Design and Fabrication of Brushless DC Motor Driven Personal Electric Vehicle (PEV)

By

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the requirements for the
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
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in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

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September 2012

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.

_____

Muhammad Izzat bin Abdul Rahman

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ABSTRACT

Personal electric vehicle (PEV) is a new innovation made by men to ease the mobility of human from one place to another. PEV able to compete with conventional motorcycle and bicycle as a mode of transport for people especially to those who live in urban area. However, in order to compete with the other mode of transport, more improvement need to be done on PEV technology since it is quite new if compared to motorcycle and bicycle. This project will be focus on the design and construction of the PEV so that it can be use by others to do testing and experimenting to improve the PEV technology. This design process will include the choice of power transmission component, material selection, concept of the PEV body design and also the drive train of the PEV. Tricycle concept is chose for this design with 1F2R configuration and brushless motor is being used to drive the wheel. The design that is made is the design that has been selected and modified from previous projects so that it can be fabricated within the timeframe of this project duration. The re-design process was made through software program and the fabrication process was made based on the design and analysis made before.

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CHAPTER 1
INTRODUCTION

1.1 Background Study

Personal electric vehicle (PEV) or also sometime known as ebike is one of the latest technology in transportation. PEV is a vehicle where an electric motor is introduced to the common personal vehicle such as bicycle or scooter. The motor is commonly powered by battery or fuel cell. This innovation can accommodate only one passenger at one time to travel for certain distance. By using this vehicle, travelling time can be shorten because PEV can travel in up to 30 km/h in range of 10 – 40 km before charging depend on the specification and condition of the vehicle itself.

Using this new innovation, human can extend their range of mobility from 1 km of walking to 10 km with this vehicle within the same time frame. It is useful for those who live in the urban area as well as in rural area who need move to shop, LRT station and also suitable for kids to go to school. With extra innovation, this vehicle also is designed for the usage for disable person like the cripples.

Figure 1: Example of PEV available in market

When most of the technologies for vehicle nowadays move towards green technology, PEV is the greenest technology available because it does not produce any emission during the operation because it only use electrical power to produce the energy to operate. Besides, it also does not produce any noise and any dripping fluid when moving.

1.2 Problem Statement

The usage of personal electric vehicle is not yet really popular especially in our country. This is because the research and development (R&D) in this technology is not really progressing unlike the R&D on cars and motorcycles technology. The reason is due to the unavailability of a platform to do research on personal electric vehicle (PEV) causing a difficulty to make improvement for the performance of the PEV itself and also to promote it into the market. Although a complete vehicle can be bought in the market, it still has a limit on the performance plus, the design and components are already fix for the unit. If any changes are made to the vehicle, it will cost more because lot of modification need to be done.

1.3 Objectives

- Modify existing design of the PEV body.
- To choose a suitable components and material to be used on the PEV.
- Come out with prototype that can be used by others for testing and experimenting.

1.4 Scope of Study

For this project, the main scope of study is to revise the design made by previous student on the PEV. The main concept is fixed where the tricycle concept with rear-wheel motor drive will be used. However, the prototype of the previous student was incomplete and not functioning. Therefore, a new prototype will be made and expected can be drive using a brushless DC motor with some modification on the body itself.

During this whole project, author is expecting to fabricate a prototype of PEV with brushless DC motor. After the designing and fabricating the PEV, author is expecting to establish a motion requirement and suitable range for PEV to work to its best performance under certain specifications and constraints. This specifications and constraints are as follow:

- Total mass (PEV + rider) = 75 kg (10 kg + 65 kg)
- Battery input = 24V, 12A

With the specification fixed as above, the author is expecting to see the limitation and capability of the PEV based on criteria below:

- Speed
- Torque
- Power consumption

However, this scope might be changed accordingly if the required battery voltage is less upon the specification of the motor. The weight of the PEV stated also is the maximum weight that is expected by the author to achieve. However, the prototype can be lighter with correct material selection.

1.5 Significance of Study

The main purpose of the study is to produce a research platform for future reference. After the completion of the PEV prototype, author is expecting a working prototype that can be used by others for another research in order to increase the capability personal electric vehicle and some innovations can be made to vary the PEV for public usage.

As the R&D in green technology increases, it is hope that a lot more technology which is environmental friendly will be produce in the future. Same goes to this project, it is hope with the availability of the platform, more research can be done to improve the personal electric vehicle technology so that it able to compete with other vehicle like motorcycle and bicycle.

CHAPTER 2
LITERATURE REVIEW

Common choice of system for PEV is mainly comprised of some basic function to drive a small vehicle like bicycle. The difference is it has energy storage system and drive system. The system that usually use for electric vehicle is shown in Figure 2. However, for this project, only motor performance in the drive system will be studied in this project.

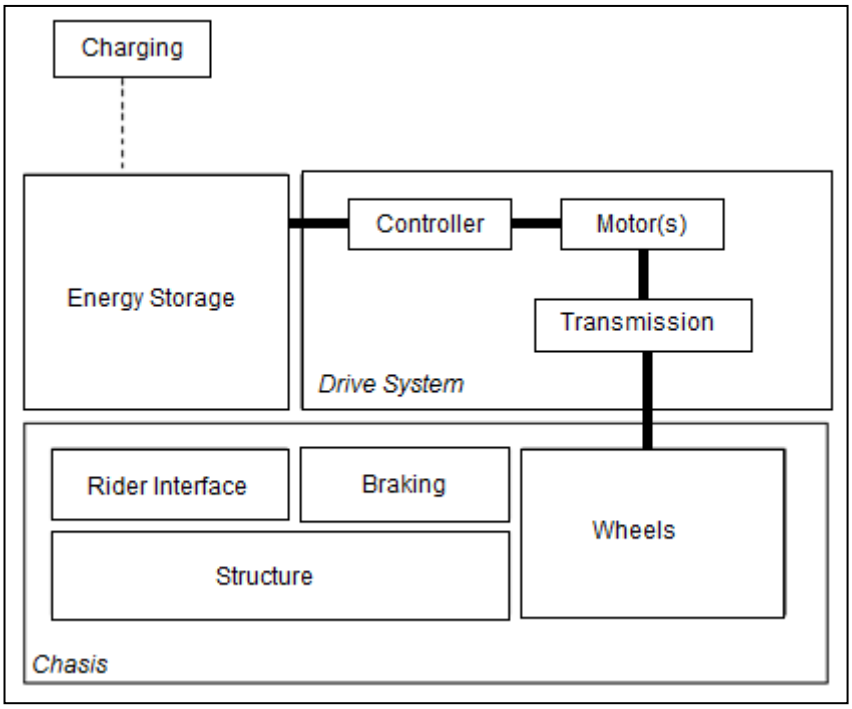

Figure 2: Basic system in the PEV[1]

2.1 Brushless DC (BLDC) Motor

Brushless DC (BLDC) motor is a synchronous electric motor powered by direct current[2]. Instead of working using brush, brushless motor use an electronic commutation to operate. Without having any brush in the operation of this motor, the lifespan of brushless DC motor is much longer compared to brush motor.

For brushless motor, the permanent magnet is put on the rotor that will rotate around the fixed armature. This is different with brush motor where the armature will

rotate around the permanent magnet and brush is used to handle the changes in polarity in the motor[3].

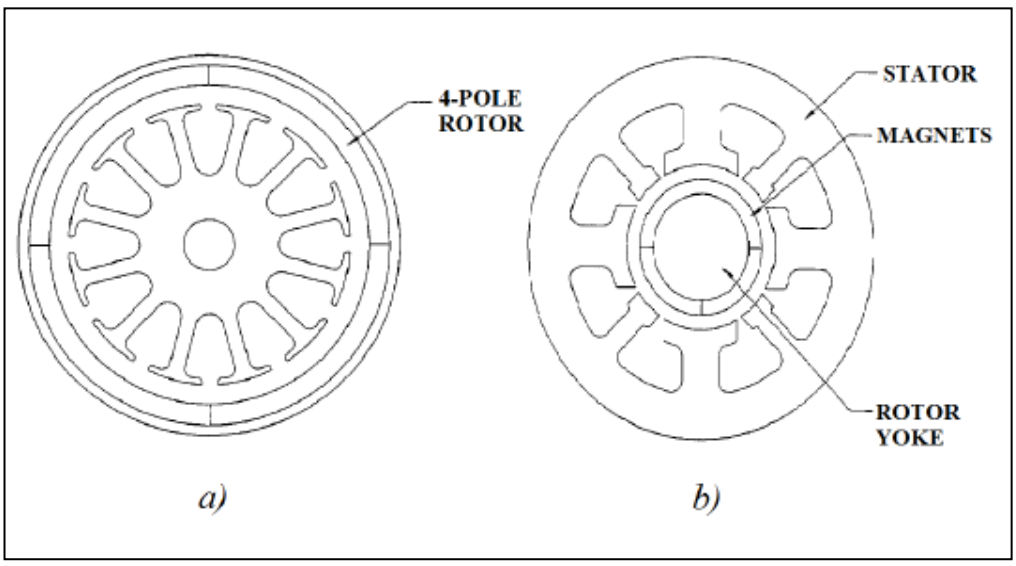

Figure 3: The two BLDC motor configurations: a) Outer-rotor BLDC motor, b) inner rotor BLDC motor [3]

Figure 4: Brushless DC motor

Due to the arrangement of rotor and stator in the motor, it provides better cooling for the motor. BLDC can operate really great with high torque but the speed is as low as 1000 rpm. This is because of the brushless motor can give a higher current compared to brush motor [1]. Although BLDC motor gives low speed in term of rpm, it is relatively enough to move a PEV with a suitable transmission system where only one gear transmission is suffice.

2.2 Power Transmission Components

To transmit power generated by motor, few choices of components can be used and taken into consideration. These components not only can transmit the power from motor to the wheel, but also can control the power amount transmitted either increase or decrease those power generated. The components used to transmit the power are usually gears, chains and belts. These three components have their own pros and cons.

To transmit power between a long distance of motor and wheel, belts and pulleys are most likely to be used. For an intermediate distance which is less than 10 meters, chain is preferable to be used as a power transmission means and for a short distance, sets of gears is the best[4].

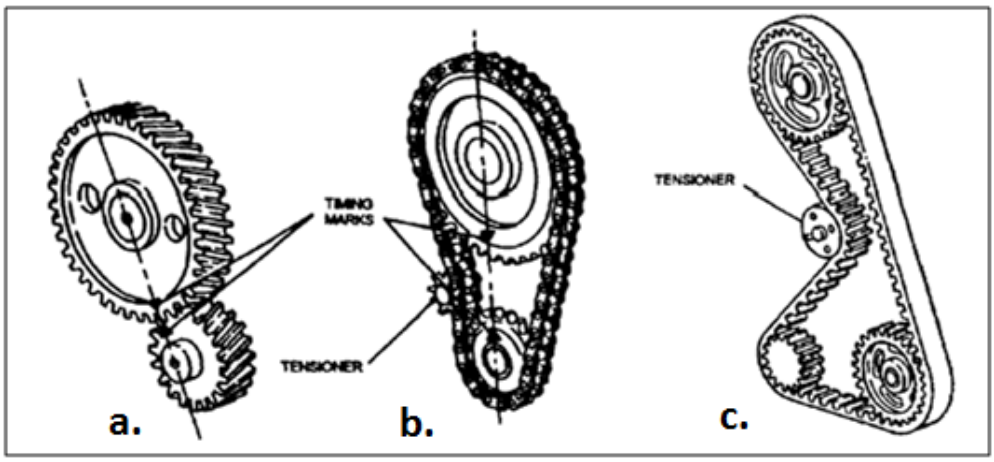

Figure 5: Power transmission components a) Gear b) Chain and sprockets c) Belt and pulley

The amount of power transmitted by the components are determined by the ratio of driven and driver pulleys, gears or sprockets. In order to increase the torque transmitted by the motor and to decrease the speed a smaller driver need to be used to rotate larger driven sprocket or gear. Both torque and speed will change according to ratio of the size of driven and driver sprocket, gear or pulley.

All three power transmission components will deliver speed and torque based on the ratio difference between the driver and driven components. This ratio difference can be obtained through the diameter of the pulley for belting system and through the number of teeth for gears and sprocket in chain drives.

$$i = \frac{Z_2}{Z_1} \quad drive\ ratio\ of\ gear\ and\ sprocket$$

$$i = \frac{D_2}{D_1}\ (drive\ ratio\ pulley)$$

By obtaining the drive ratio, the speed and torque transmitted through the components can be calculated with the formula given below:

	Belt drive	Chain and sprocket	Gear
Speed, V	$V1/V2 = D2/D1$	$V1/V2 = z2/z1$	$V1/V2 = z2/z1$
Torque, T	$T1 = \frac{P}{\omega_1}$ $T2 = \frac{P}{\omega_2}$	$T1 = \frac{P}{\omega_1}$ $T2 = \frac{P}{\omega_2}$	$T1 = \frac{P}{\omega_1}$ $T2 = \frac{P}{\omega_2}$

Table 1: Table of formula for belt, chain and gear power transmission

Where:

V_1	- Speed of driver pulley/sprocket	m/s
V_2	- Speed of driven pulley/sprocket	m/s
D_1	- Diameter of driver pulley	m
D_2	- Diameter of driven pulley	M
z_1	- Number of driver sprocket/gear	-
z_2	- Number of driven sprocket/gear	-
T_1	- Torque by driver pulley/sprocket	Nm
T_2	- Torque by driven pulley/sprocket	Nm
ω_1	- Speed of driver pulley	RPM
ω_2	- Speed of driven pulley	RPM
P	- Power	Watt

2.3 Calculation Theory

In order to determine the requirement for the output of the motor, set of formula is modelled as a theory. Main requirement of the motor can be obtained by calculating the power needed to move the PEV accounting the power to resist rolling,

power to overcome air drag, power to climb slope and power to accelerate the vehicle.

$$P = P_{rolling} + P_{air-drag} + P_{slope} + P_{acceleration}$$

To estimate rolling resistance power, formula of friction can be used to calculate it:

$$P_{rolling} \approx MgC_r v$$

Meanwhile, air drag can be approximately estimated by using following formula:

$$P_{air-drag} \approx \frac{1}{2}\rho C_d A v^3$$

Power needed to overcome any slope can be calculated by using formula below:

$$P_{slope} \approx Mgv \sin a$$

Lastly, for the acceleration, the acceleration formula can be used.

$$P_{acceleration} \approx Mv\frac{dv}{dt}$$

With the formula above, estimation for minimum power output needed by the motor can be derived as follow:

$$P = MgC_r v + \frac{1}{2}\rho C_d A v^3 + Mgv \sin a + Mv\frac{dv}{dt}$$

Where

M	- Total mass of vehicle and rider	kg
G	- Gravitational acceleration	m/s^2
C_r	- Coefficient of rolling resistance	-
C_d	- Coefficient of drag	-
V	- Velocity	m/s
P	- Air density	kg/m^3
S	- Slope	Degree (^{o})
A	- Frontal area of vehicle + rider	m^2

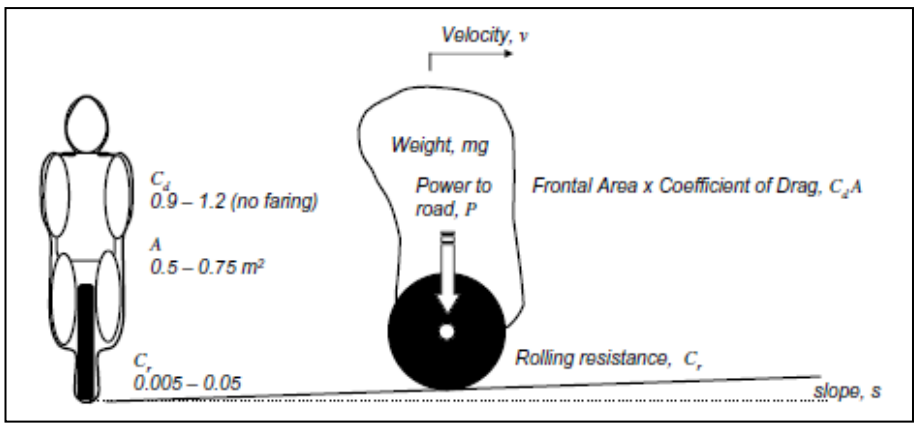

Figure 6: Representation of physics for personal transportation[1]

By knowing this power required by the vehicle, certain variables and theories can be obtained before the experimentation and testing is done in future. With this formula, efficiency of the motor also can be estimated.

2.4 PEV Design

2.4.1 Three Wheeler Vehicle

Three wheeler vehicles had been designed and tested for functionality as for the alternatives for common two and four wheeler vehicles. Three wheeler vehicle is less complex and cheaper if compared to four wheeler and it is more stable than a two wheeler vehicle. However, in terms of manoeuvrability, three wheeler design still has lot more to be improved[5].

Due to the simplicity of the design and a lot of mass has been reduced in the three wheeler vehicle design, the yaw response of the vehicle is better compared to the ordinary four wheeler vehicles[6]. If the centre of gravity of the design is low and near the two wheels portion, a rollover resistance of the vehicle will be high which almost the same as a four wheeler design.

In achieving better wind resistance, a teardrop design is favourable as it is an aerodynamic design which makes the vehicle to easily moves through wind. With this design, power consumption can be lessen thus increase the fuel efficiency of the vehicle. There are two types of configurations of three wheeler vehicle design; two front tyres (2F1R) or two rear tyres (1F2R). These configurations both will give a different effect for the vehicle when been designed but both configurations able to reduce the cost of manufacturing due to their simplicity[7].

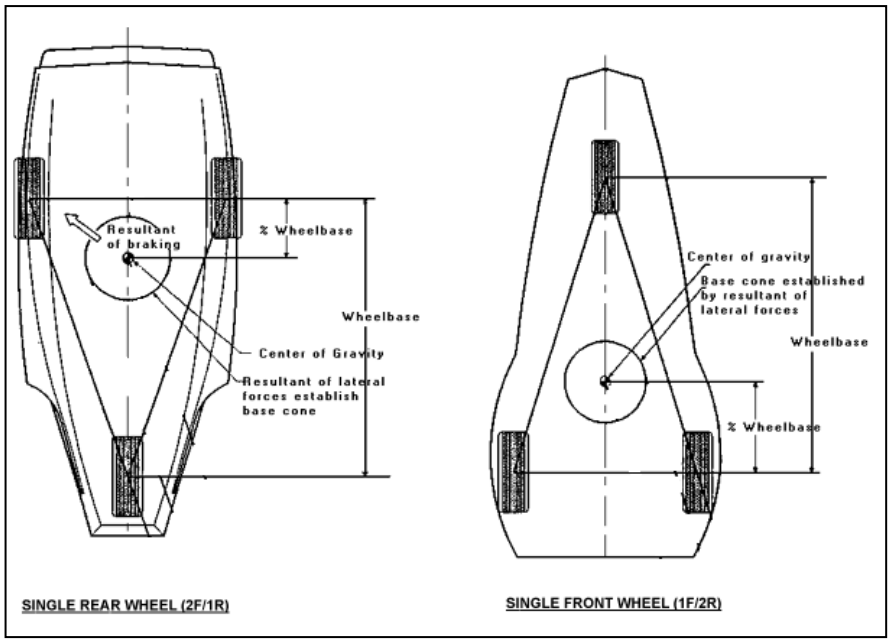

Figure 7: Configuration layouts of three wheeler vehicles[6]

2.4.2 Design Proposed by Zainor Faisal

As proposed by Zainor Faisal, the design for PEV is to be a tricycle design with rear wheel drive. In his design, the motor will drive the rear tyre without using any drive shaft to simplify the drive system of his PEV. In his design, he emphasised the PEV to be simple without having any sophisticated components to reduce the cost and make the PEV to be simple enough for a single rider vehicle.

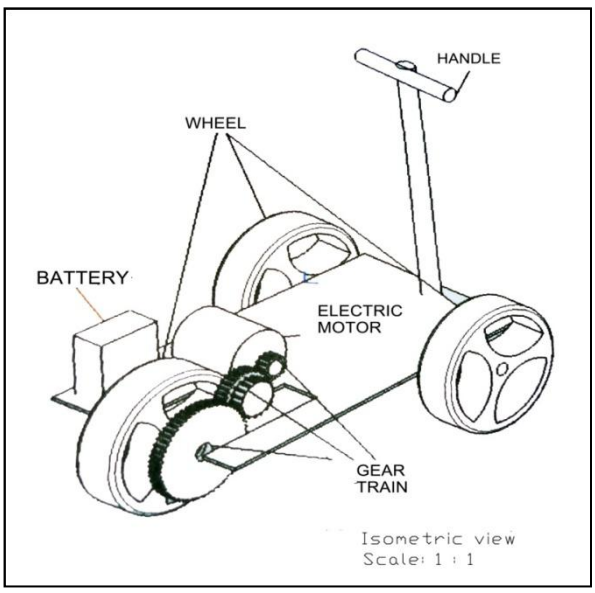

Figure 8: Isometric view of PEV[8]

In order to prevent the vehicle from flipping and to make it balance, the centre of gravity for his design is situated at the place of the rider. The red dot in the figure below indicates the centre of gravity for the design proposed by Zainor Faisal. He also had proposed the dimension of his PEV that give both benefit in term of cost and also meet the requirement of the scope that will be used in this project.

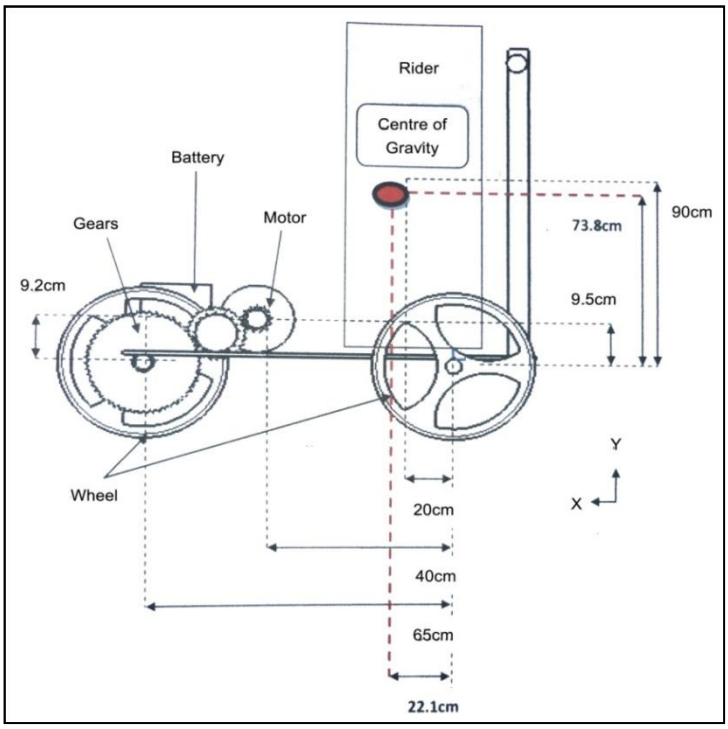

Figure 9: Dimension of PEV[8]

CHAPTER 3
METHODOLOGY

3.1 Key Milestone

In completing this project, author had followed few steps that had been planned before. Steps taken are shown in the key milestones of the projects below:

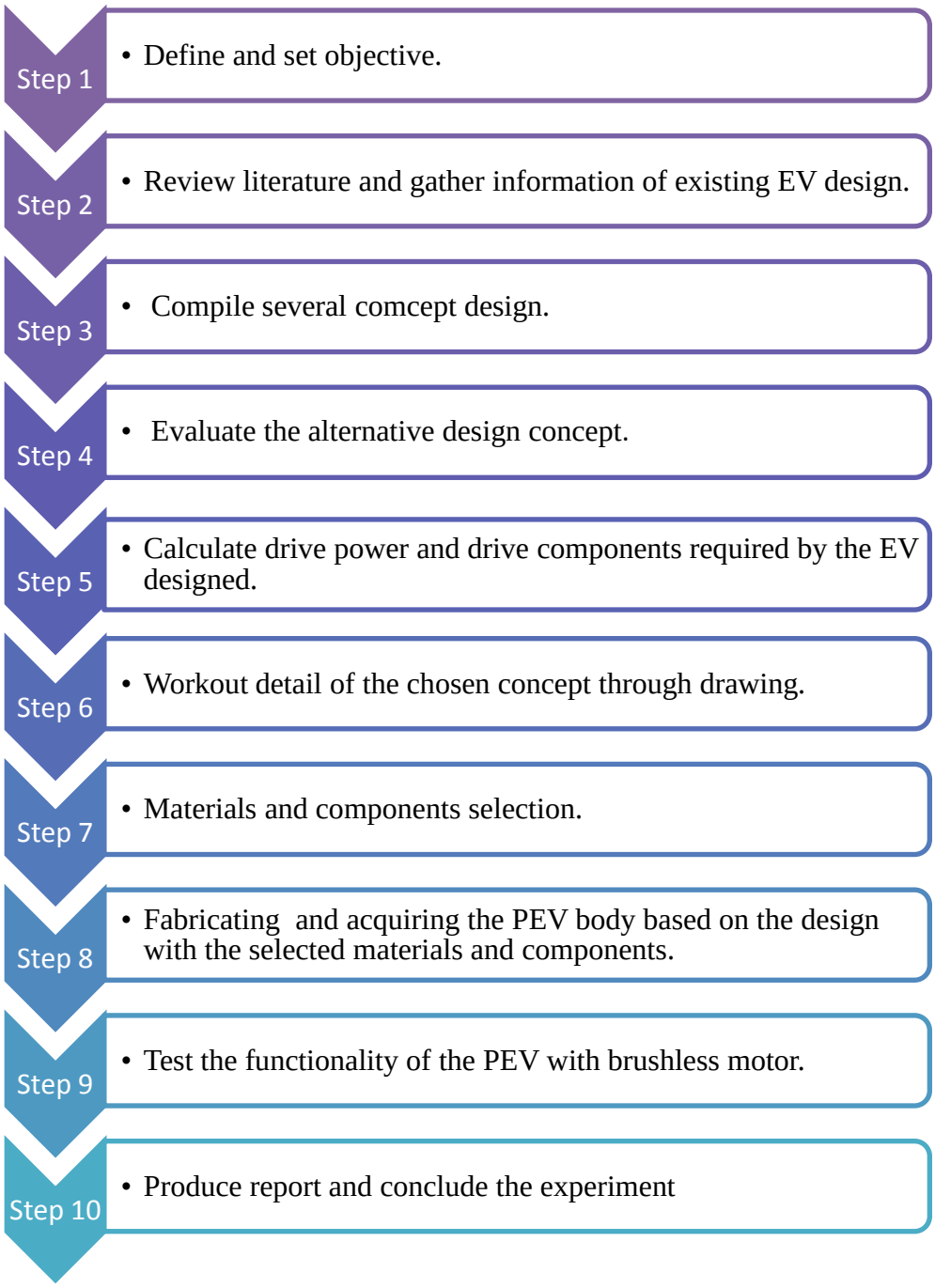

Figure 10: Key milestones of the projects

3.2 Description on Key Milestone

After the objective was defined, the author had done researches on the existing design that had been made for the PEV in the market. This research was done through reading the articles from the web on how design affects the stability and performance of the vehicle. Research also was done for the components required in fabricating the PEV and how to select the components and some calculations were done in the selection process.

Before the drawing was made, some raw sketching was made based on the research done. Then, full scale drawing was done by using CATIA V5 software to draw every part and component of the PEV in detail. Fabrication process was followed later based on the drawing made. A full scale prototype was fabricated in the lab using the selected materials and components and was made according to the drawing.

Some part and components were acquired from the hardware store and also from vendors. Those components were including the motor, PEV handle, sprockets, chain and tyres. As this project also was a continuation from previous project, some components also were obtained from previous student like the battery. The battery that was used was Lead acid battery as been proposed by him.

Whole fabrication process was done in manufacturing lab using the selected materials and components. In the fabrication process, some machines and tools were used to perform some tasks. Among the machines and tools used were:

- Milling machine
- Drilling table
- Shearing machine
- Boring tools
- Grinder
- Lathe machine
- Hand drill
- Argon welding machine
- Folding machine
- Hand saw

Among activities that were done during the fabrication process was milling, lathing, welding, slotting, and drilling. Safety precautions were taken in doing these processes especially when handling the machines and tools by following the safety

rules and regulations fixed. Since the purpose of this project is to produce a model that can be used for experimentation and improvement purpose in the future, most parts of the PEV was made to be not fixed. The height of the handle can be interchangeable, the motor bracket is made with slot for the tensioning purpose and changing purpose with other type of motor and also each parts of the body also can be dissembled for any changes.

Figure 10: a) Lathing b) Boring c) Welding

After all parts of the PEV was made and assembled, brushless motor was installed to the body of the vehicle. Then, the vehicle was driven to test its strength, functionality and stability. Lastly, analysis and conclusion was made regarding the design and the prototype produced.

3.3 Gantt Chart

This is the proposed schedule for activities and timeframe that will to be done during whole of the project

Activities	Week																										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Background study																												
Researching theories and literature review																												
Sketching and selecting the EV design																												
Do the calculation based on theory for the design																												
Draw the selected EV design based on calculation																												
Select the material and component for the fabrication																												
Build prototype																												
Run experiment and test																												
Analyze Result																												
Conclusion and Final Report																												

Table 2: Gant chart

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Overview of the PEV Design

As for the progress of the project, the design for the body of PEV is obtained. The design was made only to occupy one average adult passenger which will be the driver of the vehicle. The average size of the passenger is 165cm height and 70kg maximum weight. The design is focused more on the comfort and stability of the user while using this PEV.

This design has been improved from the design proposed by the previous report[8] as this design will use less force from the motor and weight of the vehicle body is needed to be reduced as minimal as possible. The main idea is still been used where the vehicle will be made with tricycle design for stability and the drive train will be put at the back as to increase the efficiency of the power transmission from motor to the wheel.

In this design, the PEV will be a tricycle vehicle as more stability can be achieved with two tyres at the back of the vehicle. However the design is controlled so that the weight of the vehicle is minimized in order to reduce the force needed by the motor to drive the vehicle. Hollow aluminium is used as the frame for vehicle as the both lightweight and strength capability is needed for this vehicle.

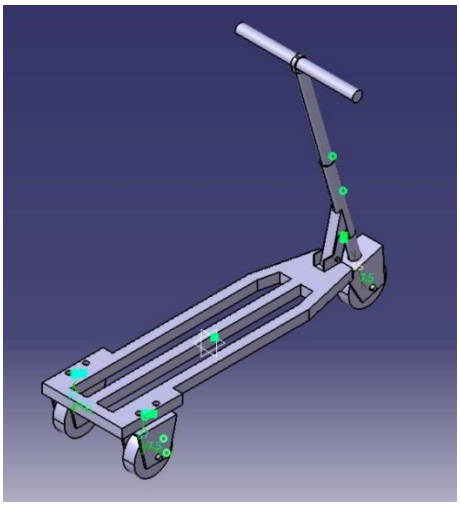

Figure 12: Isometric view of the PEV

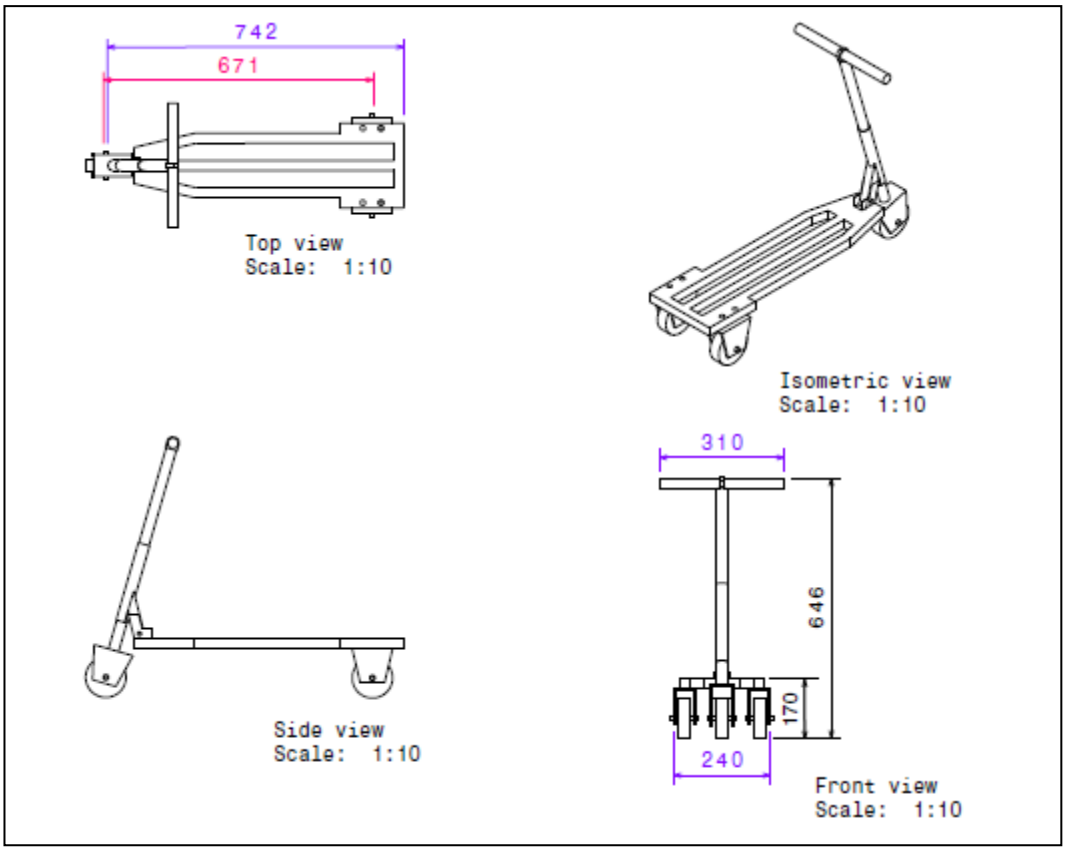

Figure 13: Orthographic projection of the PEV body

Tricycle concept with one front wheel and 2 rear wheels has been chosen as it use less cost and it is easier to be build. The mechanisms for this concept are much simpler as compared to even two front wheels and one rear wheel tricycle concept. And yet, this design might not be the best design for commercial purpose but it somehow sufficient for research purpose.

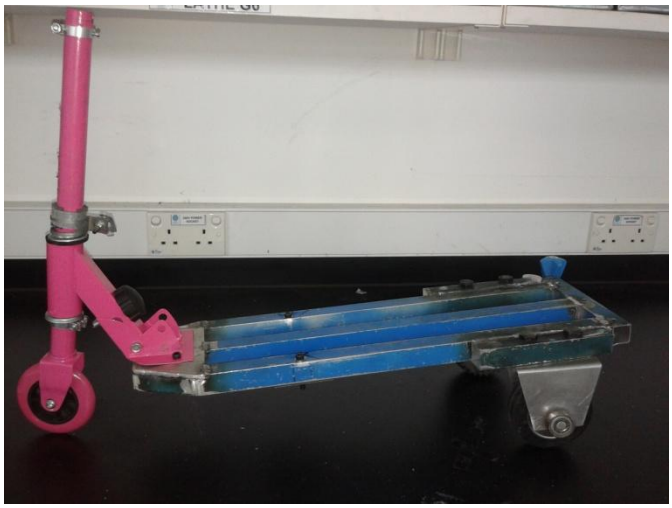

Figure 11: Body of the fabricated PEV

The battery is placed at the back of the PEV body. This placement can make the centre of gravity of the vehicle to be near the two wheels at the back, therefore, it can increase the resistance to rollover. The centre of gravity for the PEV with the battery can be calculated as follow:

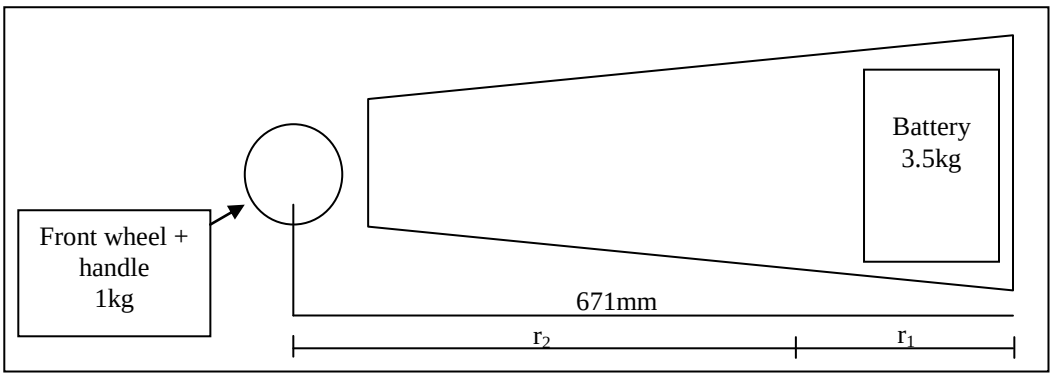

Figure 15: Sketching of the top view for the PEV

From the configuration above, centre of gravity for the PEV body can be calculated by finding the moment about the centre point. The calculation is as follow:

$$M_1 = M_2$$

$$F_1 r_1 = F_2 r_2$$

$$3.5\ r_1 = r_2 \qquad \text{----------(1)}$$

$$r_1 + r_2 = 0.671m \qquad \text{----------(2)}$$

Simultaneous equation of 1-2

$$4.5 r_1 = 0.671m$$

$$\underline{r_1 = 0.149m}$$

From the calculation, the author can conclude that the centre of gravity for the PEV is really near the rear wheel so that the ratio of front wheel and rear wheel to the centre of gravity is 0.78:0.22.

The assembly points for this concept also are made so that it can easily detach from each other. This is for the ease of carriage and also for the replacement purpose. Since this is a model that will be used for testing by others, the components might be

changed for their own purpose, therefore, this design is made to be experimental friendly.

The slot for the motor placement also is made so that it can be changed with other motor with different dimension. Motor bracket is designed so that its height can be lowered or lifted higher. By having the slots the distance between the motor and wheel can be adjusted based on the dimension of the motor itself.

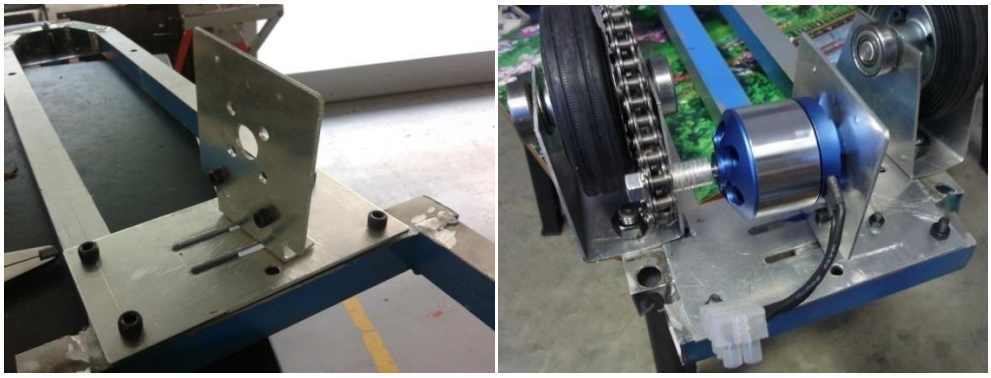

Figure 12: Slots and bracket for motor

4.2 Motor Choice

Most of the existed PEV models available in market nowadays are using brush DC motor as it is more abundant and the configuration is easier. Brush DC motor also able to produce more speed compare to brushless DC motor however, the torque of brush DC motor is lower if compare to brushless motor.

As a choice for the motor, the expected power of motor that will be purchased is already calculated with expected maximum weight for both vehicle and user and expected way the vehicle will be driven later. The parameters used are just for reference and the author is expected the performance of the PEV will be better than the given parameters.

Weight	75 kg
Frontal area	0.66 m^2
Maximum velocity	20km/h @ 5.56m/s
Slope gradient	20^o
Drag coefficient	0.2
Frictional coefficient	0.015

Table 3: Expected parameters

With the parameters above, the power required by the vehicle will be:

$$P = MgC_r v + \frac{1}{2}\rho C_d A v^3 + Mgv\sin a + Mv\frac{dv}{dt}$$

$$= 75\ \ 0.015\ \ \ 9.81\ \ \ 5.56\ + 0.5\ 1.23\ \ \ 0.2\ \ \ 0.66\ \ \ 5.56\ ^3$$

$$+\ 75\ 9.81\ \ \ 5.56\ \ \sin 20$$

$$\underline{= 1475W}$$

This power output needed by the wheel is equal to 265N traction force needed by the wheel. This is obtained from dividing the power with the velocity:

$$F = \frac{P}{v}$$

$$= \frac{1475}{5.56}$$

$$\underline{= 265N}$$

This power is calculated with the assumption the vehicle will not having any acceleration. Thus, an 1100W motor is chosen to drive this designated PEV. A model of brushless DC motor from TowerPRO is selected as the model able to give a high speed rotation and medium torque with a reasonable price.

Dimension	80mm x 51mm (L x D)
Weight	306 g
Voltage	10 V
Maximum efficiency current	70 A
Maximum power	1150 W
Speed	10200 rpm

Table 4: Motor specification

Figure 17: Model of selected motor

4.3 Power Transmission

In order to transmit power from motor to the wheel while increasing its torque, chain and sprocket is used. After making some analysis and consideration on the choice of the power transmission components, chain is the most proper choice for this design besides using gear and pulley.

The consideration of choosing the components for power transmission is based on three criteria which are availability, functionality of the components and size of the component.

Chain and sprocket is easily can be found in the market with the variety of size and tooth number. Chain and sprocket is most suitable for this design since the distance between motor and wheel is intermediate distance which only 60mm. Pulley and belt is better for a long distance configuration meanwhile gear is better for short distance configuration. Therefore, chain and sprocket is much better to be used in this PEV design.

Torque given by the motor can be determined through the power formula as below:

$$P = T\omega$$

$$T = \frac{1150}{1068}$$

$$\underline{= 1.076\ Nm}$$

Torque given out by the motor is not enough to move the PEV, therefore, larger ratio of sprocket is needed. Since the tyre is limited in size, therefore maximum sprocket size can be used is 29 tooth with the pitch of 35mm. With a 9 tooth sprocket as the driver sprocket, making the ratio of the sprockets used is 3:1. Thus, the torque at the wheel will be 3.228Nm.

4.4 Circuit Configuration

Since brushless motor is been used in the configuration of the circuit is different if compared to the brush motor circuit configuration. In brushless motor configuration, an electronic speed controller (ESC) must be use in order to operate the motor since the motor is the passive component in the circuit. Thus, it needs a component to operate it. ESC's purpose is to vary the electric motor's speed with the help from the variable resistor. Since the ESC used for this circuit is already programmable one, so there is no need for any programming job need to be done to the ESC in order to ensure the ESC functioned correctly.

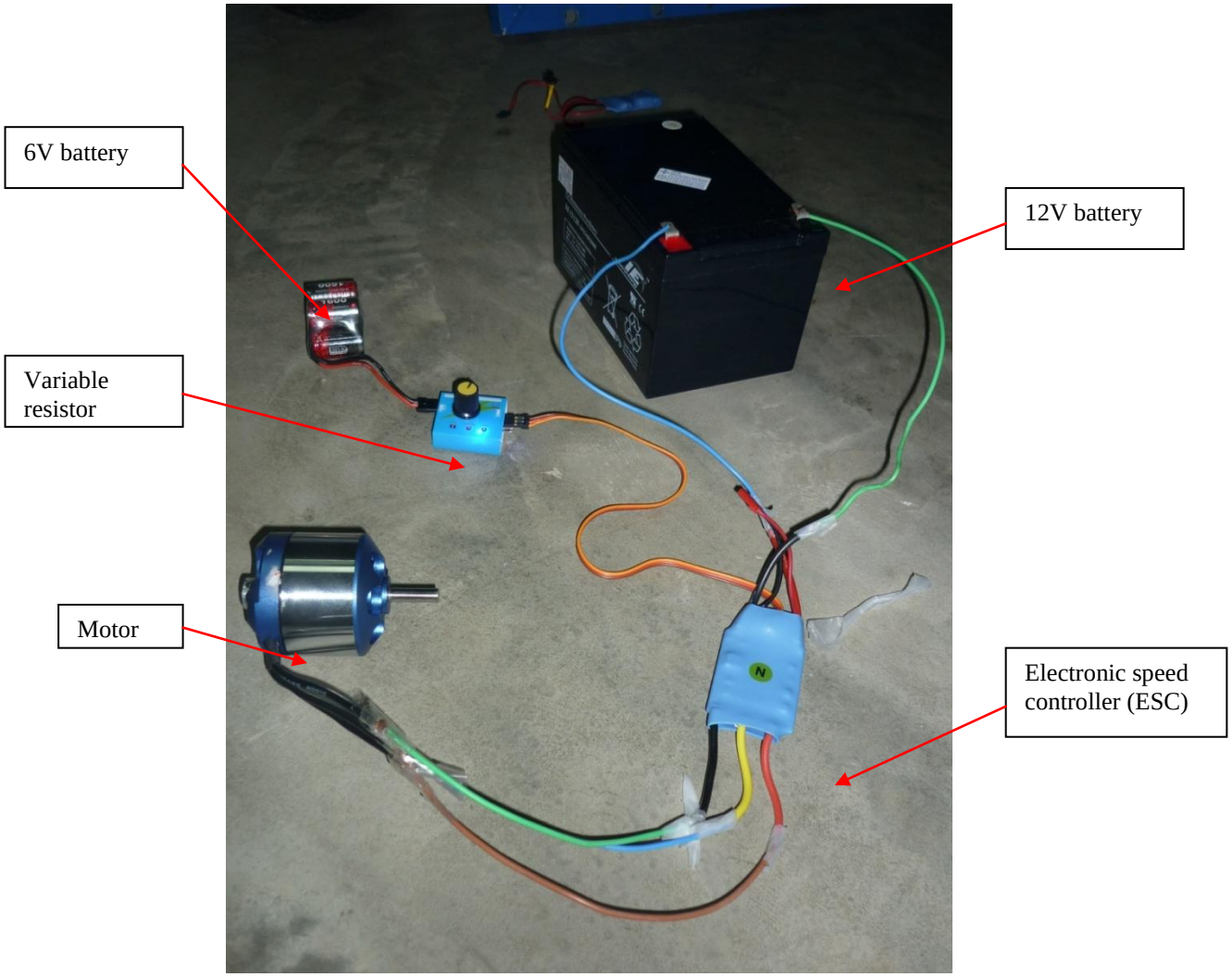

Figure 13: Components of the circuit

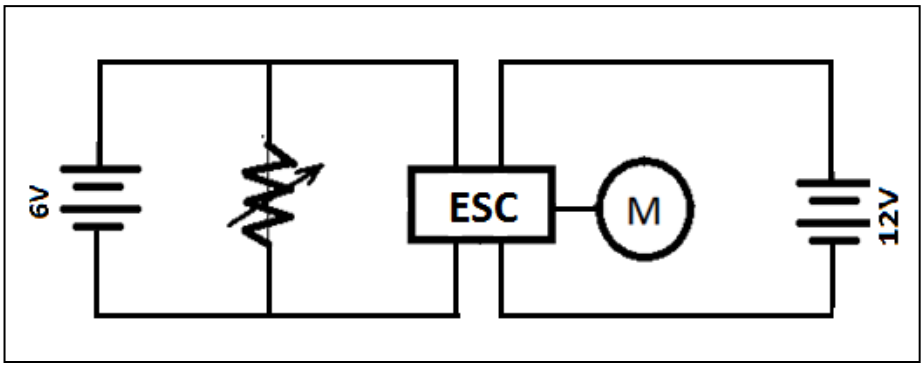

Figure 14: Circuit configuration

Table 5: Legends

	Battery
	Variable resistor
	Electronic speed controller
	Brushless DC motor

There is two batteries used in the circuit, one is to power up the ESC and another one is to power up the servo tester or variable resistor. Different batteries are used because the voltage and current to power up the resistor is lower than to power up the ESC. Plus, the current also different making it is important to use different batteries for this circuit.

Since the circuit above is just for testing the motor condition, the circuit is still incomplete without proper wiring and on/off switch to cut off the power to ESC and servo tester. However, this circuit is now working and can be put in the PEV once the body is finished.

4.5 Comparison of Tasks Achieved

Tasks Done	Previous Projects	Current Project
Design of PEV model	/	/
Design the drive train for the PEV		/
Acquiring the battery pack	/	
Acquiring motor for drive train		/
Designing the circuit configuration for the motor and drive train		/
Fabricate the body structure of the PEV	/	/
Assemble the body structure of the PEV with battery and drive train		/
Testing the capability of the PEV		/

Table 6: Tasks done comparison

CHAPTER 5
CONCLUSION AND RECOMMENDATION

The project results cannot be concluded as the motion requirement cannot be achieved since the electronic speed controller (ESC) for the motor was burnt before the testing was done. However, the design and fabrication of body of the PEV was completed.

Based on the research done, the reasons why the ESC might burn during the operation can be caused by certain factors as below:

- The usage of lead acid battery which deliver extra burst current to the ESC that causing the ESC to melt. Lead acid battery able to give out up to 20000 mAh of current which is considerably high to the ESC.
- Malfunction in the ESC's circuit.
- Excessive load given to the motor by the tyre.

After going through some research, the author found that lead acid battery able to give out 20000 mAh of current meanwhile the ESC limit is only 70A. This is the main reason that causes the ESC to burn out. This mistake happened as the battery choice is not considered in this project.

In order to operate brushless DC motor, Lithium Polymer (LiPo) battery is recommended to be used as the battery deliver lower current than lead acid battery. If lead battery is still the choice to operate the motor and ESC, more resistor is needed to control the current flow from the battery to the ESC as the variable resistor used in the circuit only functioned as the throttle to control the speed of the motor.

It is also recommended to use electronic watt meter and power analyzer that is usually used by the remote control (RC) enthusiasts to monitor the current flow in the circuit of their model. This component can be use as the drive train of this PEV is been improvised from the RC's drive train concept. The components in the drive train also are used for the RC model such as helicopter and plane.

This project is still in the early stage and a lot more can be improve in order to produce an optimal design concept of the personal electric vehicle which is practical for the public to use. PEV also can be design and improve so that it can help the disables to move around easily without harming them and people around them.

Last but not least, author really hope this project will be a reference for others in order to continue to improve PEV technology so that it suitable to be used in public. With the design and model produced, the author hopes it can benefits others in future.

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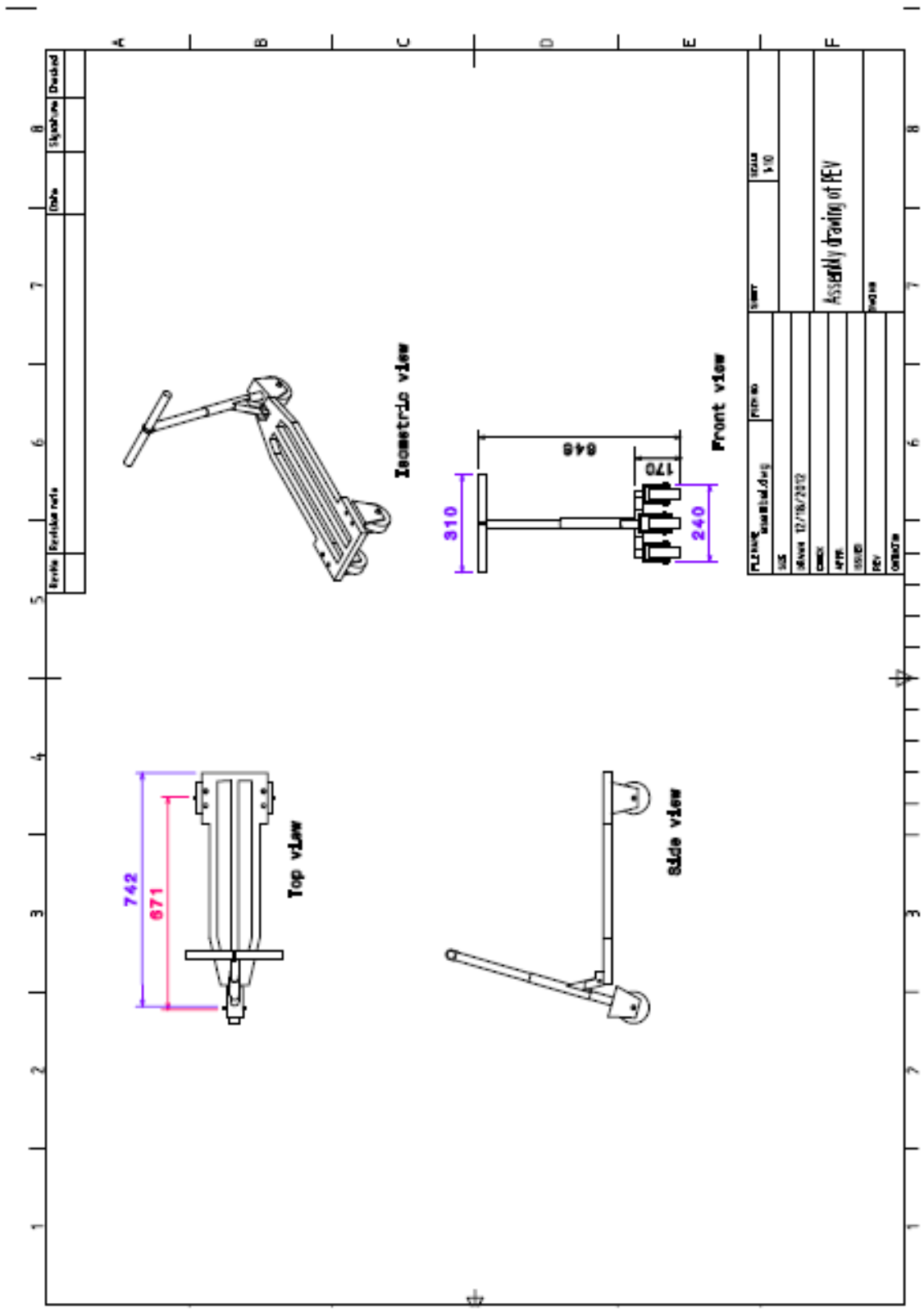
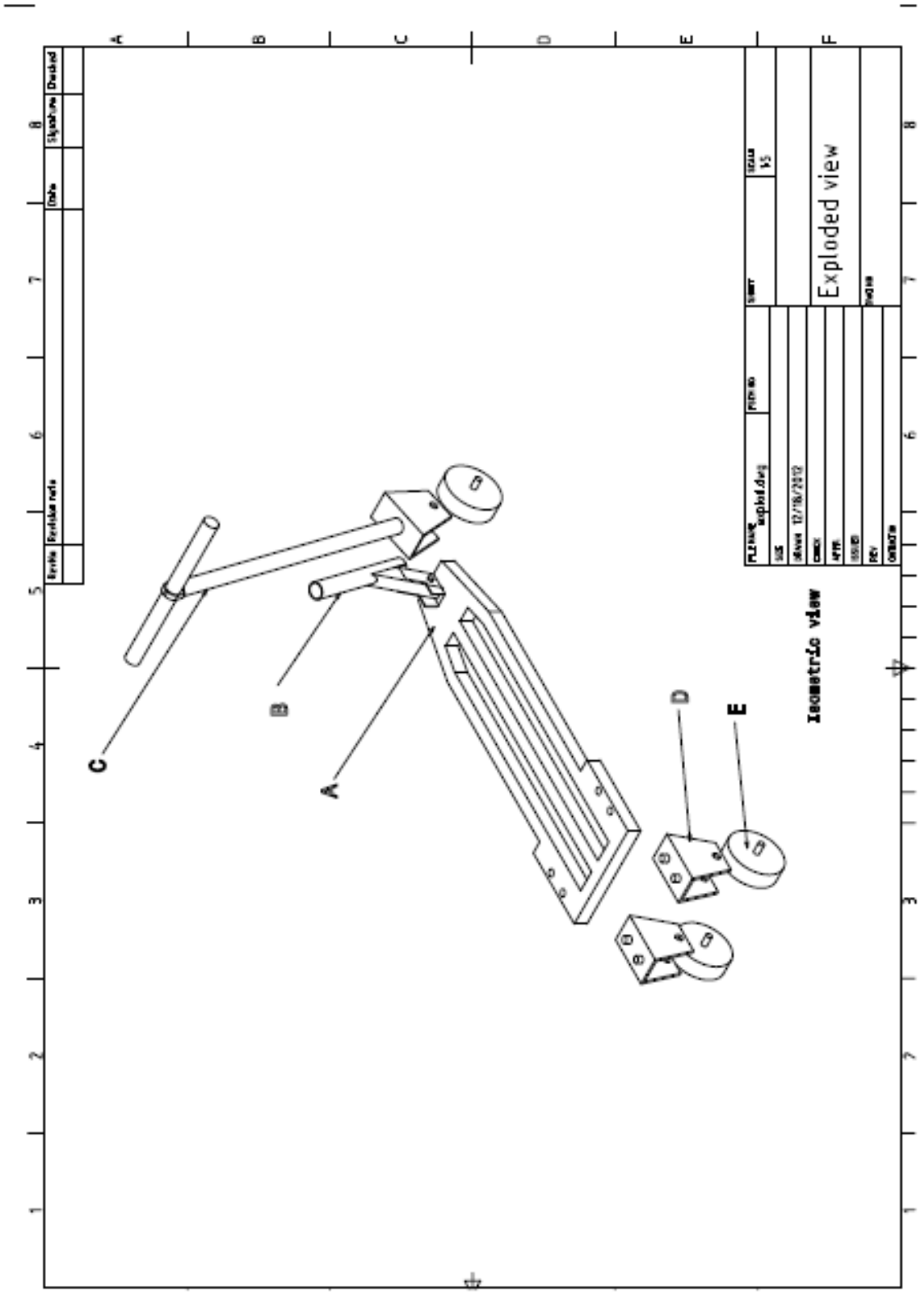
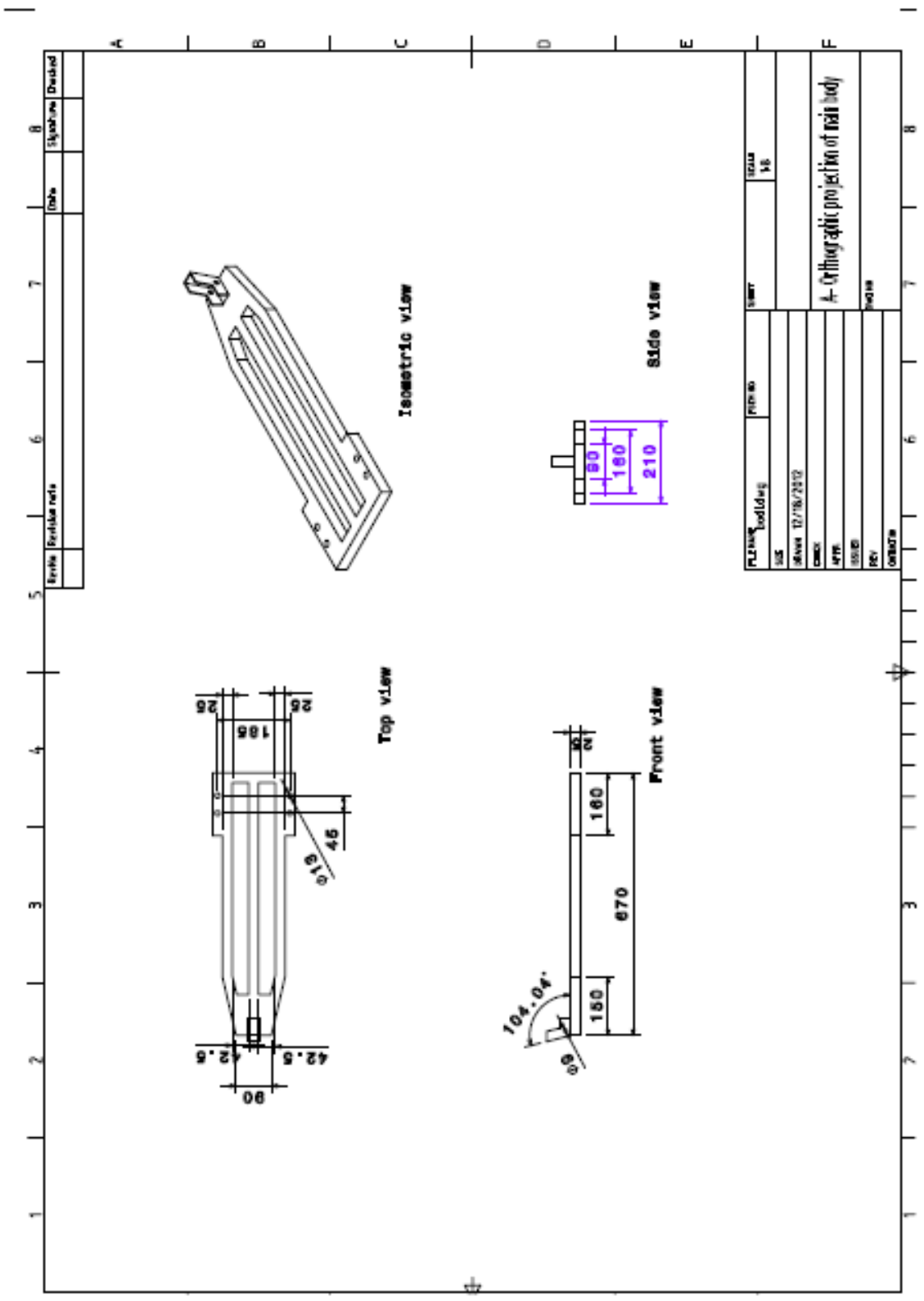
APPENDICES



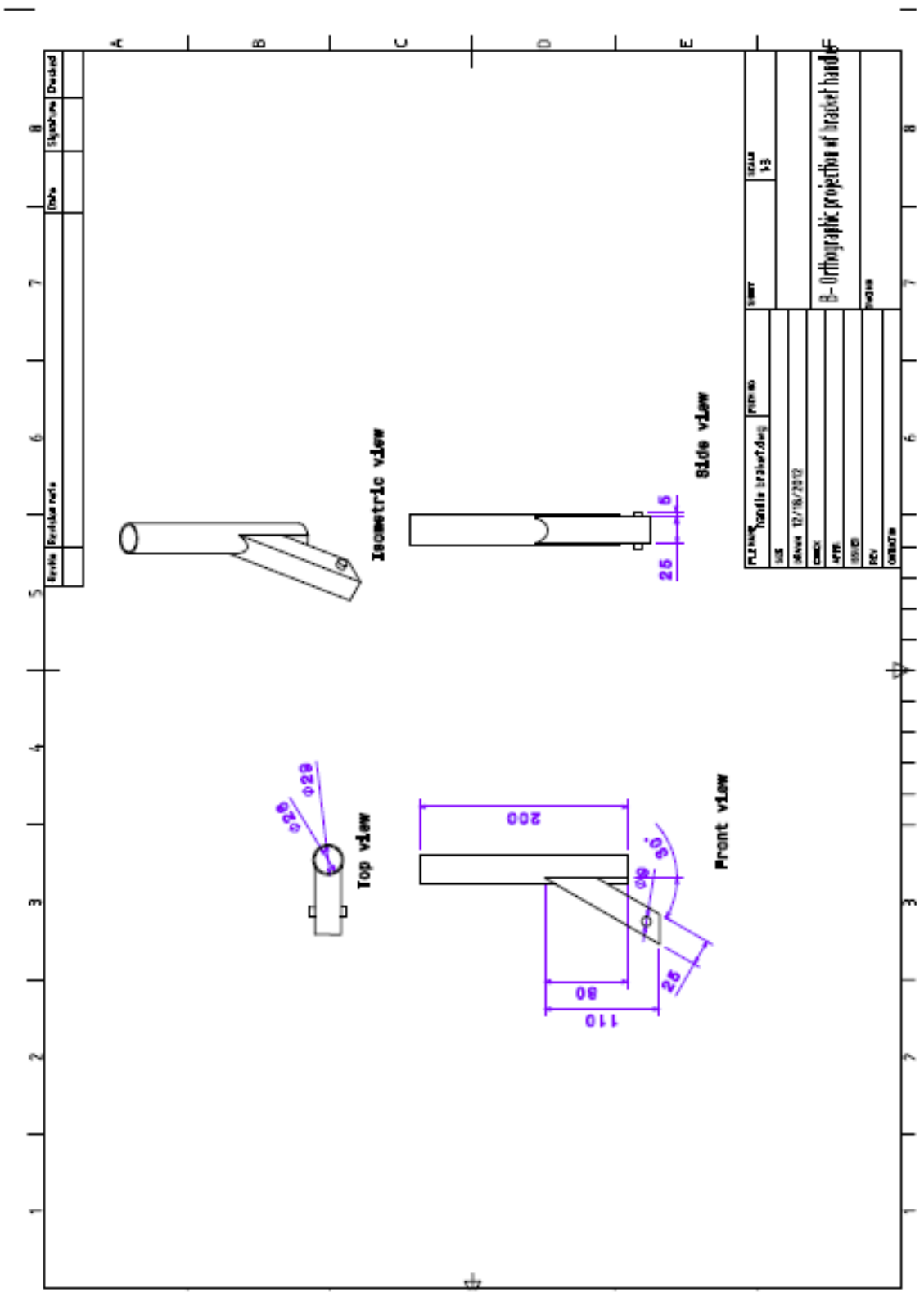
Appendix 1: Orthographic projection of full body drawing



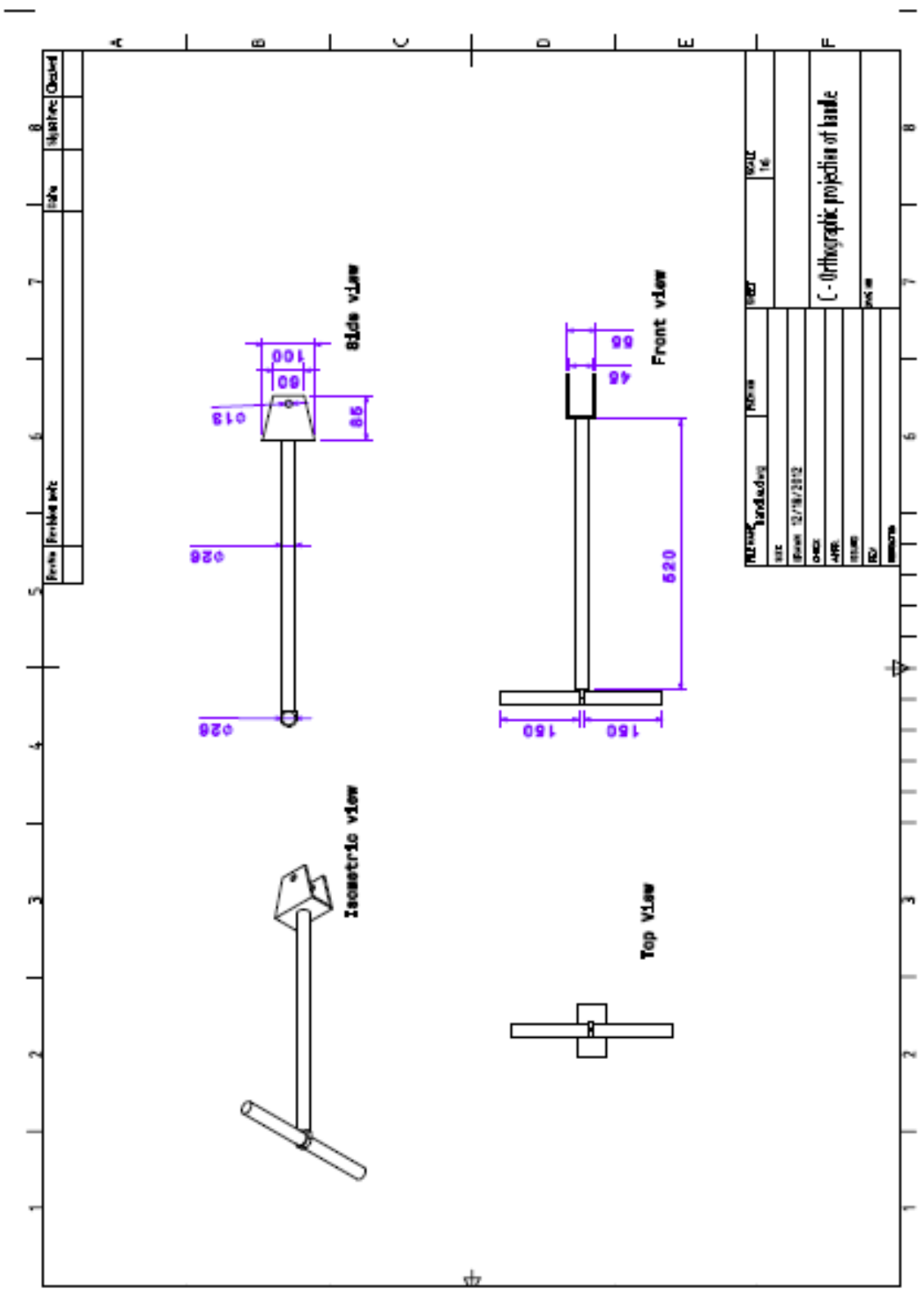
Appendix 2: Exploded view of PEV



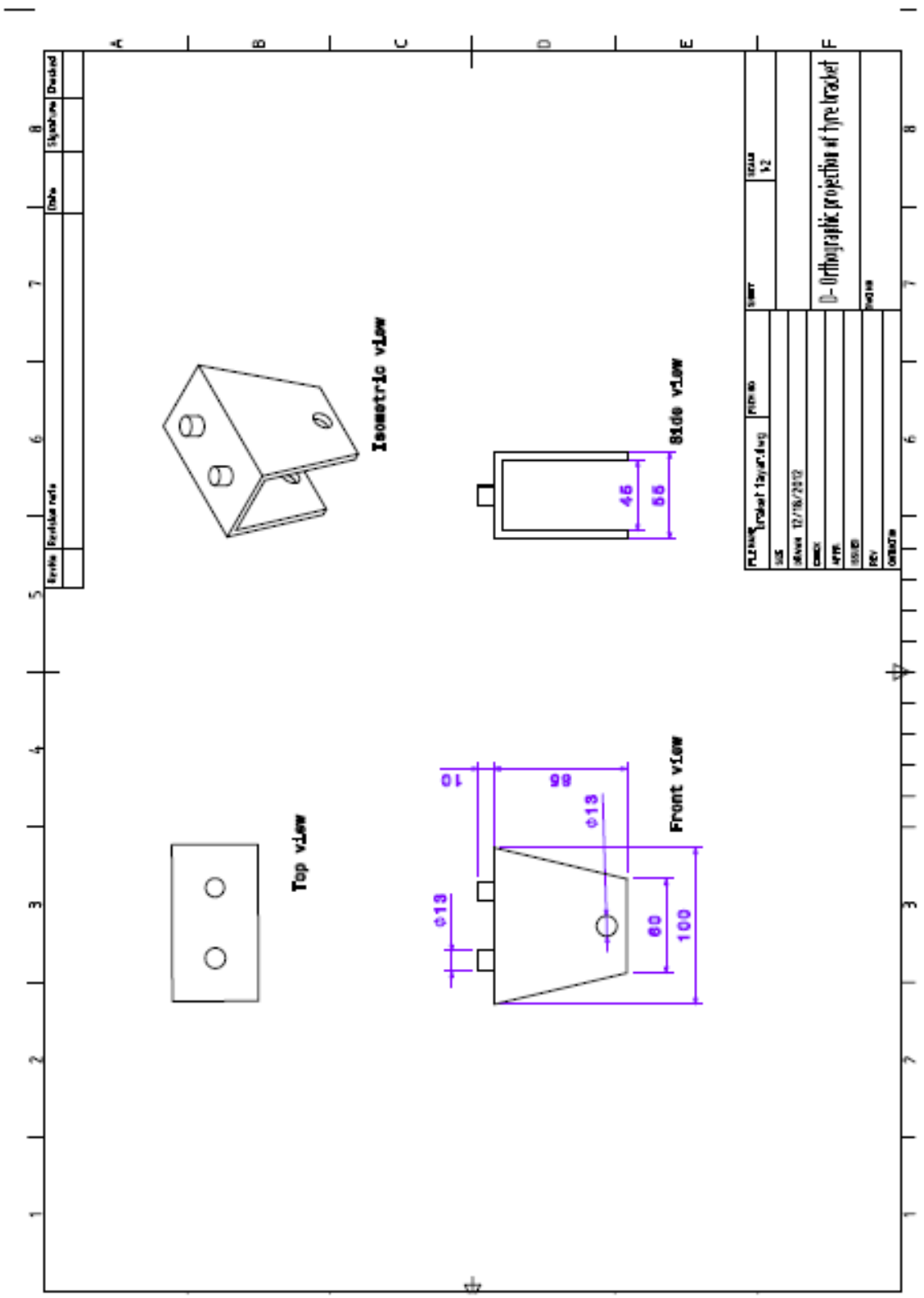
Appendix 3: Orthographic projection of main body of PEV



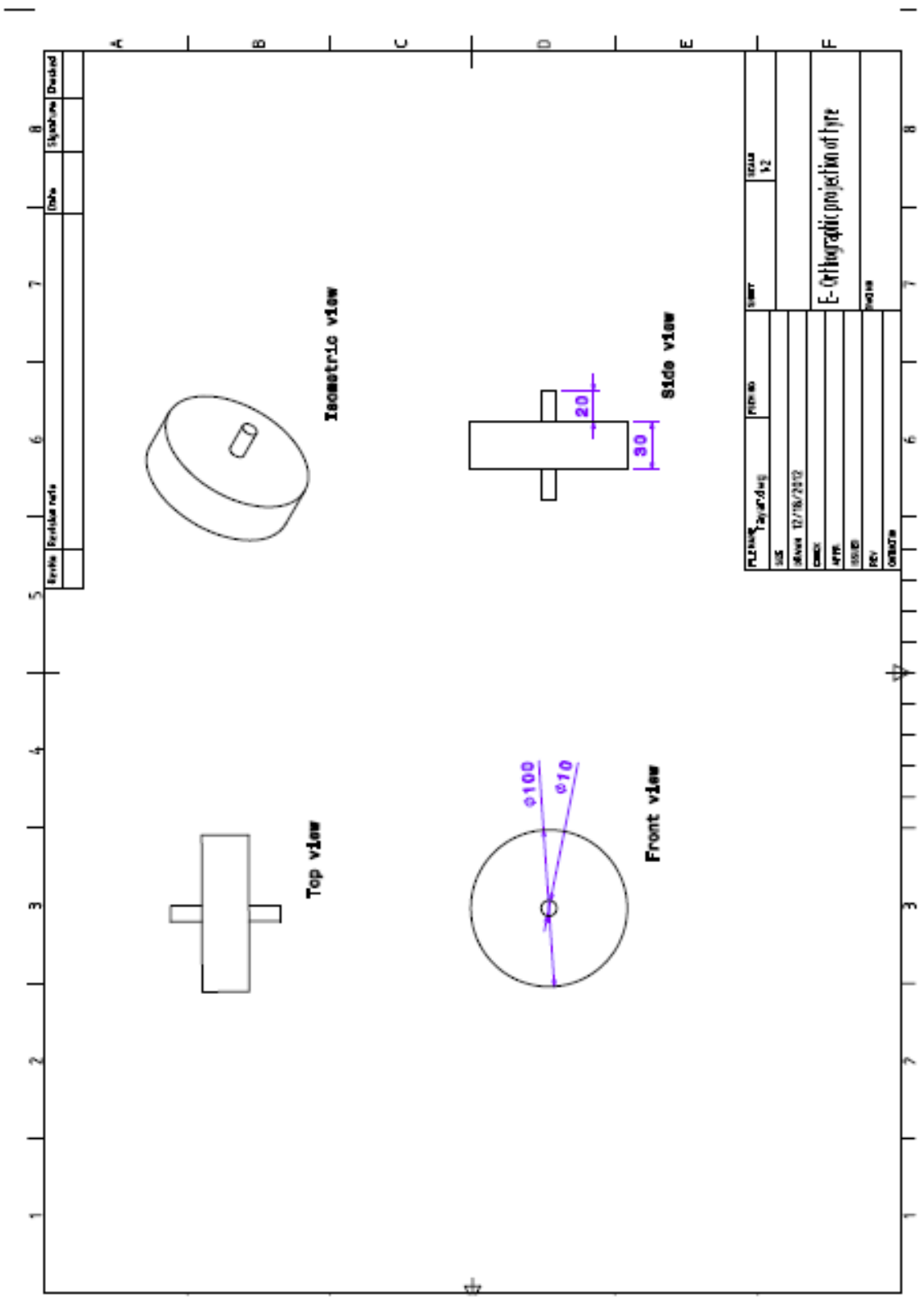
Appendix 4: Orthographic projection of handle bracket



Appendix 5: Orthographic projection of handle



Appendix 6: Orthographic projection of tyre bracket



Appendix 7: Orthographic projection of tyre