Design and Fabrication of Drive Train System for Bosch Power Tools Cordless Race 2011

by

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Dissertation submitted in partial fulfillment
of the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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CERTIFICATE OF APPROVAL

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Approved by,

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(Ir. Dr. Masri Baharom)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
SEPTEMBER 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MOHAMAD MOHAIMIN BIN MOKHLIS

ABSTRACT

Drive train system is a system to transmit power from one or multiple energy source to one or multiple output. It is an important component in vehicle to provide the driving power to move the vehicle. Drive train can be powered by an engine or motor. In this project, a drive train system is required to be designed and fabricate using BOSCH power tools as the power source for an international competition. The project aims to design a reliable drive train system that use power tools as power source that is fabricated according to design and calculation done. The system design is required to meet the regulation uphold for the competition. The finished drive train is test by accelerating the kart to maximum possible speed in a test track, which is decided at Village 4's parking lot, Universiti Teknologi PETRONAS. From the testing done, the system able to achieved top speed of 36km/h average. The speed is sufficient and reliable for the competition race track. At the end of the project, the drive train is proven to provide reliable output for the operation

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Final Year Project (FYP) is a compulsory subject that is undertaken by all the final year students. The objective of the FYP is to enhance the students' skills in knowledge application in solving design problem and/or gain and expand the knowledge by conducting research study in their respective major and course. FYP consists of two parts which are Final Year Project 1 (FYP1) and Final Year Project 2 (FYP2) respectively and it is conducted in two semesters. The students are require to do a design and/or research-based project independently with minimal guidance from their supervisor.

The author has chosen a design project entitled 'Design and Fabrication of Drive Train System for BOSCH Power Tools Cordless Race 2011'. The project is based on an international competition organized by the Robert Bosch GmbH which is BOSCH Power Tools Asia Cordless Race 2011. 5 countries have been selected for participating in the event which is Malaysia, Philippines, Thailand, South Korea and China. In the competition, a team of 5 members need to build a power tools powered kart for the race. The race aims to cultivate an innovative mindset by challenging the university student in designing the kart. The author involve in the team specifically in the drive train system where it is powered by 4 power tools. A thorough study on designing the drive train with respect to the competition's rules and regulation is need to be done in order to achieve maximum performance possible. The project is done in parallel with Muhammad Ridhwan bin Abdul Razak which conducts a design project with title 'Design and Fabrication of a Racing Kart for BOSCH Power Tools Asia Cordless Race 2011 (Chassis & Steering Components)'.

1.2 Problem Statement

For the competition, the team requires to built a kart that powered by a special drive train that driven by power tool. The team needs to build a high speed kart in order to win the race. The system need to be reliable in the operation which will minimize breakdown. Furthermore, the drive must be completed for installation to the kart before the race day.

1.3 Significant of the project

The project aims to achieve the best configuration of the drive train system which results to optimal output needed. This will help the author in further learning and understanding in how to optimize a drive train mechanism in order to achieve continuous high speed operation.

1.4 Objective and Scope of Study

The objectives of the project are as followings:

i. To design a drive train system that use power tools as power source.
ii. To fabricate the drive train according to the design and calculation done.
iii. To optimize the drive train system to improve the system reliability

The scope of the study in this project involves in design and fabrication process. The aim of the project is to create a reliable drive train that can produce highest performance possible while considering the limitation of the design and the power tools. The project will consist mainly in application of power transmission calculation.

1.5 The Relevancy of the Project

The relevance of the project lies on power transmission of a vehicle which is related to automotive major. Transmission analysis is done to measure the performance and reliability of the drive train system to move the vehicle for it desire operation. Furthermore, the author has been exposed to power tools production at Robert Bosch (Power Tools) Sdn. Bhd., Penang during his internship period.

1.6 Feasibility of the Project within the Scope and Time Frame

The project is planned so that it fit into the given time. All the planned activities and timeframe allocated shown in the Methodology section.

CHAPTER 2

LITERATURE REVIEW

2.1 Drive Train Overview

Drive train is a system to transmit power from one or multiple energy source to one or multiple output. An efficient way of transmitting power is using rotary motion via shaft that is supported by bearings. Each shaft can be connected using gear, belt, pulley or chain sprocket mechanism [1]. However, each mechanism has a range of efficiency in power transmission between shafts. Table 2.1 below showed the typical power transmission efficiency for each type of mechanism. [2]

Table 2.1: Typical power transmission efficiency

Machine	**Typical Efficiency**
V-belt drives	95%
Timing belt drives	98%
Poly-V or ribbed belt drives	97%
Flat belt drives, leather or rubber	98%
Nylon Core	98% to 99%
Variable speed, spring loaded, wide range	
V-Belt drives	80% to 90%
Compound drives	75% tp 90%
Cam-reaction drive	95%
Helical gear reducer	
Single-Stage	98%
Two-stage	96%
Worm gear reducer	
10:1 ratio	86%
25:1 ratio	82%
60:1 ratio	66%
Roller Chain	98%
Lead Screw, 60 deg helix gear	65% to 88%
Flexible coupling, shear type	99%+

To ease the project flow in design process, the scope of possible type of transmission is narrow down to gear, belt, and chain sprocket mechanism only.

2.2 Overview on Past Design

This year, the competition is held for the third time which is held in Asia region. Previously, the first competition is organized in Germany only, follow by second competition in China only. The competition is considered as a new event hence there is not much data regarding the event in the web. The only data available is from the second competition held in China. The competition use BOSCH GSR 18V-Li Professional tools (see figure 1 & 2) which has maximum torque of 56Nm for speed 0-400rpm and 18Nm for 0-1300rpm.[3] The tool has lower torque and speed compared to the current one. Figure 2.1 until figure 2.3 below are the previous design done by some competing team in the second competition in China. [4]

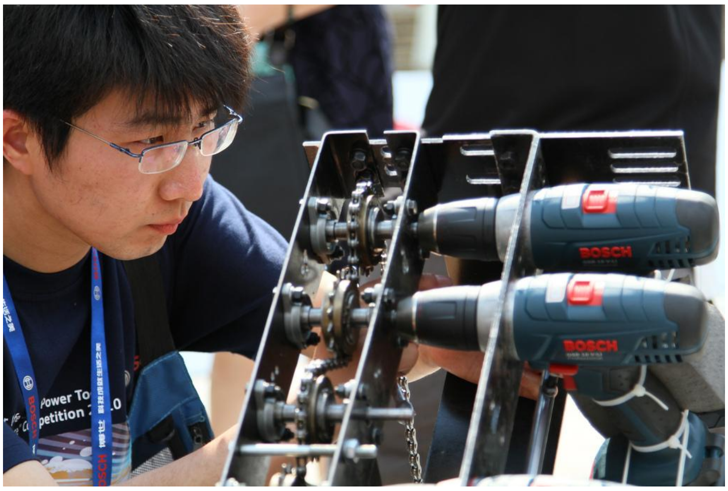

Figure 2.1: Competing Team A

Figure 2.2: Competing Team B

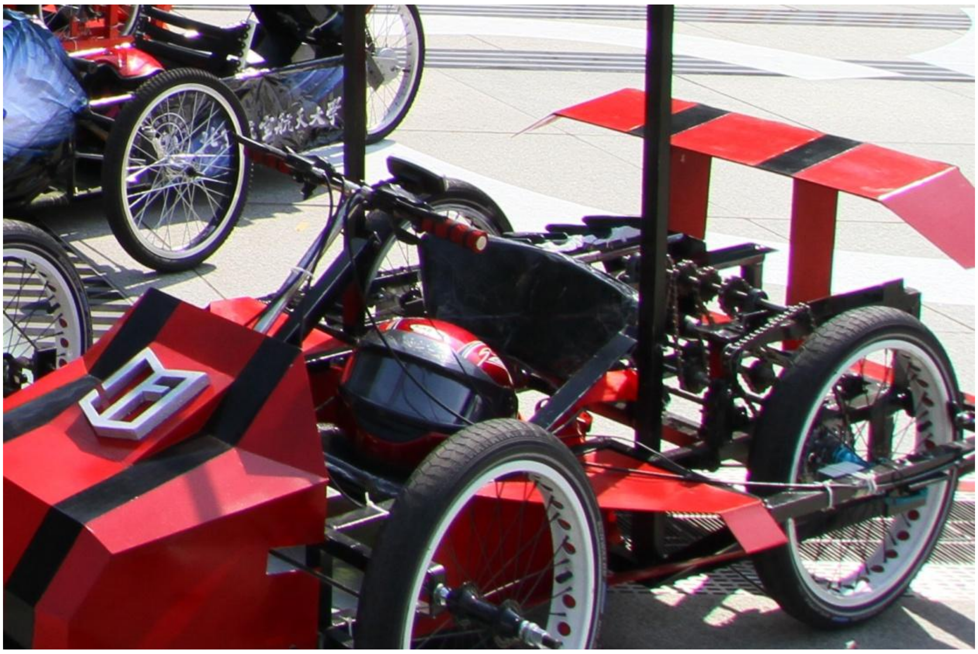

Figure 2.3: Competing Team C

Based on the observation, Figure 2.1 and 2.2 use a series assembly mechanism to combine the torque and speed of 4 tools. While, Figure 2.3 show the possibility of a parallel assembly mechanism in use.

2.3 Rules and Regulation Overview

In this competition, there are rules and regulations that need to be follow by the participant. The list of article is related to drive train design where all of it needs to be considered during the design stage. Table 2.2 shows the rules and regulation stated by the organizer on drive train aspect. [5]

Table 2.2: The Rules and Regulation of Bosch Power Tool Asia Cordless Race 2011

Aspect	Detail
1. Motor	a) The drive train shall be resolved by the use of the provided power tools b) The provided power tools may not be modified for the purpose of it to be used, it cannot be disassembled (it must not lose its original function as a drill/driver) c) for the drive of the vehicle only the individual batteries of the 4 pieces of provided power tools may be used (modification not allowed) d) For the drive all 4 power tools provided shall be utilized. e) The individual batteries of the power tools used may be utilized in the course of the preparation process. For the while period of the competition the batteries of required quantities and charge-up shall be provided to the teams by the organizer
2. Drive Chain	a) The application of free-wheel in mandatory

In addition, the drive train must be powered purely using the power tools without any additional energy source including solar-powered. Implementation of re-charging of batteries via electrical method is also prohibited since it involves tool modification. However energy saving method is allowed such as installation of flywheel.

2.4 Power Tool Specification

Power tools that used for the energy source are Bosch GSB 18V-Li Professional tools (Figure 2.4). A total of 4 power tools are required to power the drive train as mentioned by the organizer. This power tools is the latest product launched by Robert Bosch GmbH which has superior performance than their predecessor. Table 2.3 is shows the product specification of Bosch GSB 18V-Li Professional tool. [6]

Figure 2.4: BOSCH GSB 18V-Li Professional

Table 2.3: BOSCH GSB 18V-Li Professional product specification

Item		Value
Battery voltage [V]		18
Battery capacity [Ah]		2.6 or 3.0
Cell Technology		Li-ion
Charging time [min] : AL1860CV / 1820CV		Ca. 30 / 75
Tool length [mm]		195
Tool height [mm]		248
Weight including battery [kg]		1.9
Chuck capacity, max [mm]		13
Impact rate [BPM]		0-25,500
No. load speed [RPM] :1st /2nd gear		0 – 500 / 1,700
Max. torque [Nm] : Hard/ Soft Joint		67/ 28
Max. drilling diameter [mm]	Wood	35
	Steel	13
	Masonry	13
Max. screwing diameter [mm]		8
Clutch settings		18 + 1
LED light		Yes

2.5 Race Track Overview

Prior to design and fabrication of the drive train, the race track is analyzed. This is necessary to avoid under-design or over-designed of the vehicle in order to achieve optimum operating condition for the race. The race track is shown is Appendix 1.

The total length of the track is approximately 270 meters. It consists of one straight path with (length = 120m) and two corner path (length=18m) and barricade challenge path at one side. From the track length, the kart is estimated to have an average speed between 20-30km/h. Therefore, the drive train system need to be designed at higher top speed to gain the average speed required.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

For the completion of the project, the works are separate into two parts which are FYP1 and FYP2 respectively. In FYP1, the author need to do literature review on the matter regarding designing the drive train system. Preliminary design and material selection will be done during the stage. FYP2 will comprise the fabrication of the drive train system that result from the final design analysis and material selection process. The overall overview of the project flow is shown in Figure 3.1. The proposed timeline for the project is shown in Table 3.1 and Table 3.2.

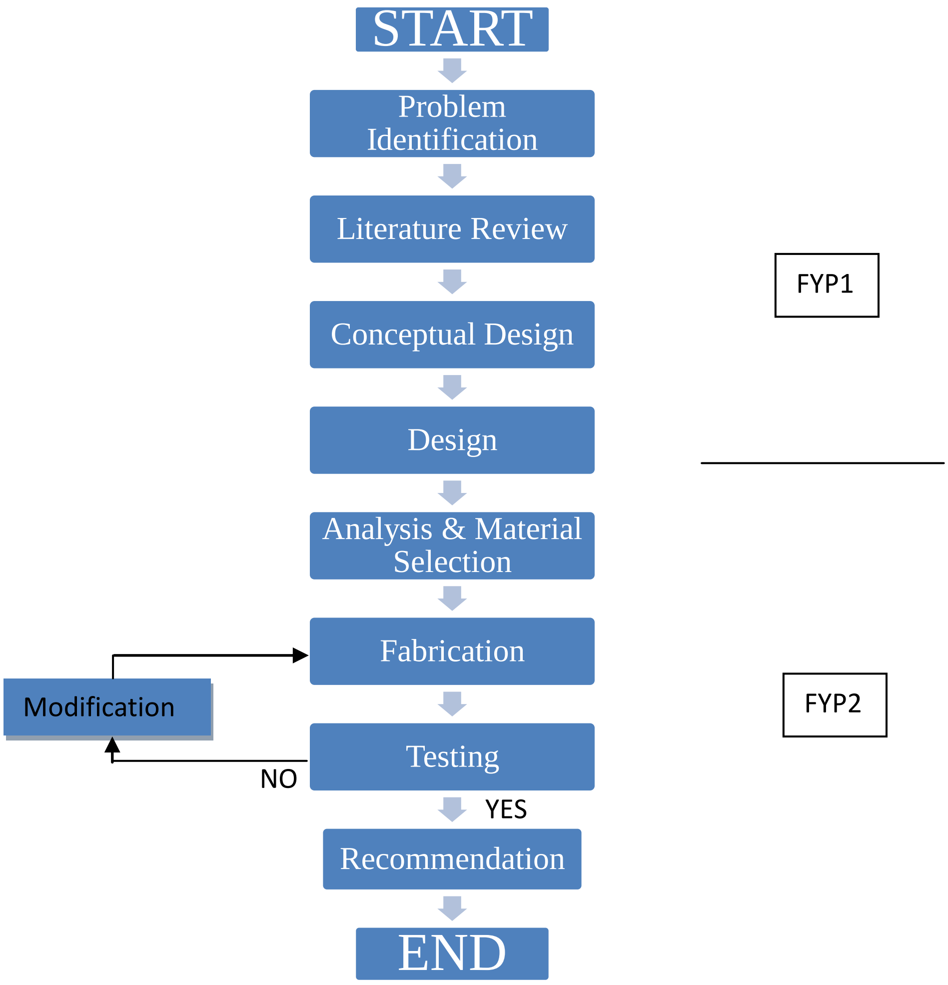

Figure 3.1: Project Flow

3.2 Project Activities

Project activities that required in order for project completion are:

1) Design Concept

The drive train's design criteria is done and analyzed. Several configuration are listed down and decision matrix is made. Finalized design is proceed with CATIA Modeling.

2) Modeling and Analysis

The drive train is design using CATIA V5 R17 and the analysis calculation is done using Microsoft Excel.

2) Material Selection

The activity is done to identify the best material for the drive train fabrication.

3) Fabrication

Fabrication of the drive train is done according to design and calculation done either for prototype or final product.

4) Troubleshooting

Activity of problem identification and troubleshoot to improve the reliability and drive train performance.

3.3 Gantt Chart

The Gantt chart below is showing the proposed allocation of the project task throughout the FYP1 and FYP2 weeks.

Table 3.1: FYP1 proposed timeline

Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project Selection														
Literature Review														
Extended Proposal														
Proposal Defense														
Preliminary Design Process														
Material Selection														
Interim Report														

Table 3.2: FYP2 proposed timeline

Detail/Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Design Process															
Fabrication Process															
Progress Report															
Product testing and optimization															
Pre-EDX															
Draft Report															
Dissertation and Technical Paper															
Oral Presentation															
Project Dissertation															

3.4 Tools Required

For the designing and analysis process, CATIA V5 will be used extensively in modeling of the product and Microsoft Excel will be used for calculation process. The fabrication process will take place at common workshop lab at block 21 for hands work while some CNC fabrication will take place at block 16 lab. Afterward, the kart is transferred to SAE lab at Automotive Research Lab (Block N1) for testing and troubleshooting. The output of the testing will be taken using a gps logger device to track the speed of the kart.

3.5 Testing Methodology

The purpose of the testing is to measure the performance of the kart to compare with the analysis that has been done. The testing is done by accelerating the kart to maximum speed possible. The kart's speed is taken using GPS logging device. From the speed graph, the input of the power tools can be calculated. The testing is done at Village 4 parking lot where it is the largest available parking lot for the testing in UTP. In the testing, the kart will be driven for 3 rounds around the test area. Figure 3.2 show the test track that is use for the testing. It is consists of two line straight path with two circular path. The straight path is approximately 128m while the cornering distance will be 20m.

Figure 3.2: Test Track

CHAPTER 4

DESIGN AND CALCULATION

4.1 Design Concept

Before a design can be done, the design concept must be listed and understood. For the product, the preliminary design concepts are as stated below:

i) Simple and Compact design

The drive train needs to be compact due to space provided for the installation of the system on the kart is limited. The system should not have been too complex on the operation.

ii) Easy for fabrication and maintenance

Due to time constraint, the fabrication process needs to be simplified. Therefore, the system should not be too complicated to be built. The parts that need to be bought must be easy to get. The system must also easy for maintenance for troubleshooting the system.

iii) Power Tool Synchronization

There are four power tools attached to the system. Since each power tools need to be individually operated, there will be slightly variance on the power tools speed. The system built need to have function to compensate the synchronization between power tools. The system needs also a function to be operated with less than 4 power tools in case of any power tool failure. The failure should not affect the other power tools during operation.

iv) Aesthetic

The system should have aesthetic value.

v) Efficient

The system need to be efficient in transmitting the required power.

4.2 Preliminary Design

Some of preliminary design has been done regardless of the preliminary design concepts stated in section 4.1. This is done to list out any possible arrangement that can fit the main purpose which is to drive the vehicle. Below are some of the early designs done. The kart is designed with two front wheel and 1 rear wheel. Therefore, the drive train system will connect to the 1 rear wheel. Figure 4.1, 4.2,4.3,4.4 showed some of the preliminary design that has been done.

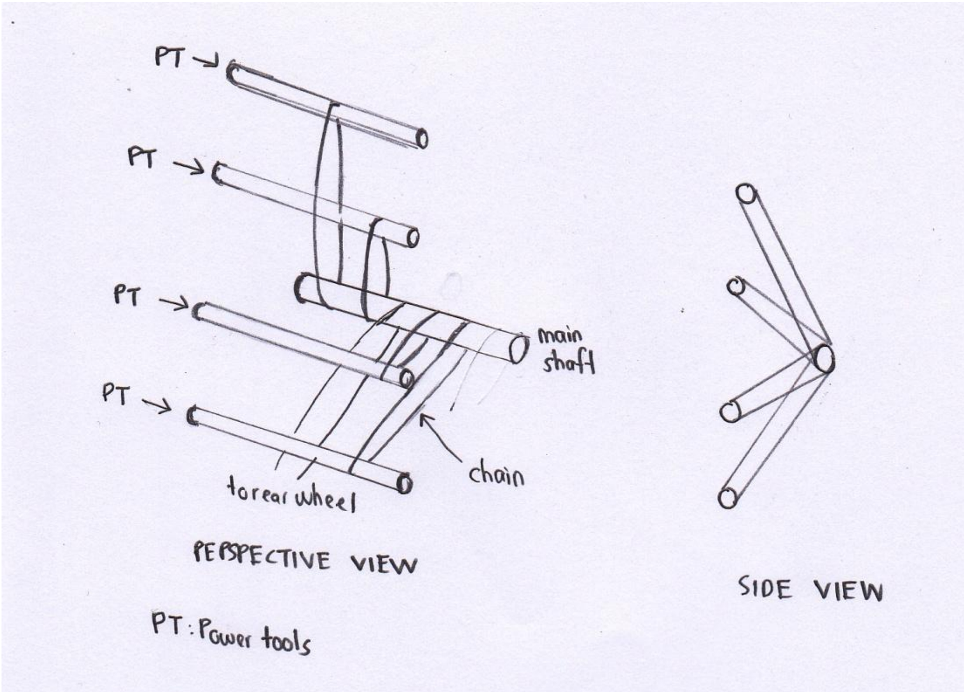

Figure 4.1: 1st Design

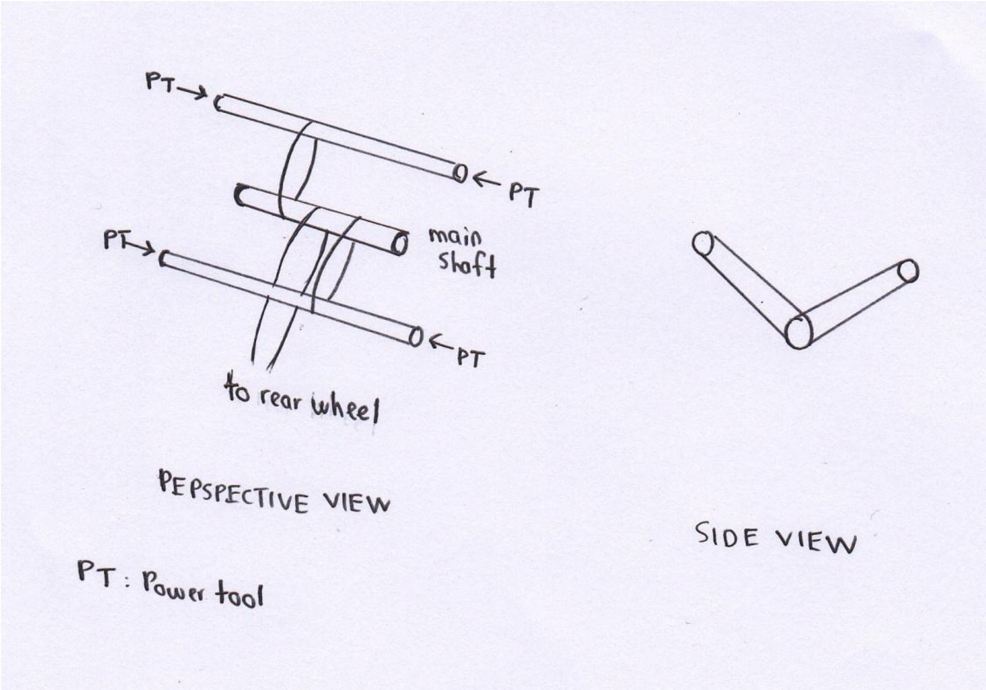

Figure 4.2: 2nd Design

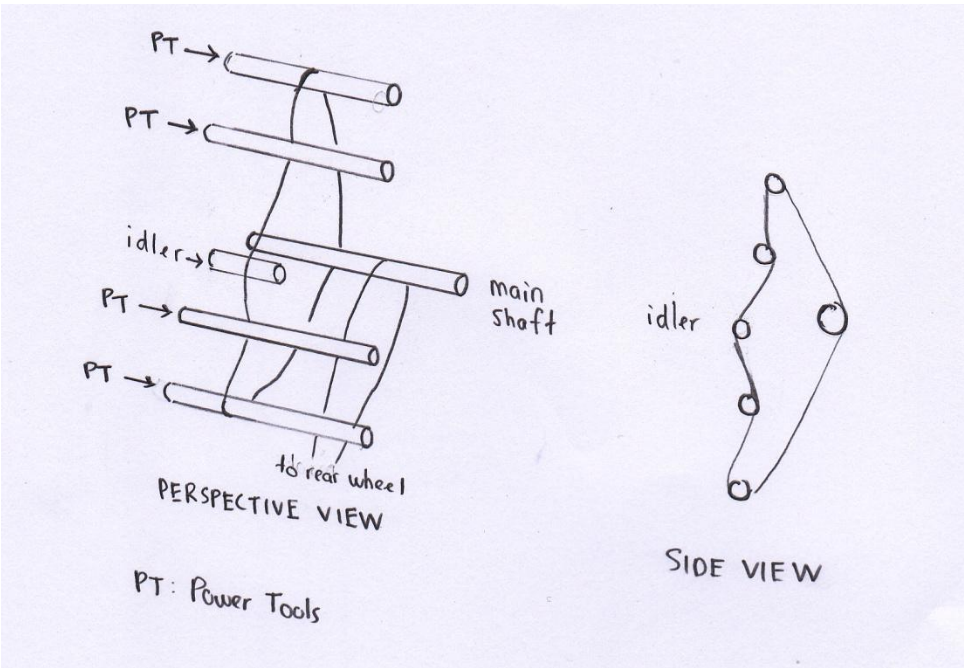

Figure 4.3: 3rd Design

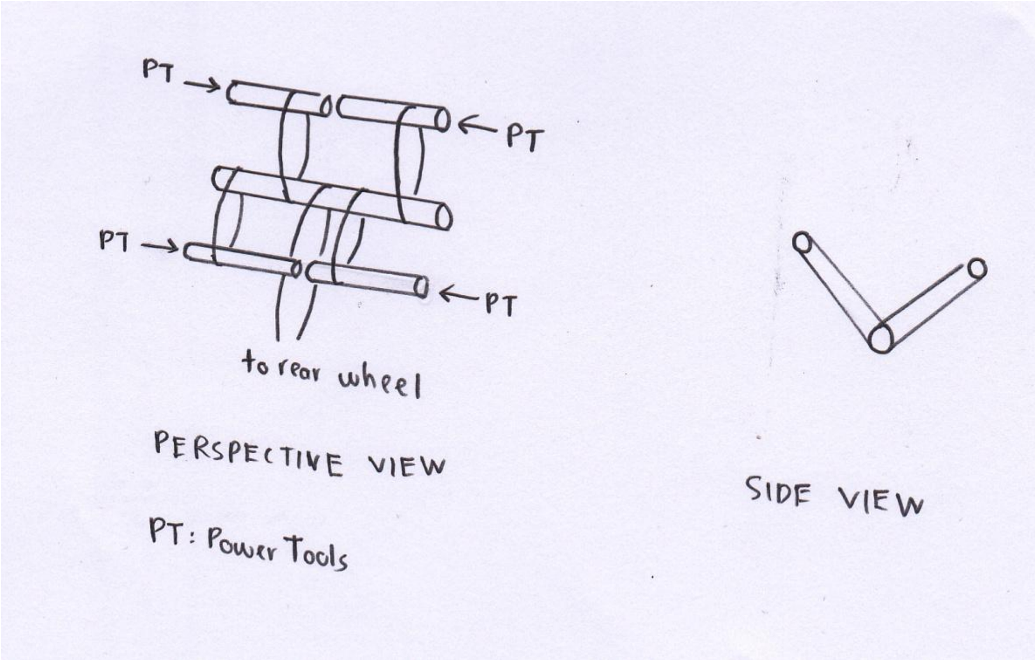

Figure 4.4: 4th Design

During the design activity, the author put the chain-driven mechanism a higher priority due to easy accessible to the components in the market. Each of the design are done roughly base on the previous drive train system.

4.2.1 Selection Criteria

To decide the most feasible design, decision matrix is used based on following criteria:

1) Design (weight = 5)
   - Compactness and design's aesthetic value
2) System Complexity (weight = 8)
   - Easy for fabrication and maintenance
3) Power Tool Synchronization (weight = 10)
   - Speed synchronization between power tools
4) Lowest Cost (weight = 6)
   - Cost effective design
5) Lowest mass (weight = 6)
   - lowest design's mass

Base on the selection criteria, the 4 design from the preliminary design is evaluated. Table 4.1 below shows the output of the decision matrix.

Table 4.1: Decision Matrix

Design/Criteria	1st	2nd	3rd	4th	Weight
Design	5	8	5	7	5
System Complexity	5	6	4	8	8
Power Tools Syncronization	10	10	10	10	10
Lowest Cost	6	8	6	8	6
Lowest Mass	5	8	5	8	6
Total	**231**	**284**	**223**	**295**	

From the decision matrix, the 4th design has the highest score, therefore the design will be evaluated for design and fabrication process.

4.3 CATIA Design of the Drive Train System

From the preliminary design in section 4.2, the 4th design is taken in consideration. The decision is made by considering the compactness of the system and the ability for each power tool to functions independently. From the design concept, the expected design is done using Catia V5 R17. Figure 4.5 shows the draft design of the drive train. The system use chain sprocket system. The system equip with freewheel sprocket which will help to improve the power and speed synchronization between power tools. Each power tool exert torque at individual drive shaft which then couple at the first transmission shaft. The second transmission shaft functions to transmit the power and speed to the rear wheel. The technical drawing of the drive train components is shown in Appendix 2. The gear ratio of the drive train is stated in section 4.5.8

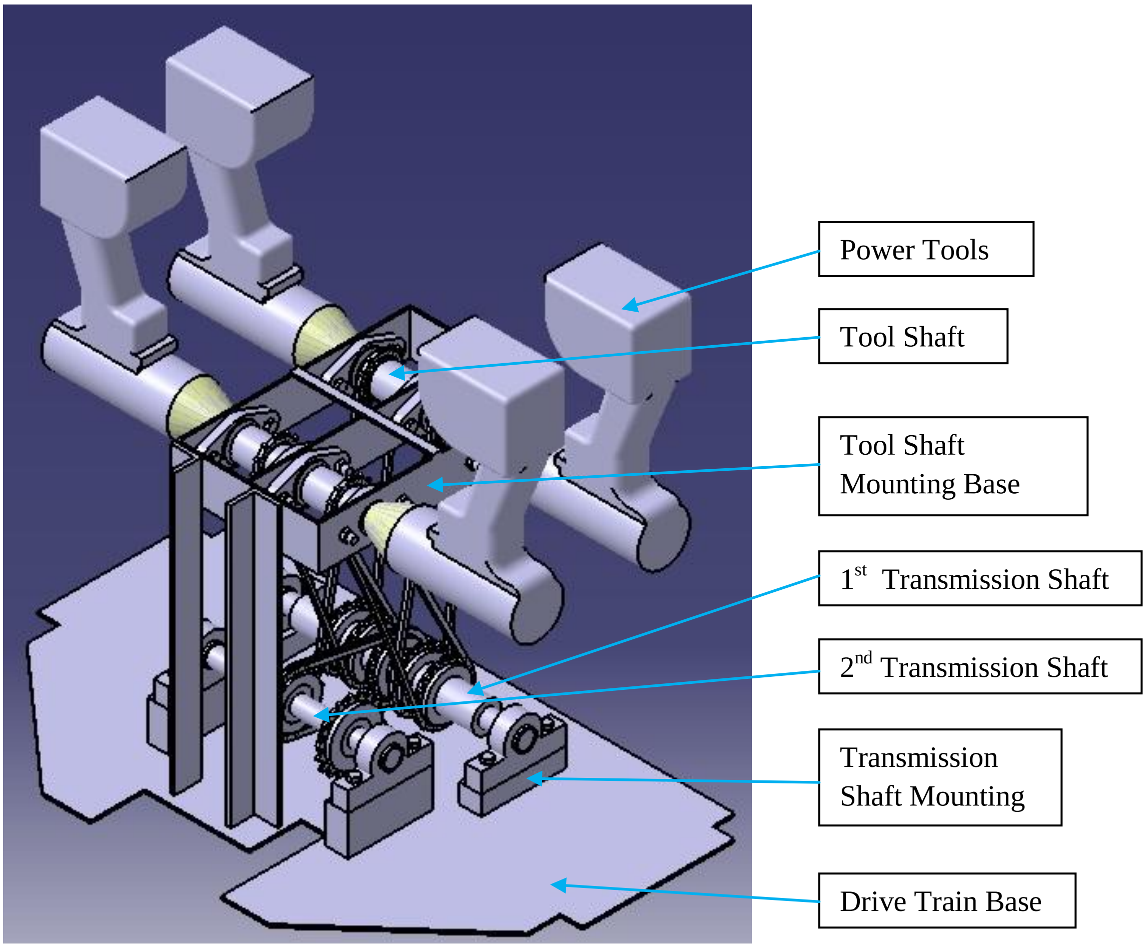

Figure 4.5: CATIA Design of the Drive Train System

4.3.1 Material Selection

Table 4.2 below show the material used for each main component.

Table 4.2: Material used for the System’s Components

Components	Material
Tool Shaft	Mild Steel
Transmission Shaft	Mild Steel
Tool Shaft Mounting Base	Mild Steel
Transmission Shaft Mounting	Wood
Drive Train Base	Aluminum

The tool and transmission shafts are made from mild steel which will have high resistance to torsion due to torque exerted by the power tools and the deceleration of the kart. The tool shaft mounting base is made of mild steel to ensure the deflection due to the weight of the tool shaft and the power tools are minimized. The transmission shaft mountings are made of wood which is easy to fabricate, since the mounting dimension is vary for each transmission mounting. Furthermore, it may act as damper for the shaft. The drive train base is made of aluminum. The selection is done due to the simplicity in the fabrication process compare to mild steel as well as it has lower mass. However, the aluminum base will create vibration to the kart.

4.4 Fabricated Drive Train System

The fabrication of the drive train system is done closely to the design's dimension of the final design. Figure 4.6 below shows the picture of the drive train. More picture is shown in Appendix 2

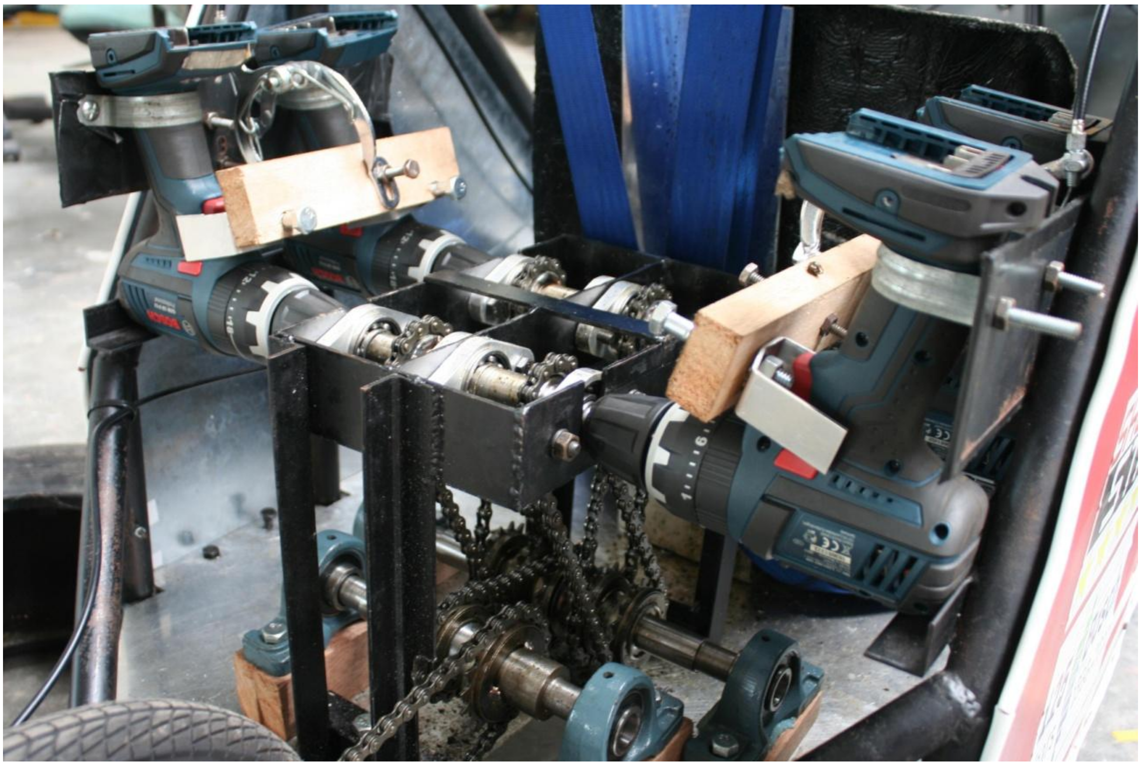

Figure 4.6: Fabricated Drive Train System

4.5 Calculation

4.5.1 Kart Specification

Below is the kart specification that will be used for calculation of the kart's theoretical performance.

1) Power tools torque and RPM = 28Nm @ 1700rpm / 67Nm @ 500rpm

2) Kart's height = 1.3m

3) Kart's width (between 2 tires) = 1.2m

4) Kart's body width = 0.6m

2) Tire effective radius, R_d = 0.2m

4.5.2 Assumption

Due to limited equipment to measure the other car specification, some of the data need to be assumed. Below is the assumption made to ease the calculation.

1) The road is flat (Grade = 0, Fg = 0)

2) Total mass (mass of the car + mass of the driver) = 100kg

3) The motor torque profile of the power tools is constant along the power tool speed.

4) System efficiency is 0.8

5) The drag coefficient, C_D = 0.3

4.5.3 Minimum Torque Required

This is to measure the minimum torque that is required for moving the car from stationary state. The calculation is done by using the formula below [7]:

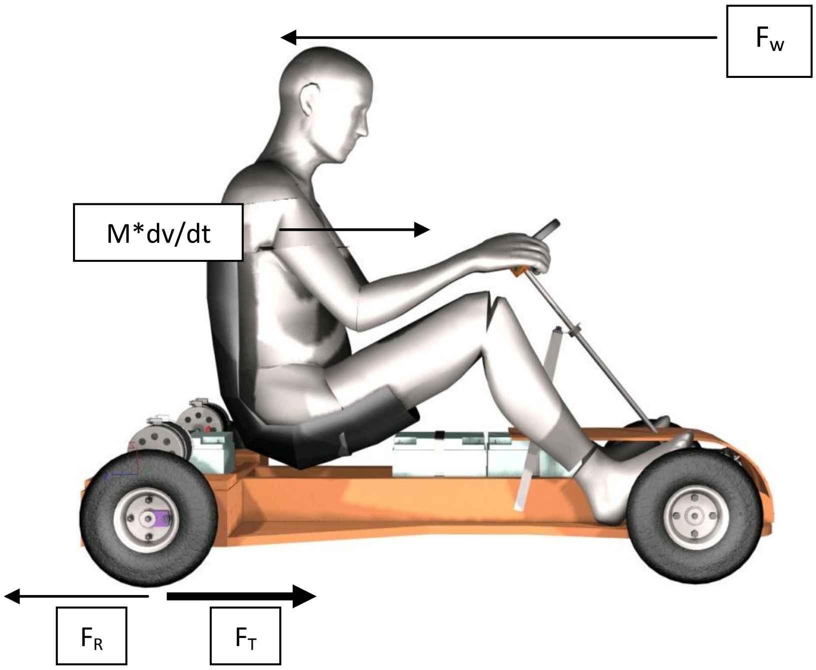

Figure 4.7: Free Body Diagram of the Kart

$$\boldsymbol{m\frac{dv}{dt} = F_T - F_R - F_w - F_G} \qquad \textbf{(1)}$$

where

F_T = Traction Force, N,

F_R= Resistance Force, N = $\mathbf{C_R mg\cos\alpha}$, where: C_R Rolling resistance = 0.015

F_W= Drag Force, N = $\mathbf{0.5C_D\rho AV^2}$, where: ρ = 1.18kg/m^3 (Air density)

F_G = Grade Force = $\boldsymbol{\mu mg\sin\alpha}$

m = mass, kg

dv/dt = acceleration, m/s^2

To calculate the minimum torque required, mdv/dt, F_R, F_w, F_G is equal to 0 at velocity of 0m/s. Therefore the equation is simplified to

$$F_T - F_R = 0$$
$$F_T = F_R$$
$$= C_R mg$$
$$= (0.015)(100kg)(9.81m/s2)$$
$$= 14.715N$$

$$\tau min = F_T R_D$$
$$= (14.715N)(0.2m)$$
$$= 2.943Nm$$

4.5.5 Minimum torque at the power tools

The minimum torque at the power tools is calculated from the minimum torque required to move the kart in section 4.5.3. The overall gear ratio is:

Overall gear ratio, $I_{gt} = I_{gAB} \times I_{gBC} \times I_{oCD}$ = 1.421 x 1 x 1.833 = **2.605**

Torque at the 4 power tools = $T_w/(I_g * I_o * \eta_t)$ [8]

= Torque at the wheel / (Overall gear ratio x system efficiency)

= 2.943 / (2.605 x 0.8)

= 1.41m

Torque at 1 power tools = 1.41Nm / 4

= **0.353Nm**

Therefore, the minimum torque of 0.353Nm at each power tools is required to move the kart from stationary

4.5.6 Tractive force required

Tractive force required is calculated to determine the force required to maintain the speed of the karts. It is measured at speed from 0 km/h to 100km/h. The vehicle speed calculation is done using the Equation 1 from 4.5.3. Figure 4.8 shows the graph the tractive force required as well as the kart's resistive forces.

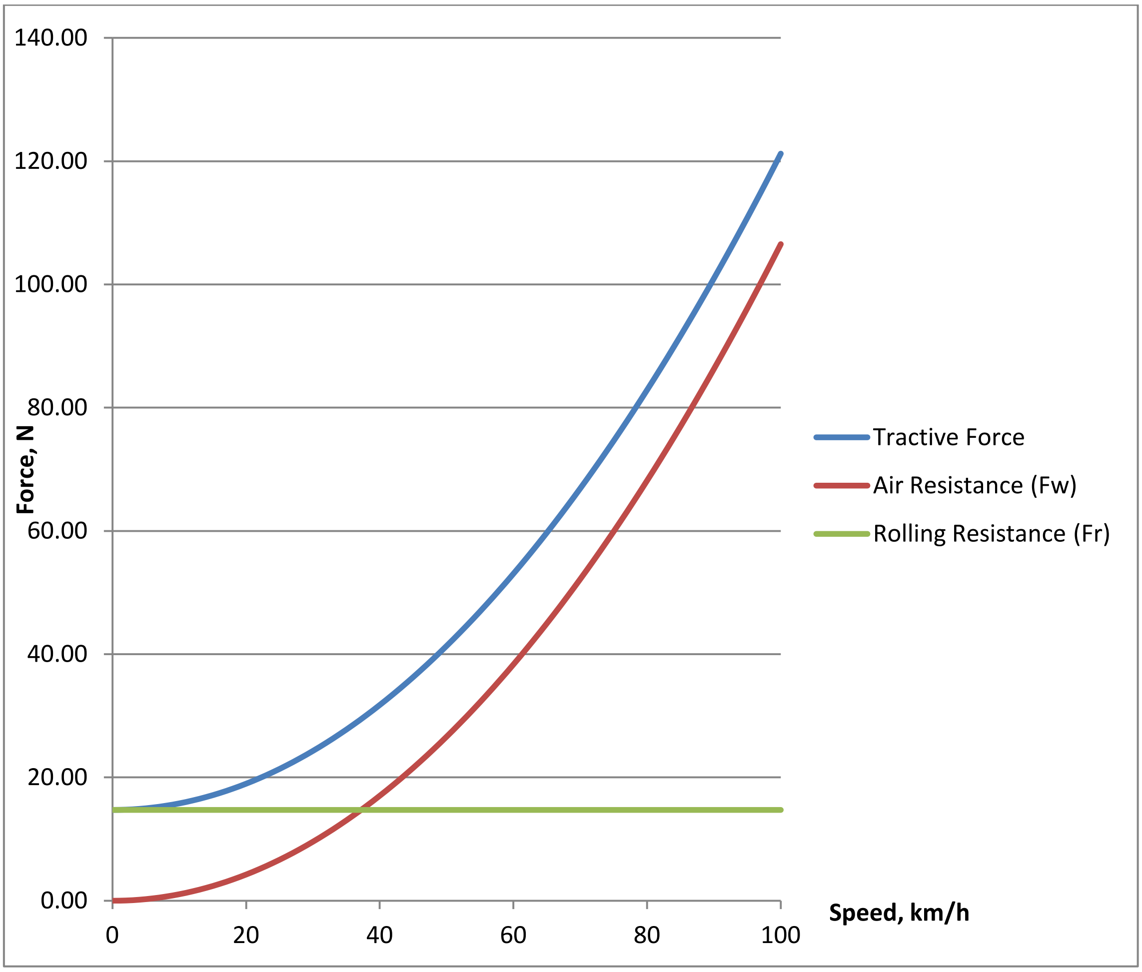

Figure 4.8: Tractive force and the Resistive Force acted on the Kart.

From the figure, it can be seen that the rolling resistance is the dominant resistive force at speed lower than 38km/h while the air resistance dominating only after 38km/h. As for the competition, the race track is consist of short distance, therefore the air resistance will be insignificant.

4.5.7 Constant Velocity Analysis

The constant velocity analysis is done to study the power tool's torque requirement at constant speed operation. To calculate the torque, the equation (1) from Section 4.5.3 is used. Table 4.3 below show the result of the motor torque at constant speed from 0km/h to 100km/h

Table 4.3: Power Tool Torque and Speed Analysis

Vehicle Speed, m/s	Vehicle Speed, km/h	Min tractive force, N	Wheel Torque, Nm	Power tools torque, Nm	Wheel angular speed, rpm	Power Tool Speed, rpm
0.00	0	14.72	2.94	0.37	0.00	0.00
1.39	5	14.98	3.00	0.37	66.31	172.74
2.78	10	15.78	3.16	0.39	132.61	345.49
4.17	15	17.11	3.42	0.42	198.92	518.23
5.56	20	18.98	3.80	0.47	265.22	690.98
6.94	25	21.37	4.27	0.53	331.53	863.72
8.33	30	24.30	4.86	0.60	397.84	1036.47
9.72	35	27.76	5.55	0.69	464.14	1209.21
11.11	40	31.76	6.35	0.79	530.45	1381.96
12.50	45	36.29	7.26	0.90	596.75	1554.70
13.89	50	41.35	8.27	1.03	663.06	1727.44
15.28	55	46.94	9.39	1.16	729.37	1900.19
16.67	60	53.07	10.61	1.32	795.67	2072.93
18.06	65	59.72	11.94	1.48	861.98	2245.68
19.44	70	66.91	13.38	1.66	928.28	2418.42
20.83	75	74.64	14.93	1.85	994.59	2591.17
22.22	80	82.89	16.58	2.06	1060.90	2763.91
23.61	85	91.68	18.34	2.28	1127.20	2936.66
25.00	90	101.00	20.20	2.51	1193.51	3109.40
26.39	95	110.86	22.17	2.75	1259.81	3282.15
27.78	100	121.24	24.25	3.01	1326.12	3454.89

From the analysis, we can see that to maintain constant speed, the torque requirement is very low. The torque required is not higher than 3.01Nm to maintain the speed. From the result, it can be seen that the power tools speed is limiting the kart's speed in between 45 to 50km/h. However, this analysis will be less significant since the kart will not be able to maintain speed at all the time. The acceleration analysis need to be done to determine the maximum torque required to accelerate the kart.

4.5.8 Drive Train Configuration

The drive train consists of 3 level of gear train (see figure 4.9). It starts from the tool shaft (A) to the first transmission shaft (B), to the second transmission shaft (C) and finally to the rear wheel (D). The drive train is designed as such to achieve the speed that is suitable for the race. This section explains about the output calculation for the drive train configuration at maximum power tool output and efficiency of 1 for each configuration.

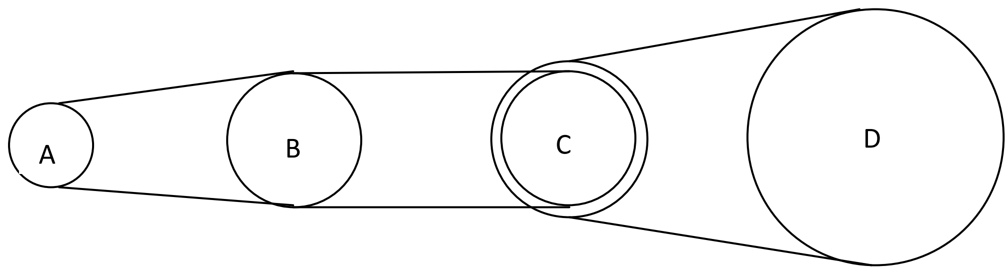

Figure 4.9: Drive Train Configuration

Legend:

A – Tool Shaft	B – 1st Transmission Shaft
C – 2nd Transmission Shaft	D – Rear Wheel

<u>From A to B</u>

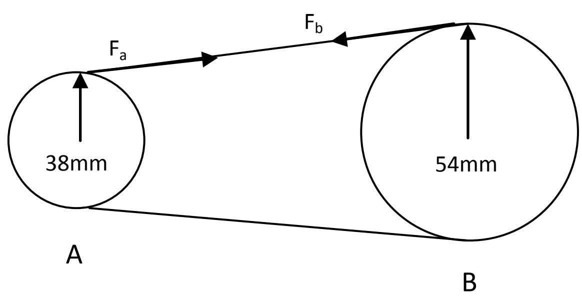

Figure 4.10: Gear train from Tool Shaft to 1st Transmission Shaft

\

Gear ratio, I_{gAB} = 54mm/38mm = **1.421**

Torque at A, T_A = Torque from power tools,T = **28Nm**

$F_A = T_A/r_A$ = 28Nm/0.038m = **736.8N**

$F_B = F_A =$ **736.8N**

Torque at B,$T_B = F_B r_B =$ **39.79Nm**

Speed at A, $\omega_A =$ **1700rpm**

Speed at B, $\omega_B = \omega A/IgAB$ = 1700rpm/1.421 = **1196.34rpm**

From B to C

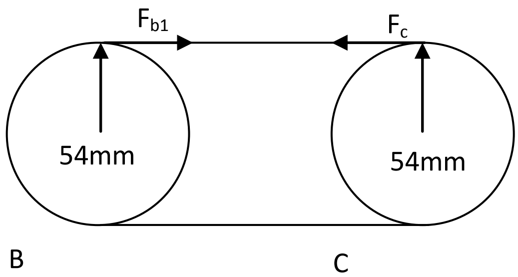

Figure 4.11: Gear Train from 1st Transmission Shaft to 2nd Transmission Shaft

At B, the torque from 4 power tools is coupled, therefore,

T_{b4} = 39.79Nm*4 = **159.16Nm**

Gear ratio, I_{gBC} = 54mm/54mm =**1**

$F_B = T_B/r_B$ = 159.16Nm/0.054m = **2947.41N**

$F_B = F_A =$ **2947.41N**

Torque at C,$T_C = F_C r_{C1}$ = 159.16**Nm**

Speed at B, $\omega_B =$ **1196.34rpm**

Speed at C, $\omega_C = \omega_C/I_{gBC}$ = 2415.7rpm/1 = **1196.34rpm**

From C to D

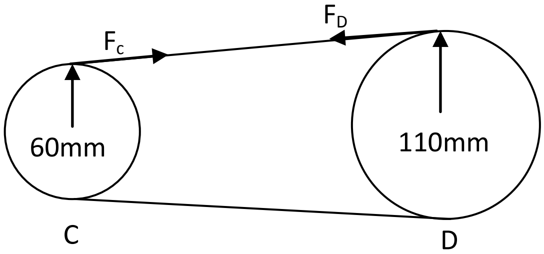

Figure 4.12: Gear Train from 2nd Transmission Shaft to Rear Wheel

Gear ratio, I_{oCD} = 110mm/60mm =**1.833**

$F_C = T_B/r_{C2}$ = 159.16Nm/0.060m = **2652.67N**

$F_D = F_C$ = **2652.67N**

Torque at D,$T_D = F_D r_D$ = **291.79Nm**

Speed at C, ω_C = **1196.34rpm**

Speed at D, $\omega_D = \omega_C/I_{gCD}$ = 1196.34rpm/1.833 = **652.67rpm**

From the drive train calculation, it is observed that the maximum torque and maximum rpm at the rear wheel is 291.79Nm and 652.67rpm. The maximum speed possible by this configuration is:

$$V = \frac{\pi N_D R_D}{30} = \frac{\pi(652.67)(0.2)}{30} = 13.67\frac{m}{s} = \mathbf{49.21}\,\frac{\boldsymbol{km}}{\boldsymbol{h}}$$

4.5.9 Acceleration Analysis

The acceleration analysis is done to study the maximum torque required to accelerate the kart to the maximum speed possible. To do the analysis, the acceleration will be varied according to the acceleration time. The analysis will be done for accelerating the kart from stationary to maximum speed of 49.21km/h for acceleration time from 1 second to 12 seconds. Table 4.4 is show the result of the calculation done.

Table 4.4: Relationship between acceleration time with motor torque

Acceleration Time	Motor Torque (at 1 power tools)
1	50.4
2	25.93
3	17.77
4	13.69
5	11.24
6	9.61
7	8.44
8	7.57
9	6.89
10	6.35

From the table, we can see that the kart can accelerate to maximum speed at minimum time of 2 seconds. As the acceleration time increase, the maximum torque required will be lowered. This concludes that to maintain the operability of the power tool, the kart need to accelerate slowly to the maximum speed.

CHAPTER 5

RESULT AND DISCUSSION

5.1 Testing Setup

Based on section 3.5, the kart was test at Village 4 parking. The gps logger was put into the kart prior to testing. The kart was then driven to the highest possible speed in the parking lot. The power tools are set to operate at Mode 1 which is at 28Nm with 1700rpm. The test is done for approximately 3 rounds and a few tests is done. This chapter consists of the compilation of the results done.

5.2 Testing Result

This section shows one of the test results of the kart testing. Figure 5.1 below is show the kart speed of the testing done.

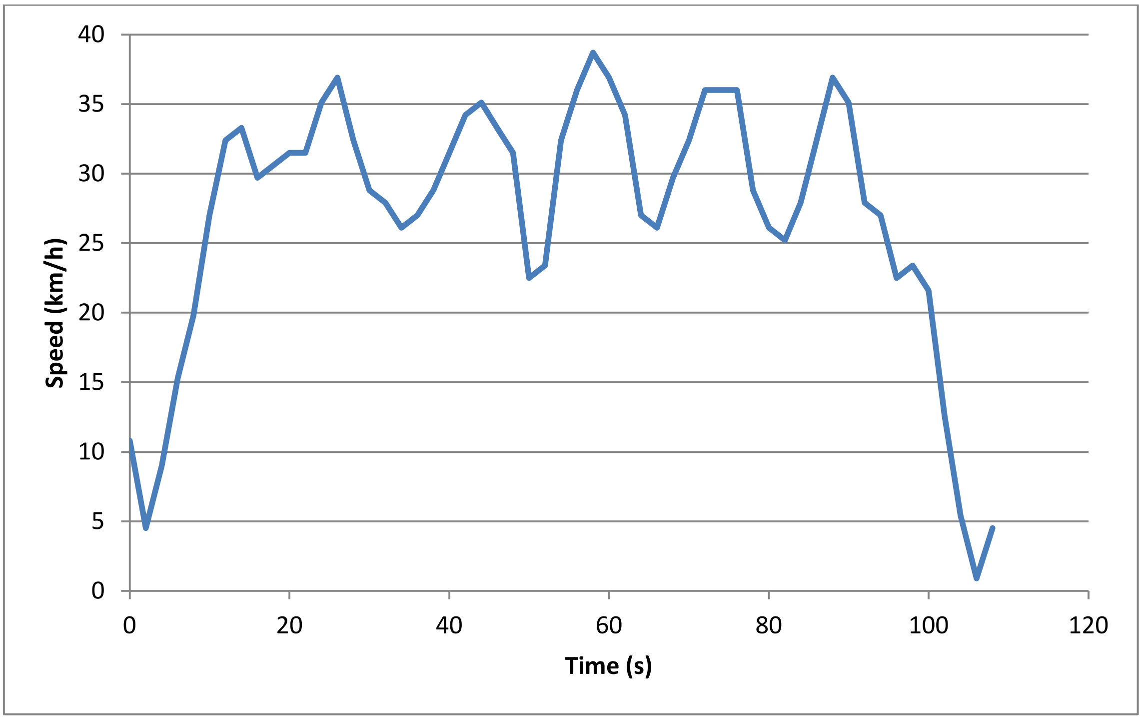

Figure 5.1: Kart Speed

From the figure, we can see that the kart maximum speed is 38.7km/h. The speed seems to be average in between 25km/h to 35km/h. The fluctuation of the speed is due to speed reduced when taking a turn at the corner. Several testing with similar track course has been done. From the testing, the maximum speed is taken. Table 5.1 is shows the summary of the testing done.

Table 5.1: Summary of testing done

Test	Maximum Speed (km/h)
1	38.7
2	36.9
3	36.9
4	36.9
5	36
6	36
7	35.1
8	35.1
9	35.1
10	33.3
Average	36

From all maximum speed of all the testing, we can conclude that the average maximum speed of the kart is 36km/h.

5.3 Discussion

From the result obtained, the average maximum speed is 36km/h. the value is very far from the theoretical maximum speed which is 49.21km/h. There is several factors that contributing to the results, which are:

1) Motor Torque Profile
    - From the assumption made, the motor torque profile is considered to be constant for all the speed range. However the actual profile is unknown. In a normal motor torque profile, the torque is constant at low speed and the torque reduced after a certain speed. From the analysis, it can be conclude that the torque is decreased at high speed, which give the limiting torque for the kart acceleration at high speed. The torque is only able to maintain the kart at speed of 36km/h

2) Improper fabrication
    - It is identified that there is misalignment at the weld from the gear to the transmission shaft. This create an unbalance motion when the gear is rotating, which results to rapid chain loosen and tighten. This will reduce the efficiency as the power transmitted is greatly reduced. Furthermore, the unbalance motion creates unbalance vibration to the drive train system. This further decrease the efficiency of the drive train.

3) Grade effect at the test track
    - It is noticed that the Village 4 parking lot is not fully flat, there is a small elevation which may affect the vehicle maximum output. The grade will increase the tractive force required which reduce the acceleration rate.

4) System efficiency
    - Throughout the design and calculation, the system is design with assumption that the efficiency of the system is 0.8. This is not true on the fabricated system. Due to improper fabrication, the efficiency drop

for each configuration as there is loss in power transmitted in each of power tools configuration. Further analysis done should include the actual efficiency of the system.

-

5.3.1 Power Tools Analysis

Based on the testing result, the power tools torque and speed output is computed (see figure 5.2 and figure 5.3). The formula use for the calculation of the torque and speed is shown in Appendix 4. The acceleration is computed with interval of 2 seconds (between two velocity data point).

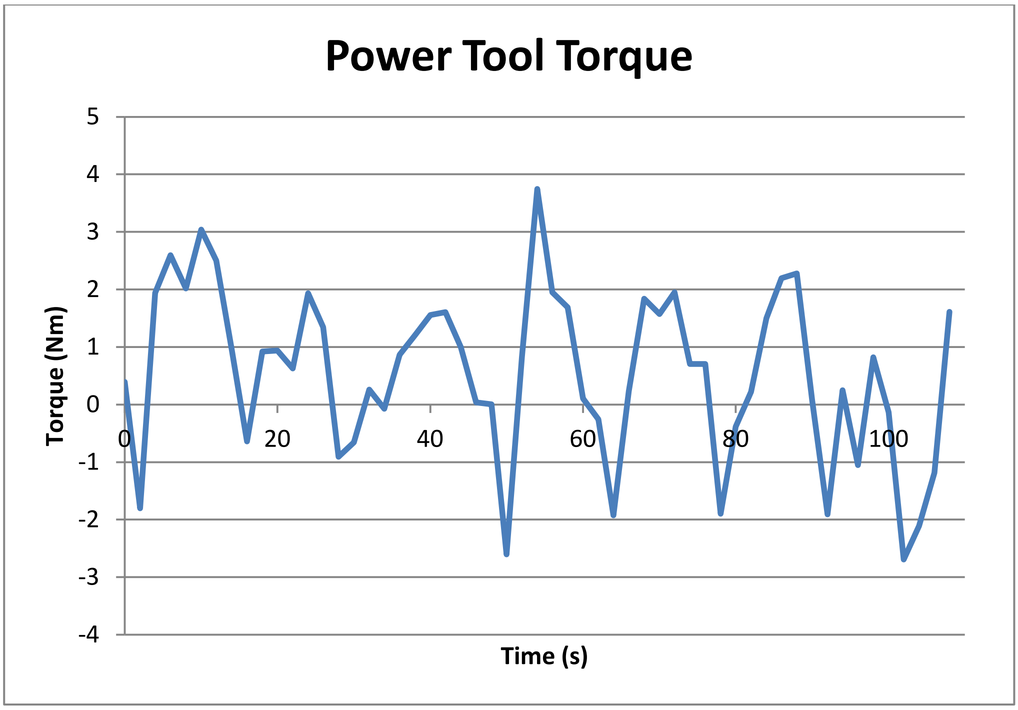

Figure 5.2: Power Tool Torque

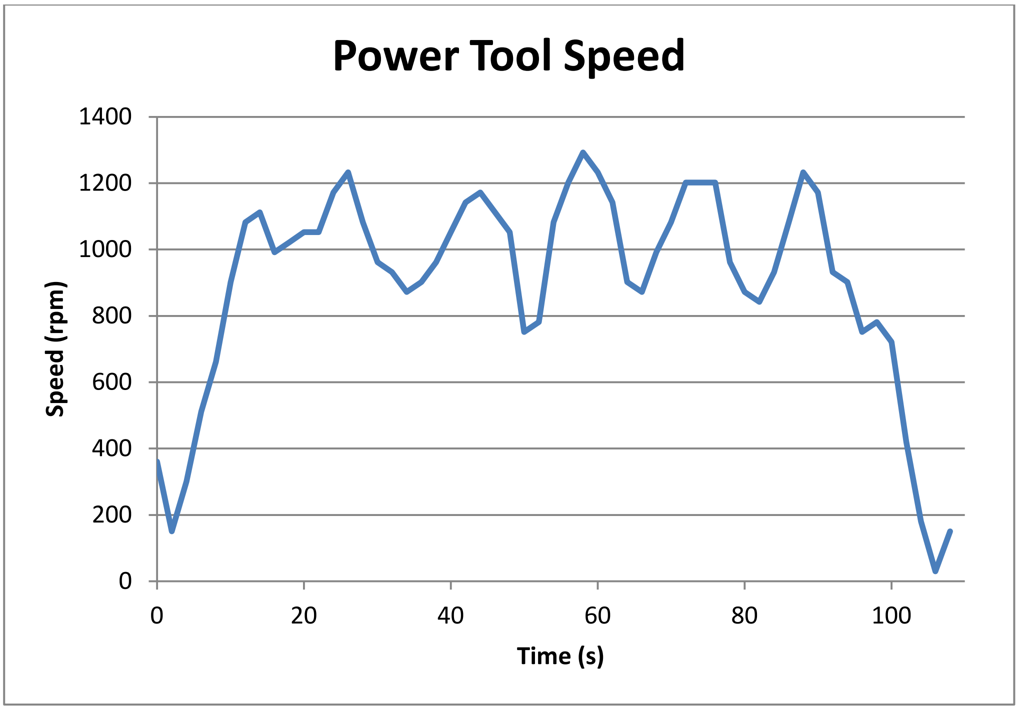

Figure 5.3: Power Tool Speed

From the figure, it can be seen that the power tool torque exerted is small and the power tool speed is average between 1000rpm to 1200rpm. It also can be seen that the torque exerted is lower than expected, which is at the maximum torque of the power tool. This is showing that the average torque required is between 0 to 3Nm only for each of the power tools. This happen because the acceleration value between two points is low, resulting to low torque value at each point. To further clarify the data, the test is continue with the kart is driven using 3 power tools. The result of the testing shown that it achieved the maximum speed at the average maximum speed as shown in figure 5.4 and the torque required is as shown in figure 5.5.

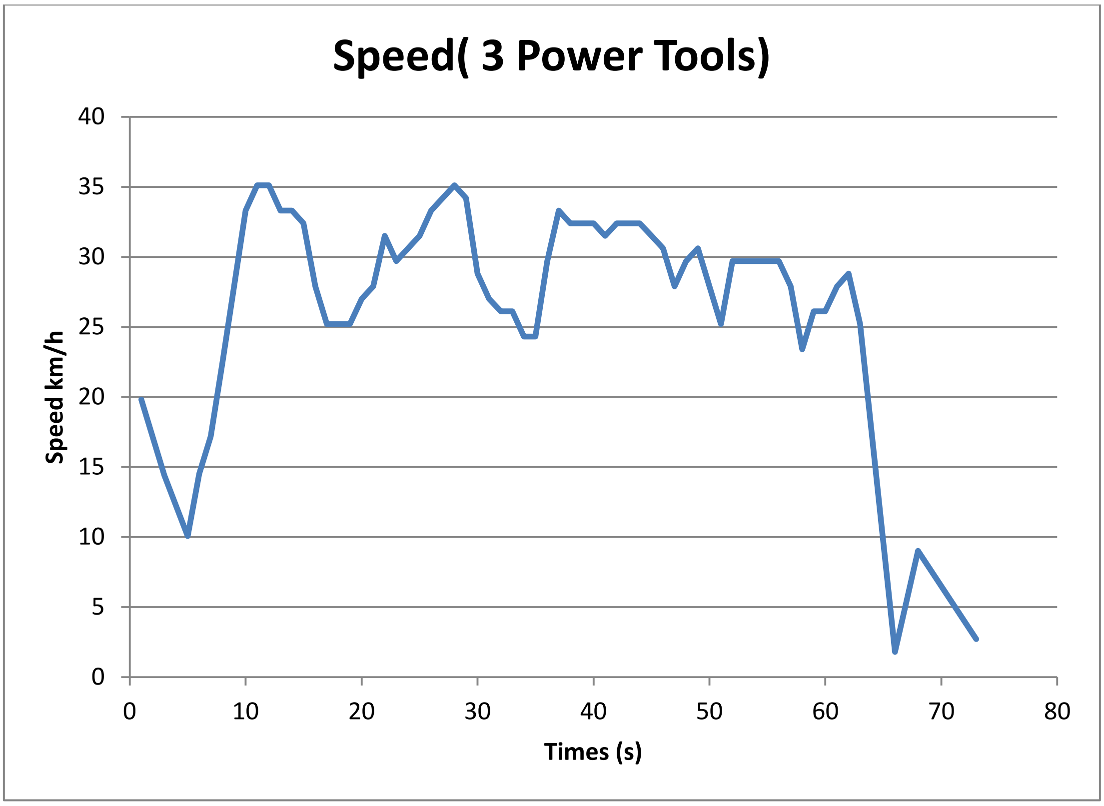

Figure 5.4: The speed profile for kart operation with 3 power tools

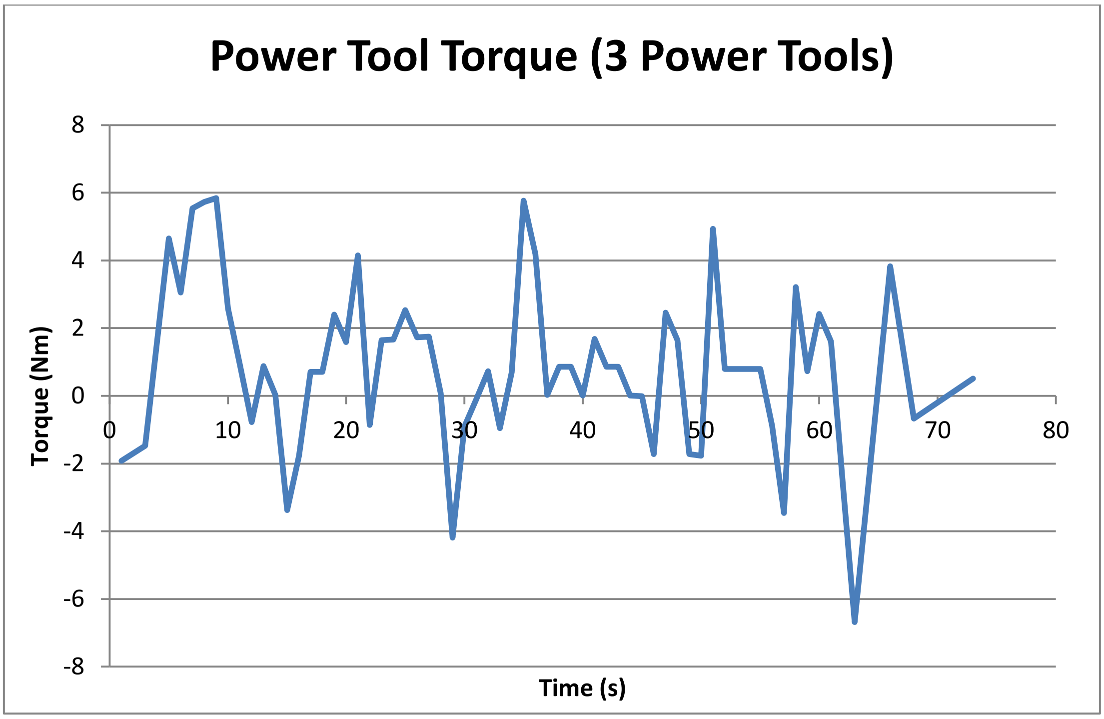

Figure 5.5: Power Tool Torque for kart operation with 3 power tools

It can be seen that the torque exerted is higher when using less power tool, however it manage to achieve the speed similar to the output speed when operating using 4 power tools. From the result, it can be seen that the drive train can still function well even with less number of power tools operating. This will help to increase the system reliability to maintain the speed in case of power tool failure during the race.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The kart able to achieved average maximum speed of 36km/h during operation. Although it may not be able to get the theoretical maximum speed, it is fast enough for the competition as the race track is only 270m. All of the testing done shows that the kart is able to achieve the maximum speed which means the drive train is reliable to operate at the maximum speed.

6.2 Relevancy of the Objective

At the end of the project, the author aims to achieve the entire objectives stated at the early of the project. The drive train that powered by power tools is successfully fabricated according to design and calculation made. The testing result show that the vehicle can perform at same speed at each testing. Thus the drive train provide system reliability for operation.

6.3 Suggested Future Work for Expansion and Continuation

This project progresses are strictly limited to the competition rules and regulations. The design and fabrication of the drive train can be expanded further in order to improve efficiency of the system. Furthermore, the time constraint which is two semester period for project completion is insufficient to conduct more thoroughly drive train system. Therefore, the work should not end in this project only. This system can be expanded by using more sophisticated and reliable system such as implementing the electrical circuit into the system, better arrangement and else.. The power tools torque profile should be analyzed first before the design of the system was made.

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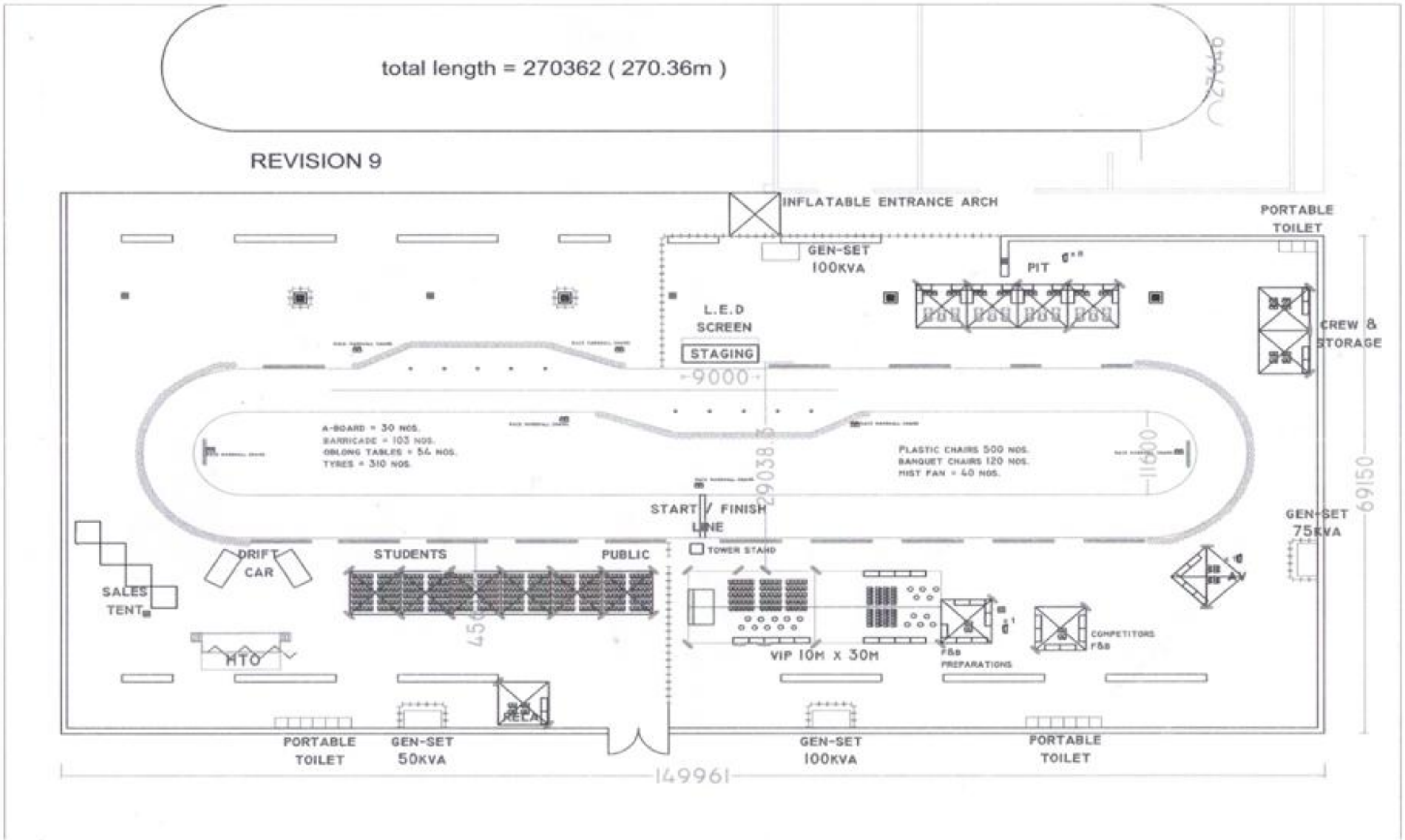
APPENDIX

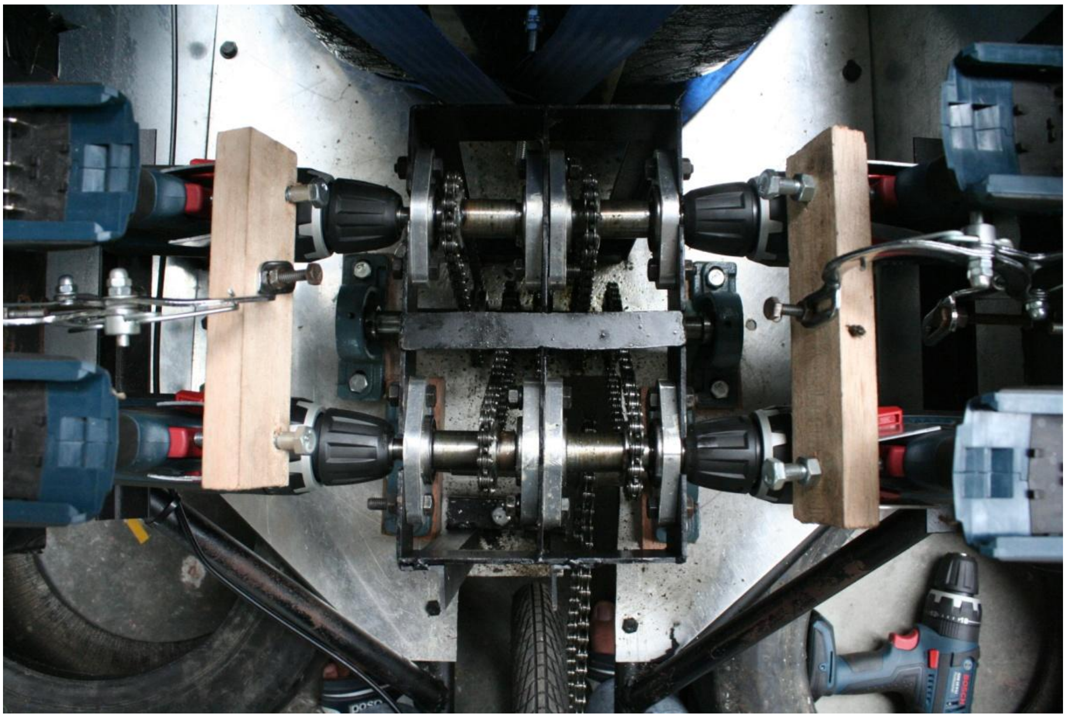
APPENDIX 1: Race Track Layout



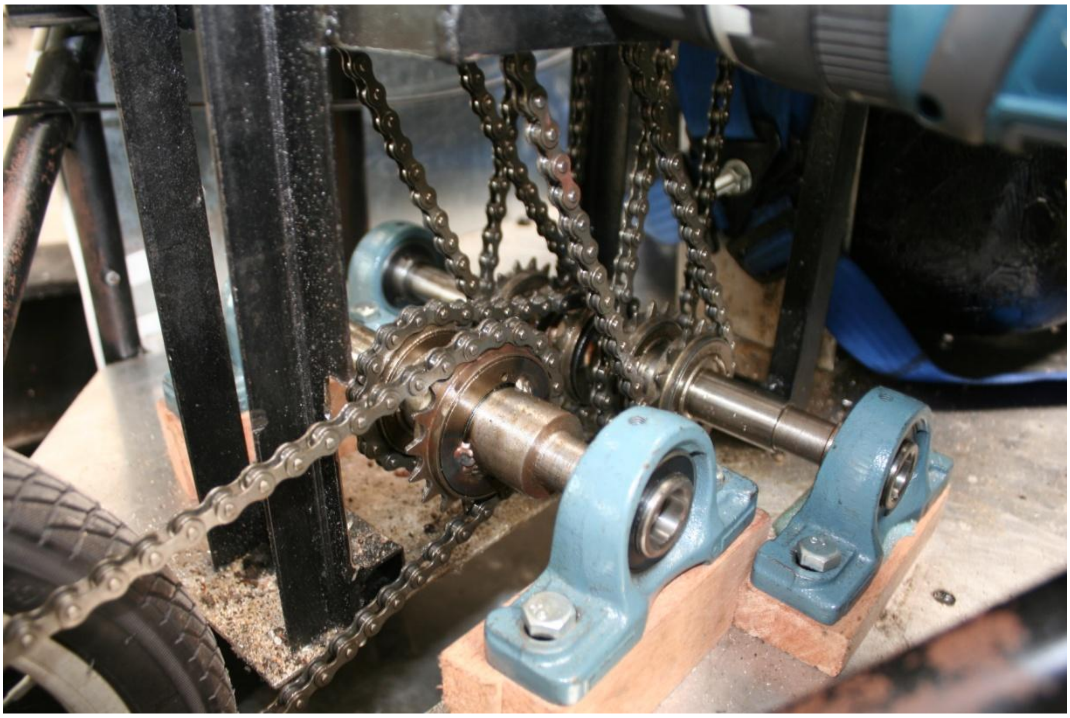
APPENDIX 2

Technical Drawing of Components and System

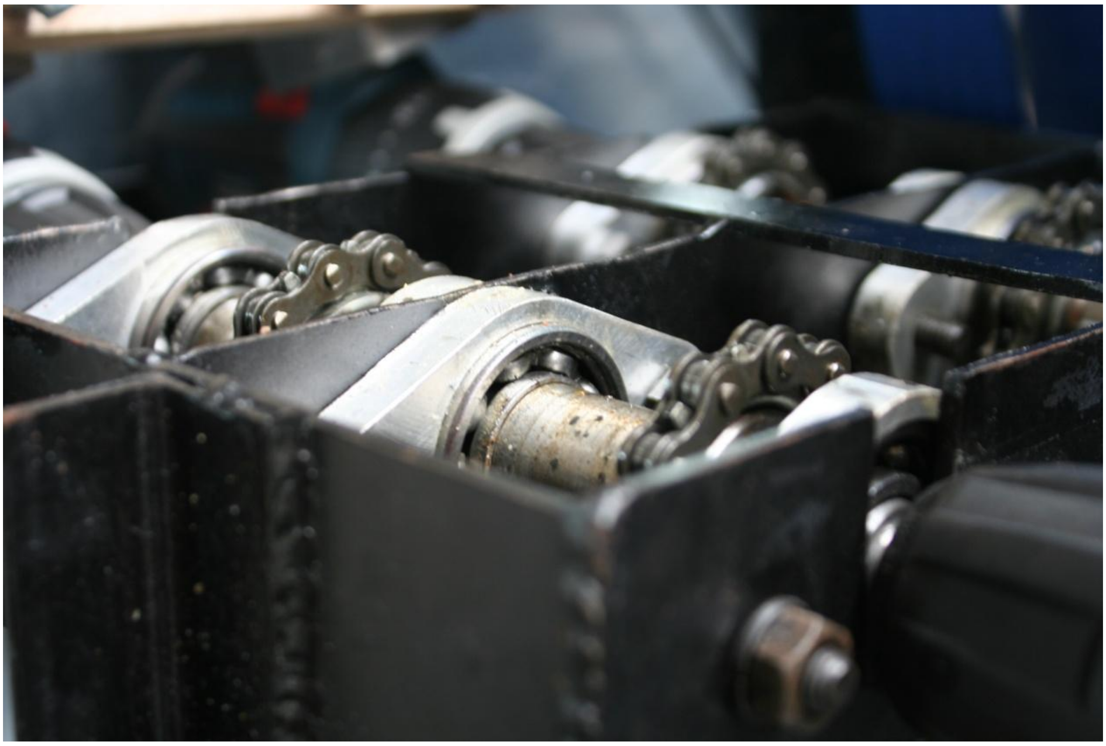
APPENDIX 3: Figure of Fabricated Drive Train System



Top view of the Drive Train System



Configuration of 1st and 2nd Transmission Shaft



Configuration of Tool Shaft

The kart which the drive train is installed

APPENDIX 4: Example Calculation for Power Tool Analysis

For the analysis of torque and speed at wheel, the formula use is [7]:

$$\boldsymbol{m\frac{dv}{dt} = F_T - F_R - F_w - F_G} \qquad \textbf{(A)}$$

where

F_T = Traction Force, N,

F_R= Resistance Force, N = $\mathbf{C_R mgcos}\ \boldsymbol{\alpha}$, where: C_R Rolling resistance = 0.015

F_W= Drag Force, N = $\mathbf{0.5C_D\rho AV^2}$, where: ρ = 1.18kg/m^3 (Air density)

F_G = Grade Force = $\boldsymbol{\mu mgsin\alpha}$

m = mass, kg

dv/dt = acceleration, m/s^2

For a change of from 10km/h (2.78m/s) to 20km/h (5.56m/s) is 5seconds,

$$\boldsymbol{\frac{dv}{dt}} = \boldsymbol{\frac{5.56-2.78}{5}} = 0.556\,\frac{m}{s^2}$$

Thus, to get the traction force, the formula (A) is arranged to:

$$F_T = m\frac{dv}{dt} + F_R + F_w + F_G$$

Using the data from Section 4.5, the traction force for the value above is

$$F_T = 100kg\left(0.556\frac{m}{s^2}\right) + (0.015)(100kg)(9.81\frac{m}{s^2})$$
$$+ \frac{1}{2}(0.3)(1.18kg/m^3)(0.78m^2)(5.56m/s)^2 + 0$$

$$F_T = 74.58N$$

Therefore, the wheel torque is the product of tractive force with the effective radius of tire:

$$\tau = F_T \ x \ R_d = 74.58N \ x \ 0.2m = 14.916Nm$$

The wheel rotational speed is calculated from the wheel speed using the formula

$$\omega = V \ x \ \frac{30}{\pi \ x \ R_d} = \frac{5.56m}{s} x \frac{30}{3.142 \ x \ 0.2m} = 265.44rpm$$

The torque and speed of the power tool can be calculated from the wheel torque and rotation speed using the formula:

$$\tau_{Power\ Tool} = \frac{\tau_{wheel}}{Gear\ Ratio\ x\ \eta_T}$$

$$\omega_{Power\ Tool} = \omega_{Wheel}\ x\ Gear\ Ratio$$

The driveline efficiency, η_t is equal to 0.8, the power tool's torque for each tool at corresponding condition is:

$$\tau_{Power\ Tool} = \frac{14.916}{2.605\ x\ 0.8} x \frac{1}{4} = \mathbf{1.79Nm}$$

The power tool speed at the corresponding condition is:

$$\omega_{Power\ Tool} = 265.44\ x\ 2.605 = \mathbf{691.47rpm}$$