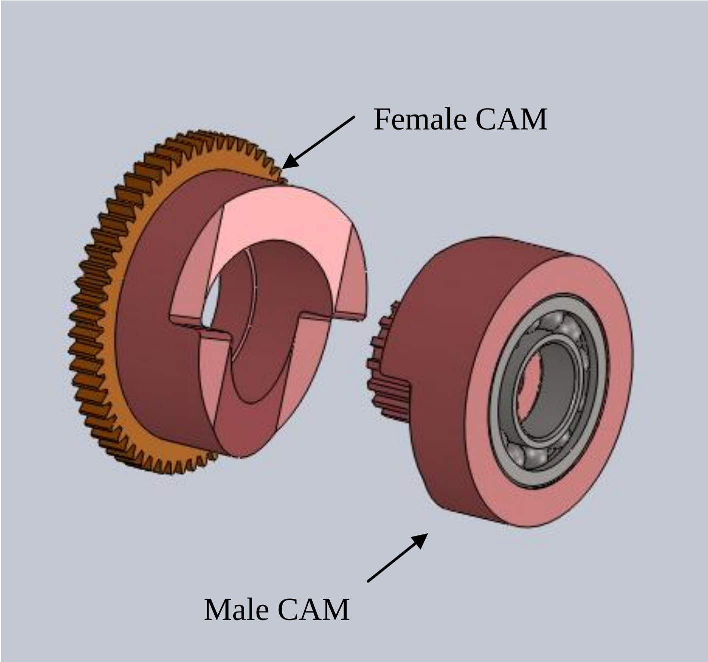

Figure 4.3: Explode View of CAM set

The CAM set is the main mechanism for the movable pulley to move in X axis to change the diameter of the belt driver pulley, resulting in ratio change in the transmission. The CAM is control by a DC electric motor through a train of gears so that the torque for the CAM to rotate at high rpm can be step down.

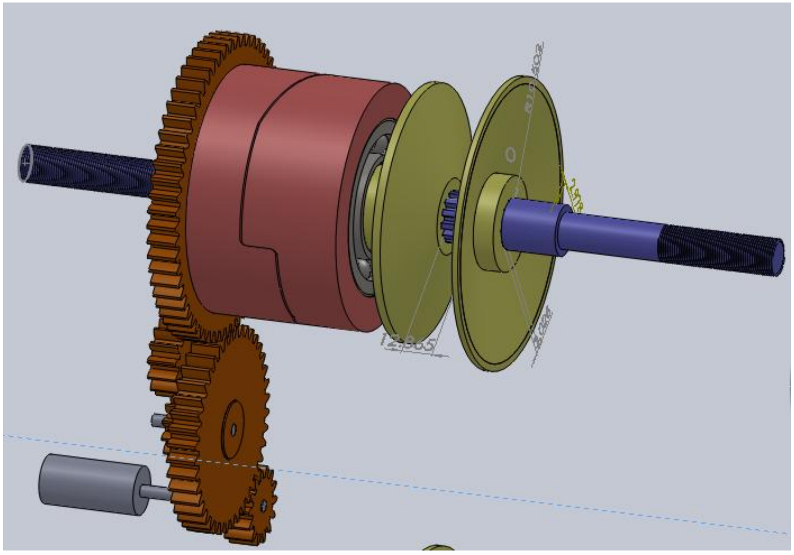

Figure 4.4: Complete Assemble of Electro-Mechanical Driver Puller

The analysis of the train gear and Cam set will shown at the mechanism analysis to show capability of this new mechanism toward the CVT system.

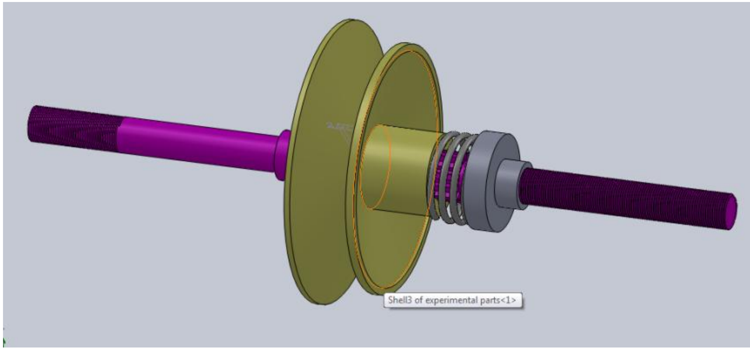

Figure 4.5: Driven Pulley

The Driven pulley (figure 4.5) has been modify to simply the design from the centrifugal CVT. Since the new concept change the gear ratio manually, there are no used for clutch and weight to maintain the of the driven pulley when the RPM from the engine is idle.

4.3 MODIFICATION

In this project SolidWorks is used to model the design. The model is drawn according to actual dimension. In this stage the selected design is redesign to simplification. Some of the part is modified to make sure it's easy and time constraint to fabricate, assemble and reassemble. The dimension of the design is also conversion to metric SI from imperial value consider tolerance, clearance, and fit component and material selection.

4.3.1 Modified Components

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The first stage of modification is done at movable sheaves and fix sheaves to suit the new mechanism. With the pulley modified, the shafts for both driver and driven pulley also have to be modified.

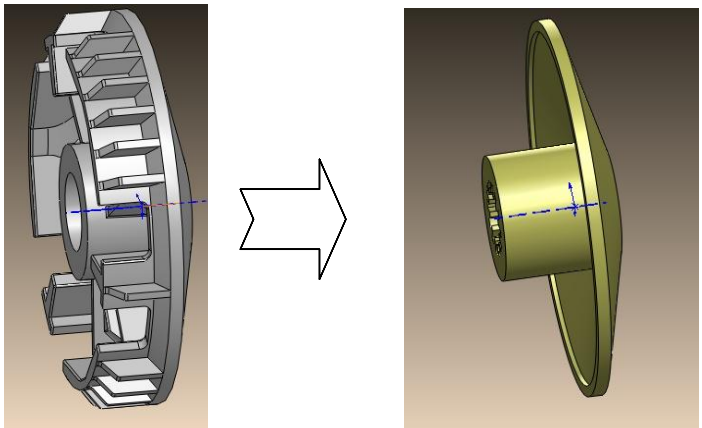


Figure 4.6: Comparison of Movable Sheaves

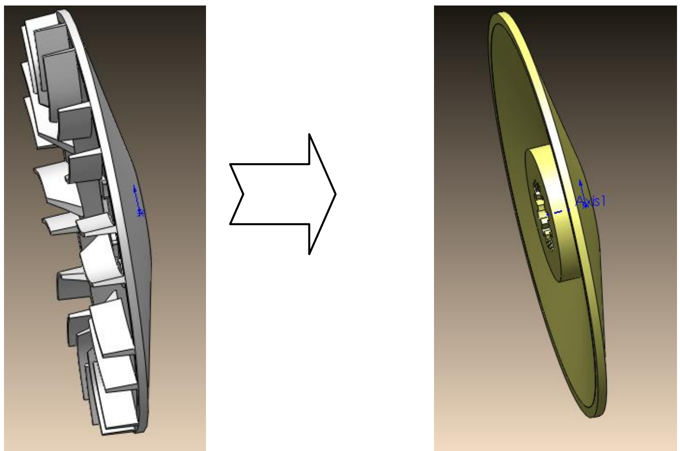


Figure 4.7: Comparison of Fix Sheaves

Second stage, modification continues with shaft component. **Figure 4.8** and **Figure 4.9** shows the minimum modification but maximum of function. The modifications of both shafts are to suit the new design of mechanism. The modification is based on Centrifugal force CVT.

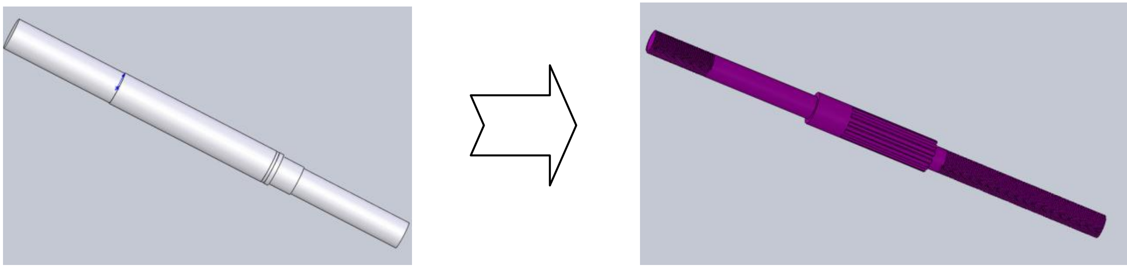


Figure 4.8: Comparison of Driven Shaft before and After Modification

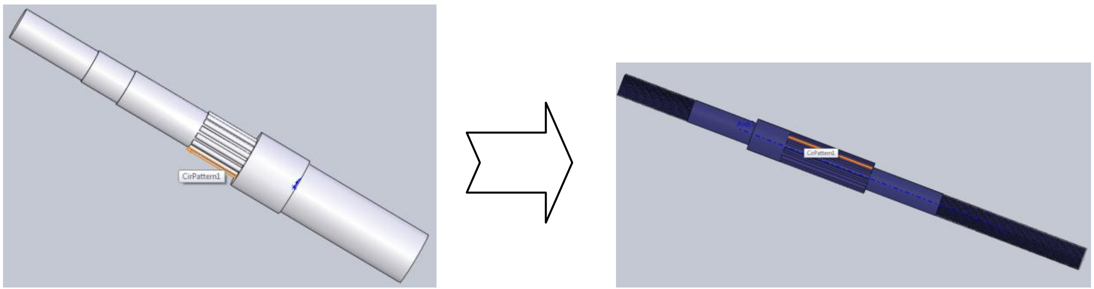


Figure 4.9: Comparison of Driver Shaft before and After Modification

4.4 DETAIL SKETCHING AND FUNCTION

After get conceptual of design that wants to be creates, model from free sketching is drawn in engineering drawing and then transfer to 3D software, which is the model is come out like real model. Table 4.1 shows the result of sketching in Solidworks software.

Table 4.2: Parts of Sketching by Solidworks Software

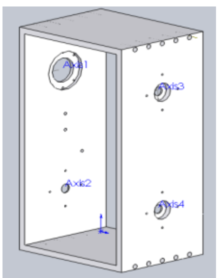
Part	Descriptions
1. Casing 	Place were CVT system running. Very hard to support heavy CAM and Pulleys Made from Aluminum Alloy

Table 4.1: Continue

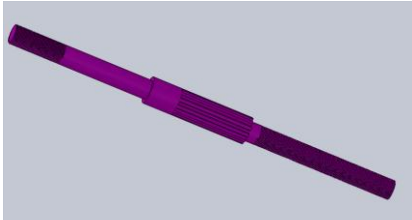
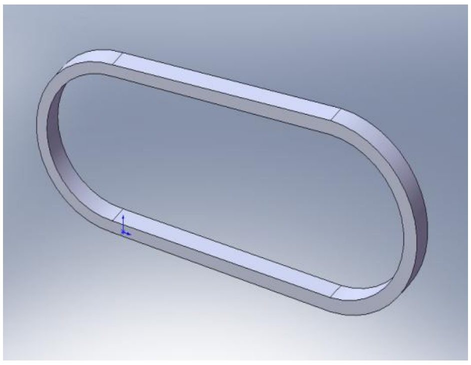
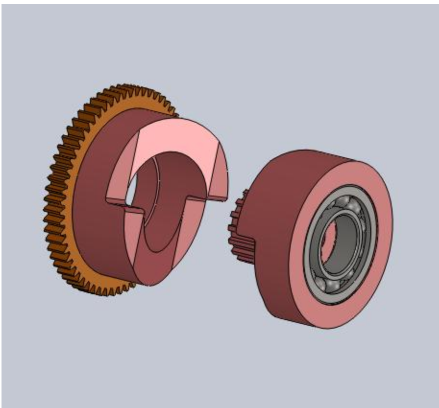
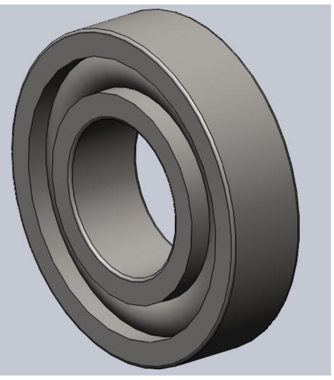
Part	Descriptions
2 Driver and Driven Shafts	
 	ıve an otter at the surface to fix the pulley d controller. Material used is steel.
3 belt	
	This V-belt drive is to transmit rotational motion and torque from pulley Made of fabric and cord, usually cotton, Rayon, or nylon, and impregnated with rubber.
4. Female and Male CAM	
	Main mechanism to move the moveable sheave to change the diameter of belt at driver pulley. Made from Carbon Alloy to prevent wear and has high hardness.

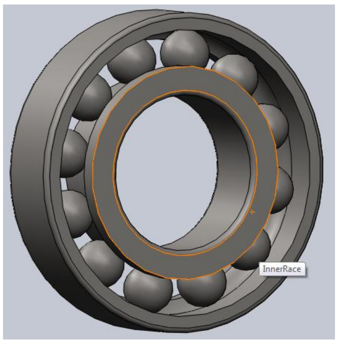
Table 4.1: Continue

5. Radial ball bearing



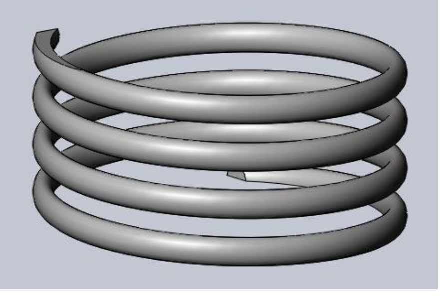
This part enables both driver and driven shaft rotate with minimum resistant with the casing.

6. Contact ball bearing



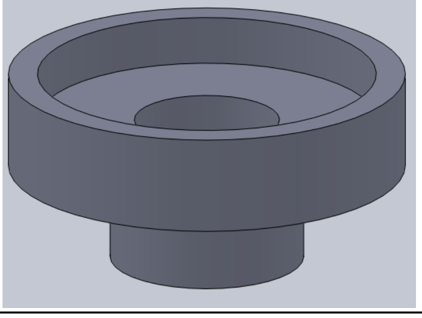
This part is enable the moveable sheave to rotate with the shaft well moving in X axis with the influence of CAM set.

7. Spring



This spring is controlling the movement of pulley for X-axis. This part also to maintain the belt is always tight.

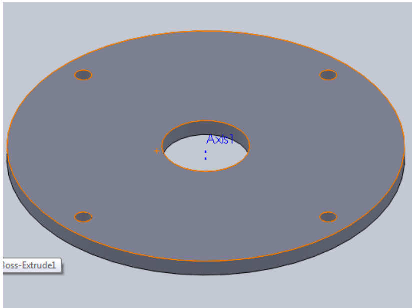
8. Clutch bell



This function of this part is holding the spring in position and provides support to the spring well it is compressed.

Table 4.1: Continue

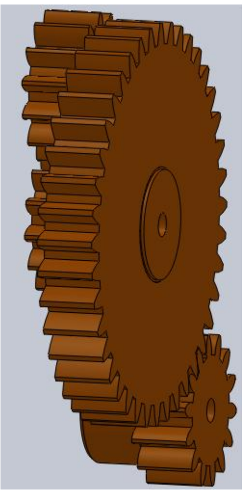
9. Radial Bearing Cover



This part function as cover for radial ball bearing that installed in the casing. Other then that is also provide support for the bearing well rotating.

Made from Steel

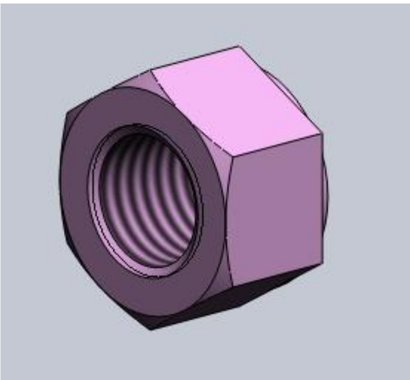
10. Gear Set



The set of gear is the connection medium between the DC electric motor and the CAM. Its anpplified the torque from the motor to CAM.

Made from Cobalt steel.

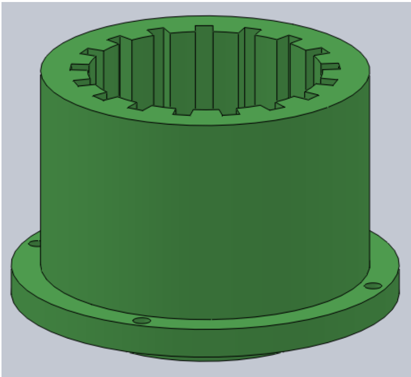
11. Hex Bolt Nut



This bolt is to tighten the shafts to the casing.

Table 4.1: Continue

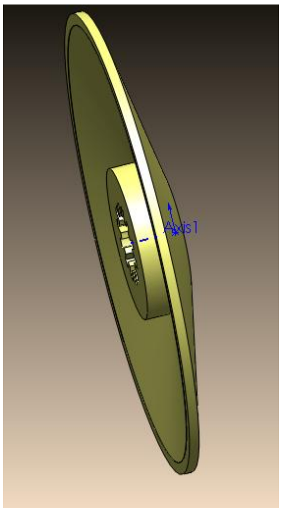
12. CAM Sitter



This part provide support for CAM and preventing it from rotate with the shaft. Other then that this part also enable the Male CAM to move in X axis.

---

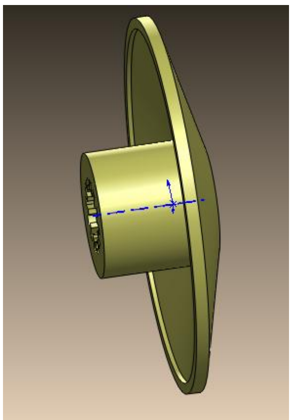
13. Fix Sheave



This is the fix side of the pulley where it only rotate with the shaft

---

14. Movable Sheave



The is the moveable side for the pulley which change enable the belt to change diameter in both driver and driven pulleys

4.5 ANALYSIS BETWEEN CAM AND PULLEY MOVEMENT AND FORCE ANALYSIS

4.5.1 CAM Parameter

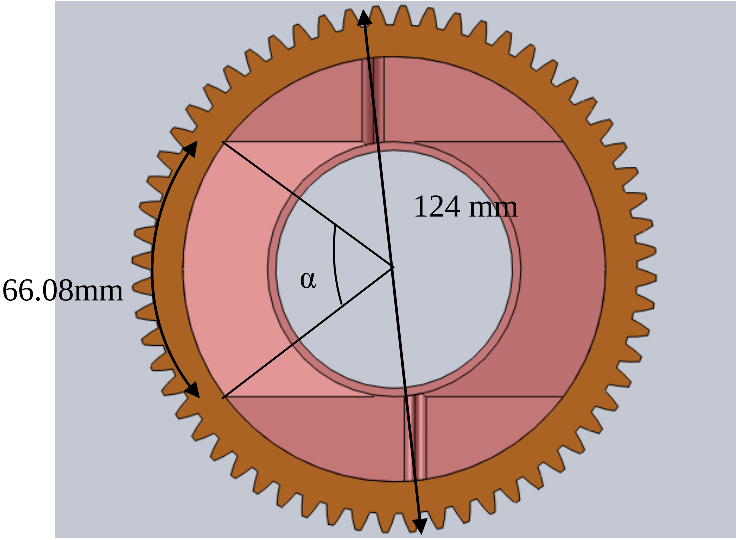


Figure 4.10: Top View of Female CAM

Alpha is the maximum rotation degree for the CAM to operate, further rotation will not result in movement in X axis as the incline surface already reach it maximum at alpha. Calculation of alpha is at follows;

$$c = 2\pi r$$
$$c = 2\pi(50mm)$$
$$c = 314.166mm$$

$$a = f.c$$
$$66.08 = f.314.16$$
$$f = 0.21$$

$$\frac{\alpha}{360} = f$$
$$\frac{\alpha}{360} = 0.21$$
$$\alpha = 75.6°$$

Therefore, the maximum rotation of the CAM 75.6° and based on the design maximum X axis distance for male CAM to travel is 15mm and it shown at **(figure.4.11).**

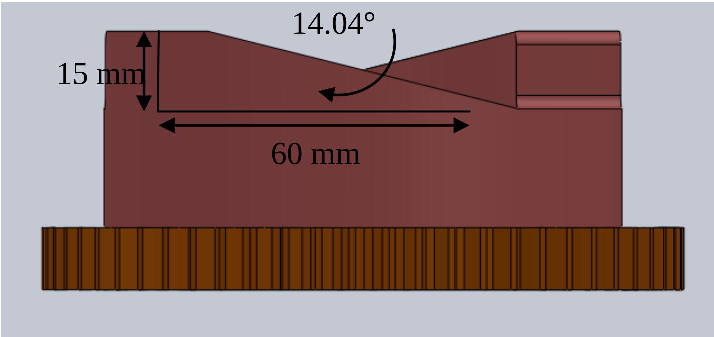


Figure 4.11: Side View of Female CAM

4.5.2 Movement relation between CAM and moveable Sheave

The rotation motion of the CAM will cause movement in X axis at moveable sheave of the driver pulley and the relation of the two motions is as follow.

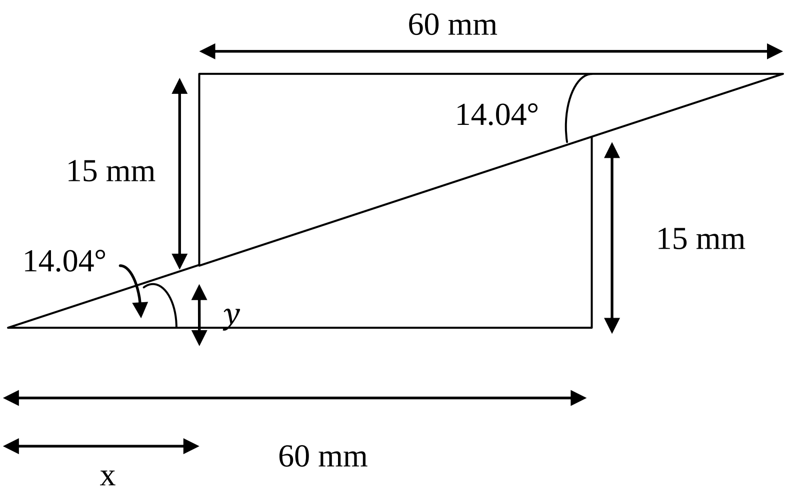


Figure 4.12: Sketching of CAM Movement

Because the incline surface of the CAM the CAM expend then it is rotated. The expansion x can be determine as follow;

$$\frac{60mm}{75.08°} = \frac{0.8mm}{1}$$

The equation means that every 1° of CAM movement, it will travel x distance at X axis and the x distance is 0.8mm. The calculation for y distance is as follow

$$\tan 14.04° = \frac{y}{0.8\ mm}$$

$$y = 0.2\ mm$$

In every 1° of CAM movement the CAM will expansion 0.2 mm. the expansion of CAM is directly proportional to the distance travel by moveable sheave at driver pulley. The relation is at follow;

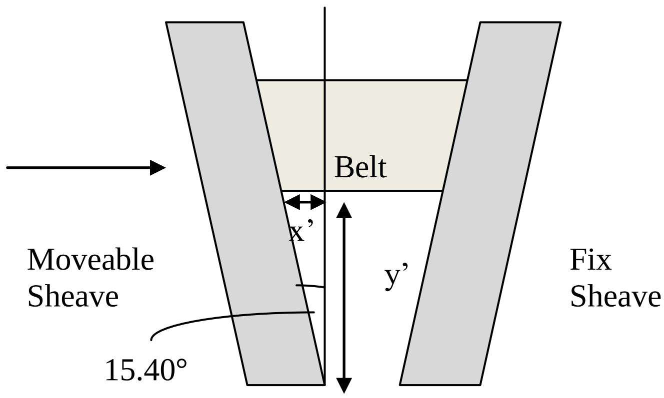


Figure 4.13: Sketching of Belt and Pulley Movement

$$y = x'$$

$$x' = 0.2\ mm$$

$$\tan 15.40° = \frac{x'}{y'}$$

$$\tan 15.40° = \frac{0.2\,mm}{y'}$$

$$y' = 0.726\,mm$$

The relation shows that, when the moveable sheave move 0.2 mm in X axis, the belt diameter at driver pulley increase 0.726 in radial.

4.5.3 Geometrical analysis of rubber belt

The pulley, with a circumferential groove carrying the belt, is called a sheave. The size of a sheave is indicated by its pitch diameter, slightly smaller than the outside diameter of the sheave. The speed ratio between the driving and the driven sheaves is inversely proportional to the ratio of the sheave pitch diameters. Thus the linear speed of the pitch line of both sheaves is the same and equal to the belt speed, vb. Then,

$$v_b = R_1\omega_1 = R_2\omega_2$$

But R1 = D1 / 2 and R2 = D2/2.

Then,

$v_b = D_2\omega_1/2 = D_2\omega_2/2$

The angular velocity ratio is

$$\frac{\omega 1}{\omega 2} = \frac{D2}{D2}$$

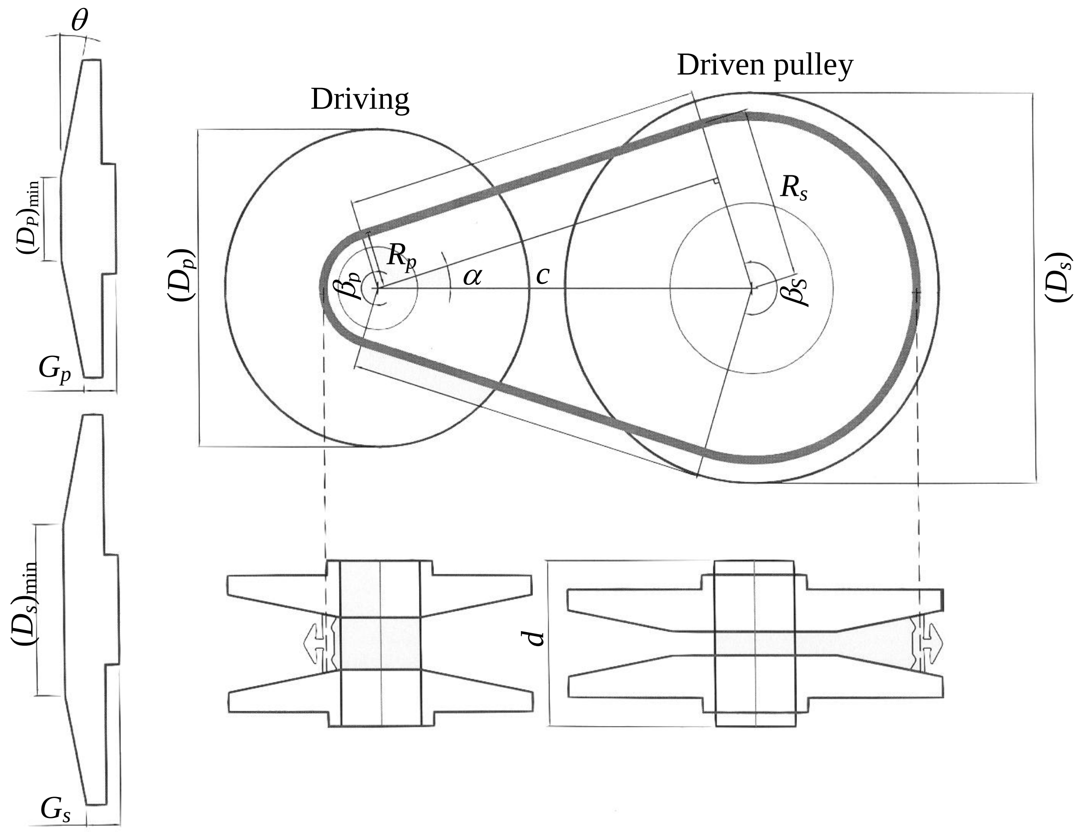


Figure 4.14: Basic **Belt Drive Geometry**

The relationships between pitch length, L, center distance, C, and the sheave diameter are

$$L = 2C + 1.57(D_2 + D_1) + \frac{(D_2 + D_1)^2}{4C}$$

Based the design the distance between both pulley C is 203 mm and the length of the belt is constantly 649.68 mm, we can simulate the ratio change by using Xcel software of based on the appendix c attached. And the result of the simulated is as follow.

Table 4.3: Parameter of Pulley and CAM

R_1 (mm) front pulley	R_2(mm) Rear pulley	CAM Rot. Degree	L (mm) Length	Ratio D_2/D_1
24.40	51.97	0.0	649.68	2.13
25.25	51.25	1.2	649.68	2.03
26.10	50.53	2.3	649.68	1.94
26.94	49.80	3.5	649.68	1.85
27.78	49.07	4.7	649.68	1.77
28.62	48.34	5.9	649.68	1.69
29.45	47.60	7.0	649.68	1.62
30.28	46.85	8.2	649.68	1.55
31.11	46.10	9.4	649.68	1.48
31.93	45.35	10.5	649.68	1.42
32.75	44.59	11.7	649.68	1.36
33.57	43.83	12.9	649.68	1.31
34.38	43.07	14.0	649.68	1.25
35.19	42.30	15.2	649.68	1.20
35.99	41.52	16.4	649.68	1.15
36.80	40.75	17.6	649.68	1.11
37.59	39.96	18.7	649.68	1.06
38.39	39.18	19.9	649.68	1.02
39.18	38.39	21.1	649.68	0.98
39.96	37.59	22.2	649.68	0.94
40.75	36.80	23.4	649.68	0.90
41.52	35.99	24.6	649.68	0.87
42.30	35.19	25.8	649.68	0.83
43.07	34.38	26.9	649.68	0.80
43.83	33.57	28.1	649.68	0.77
44.59	32.75	29.3	649.68	0.73
45.35	31.93	30.4	649.68	0.70
46.10	31.11	31.6	649.68	0.67
46.85	30.28	32.8	649.68	0.65
47.60	29.45	34.0	649.68	0.62
48.34	28.62	35.1	649.68	0.59
49.07	27.78	36.3	649.68	0.57
49.80	26.94	37.5	649.68	0.54
50.53	26.10	38.6	649.68	0.52
51.25	25.25	39.8	649.68	0.49
51.97	24.40	41.0	649.68	0.47

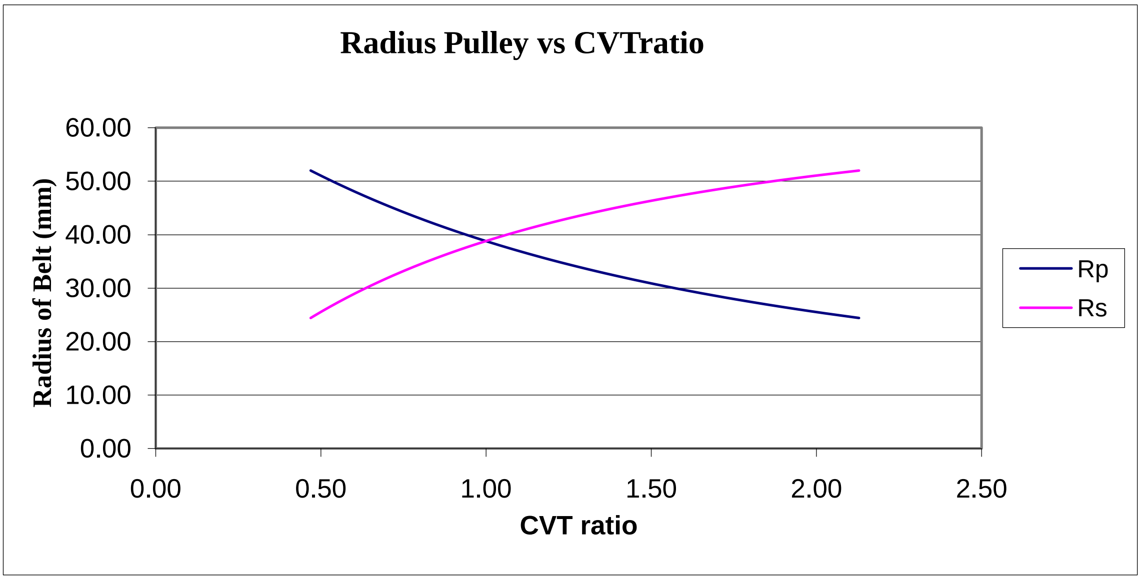


Figure 4.15: Radius Pulley vs CVT ratio

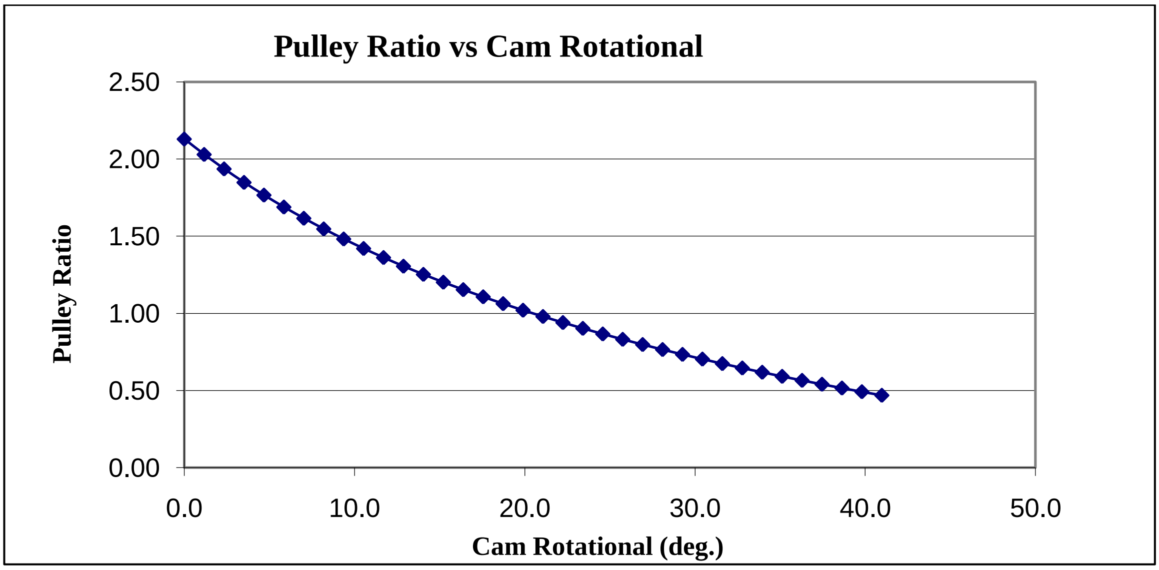


Figure 4.16: Pulley Ratio vs Cam Rotational

4.5.3.2 The contributors to the stress in the belt are:

i. The tensile force in the belt, maximum on the tight side of the belt.

ii. The bending of the belt around the sheaves, maximum as the tight side of the belt bends around the smaller sheave

4.5.3.3 Center Distance

The distance from the center that the v-belt contacts the pulley is determined by the distance between them, the further apart they are, the lower the belt rides and the smaller the pitch radius. In CVT system, center distance is fixing with variable ratio of pulley. Provision for increasing the center distance must be made to permit the initial tensioning of the drive and to take up for belt stretch. The nominal range of the center distances should be

$$D_2 < C < 3(D_2 + D_1)$$

Hence, can write:

$$103.94 < C < 3(48.8 + 103.94)$$

$$\mathbf{103.94 < C < 458.22}$$

So, the center distance of 203 mm is use in 4.2 is locate in a range between 103.94-458.22 and this center is reasonable to propose in this project.

4.5.4 Force analysis of CAM relative to RPM of the driver pulley

The force acting on the pulley relative to rpm of the shaft is basically the same as CVT that used centrifugal force. Therefore the analysis of force can do by referring to the centrifugal force concept and relate it to the new design. The analysis begin by determine the maximum centrifugal force acting on the driver pulley at the maximum RPM. The maximum centrifugal force at maximum RPM will be used as a reference for new design mechanism.

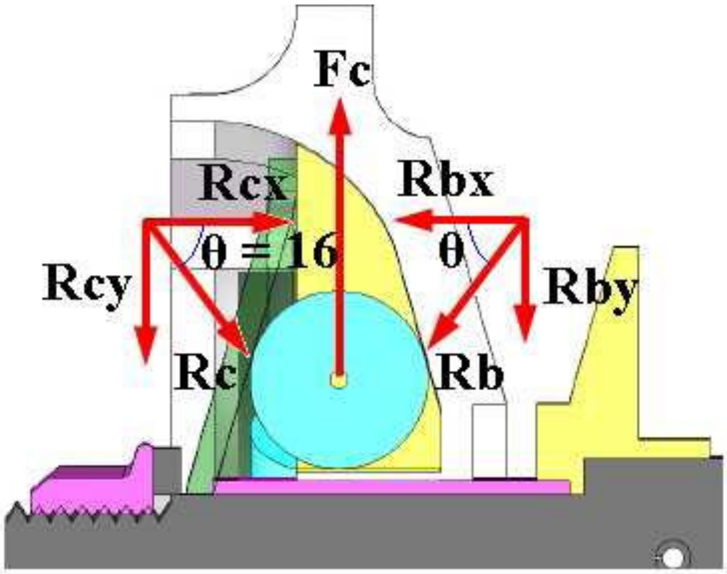


Figure 4.17: Free Body Diagram of Roller in The Centrifugal Force CVT

According to Newton's second law of motion

$$F = mass\ \times acceleration$$

In this case the acceleration is centripetal acceleration

$$F = mass\ \times centripetal\ acceleration$$

$$Fc = m\ \times \frac{v^2}{r}$$

The linear velocity and angular velocity is as follow

$$v = r\ \times w$$

Hence sub v into F

$$Fc = m\ \times \frac{v^2}{r}$$

$$Fc = \frac{m(wr)^2}{r}$$

$$Fc = \; mrc^2$$

In centrifugal CVT, the rotation of the roller inside the CVT generates the force to push the pulley in X axis. Therefore the force generated by six 10g roller with respect to RPM of engine is as follow.

$$m = \frac{10}{1000} \times 6$$
$$m = 0.06 \; g$$

Initial RPM, *w = 1000*

Radius of rotation rollers, *r = 0.035*

$$Fc = (0.06)(0.035)((2\pi \; \times 1000)/60)^2$$
$$Fc = 23 \; N$$

Table 4.4: Value of Fc With Respect to RPM

RPM	Fc,N
1000	23.02
1500	51.81
2000	92.11
3000	207.26
3500	282.10
4000	368.46
4500	466.33
5000	575.72
5500	696.62
6000	829.04

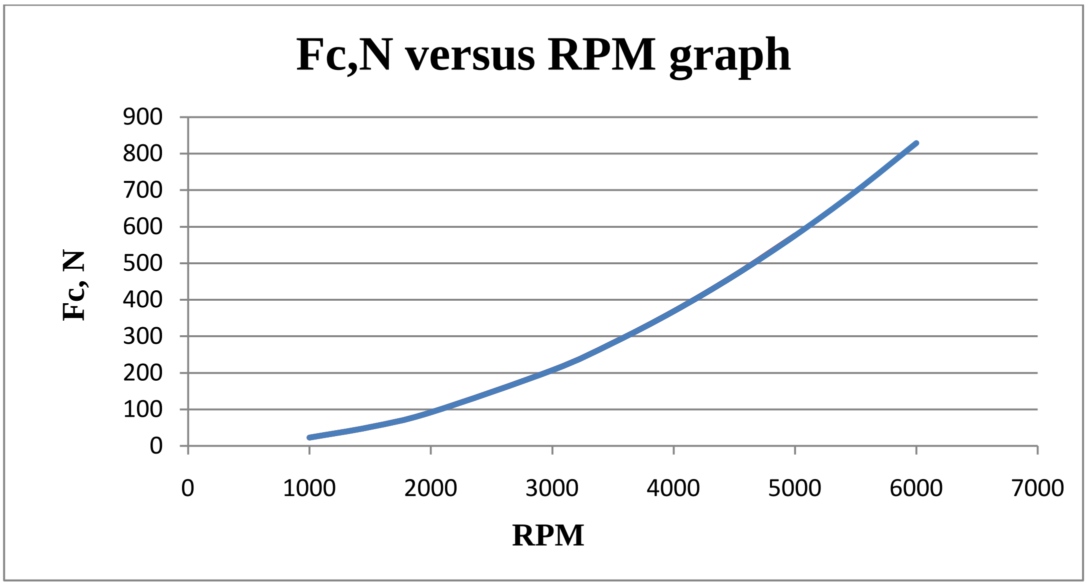


Figure 4.18: Fc,N Versus RPM Graph

Therefore, at RPM 6000, the engine running in on idle high revolution before it when over rev and decrease the fuel efficiency. Based on the maximum Fc we can conclude that amount torque that the CAM needed to push the moveable sheave at maximum idle RPM is equal to maximum Fc.

The pitch radius of the gear attach at the Female CAM, r = 62 mm = 0.062 m

Fc max = 829.04 N

$$\tau = Fc \max \times r$$

$$\tau = 829.04\ N \times 0.062m$$

$$\tau = 51.04\ N$$

The CAM needed 51.04 N forces to need to push the moveable sheave at 6000 RPM. Therefore the DC electric motor used must at that capability to amount of torque. However the torque from CAM is step down by the train gears connecting CAM and DC electric motor. With that the torque produce by the DC electric motor can be less than the 51.04 N.

4.5.5 Train gear analysis

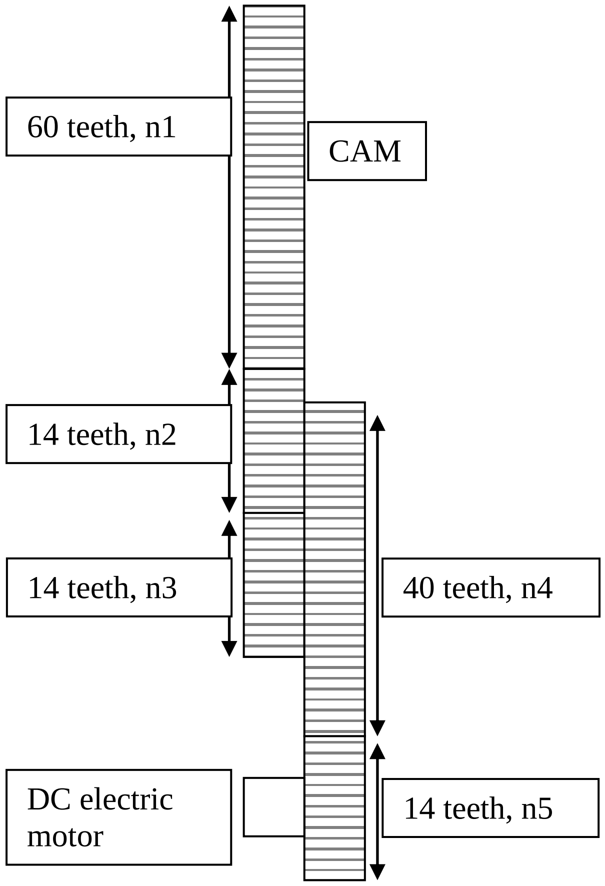


Figure 4.19: Sketching of Train Gears

Assume n1 = 1 rev/sec

$$n2 = \frac{N1}{N2} \times n1$$

$$n2 = \frac{60}{14} \times 1$$

$$n2 = 4.3\frac{rev}{sec}$$

$$n2 = n3 = n4$$

$$n5 = \frac{N4}{N5} \times 4.3$$

$$n5 = \frac{40}{14} \times 4.3$$

$$n5 = 12.3\ rev/sec$$

Therefore the motor have to turn 12.3 revolutions in order to turn 1 rev of the CAM. In order to turn 75.08° to expend the cam to limit, the motor have to turn;

$$1rev = 360°$$

$$\frac{75.08°}{360°} \times 1\ rev \approx 0.2\ rev$$

$$n5' = \frac{0.2}{1} \times 12.3\ rev$$

$$n5' = 2.46\ rev$$

4.5.6 DC motor analysis

After knowing the maximum torque and also the speed gear ratio attach between the DC motor and the CAM, the choice of motor have to be suitable and fulfill the minimum specification in order to provide prefect control to driver to control the transmission ratio..

The ratio of the gear is $1 : 12.3$, that means the torque that need to supply by the DC motor is 12.3 times less than the amount the need to turn the CAM at 6000 rpm. Therefore amount of torque of the motor is;

$$\tau' = \frac{51.04\ N.m}{12.3}$$

$$\tau' = 4.14\ N.m$$

Therefore the motor must be capable to produce 4.14 N.m or more of torque in order to mechanism to function perfectly until it reach it limit. The choice of motor is as follow.

ADLEE
Powertronic Co., Ltd.

Brushless DC motors with DC drive

Table 4.5: DC motor Specification

Model No.		BM-180	BM-250	BM-370	BM-600A	BM-600B	BM-600C
Voltage	VDC	24	36	24	48	48	48
Rate Torque	Kg-cm	9	97	12	6.8	7.6	9.3
Rate Power	W	180	250	370	600	600	600
Rate Speed	RPM	1950	250	3000	8600	7700	6300
Rate Current	A	9	8.7	18	18	18	16
Max. Torque	Kg-cm	22	250	40	52	60	70
Max. Power	W	270	350	550	2400	2400	2400
Max. Speed	RPM	2500	310	3500	9000	8000	7000
Max. Current	A	22	15	48	85	85	85
Motor Dimension		1	2	3	4	4	4
Driver Dimension		A	B	A	C	C	C

Source: http://www.adlee.com/brushless_dc_motors_with_dc_driver.htm

Based on the table provided by the 'ADLEE Powertronic Co., Ltd' model 'BM-250' is the best solution. It capable to produce 250 kg.cm torque which mean 25 N.m, the model also equip with DC drive which mean the speed and the torque can be adjust to fit any application. The no load speed for this model is 250 RPM; the speed for the CAM to finish the 75° rotation is as follow.

Motor speed is 230 RPM = 4.1666 rev/s

Gear ratio 1:12.3

Speed of CAM, *x*, rev/s

$$\frac{1}{12.3} = \frac{x}{4.133}$$

$$x = 0.338\,\frac{rev}{sec} \times 360°$$

$$x = 121.68\ deg/sec$$

Time to complete 75.08° rotation,

$$t = \frac{75.08°}{121.68°}$$

$$t = 0.617\ s$$

The time to complete the rotation of the CAM is 0.617 s, and it consider too fast to control. Therefore, the equip DC driver is important to lower the speed and also the torque.

4.6 SUMMARY

To preliminary design and development of single rubber belt system, many aspects must be considered. For instant, the mechanism use, the result of calculation, material selection, pulley design, shaft design and others. All of these aspects will influent the data and the result in the research and development for this project. In other to come out with an effective mechanism in double rubber belt CVT, a research done to collect as much information about the existing implementation of CVT and the analysis have been done to make a suitable mechanism and also to improve the disadvantages of existing of CVT.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Based on the preliminary design and calculation, single belt electro-mechanical CVT proven possible to be apply to the real application of 250 cc engine and it improve the control of the transmission ratio change compare to centrifugal which relay only on the weight in the clutch to maintain the speed when the engine is idle.

The study on the relation between the mechanisms of electro- mechanical to the ratio change in the CVT shows it able to change the transmission ratio from low gear to top in only around 1 second and it is reversible depend on the engine RPM and the driver prospection toward the road profile to improve fuel efficiency.

A working prototype can be derived from the technical drawing available. The design can be use by the manufactured in the fabrication process. Some refinement and modification were done on the design to ensure all the components can be assembled correctly. As an overall conclusion, the objective designing the suitable electro-mechanical single belt CVT to apply to the 250 cc engine application has been achieved.

5.2 RECOMMENDATION

This development still has to carry forward to improve accuracy of the result before continuing to the next phase. The selected design of the electro-mechanical single rubber belt system can still be refined and there are spaces to improve it. Further work that are strongly recommended:

i. Develop this concept into double rubber belt CVT to enable it be apply on higher power engine.
ii. Analytical of other component is also further study for improvement of selected design. The inclination of the pulley needs more analytical research to get the optimum result.
iii. Reverse on the profile of the CAM is needed to improve the stability and accuracy of the expansion.
iv. Redesign the pulleys structure and also material used to enable compound belt to improve the durability in higher power engine application.
v. Reverse on the gear set to improve the torque from DC motor.

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APPENDIX B1

DRAWING BLOCK

(FULLY ASSEMBLE)

APPENDIX B2

DRAWING BLOCK

(COMPONENT)