CHAPTER 1: INTRODUCTION

1. INTRODUCTION

1.1 Project Background

Shell Eco Marathon 2012 (SEM) is a competition that organizes by Shell with such annual events in the Americas, Europe, and Asia. Shell Eco-marathon Asia will take place from 4-7 July 2012 at Sepang International Circuit in Kuala Lumpur, Malaysia. The purpose of this competition is to challenges high school and college student teams from around the world to design, build and test energy efficient vehicles.

Generally, the winners for this competition are the teams that go the farthest distance using the least amount of energy. There are two types of categories which are Prototype and Urban Concept. For the Prototype Group, futuristic streamlined vehicles where the primary design consideration is reducing drag and maximizing efficiency. While for Urban Concept, vehicles built to more conventional four-wheel roadworthy criteria. Any teams can choose to use either internal combustion such as Gasoline, Diesel, Ethanol E100 (100% Ethanol), Gas to Liquid (100% GTL), Fatty Acid Methyl Ester (100% FAME) or electric mobility such as hydrogen, solar, and battery electric for energy source.

Universiti Teknologi PETRONAS (UTP) will participate in this race which is in urban concept and Prototype. Urban concept will be use Gasoline Internal Combustion Engine (ICE) while for prototype group will be use electric mobility as the energy source. In the case of the urban concept vehicle, one potential solution to this fuel efficiency is the continuously variable transmission (CVT). Rather than selecting one of four or five gears, a CVT constantly changes its gear ratio to optimize engine efficiency with a perfectly smooth torque-speed curve. This improves both gas mileage and acceleration compared to traditional transmissions.

The particular CVT consist of rubber V-belt type that connected two pulleys. Engine will directly drive the primary sheave while the secondary sheave provides input to a secondary reduction. This is how the common arrangement in small vehicles using CVTs. As stated above, there are two types of pulleys which are primary and secondary. The main components of the primary pulley are fixed and movable sheaves, a set of two flyweights, and a compression spring. As the engine speed increases, the flyweights tend to swing open and push the movable sheave inward toward the fixed sheave. However, this movement is not possible until the force created by the flyweights is able to overcome the force caused by the primary spring. Once this is occurs, the flyweights must also overcome the resisting force caused by friction between the belt and the sheaves as well as the spring forces in both the primary and secondary pulleys.

The secondary pulley includes fixed and moveable sheaves and a spring loaded in compression. As the primary begins to shift, its two sheaves move closer together. Thus, it will narrow the width of the v-slot driving the belt to a larger diameter. The normal force caused by the wedging of the belt between the sheaves forces the secondary sheaves apart, which allows the belt to move to a smaller diameter on the secondary. This is the process that shifts the system to a higher gear ratio.

Figure 1.1: Common arrangement of CVT

Changing the diameter of the pulleys will vary the transmission's ratio. Making the input valley smaller and the output pulley larger gives a low ratio for better low speed acceleration. As the car accelerates, the pulleys will vary by making the input getting bigger and output pulley smaller. This is how CVT works.

1.2 Problem Statement

With the advantage of improving fuel efficiency, smooth uninterrupted power without step discontinuities, without jerk and naturally changes ratio continuously lead to steady acceleration, CVT will be installing in the vehicle which is also an important factor to win in SEM2012. Previously, the CVT is working but with some problem that occurs such as slippage during high torque and ratio of the drive pulley and driven pulley are constant, trial-and-error method have been used which is quite costly.

Table 1.1: Details of the car

Specification	Overall length	130
	Overall width	0.9m
	Overall height	1.4m
	Wheel base	1m
	Weight with driver	262kg
	Tyre radius	0.45m
Engine	Type	SOHC, 4-stroke, single cylinder
	Bore x stroke	51.5 x 60mm
	Displacement	124.9 c.c
	Compression ratio	9.2 : 1
	Induction	Carburetor
Transmission	Type	CVT
	Clutch	centrifugal, dry type
	Reduction ratio	2.4 ~ 0.8
	Driving system	V- belt

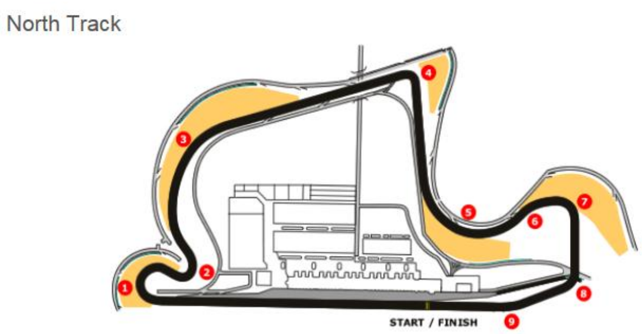


Figure 1.2: Track for SEM2012

Based on the detail above, the configuration of CVT and the engine will be tested on expected Sepang International Circuit (SIC) drive cycle and then compare it to the actual result during competition. The circuit has a maximum upwards gradient of 3.675%, and a maximum downwards gradient of 5.625%. Then the best combination of tuning the primary and secondary pulley will be determined in order to improve the fuel efficiency and vehicle performance.

1.3 Objective & Scope of Study

The scope of this study will be focusing on the designing of CVT for SEM2012. . Below are the objectives of this study:

i. To study behaviour and the and characteristics of CVT
ii. To design and compare the total fuel consumption between expected Sepang International Circuit (SIC) with actual result during Shell Eco Marathon competition.
iii. Determine the best combination of tuning the primary and secondary pulley
iv. Determine the ratio will be produce by the CVT

1.4 Relevancy and Feasibility of the project

This project is relevance since CVT is promising the better efficiency than conventional automatic transmission. Besides that, by using CVT will comply with rule stated in article 34: Clutch and Transmission:

"For Urban Concept only: The vehicle must have 'idling capabilities', i.e. the vehicle must remain stationary with the engine running." [1]

As stated in article 119: Urban Concept Group, the average speed required is 25km/h. Thus, CVT is the most suitable transmission that can work at optimum load for that speed.

“Minimum speed: For their attempt to be validated, teams must complete the four laps in a maximum time of 28 minutes with an average speed of approximately 25 km/h. The total distance to cover is 11.2 km (4 laps of 2.8 km minus the distance between the start and finish lines).” [1]

The advantages of using CVT are low cost simple arrangement with continuously ratio, without jerk and steady acceleration. Figure 2, below show the comparison of efficiency between conventional automatic transmissions with various CVT [7].

Gear	Efficiency
1	60-85%
2	60-90%
3	85-95%
4	90-95%
5	85-94%

Table (1) Efficiency vs. Gear Ratio for Automatic Transmission[6]

CVT mechanisms	Efficiency
Rubber Belts	90-95%
Steel Belts	90-97%
Toroidal Traction	70-94%
Nutating Traction	75-96%
Variable Geometry	85-93%

Table (2) Efficiency of Various CVT Designs [6]

Figure 1.3: Comparison of efficiency between conventional automatic with CVT

Based on Gantt chart, this project is within the scope and timeline frame for FYP II.

CHAPTER 2: LITERATURE REVIEW

2. LITERATURE REVIEW

The design of CVT has been introduce long time ago. There's no proof to state that the continuously variable transmission (CVT) is new pattern. Leonardo da Vinci has sketched his idea for a CVT in 1490 [2]. Meaning that, the existence of CVT is nearly as long as the existence of the car itself specifically as long as conventional automatics. As a proof, in the early 1930s, General Motors actually developed a fully toroidal CVT and conducted extensive testing due to cost concerns before eventually deciding to implement a conventional. Then General Motors Research worked on CVTs again in the 1960s, but none ever saw it production [3]. Austin, British manufacturer used a CVT for several years in one of its smaller cars, but it was dropped due to its high cost, poor reliability, and inadequate torque transmission [3].

One of the expertise in CVT design and tuning, Olav Aaen has published nine editions of the Clutch Tuning Handbook [4]. In his book, a lot of background information that necessary for a beginner to tune a CVT without having detailed knowledge of the workings of the internal mechanisms. A best tuning strategy has been propose tuning strategy which need the user must go to a facility with consistent track conditions. Then, the user need to make combinations of weights and springs to see which set produces the best performance. After that, the user must decide on the best combination that will produce the desired results for instance maximum top-end speed. He also explained in Chapters 4 and 5 how the common primary and secondary pulleys work.

Further information from SAE paper " A Hybrid Transmission for SAE Mini Baja Vehicles" [5], which describe the design of a transmission involving a CVT and a fixed ratio gear box in the SAE paper. Mark Allen and Robert Le Master from the University of Tennessee at Martin discuss the design of a manual transmission to be used with a Salsbury style CVT. Allen and LeMaster used Lagrange's equations to determine the forces acting in the pulleys. Estimated overall top speed can be achieve based on the gear ratio used in the manual transmission describe by the software.

A title of "A Theoretical and Experimental Procedure for Design Optimization of CVT Belts" [6] published by SAE, Sergio Lolli describes a theoretical and experimental method for designing CVT belts. In this paper Lolli develops equations described the stress within the belt and provide a method for determining the tensile forces seen within the belt. Finite element modeling method was used to determine stresses and predict the lifespan of a CVT belt from the information observed.

Michael A. Kluger and Denis M. Long from the Southwest Research Institute describe several transmission types and their properties in "An Overview of Current Automatic, Manual and Continuously Variable Transmission Efficiencies and Their Projected Future Improvements" [7]. This paper describes the various types of transmissions including: automatic, manual and continuously variable. Further information observes the efficiency as well as the areas for improvement for each, advantages and disadvantages of CVT, and help to determine the overall CVT efficiency at different operating speeds and loading conditions.

From a thesis entitled " A Kinematic Analysis and Design of a Continuously Variable Transmission" [8] Christopher Ryan Willis from the faculty of Virginia Polytechnic Institute and State University describe the method for analyzing and designing Team Industries brand CVT that applied to Virginia Tech Mini Baja Team for use in competitions sponsored by the Society of Automotive Engineers (SAE).

Further MATLAB equation and simulation can obtain from a technical paper entitled "Computer Modeling of CVT Ratio Control System Based on MATLAB" [9] written by Wang Cheng and Jiang Chang-song from Jilin University Changchun, China. They described the modeling of CVT ratio control system and modeling of CVT vehicle. Equation generate below is for the simulation modeling.

The engine dynamic output torque is shown as the following equation:

$$T_{ed} = T_e - \lambda\omega_e \qquad (1)$$

Ted - engine dynamic output torque;

Te - engine steady-state output torque;

λ - correction coefficient;

ω_e- engine angular velocity.

The CVT object ratio includes the optimal-economy object ratio and the optimal-power object ratio according to the engine optimal-economy working mode and the engine optimal-power working mode [4]. The CVT object ratio was shown as the following equations:

$$i_{OS} = B\frac{N_{es}}{V} = \frac{3\pi r_w f_1(\alpha)}{25 i_a V} \qquad (2)$$

$$i_{OE} = B\frac{N_{eE}}{V} = \frac{3\pi r_w f_2(\alpha)}{25 i_a V} \qquad (3)$$

i_{OS} – SVT optimal power object ratio;

i_{OE} – CVT optimal-economy object ratio;

B – object ratio coefficient;

N_{es} – engine optimal-power rev;

N_{eE} – engine optimal-economy rev;

$f_1(\alpha)$ – engine optimal-power curve relation;

$f_2(\alpha)$ – engine optimal-economy curve relation;

i_a – CVT total reduction ratio.

CVT real ratio was shown as the following equation:

$$i = \frac{\omega_{in}}{\omega_{out}} = \frac{\omega_e}{\omega_{out}} \qquad (4)$$

I - CVT real ratio;

ω_{in} - CVT input shaft angular velocity;

ω_{out} - CVT output shaft angular velocity.

The torque of CVT input shaft and output shaft were shown as the following equations:

$$T_{in} = T_{ed} - I_e \frac{d\omega_e}{dt} \tag{5}$$

$$T_{out} = T_d - I_d \frac{d\omega_{out}}{dt} \tag{6}$$

T_{in} - torque of CVT input shaft;

T_{out} - torque of CVT output shaft.

The angular acceleration of CVT input shaft and output shaft were shown as the following equations:

$$\frac{d\omega_e}{dt} = \frac{di}{dt}\omega_{out} + i\frac{d\omega_{out}}{dt} \tag{7}$$

$$\frac{d\omega_{out}}{dt} = \frac{di}{dt}\frac{\omega_e}{i^2} + \frac{iT_{ed} - T_{out}}{i^2 I_e} \tag{8}$$

The torque of driving shaft was shown as the following equations:

$$T_Q = i_O T_{out} = K\theta + C\dot{\theta} \tag{9}$$

$$\dot{\theta} = \omega_w = \frac{\omega_e}{ii_0} i\omega_w \tag{10}$$

i0 - reducer ratio;

TQ - driving shaft torque;

ω_w – wheel angular velocity;

$K\theta$ - torsional stiffness;

$C\dot{\theta}$ – damping coefficient;

θ – driving shaft rotation angle.

The wheel angular velocity was shown as the following equation:

$$\omega_w = \frac{T_Q - T_t - T_b}{I_w} \quad (11)$$

T_t - vehicle driving torque;

T_b - brake torque;

I_w – wheel rotational inertia.

The vehicle driving torque is shown as the following equation:

$$T_t = \left(mgf\cos\theta + mg\ \sin\varphi + \frac{C_D A}{21.15}V^2 + \delta m\frac{dV}{dt}\right) r_w \quad (12)$$

M - whole vehicle mass;

F - rolling resistance coefficient;

φ - slope angle;

C_D - air resistance coefficient;

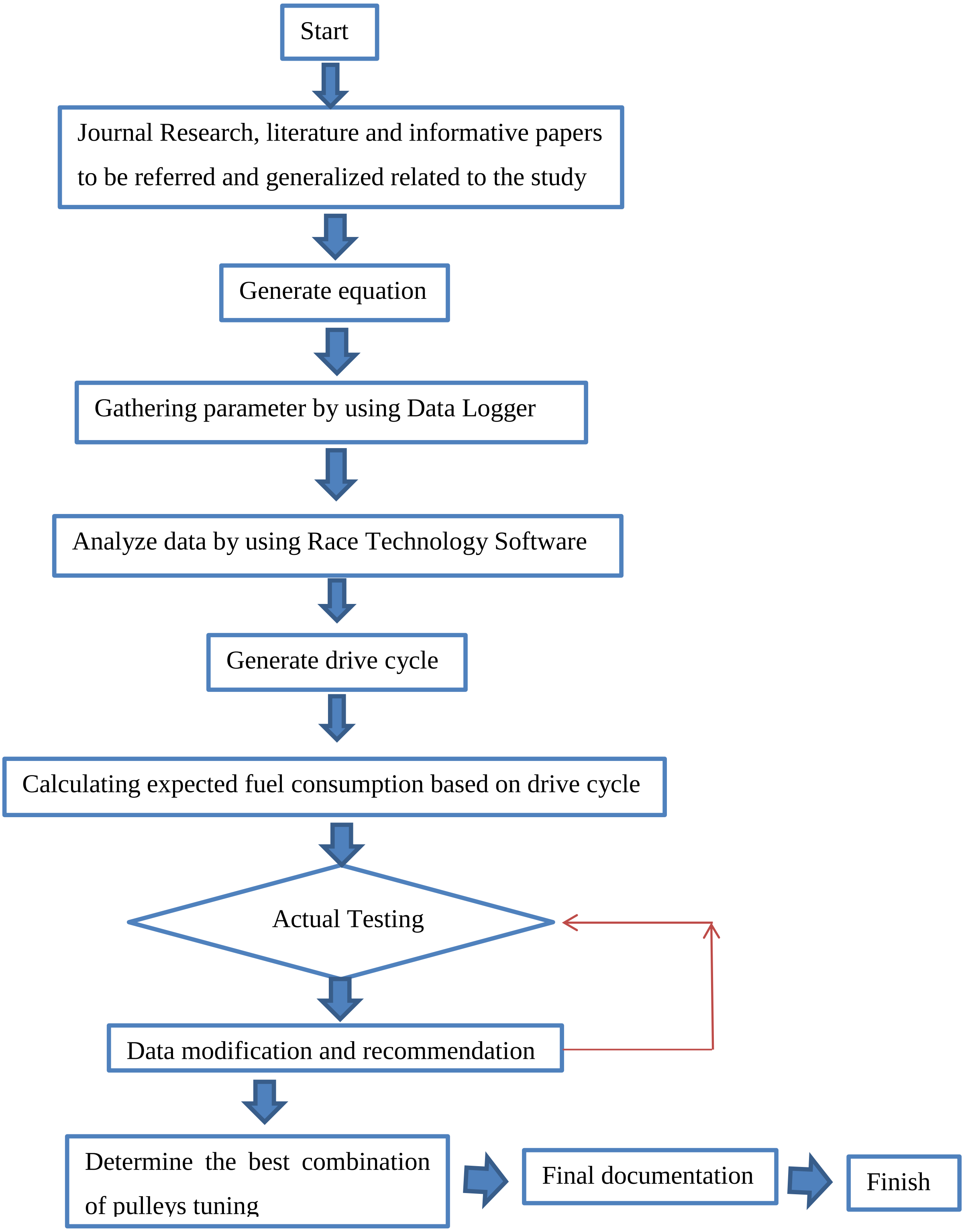
A – frontal area;

δ – vehicle gyrating mass coefficient.

CHAPTER 3: METHODOLOGY

3. METHODOLOGY

3.1 Research Methodology



3.2 Project Activities

The project is following the timeline stated in Gantt chart. After finish installed the engine, CVT, tyres, steering system and braking system, the car has been tested to assure the system is work completely. Then the coast down testing takes place to determine the vehicle parameter and then created drive cycle for Village 4 to be reference for the expected SIC drive cycle and expected fuel consumption. With the same parameter, expected SIC drive cycle was created and expected fuel consumption was calculated. Then, the actual result during competition will be compare with the expected result. After that, the best combination of primary and secondary pulley will be determine respected to the revolution of the pulleys, thus determining the gear ratio provided

Figure 3.1: With team members

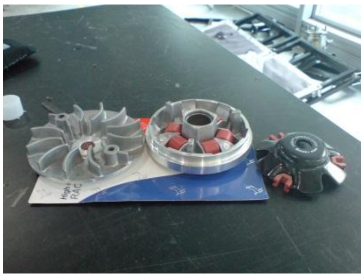


Figure 3.2: Primary pulley with roller weight

Figure 3.3: Gen89 Urban Concept car

Figure 3.4: Testing

Figure 3.5: Data logger

Figure 3.6: Receiver for data logger installed at the car

3.2 Key Milestone

Below is the prospect that would be needed to complete in Final Year Project II:

3.3.1. Further study the characteristics of CVT

3.3.2. Build up the car with all mechanical system workable (steering, brake, etc)

3.3.3. Install engine and CVT to the car

3.3.4. Test drive the car to assure all mechanical system workable

3.3.5. Coast down testing to obtain vehicle parameter

3.3.6. Creating expected SIC drive cycle

3.3.7. Calculate expected fuel consumption for SIC drive cycle

3.3.8. Tuning for the best combination of the pulleys

3.3.9. Final report

3.3 Gantt Chart

No	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Maintaining the study of literature review								Mid Semester Break							
2	Completing the car system															
3	Testing to avoid any error occurs and doing some modification															
4	Equipment preparation for the experiment															
5	Get the result and doing some modification															
6	Results compiled and researches been done															
7	Final report															

Appendix 1: Gantt chart for FYP II

3.4 Tools

The tools and equipment use to tune the CVT are:

Table 3.1: Tools

Tachometer 	To get rpm for primary pulley and secondary pulley
RPM meter 	To get revolution of the engine
Secondary spring 	As variable
10g, 12g roller 	As variable
Air impact gun with set of socket 	To open the nut for primary pulley and secondary pulley
Data logger 	To Create Village 4 drive cycle and doing coast down testing to get vehicle parameter such as drag coefficient and rolling resistance.
Race Technology(RT) Software	Analyze data obtain from data logger that can determine the maximum power, speed, acceleration, vehicle parameter and so on.
Drive cycle spreadsheet (Microsoft Excel)	Generate drive cycle for Village 4 by using data from RT software. Then create expected SIC drive cycle.

CHAPTER 4: RESULT AND DISCUSSION

4. RESULT AND DISCUSSION

4.1 Result

In order to design proper CVT appropriate to the capability of the engine, vehicle parameter such as coefficient of drag, C_d and rolling resistance C_f, expected drive cycle for Sepang International Circuit (SIC), and then fuel consumption based on SIC drive cycle need to be determine. Then tuning of the combination of primary and secondary pulley also important to increase the performance hence improves the efficiency.

4.1.1 Vehicle Parameter

Vehicle parameter such as coefficient of drag, C_d and rolling resistance C_f is calculated by doing coast down testing at 13.2mph @ 21.24km/h at village 4. Total distance for this test is 0.58km.

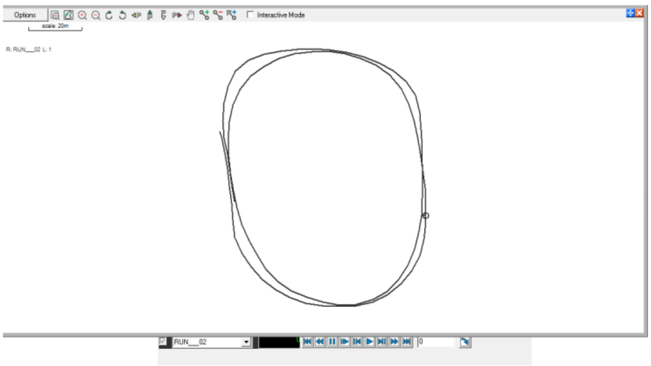


Figure 4.01: Village 4 track testing

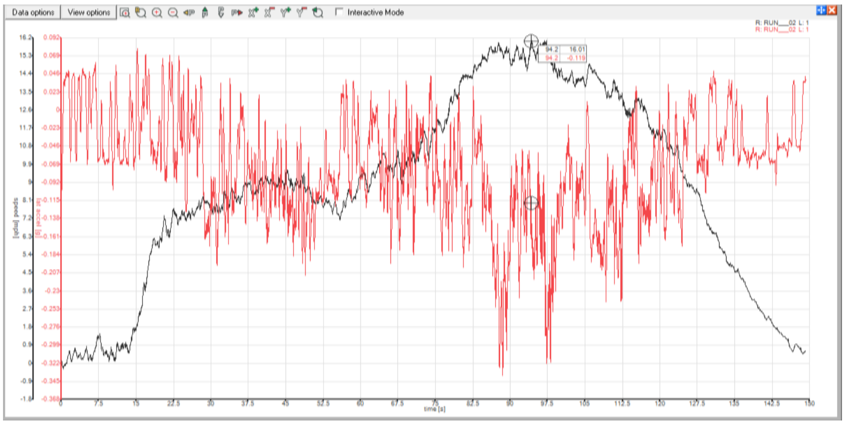


Figure 4.02: Speed and acceleration vs. time

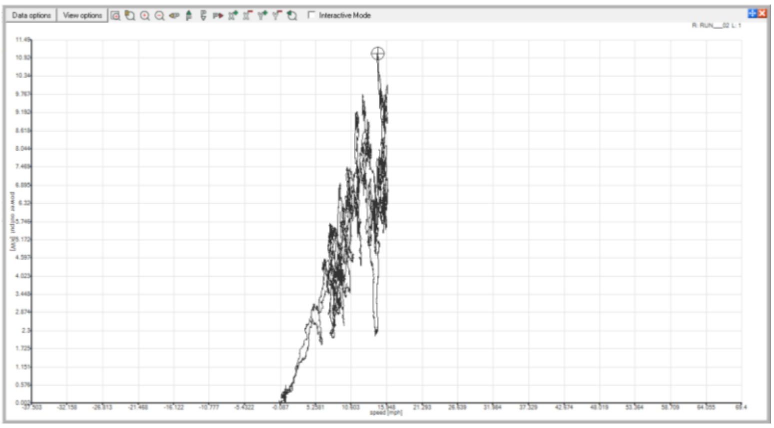


Figure 4.03: Power curve vs. time

A lot of information can be taken from data above as reference. The highest speed achieved is 16.4 mph @ 26.4 km/h which is at 94.2 seconds that occur during acceleration almost zero. Highest acceleration is 0.081g at 21.68 second that occurred at speed of 6.238mph @ 10km/h and the highest power that can be achieved is 11.05kw at 14.59mph. Below is the calculation to determine C_d and C_{rr}.

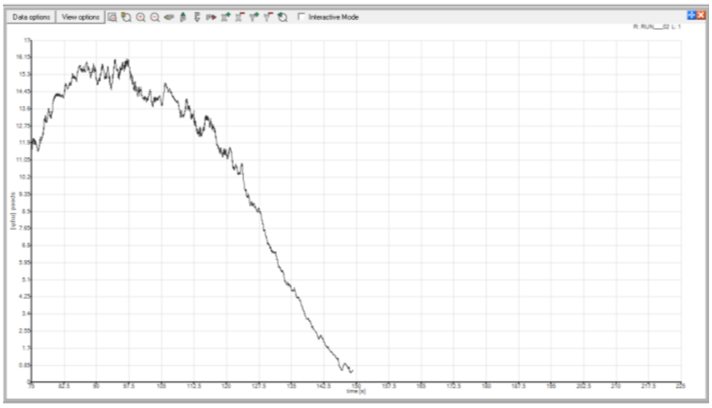


Figure 4.04: Coast down testing data

$$m\left(\frac{dV}{dt}\right) = F_x - C_{RR}W - \frac{1}{2}C_d\rho_{air} - W_\theta$$

$F_x = W_\theta = 0$

Mass of Car = 262 kg

Air density = 1.2 kg/m^3

Frontal area = 0.9m x 1.4m = 1.26m^2

Use point v = 13.2 mph @ 5.9 m/s

$$262(-1.68) = -(262)(9.81)C_{RR} - \frac{1}{2}C_d(1.2)(1.26)(5.9)^2$$

$$C_d = \frac{440.16 - 2570.22C_{RR}}{26.32} \qquad \text{(E1)}$$

Use point v = 2.238 mph = 1m/s

$$262(-0.601) = -(262)(9.81)C_{RR} - \frac{1}{2}C_d(1.2)(1.26)(1)^2$$

$$C_d = \frac{157.46 - 2570.22C_{RR}}{0.756} \qquad \text{(E2)}$$

(E1) = (E2) yields

$$C_{RR} = 0.058$$

Substitute C_{RR} into (E1) yields $C_d = 11.09$

After this test, the total fuel consumption produce by the car is calculated. For a level road with increment of velocity till about 25mph @ 40.2km/h, about 14.5ml of fuel was used. The total consumption for Village 4 drives cycle as below:

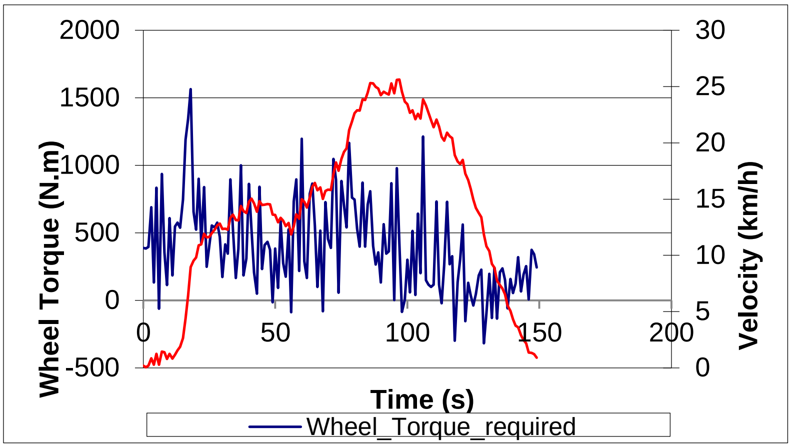


Figure 4.054: Village 4 drive cycle

$$\text{Total fuel consumption} = \frac{0.58km}{0.0145l}$$

$$= 40km/l$$

4.1.2 SIC Drive Cycle

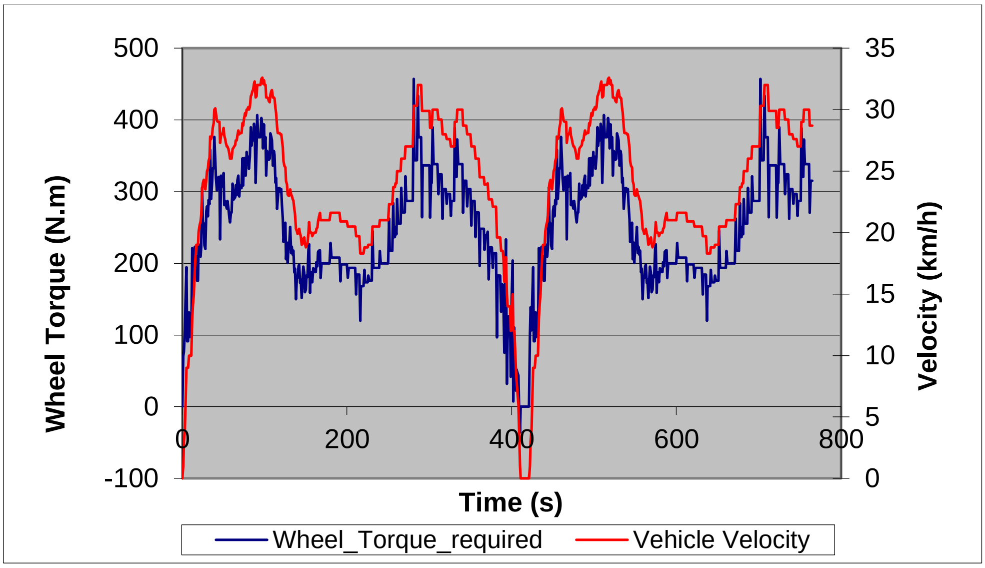


Figure 4.06: SIC expected drive cycle

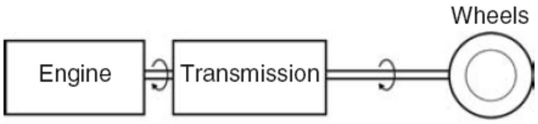


Figure 4.07: Configuration of the drivetrain

From drive cycle above, the maximum wheel torque that can be achieved is 457 N.m at speed of 30.3km/h that produce power at the wheel 8.552kW. Average speed for every single lap is about 15km/h @9.32mph that can produce 223 N.m of wheel torque with power at the wheel is 2.34kW. The configuration from the engine to the wheel and calculation of total fuel consumption for SIC drive cycle are as below:

$P_{w,}$ Power at the wheel 2.34 kW

P, Power = P_w x gear ratio (assumption of gear ratio = 1)

$$P = 2.34 \times 1 = 2.34kW$$

N, Number of gallons of gas in tank less reserves = 0.0925gal

V, Velocity = 15km/h @ 9.32mph

e_G, energy density of gasoline = 33.7 kWh/gal

Energy of full gas in tank less reserves = e_G x N

$$Eg = \frac{33.7kWh}{gal} \times 0.0925gal = 3.117\text{kWh}$$

Range for the vehicle, $R = \frac{\text{VE}}{\text{P}}$

$$R = \frac{(9.32mph \times 3.117kWh)}{2.34W} = 12.41\, miles$$

Miles per gallon, $mpg = \frac{R}{N}$

$$mpg = \frac{12.41miles}{0.0925gal} = 134.16\, mpg\ @\ 57.04\, km/l$$

With SIC drive cycle, expected total km/l produce is higher than the coast down testing at Village 4 which is only produce 40km/l.

4.1.3 Tuning for best combination of primary and secondary pulley

In order to increase the efficiency and performance of the CVT, the best combination of the primary and secondary pulley need to be determined. This tuning process consist of two type of testing which are testing without load and testing with connected to the load. The variable for these testing are 12g roller weight, 10g roller weight, high stiffness of secondary pulley and low stiffness of secondary pulley.

The results obtain from experimental test measurement using tachometer to determine the rpm for the primary pulley and secondary pulley. This method can be determine by constant the revolution of the engine, then measure the revolution for the driven pulley and secondary pulley which respect to the revolution of the rpm.

4.1.3.1 Testing without load

12g roller weight with high stiffness secondary pulley

First, without connected the load to the output by using the highest stiffness secondary pulley with the weight roller 12g, the revolution of primary pulley and secondary pulley were taken as data. Then, increase the revolution of the engine and repeat the same procedure to determine the gear ratio till the maximum revolution of the engine.

Below is the result:

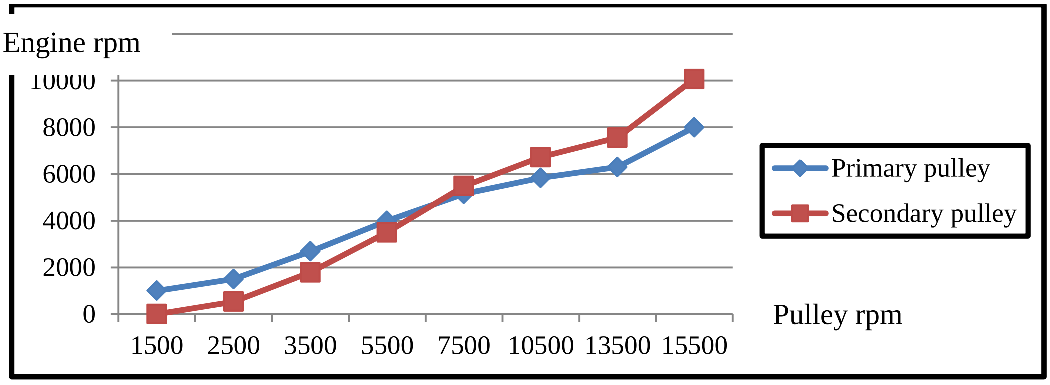


Figure 4.08: Data for 12g roller weight with high stiffness secondary spring

10g roller weight with high stiffness secondary pulley

Change the roller weight from 12g to 10g without connected the output to the load. The result obtain is:

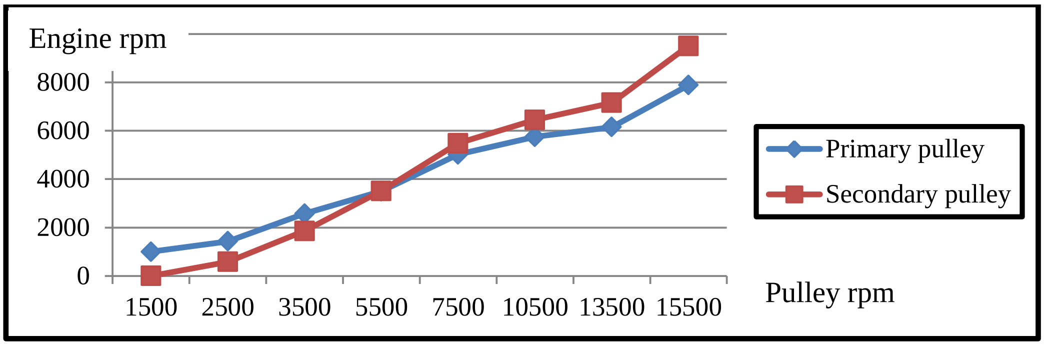


Figure 4.09: Data for 10g roller weight with high stiffness secondary spring

12g roller weight with low stiffness secondary pulley

Change the stiffness of the spring to the lower stiffness with the roller weight 12g and the result is as below:

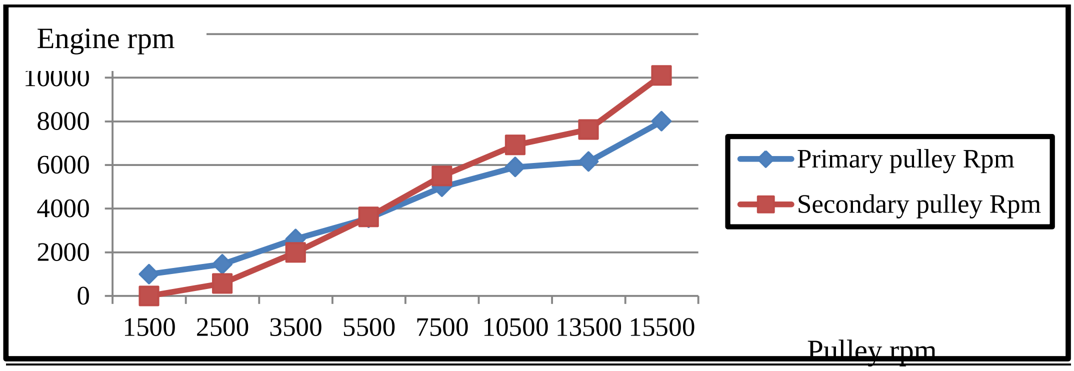


Figure 4.10: Data for 12g roller weight with low stiffness secondary spring

4.1.3.2 Testing with connected to the load

12g roller weight with high stiffness secondary pulley

After that, by applying load with roller weight 12g and high stiffness secondary spring, the result as below:

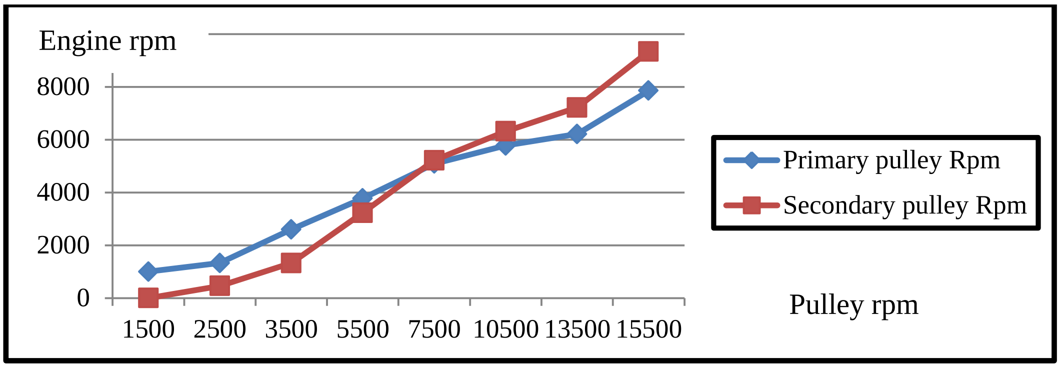


Figure 4.11: Testing with load

4.1.4 Actual result during competition

Figure below show the actual result during competition which the car can only produce 37km/l.

Rank	Team no.	Team name		Institution name	Competition category	Energy type	Best result (km/l)
1	515	Cikal Cakrasvarna		Institut Teknologi Bandung	Urban concept	Gasoline	196
2	511	Sadewa		Universitas Indonesia	Urban concept	Gasoline	152
3	516	Zeal Eco-Power UC		Tongji University	Urban concept	Gasoline	108
4	513	Mesin Polnep 3		Pontianak State of Polytechnic	Urban concept	Gasoline	91
5	504	UMech-i		University of Malaya	Urban concept	Gasoline	85
6	522	SAE UTM SECOM		UTM Sekudai, Johor (Undergraduate)	Urban concept	Gasoline	81
7	521	HORAS		University of Sumatera Utara	Urban concept	Gasoline	79
8	519	Putra Siliwangi		Universitas Pendidikan Indonesia	Urban concept	Gasoline	75
9	507	NUSTAG UC		National University of Sciences and Technology	Urban concept	Gasoline	68
10	506	NUST-PNEC-Urban		National University of Sciences and Technology	Urban concept	Gasoline	66
11	512	PNJ-1		Politeknik Negeri Jakarta	Urban concept	Gasoline	58
12	510	NED Pakistan		N.E.D University of Engineering and Technology	Urban concept	Gasoline	50
13	503	Team Lakshya		Chitkara Institute of Engineering and Technology	Urban concept	Gasoline	49
14	518	Curtin Eco Racing Team (CERT)		Curtin University Sarawak	Urban concept	Gasoline	43
15	517	Kanayakan 21		Bandung Polytechnic for Manufacturing	Urban concept	Gasoline	41
16	509	YUSAE		Yeungnam University, Republic of Korea	Urban concept	Gasoline	39
17	508	UTP Gen89		Universiti Teknologi PETRONAS	Urban concept	Gasoline	37

Figure 4.12: Actual result during competition [1]

4.2 Discussion

There's a lot of difference in the result of Village 4 drive cycle, expected SIC drive cycle and also the actual run during competition. For Village 4 drive cycle, only 40km/l produce while expected SIC drive cycle is 41.75km/l and only 37km/l for actual result during competition. The difference between theoretical and actual is:

Percentage difference= (|Actual value - Theoretical Value| / Theoretical Value) x 100

$$\% = |(37km/l - 57.04km/l)|/57.04km\ \ /l\ \ \times 100\%$$
$$= 35.13\%$$

The differences are cause by several effects such as the vehicle parameter, weight, driver input, traffic, weather, and so on. For vehicle parameter likes drag coefficient, rolling resistance, head or tail wind, gradient are difference depends on the road load and situation. The upwards gradient for the track is 3.675%, and downwards gradient is 5.625%. The total weight also effect by increasing the value of it because of the weight of ballast, equipment, helmet, racing suit and others.

Driver input also is one of the important factors that contribute to the difference. The driver need to determine the load required for acceleration, constant speed, cornering by adjusting the throttle, braking, shut off the engine and so on. Difference driver, difference lap will obtained difference result. Weather and temperature of the track also related since it will change the air fuel ratios that conduct to difference mass flow rate of air and fuel required.

The efficiency and performance of CVT can be increase by tuned the combination of primary pulley and secondary pulley. The differences of roller weight which is located in the primary pulley will conduct to the difference result. The differences of the stiffness of the secondary spring also conduct to difference result.

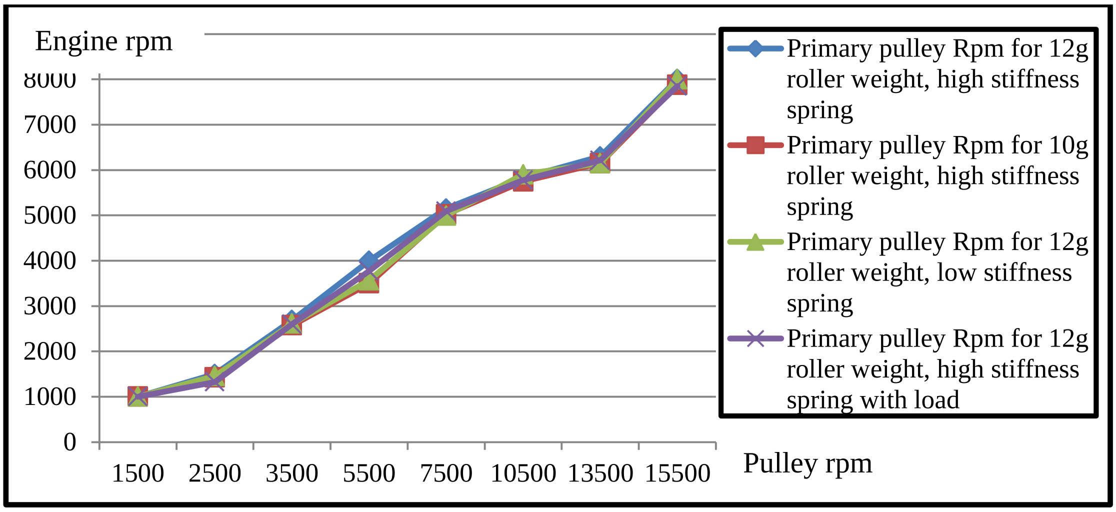


Figure 4.13: Graph for primary pulley

By refer to the chart above, using of 12 g roller weight need to increase the engine rpm to engage the secondary pulley which slowing down the changing of the gear ratio at low rpm and will be useful during high rpm. The revolution of the primary pulley for 12g roller weight at higher rpm is greater than 10g roller weight. During low rpm, the centrifugal force for the 12g roller weight that occurs is lower than 10g. Then, with the aid of the inertia, the centrifugal force become greater at high rpm then provides more power during overdrive.

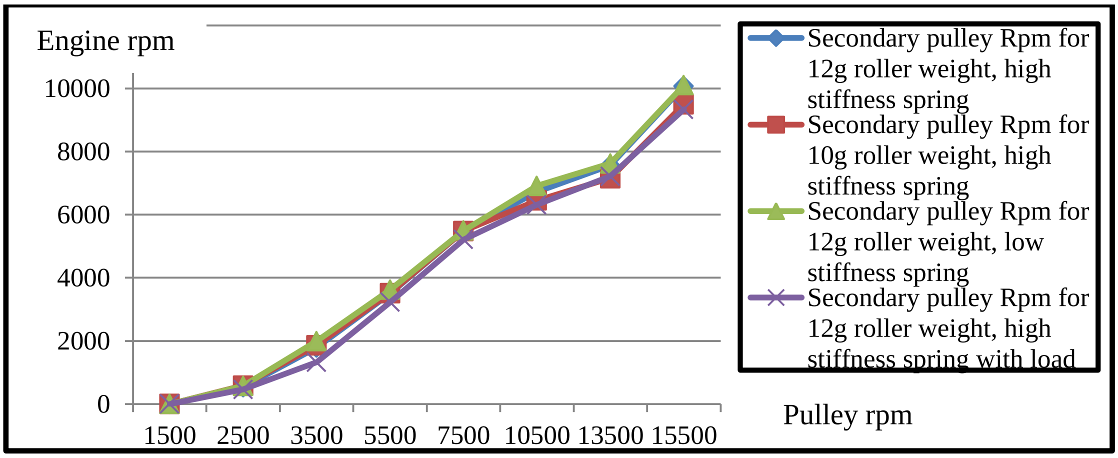


Figure 4.14: Graph for secondary pulley

While for the secondary pulley, the effect of 10g roller weight is allowing the earlier engagement than 12g roller weight. Use of low stiffness secondary spring will promote better down shifting, resulting in improved acceleration and a higher overall speed. In some cases such as climbing hill, the low stiffness of secondary spring will make the slip of the belt occur since the load is high.

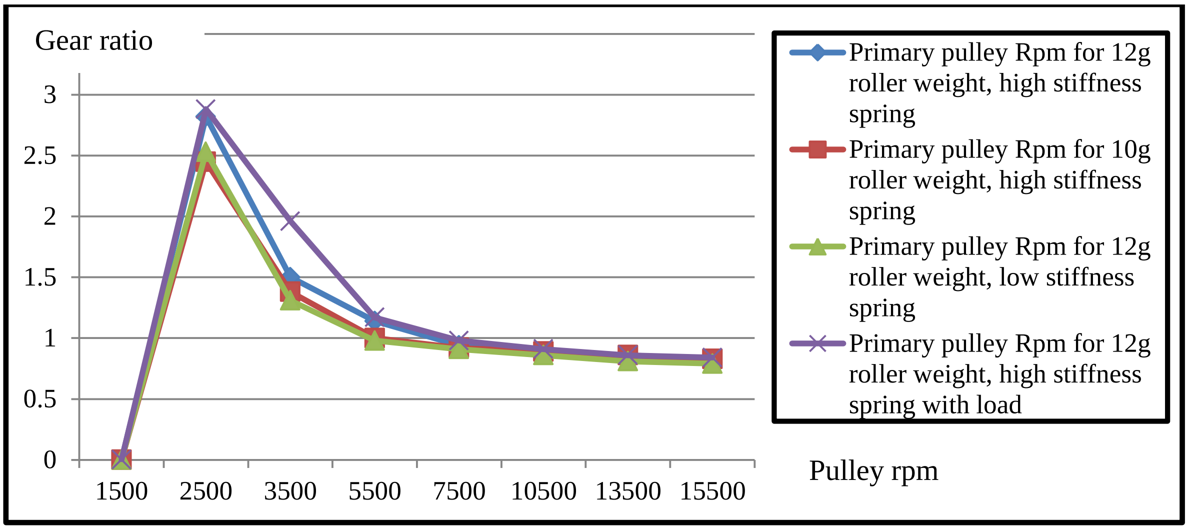


Figure 4.15: Graph for gear ratio

From the chart above, the changing of the gear ratio is very smooth. Thus provide uninterrupted power without step discontinuities and without jerk. It naturally changes ratio continuously lead to steady acceleration. This distinguishes the advantages of using CVT and other conventional transmission. So, the best combination for the CVT is using 10g roller weight and low stiffness secondary spring to provide early engagement, improve acceleration and higher overall speed.

CHAPTER 5: CONCLUSIONS

5. CONCLUSIONS

5.1 Conclusion

The study on behavior characteristics and parametric of CVT for designing the transmission for GEN89 urban car is important in order to improve the fuel efficiency. The objectives shown in Section 1.3 could be achieved within the time given as stated in Gantt chart.

Based on the result and discussion in section 4.1 and 4.2, the km/l produce by the car during competition 37km/l, while the expected km/l produce is about 57.04km/l. Since the difference is only 35.13%, the result is accepted. Besides that, the CVT is appropriate with the capability of the engine since the gear ratio is varied form the lower rpm to high rpm of the engine. The highest gear ratio that can be achieved is 2.88 while the lowest gear ratio is 0.79. The best combination for the CVT is using 10g roller weight and low stiffness secondary spring to provide early engagement, improve acceleration and higher overall speed.

Thus, with this advantages CVT provide the smooth changing of gear ratio without step discontinuities, without jerk and increase the fuel efficiency.

5.2 Recommendation

A big difference obtained if comparing the result of the car with the best result which is 196km/l than 37km/l. A lot of improvement needed to increase the result. For CVT, mechanical control is not sufficient enough to assure the engine load passes through the CVT is working at optimum condition. The mechanical control just depends on the centrifugal force acting on the roller weight and also the stiffness of the spring. This transmission should have PID controller which required a lot of sensors and electrical devices that give feedback to correct the ratio thus conduct to work at optimum condition.

Another improvement should be considered is the engine performance. This also plays the main role to obtained fuel efficiency. The engine chosen for this car need to work at high rpm to work at optimum condition thus required a lot of fuel during low rpm. The modification should be done such as lighten the engine, remapping the CDI, using EFI, remapping the camshaft and so on.

Lastly, the material selection to develop the chassis and body panel is also important which is affecting the total weight of the car. Stainless steel is use for chassis while using aluminum sheet and Perspex for body panel. Aluminum alloy should be used for chassis while using carbon fiber for the body panel for better reduction of weight.

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APPENDICES

Appendix 2: Coast down testing

Appendix 3: The car being tow because of breakdown

Appendix 4: The car on the track

Appendix 5: The rate of fuel used calculated

Appendix 2: Table data for 12g roller weight with high stiffness secondary spring

Engine Rpm	Primary pulley Rpm	Secondary pulley Rpm	Gear Ratio
1500	1000	0	0
2500	1500	532	2.82
3500	2687	1790	1.50
5500	3997	3500	1.14
7500	5150	5483	0.94
10500	5831	6725	0.87
13500	6298	7561	0.83
15500	8004	10070	0.80

Appendix 3: Table data for 10g roller weight with high stiffness secondary spring

Engine Rpm	Primary pulley Rpm	Secondary pulley Rpm	Gear Ratio
1500	1000	0	0
2500	1429	584	2.45
3500	2575	1862	1.38
5500	3500	3513	1.00
7500	5022	5483	0.92
10500	5750	6450	0.89
13500	6150	7155	0.86
15500	7882	9500	0.83

Appendix 4: Data for 12g roller weight with low stiffness secondary spring

Engine Rpm	Primary pulley Rpm	Secondary pulley Rpm	Gear Ratio
1500	1000	0	0
2500	1455	575	2.53
3500	2612	1993	1.31
5500	3568	3622	0.98
7500	4993	5500	0.91
10500	5903	6911	0.86
13500	6150	7622	0.81
15500	7996	10100	0.79

Appendix 5: Testing with load

Engine Rpm	Primary pulley Rpm	Secondary pulley Rpm	Gear Ratio
1500	1000	0	0
2500	1326	460	2.88
3500	2599	1324	1.96
5500	3772	3228	1.17
7500	5092	5215	0.98
10500	5777	6314	0.91
13500	6213	7218	0.86