Design and Development of Steel Pipe Profiling Prototype

by

Mohd Yasser Rabanie Bin Jamaluddin

Dissertation report submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

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Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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Approved by,

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(Dr. Syed Ihtsham Ul-Haq Gilani)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JUNE 2010

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.

MOHD YASSER RABANIE BIN JAMALUDDIN

ABSTRACT

Large steel structures like pipelines, bridges and offshore platforms are fabricated at fabrication yards to ease mobilization. The main components include the cylindrical steel pipes for bracings, support column, nodes etc. To join steel pipes at various angles, the edges need to be prepared accordingly. At the moment, most of these activities are done manually by plotting the profiles using drafting on papers and then transferring it to the steel pipe. Thus, methods to improve productivity rate are highly sought by fabricators or contractors. This project aims to develop a mechanical prototype to improve plotting and marking activities for profiling. The prototype shall be able to adapt to fit to 6" nominal diameter schedule 40 steel pipes commonly used in oil and gas industries, plot curvature of profiling on the surface of steel pipes, plot curvatures associated with 45°, 60° and 90° angles of joints and fixture on steel pipes with minimum preparation.

ACKNOWLEDGEMENT

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MOHD YASSER RABANIE BIN JAMALUDDIN

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ABBREVIATIONS

COG	-	Center of Gravity
DOF	-	Degree of Freedom
ND	-	Nominal Diameter
NPS	-	Nominal Pipe Size
OC	-	Outside Circumference
OD	-	Outside Diameter
OR	-	Outside Radius
ROT	-	Radius of Turn
SCH	-	Schedule
VIV	-	Vortex Induced Vibration

NOMENCLATURE

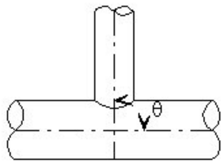
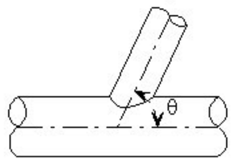
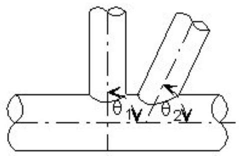
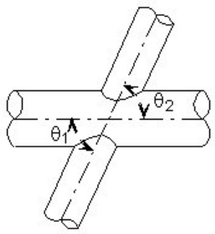
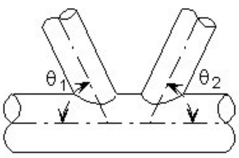
d	- Major diameter
dm	- Mean diameter
f	- Friction factor
F	- Force exerted (N)
F_C	- Centripetal force
g	- Gravitational pull (m/s^2)
I	- *Current (Ampere)*
l	- Lead
m	- Mass of prototype (kg)
r_{motion}	- Radius of motion (m)
r_{wheel}	- Radius of wheel (m)
r_{outer}	- Radius of outer diameter of pipe (m)
rpm	- Revolution per minute
V	- Voltage (Volt)
θ	- Angle (°)
ω_{motion}	- Motion angular velocity (rad/s)
$\omega_{sprocket}$	- Sprocket angular velocity (rad/s^2)
ω_{wheel}	- Wheel's angular velocity (rad/s)

CHAPTER 1: INTRODUCTION

1.1 Background of Study

Curvature of profiling on steel pipes is a very imperative element to be calculated, plotted and cut essentially for joinings. The classification of joints is dependent on the joint geometry;

Table 2-1: Classification of steel pipe joints [1]

Type of Joint	**Illustration**	**Angle, θ**
T Joint		$\theta = 90°$
Y Joint		$\theta \neq 90°$
N Joint		$\theta_1 = 90°$ $\theta_2 \neq 90°$
X Joint		$\theta_1 = \theta_2$
K Joint		$\theta_1 \neq 90°$ $\theta_2 \neq 90°$

There are four variables need to be identified by the engineers in order to calculate and plot the curvature of profiling [1];

1. Nominal diameter of steel pipe
2. Angle of joining
3. Thickness of steel pipe
4. Angle of bevelling

Steel pipes are used extensively for offshore structures, pipings and pipelines. Steel is the main material used due to its high yield strength and lightweight compared to concrete or reinforced concrete. In terms of design, steel gives simpler design as compared to reinforced concrete.

Pipes are also a major part of an offshore structure because it has advantages compared to a solid tubular or a square beam in terms of moment. For substructures, tubular shape of the pipes will reduce ‘vortex induced vibration’ (VIV). [2].

1.2 Problem Statement

All fabrication yards in Malaysia apply manual plotting of profile curvature on the surface of steel pipes. The activity consumes a lot of time to mark the surface by using puncher and markers. Prior to marking, the development drawings have to be made and in some cases, profiling prototypes are to be developed. Human error is one of the major contributors of wrong marking. Manual profiling method also acquires labour forces to gradually turn steel pipe while marking activity is taken into place. This exposes potential hazards to the labours such as sliding, sudden fall etc.

1.3 Objectives

There are three main objectives of this project. They are:

1. Designing of the steel pipe marking profiler prototype with relevant calculations.
2. Fabricating the prototype based on design specifications and dimensioning.
3. Testing of vertical circulating and translational motions of the assembled prototype by implying simple circuit configuration.

1.4 Design Requirements

1. Translational displacement of the end-effector shall cover the distance of maximum and minimum amplitudes of the profiling curves.
2. The size of wheel shall provide tolerances between base of prototype and outer diameter of pipe to allow circumferential motion of the prototype without any obstruction by its own structure.
3. The total height of the prototype shall not exceed 20 inch to minimize working space.
4. The prototype shall be equipped with a tightening mechanism to ease installation process onto pipes.

1.5 Scope of Study and Limitations

The scope of the project includes design of prototype mechanical system; perform statics analysis, material selection, development of assembly drawing, fabrication of the prototype and testing of mechanical motions. The design limitations are:

1. Fit to Nominal Diameter 6”: Schedule 40 pipes with minimum fixture.
2. Plot curvature of profiling on the surface of steel pipes.
3. Plot curvatures associated with 45°, 60° and 90° angles of joints.
4. Plot curvature of profiling for pipe end or notching.

CHAPTER 2: LITERATURE REVIEW

2.1 Design Phase

In design phase, there are two major components covered: material selection process and mechanical design of the prototype.

2.1.1 Material Property Information

Engineering material selection process is one of the most important steps for a competitive mechanical design. Much of the selection process involves trade-offs among the different parameters. Various charts are available for comparing different parameters with respect to others. These charts are helpful for doing the trade-off optimally [3].

2.1.1.1 Density

Density is a measure of how heavy an object is for a given size, i.e. the mass of material per unit volume. Many materials have a uniform internal structure. For example, in metal the atoms are regularly packed together in a crystal structure. The density of these materials is therefore well defined - there will be little variation in different samples of the same material. Some materials have a variable internal structure, for example wood is made of hollow cells which can vary in size and thickness between trees. Because of this, the density between different samples of the same material will be more variable [3].

2.1.1.2 Young’s Modulus

Young's modulus measures the resistance of a material to elastic deformation under load. A stiff material has a high Young's modulus and changes its shape only slightly under elastic loads. A flexible material has a low Young's modulus and changes its shape considerably. A stiff material requires high loads to elastically deform it. The stiffness of a component determines how much it deflects under a given load. This is dependent on the Young's modulus of the material, but also on how it is loaded and the shape and size of the component [3].

2.1.1.3 Yield Strength and Specific Strength

The strength of a material is its resistance to failure by permanent deformation. A strong material requires high loads to permanently deform it, which requires high loads to elastically deform it. For metals, polymers, woods and composites, strength on the selection charts refers to loading in tension. For brittle materials like ceramics, failure in tension is by fracture, and the tensile strength is very variable. The strength on the selection charts is then compressive strength which requires a much higher load. Specific strength is strength divided by density [3].

2.1.1.4 Toughness

Toughness is the resistance of a material to being broken in two, by a crack running across it when the material absorbs energy. The amount of energy absorbed per unit area of crack is constant for a given material, and this is called the toughness. A tough material requires a lot of energy to break it, usually because the fracture process causes a lot of plastic deformation; a brittle material may be strong but once a crack has started the material fractures easily because little energy is absorbed [3].

2.1.1.5 Elongation

Elongation to failure is a measure of the ductility of a materials, in other words it is the amount of strain it can experience before failure in tensile testing. A ductile material, most metals and polymers will record a high elongation. Brittle materials like ceramics tend to show very low elongation because they do not plastically deform [3].

2.1.1.6 Hardness

Hardness is the property of a material that enables it to resist plastic deformation, penetration, indentation and scratching. Therefore, hardness is important from an engineering standpoint because resistance to wear by either friction or erosion by steam, oil and water generally increases with hardness. Several methods have been developed for hardness testing. Those most often used are Brinell, Rockwell, Vickers, Tukon, Sclerscope, and the files test. The first four are based on indentation tests and the fifth on the rebound height of a diamond-tipped metallic hammer. The file test establishes the characteristics of how well a file takes a bite on the material. The tests are empirical, based on experiments and observation, rather than fundamental theory. Its chief value is as an inspection device, able to detect certain differences in material when they arise even though these differences may be indefinable [3].

2.1.1.7 Machinability

Machinability is a characteristic of a material that makes it easier to cut, drill, grind, shape, etc. It can be assessed based on the material removal rate, cutting forces, surface finish and chip control. Machinability is influenced by the material's thermal properties, chemical properties and mechanical characteristics (resistance, hardness, stretching, work hardening, etc.) [3].

2.1.1.8 Cost

Materials are usually sold by weight or by size. Material costs are therefore given as cost per unit weight or cost per unit volume. Many materials are initially made in bulk. They are usually shaped into standard stock items before being bought by a manufacturer. As a result, the cost of a material to a manufacturer is often higher than the cost of the raw material. Also, as a general rule, the more a material is improved, for example, by alloying, the more expensive it becomes [3].

2.1.2 Materials selection charts

Materials selection charts are a graphical method of presenting material property information. Each property could be plotted as bar charts, but a 2D diagram of a couple of properties is much more convenient. *Figure 2-1* shows an example of Young's modulus versus density. It depicts where the information for the diverse classes of materials fall [3].

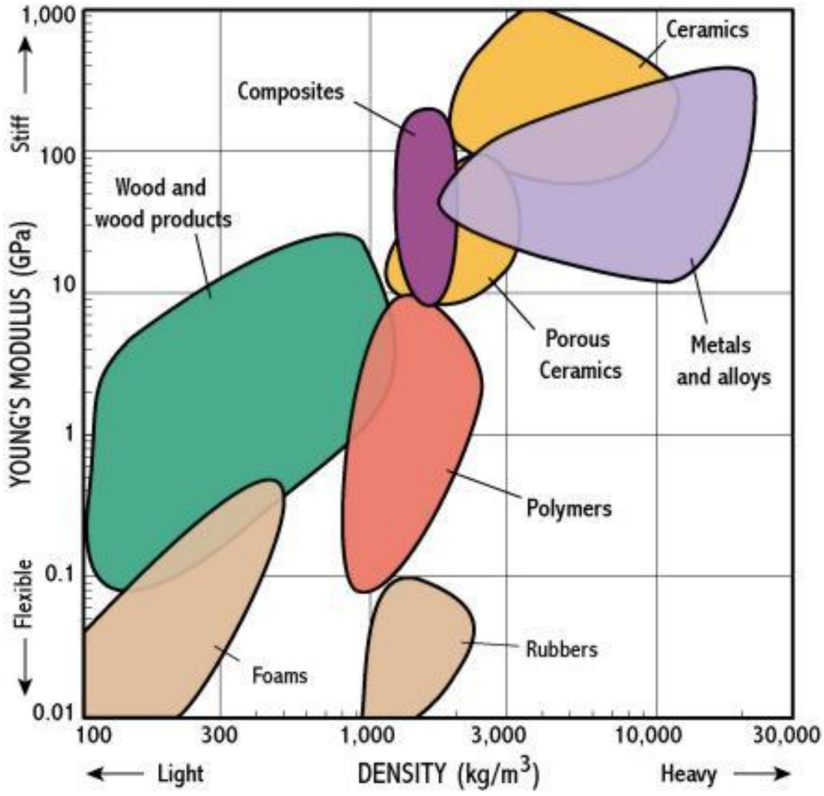


Figure 2-2: Young's modulus against density of materials selection chart [3]

This chart gives an overall view of the relative values of Young's modulus for the different classes of material. The densities of the different classes are also easily compared.

A 2-D plot enables a good visual appreciation of the ranges and relative magnitudes of the two properties considered individually, simply by spreading the materials out on the diagram. Firstly, it's no coincidence that metals, polymers and so on cluster on a Young's modulus versus density chart. These properties reflect the characteristic atomic packing and bonding in each class, which are very well-defined [2].

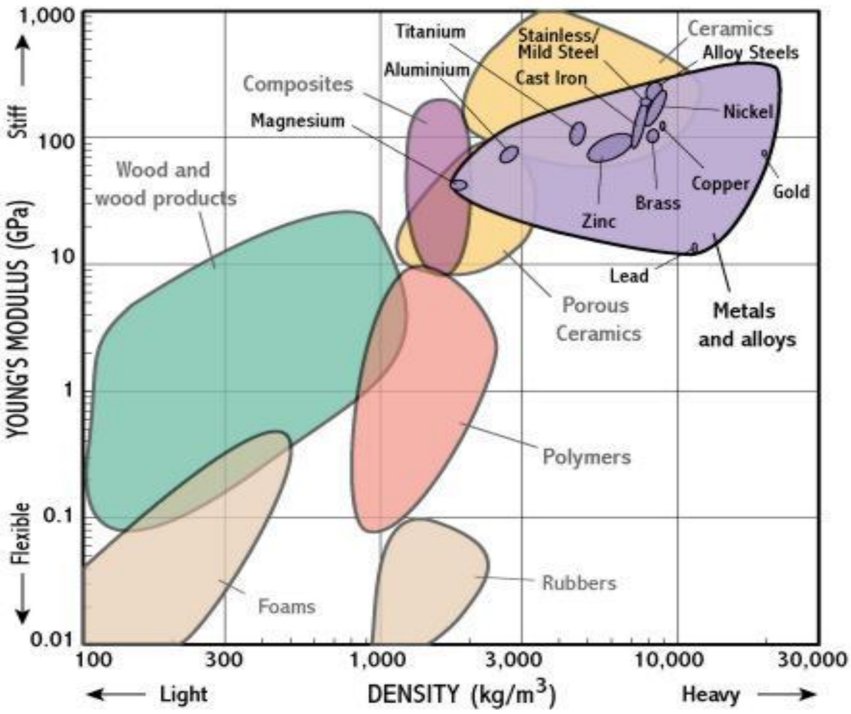


Figure 2-3: Metal selections in Young's modulus-density chart [3]

The bubbles for a type of metal or polymer (steels, or aluminum alloys, or nylon) are mostly small. The density and Young's modulus of steel only depends on the way the iron atoms are packed, and the bonding between them. The spread of the data on a selection chart therefore enhances our appreciation of the underlying physics of each property.

As the name suggests, materials selection charts are also a valuable tool in engineering design. Designers have a challenging task in choosing materials for products, as they usually have to consider many competing objectives and constraints at once. Materials selection in design is therefore a matter of assessing trade-offs between several competing requirements. Traditionally designers have used extensive handbooks and their own experience to guide the choice of material in design. Selection charts provide insight into these trade-offs by pairing properties which must commonly both be considered, avoiding the need to work with tedious tables of numerical data [3].

In ductile materials they are controlled by plastic flow, which works by motion of defects called 'dislocations'. The motion of dislocations can be impeded by changing the microstructure (by alloying and heat treatment), which makes the material harder, but usually reduces its toughness. In brittle materials like ceramics, strength and toughness depend on the flaws which this type of material always contains. The chart also shows compressive strength for ceramics (which are high), but they are much weaker in tension [3].

The wider ranges of strength and toughness data are even more apparent if the material classes on this selection chart are populated. *Figure 2-3* shows the strength-toughness chart with a selection of metals illustrated. In general, the toughness of a type of alloy falls as its strength is increased [3].

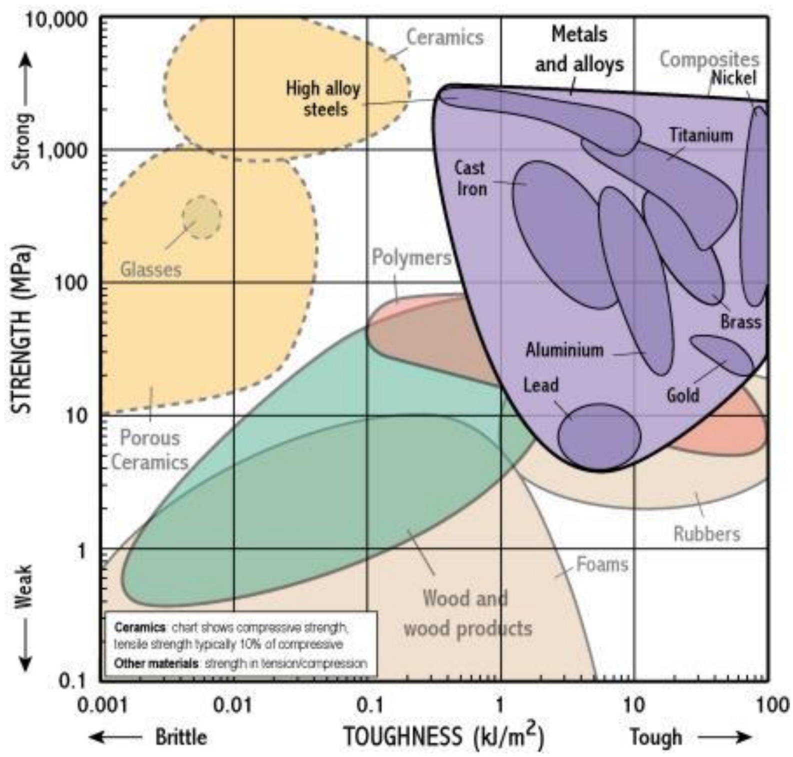


Figure 2-3: Metals selections in strength-toughness chart [3]

2.1.3 Mechanical Device Mechanism

2.1.3.1 Locomotion

Locomotion mechanisms enable mobile robots/mechanical devices to move from one place to another. Wheel is one of the major types of locomotion. The configuration of the locomotion elements also affects the locomotion mechanisms in terms of stability and kinematics. In designing the locomotion mechanism, the core issues are stability, contact characteristics, and environmental type [4].

2.1.3.2 Kinematics

Kinematics is a study of the mechanical device's motion in term of manoeuvrability and movement of the manipulators. To evaluate the paths and trajectories of the device, the understanding of motion begins from the process of describing the motion of the individual wheels up to describing the device as a whole. Kinematics provides theoretical workspace of the device. To effectively manoeuvre or manipulate, motion control that requires further analysis of forces need to be implemented [4].

2.1.3.3 Motion Control System

Motion control system typically consists of actuators, motor driver, and feedback sensor. It can be either closed or opened loop. One of the most critical parts in designing the motion control system is the selection of motor and the feedback sensors. There are various types of motor available such as servo motor, brushless motor, brushed motor, and stepper motor. Each motor has its advantages and disadvantages whereby the selection of the best motor depends solely on the feasibility to the design specification [5].

2.1.3.4 Power Transfer Mechanisms

Power transfer mechanisms are typically divided into belts, chain, plastic-and-cable chain, friction drives, and gears. These mechanisms basically function to reduce or increase torque, reduce or increase speed, and to transmit power. Apart from the aforementioned mechanisms, couplings and torque delimiters are also considered as power transfer mechanisms. Coupler is being used whenever there is a need to couple two rotating shafts together [5].

2.2 Fabrication Phase

Several manufacturing process and technology are used to develop the prototype.

2.2.1 Gas Welding Proces

Welding specifications are derived from the American Welding Society (AWS) D-19.0, *Welding Zinc Coated Steel*. This specification, relating to preparation of the metal and the actual welding process, calls for the weld to be made on steel that is free of zinc, although the component has already been galvanized. The zinc coating should be removed at least 1-4 inches from either side of the intended weld and on both sides of the workpiece. Grinding is the most effective means of removing galvanized coating.

Oxyacetylene welding, commonly referred to as gas welding or oxy-fuel welding, was practiced to join several parts of the prototype during fabrication phase. It is a process which relies on combustion of oxygen and acetylene. When mixed together in correct proportions within a hand-held torch or blowpipe, a relatively hot flame is produced with a temperature of about 3,200°C. The chemical action of the oxyacetylene flame can be adjusted by changing the ratio of the volume of oxygen to acetylene [6].

Three distinct flame settings are used, neutral, oxidising and carburising.

(a) (b) (c)

Figure 2-4: (a) Neutral flame, (b) Oxidising flame, and (c) Carburising flame [6]

Welding is generally carried out using the neutral flame setting which has equal quantities of oxygen and acetylene. The oxidising flame is obtained by increasing just the oxygen flow rate while the carburising flame is achieved by increasing acetylene flow in relation to oxygen flow. Because steel melts at a temperature above 1,500°C, the mixture of oxygen and acetylene is used as it is the only gas combination with enough heat to weld steel. However, other gases such as propane, hydrogen and coal gas can be used for joining lower melting point non-ferrous metals, and for brazing and silver soldering [6].

Oxyacetylene equipment is portable and easy to use. It comprises oxygen and acetylene gases stored under pressure in steel cylinders. The cylinders are fitted with regulators and flexible hoses which lead to the blowpipe. Specially designed safety devices such as flame traps are fitted between the hoses and the cylinder regulators. The flame trap prevents flames generated by a 'flashback' from reaching the cylinders; principal causes of flashbacks are the failure to purge the hoses and overheating of the blowpipe nozzle.

When welding, the operator must wear protective clothing and tinted colored goggles. As the flame is less intense than an arc and very little UV is emitted, general-purpose tinted goggles provide sufficient protection [6].

2.2.2 Conventional Milling

In milling, a rotating cutter removes material while traveling along various axes with respect to the workpiece [7].

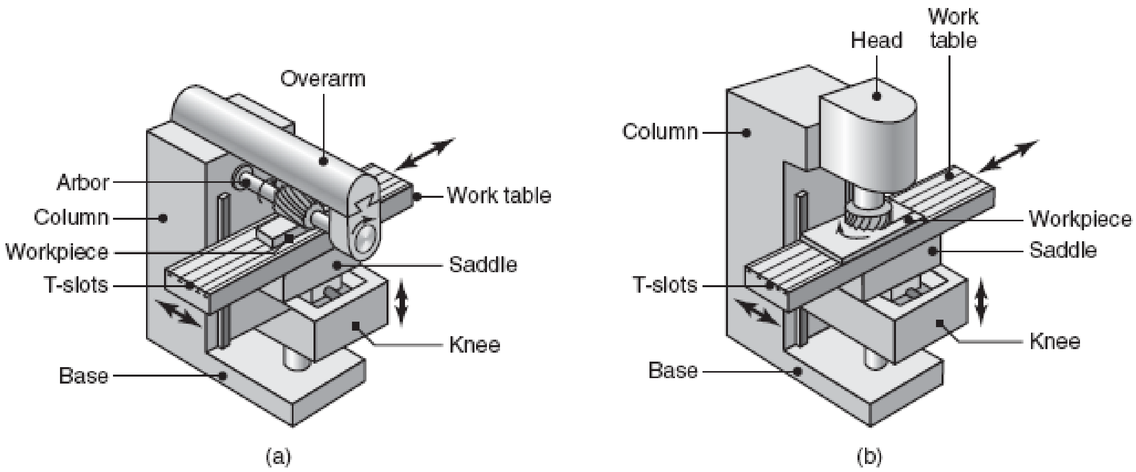


Figure 2-5: (a) Horizontal-spindle column-and-knee type milling machine, (b) vertical-spindle column-and-knee type milling machine [7]

There are three types of milling operations:

- Peripheral milling.
- Face milling.
- End milling.

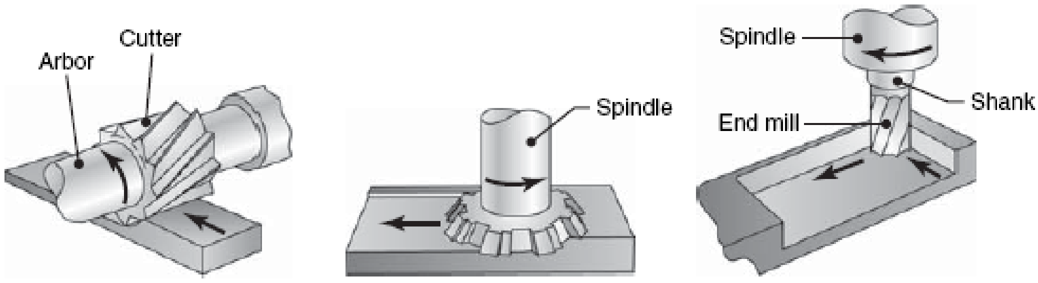


Figure 2-6: (a) Peripheral milling, (b) Face milling and (c) End milling [7]

2.2.2.1 Peripheral Milling

In peripheral (or slab) milling, the milled surface is generated by teeth located on the periphery of the cutter body. The axis of cutter rotation is generally in a plane parallel to the workpiece surface to be machined [7].

The cutter body, which generally is made of high-speed steel, has a number of teeth along its circumference; each tooth acts like a single-point cutting tool.

When the cutter is longer than the width of the cut, the process is called slab milling. Cutters for peripheral milling may have straight or helical teeth, resulting in orthogonal or oblique cutting action, respectively [7].

2.2.2.2 Face Milling

In face milling, the cutter is mounted on a spindle having an axis of rotation perpendicular to the workpiece surface [7].

2.2.2.3End Milling

End milling is an important and common machining operation because of its versatility and capability to produce various profiles and curved surfaces. The cutter, called an end mill has either a straight shank (for small sizes) or a tapered shank (for larger cutter sizes) and is mounted into the spindle of the milling machine [7].

2.2.3 Conventional Lathe

Lathe or turning is One of the most basic machining processes is turning, meaning that the part is rotated while it is being machined [13].

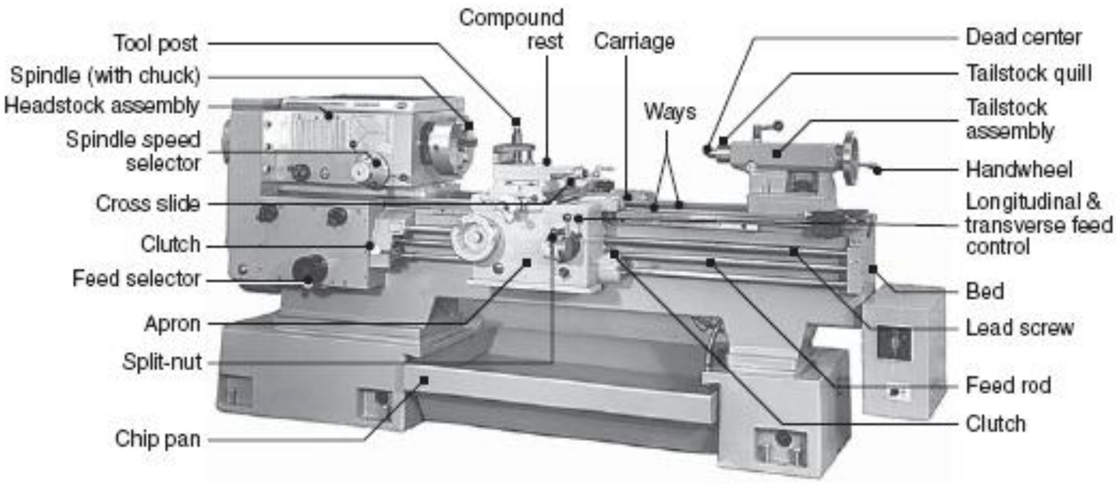


Figure2-7: A typical lathe machine [7]

These machines are very versatile and capable of producing a wide variety of shapes as outlined below [7]:

- Turning: to produce straight, conical, curved, or grooved workpieces such as shafts, spindles, and pins.
- Facing: to produce a flat surface at the end of the part and perpendicular to its axis useful for parts that are assembled with other components.
- Cutting with form tools: to produce various axisymmetric shapes for functional or aesthetic purposes.
- Boring: to enlarge a hole or cylindrical cavity made by a previous process or to produce circular internal grooves.
- Drilling: to produce a hole which may be followed by boring to improve its dimensional accuracy and surface finish?
- Parting: also called cutting off, to cut a piece from the end of a part, as is done in the production of slugs or blanks for additional processing into discrete products
- Threading: to produce external or internal threads.

2.3 Testing Phase

The testing phase is conducted to prove the workability of the design and assembly of components.

2.3.1 Basic Electric Circuit Connection

Battery cells get their desired operating voltage by connecting several cells in series. However, if higher capacity and current handling is required, the cells are connected in parallel.

2.3.1.1 Series connection

Device with high-energy needs is powered with battery packs in which two or more cell are connected in series. *Figure 2-8*shows a battery pack with four 1.2V cells in series. The nominal voltage of the battery string is 4.8V.

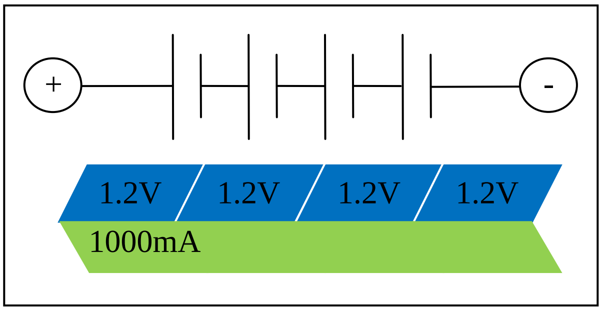


Figure 2-8: Serial connection of four cells

High voltage batteries have the advantage of keeping the conductor and switch sizes small.

Similar to a chain, the more links that are connected in series, the greater the odds of one failing. A faulty cell would produce a low voltage. In an extreme case, an open cell could break the current flow. Replacement of a faulty cell is difficult because of matching. The new cell will typically have a higher capacity than the aged cells [8].

2.3.1.2 Parallel connection

To obtain higher ampere-hour (Ah) ratings, two or more cells are connected in parallel. The alternative to parallel connection is using a larger cell. This option is not always available because of limited cell selection. In addition, bulky cell sizes do not lend themselves to build specialty battery shapes.

Figure 2-9 illustrates four cells connected in parallel. The voltage of the pack remains at 1.2V but the current handling and runtime are increased four folds. Thus, the current is 4A.

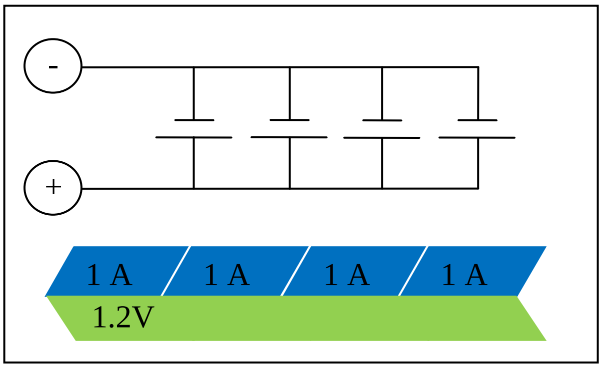


Figure 2-9: Parallel connection of four cells

A high resistance or open cell is less critical in a parallel circuit than the serial configuration but the parallel pack will have reduced load capability and a shorter runtime. An electrical short would be more devastating because the faulty cell would drain the energy from the other cells, causing a fire hazard [8].

CHAPTER 3: METHODOLOGY

The methodology is formulated based on Morris Asimow's morphology of design [9]. The process flow is divided in accordance to FYP I and FYP II activities.

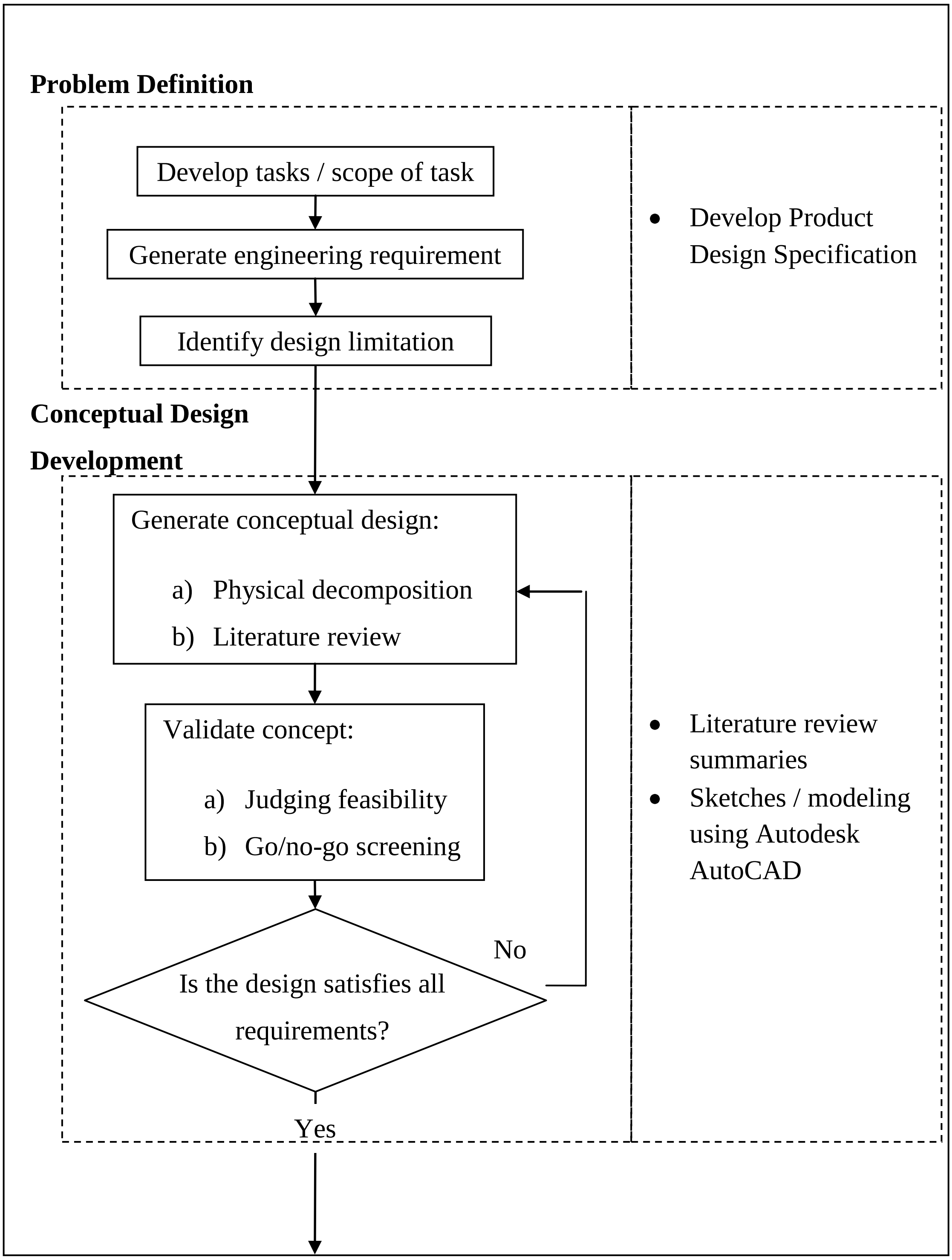


Figure 3-1: FYP I activities

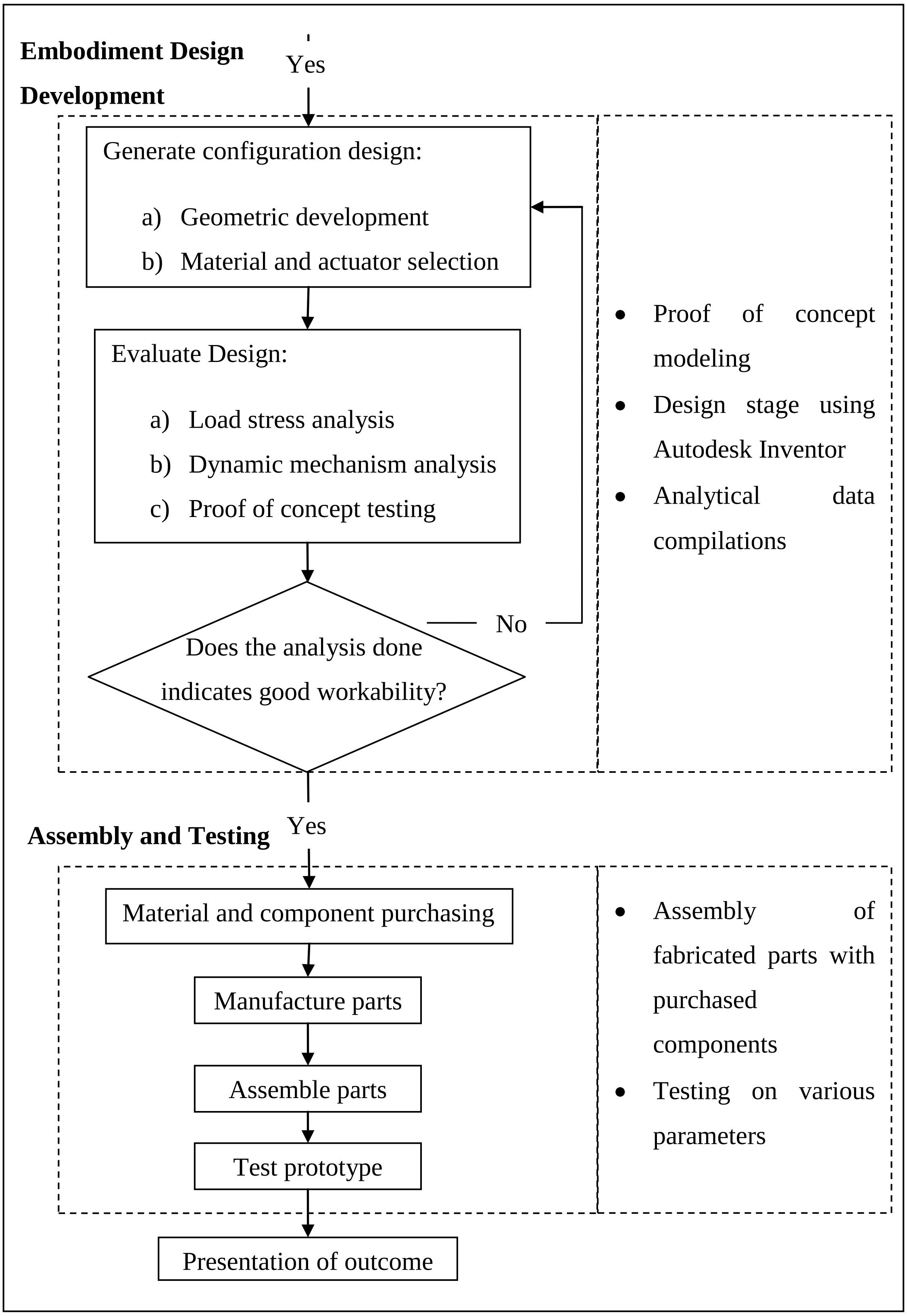


Figure 3-2: FYP II activities

The key milestone and datelines for each activity are specified in the Project Gantt Chart as shown in Appendix 1 and II.

3.1 Design Phase

The design of the prototype is basically derived from a straight pipe cutter device available in some yards in Malaysia. It is has only one degree of freedom, mechanically controlled by human force. This allows vertical circular motion of the device *y-z* plane. Refer figure below:

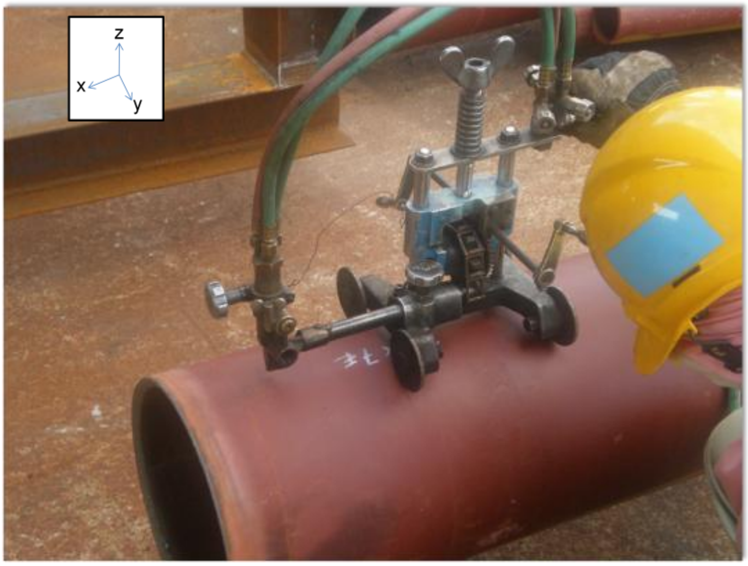


Figure 3-3: Pipe cutter used in the oil and gas industry

The vertical circular motion is made possible with the use of chain acting as the track for the sprocket, hence the device, to move in a circular path. The number of chain is very much dependent on the diameter of the workpiece. The tension of the chain can then be controlled by adjusting the height of the sprocket fixer (blue colored part).

However, for the interest of this project, another degree of freedom is added to manipulate the *x*-axis. Adding one degree of freedom to the device would bring a whole new level of the device's application. Simultaneous control of motions in *y-z* plane and *x*-axis enables profiling activities to be conducted onto pipe.

The prototype design is based on the available design and the additional feature needed to be added to it. There are three major parts identified in the prototype. They will be discussed in the physical decomposition section. . Stress analysis result of the design can be referred in Appendix V.

3.1.1 Physical Decomposition

The prototype is divided into 3 major segments as per shown in the figure below;

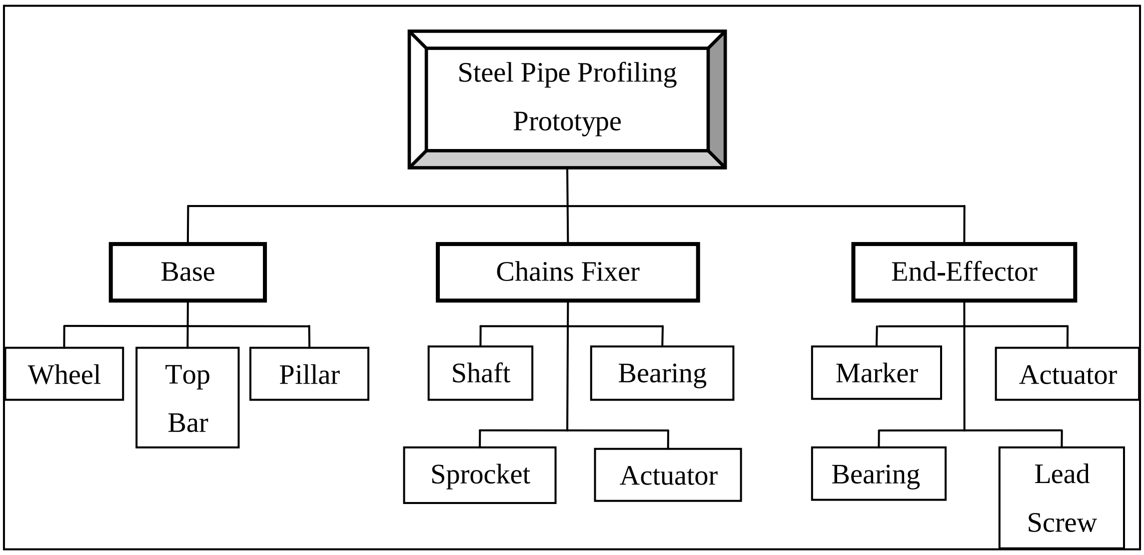


Figure 3-4: Physical decomposition diagram

3.1.1.1 Base Design

The base design is dependent on the wheels size as well as the components incorporated. There are 2 pillars erected from the base and supported by a plate. These pillars are used to support the sprocket height adjuster to further tighten the chains binding steel pipe.

3.1.1.2 Chains Fixer

The sprocket and chains are one of the major attributes of the device. They function to bind steel pipe as well as to allow motion of the device in circumferential axis. The sprocket rotation is controlled by an actuator to circulate around pipe.

3.1.1.3 End-Effector Design

The end-effector is actuated by a lead screw rotation controlled by an industrial DC motor. The shafts will guide the end-effector to move in one axis. A marker is set on the holder so that it can be adjusted conveniently. The calculated maximum displacement of the marker is 16cm - enough to cover profiling curve of 45°, 60° and 90° angle of joint.

3.1.2 Material Selection

The selection of suitable material is a key step in the product design process. An improperly chosen material can lead not only to failure of the part or component, but also to unnecessary cost. The steps in the process of material selection are defined as follows [8]:

1. Analysis of the materials requirements.
2. Screening of the candidate materials.
3. Selection of the candidate materials.
4. Development of design data.

Based on the guidelines above, one material will be chosen to be used in major structures of the prototype.

3.1.2.1 Analysis of materials requirements

Material analysis start with a listing of all the important material properties associated with the design, e.g: strength, stiffness and cost this can be prioritized by using a weighting measure depending on what properties are more important than others. Material properties are determined from the functions needed for the design of the prototype. *Table 3-1* underlines the requirement and the attributes of material:

Table 3-1: Material properties consideration

Material Selection Criteria	**Material Properties**
Low mass	Density
High ductility	Elongation
Ability to withstand sudden impact	Hardness
Exhibit elastic deformation	Yield strength
Ease of manufacturing	Machinability
Low cost	Price

3.1.2.2 Screening of the candidate materials

In this step, the required properties are compared with a large material property database to select a few materials that look promising for the application of this project.

Table 3-2: Screening of the candidate materials

Material	Material Properties						Screening
	Density ($\frac{lb}{in^3}$)	Yield Strength (MPA)	Elongation (%)	Hardness (HV)	Machinability Index	Price per pound	
Polyethylene (PE)	0.034	13	600	-	-	0.30	Discarded
Nylon (PA)	0.042	62	27	-	-	3.00	Discarded
Carbon Steel (1010)	0.28	275	35	110	100	0.40	Accepted
Stainless Steel (430)	0.28	275	20	260	165	1.25	Accepted
Aluminum Alloy (1100-H14)	0.098	117	9	26	180	0.73	Accepted
Copper Alloy (C11000)	0.323	344	4	60	150	0.92	Accepted
Nickel Alloy (N02200)	0.321	186	50	170	340	5.30	Discarded

The materials are evaluated for their suitability based on mechanical properties. Polyethylene and nylon are discarded as the information on hardness value and machinability index are absent. Nickel alloy is also rejected due to high price.

3.1.2.3 Selection of the candidate materials

Decision matrices are tools that have been developed for selecting the best option among several candidates. Candidate materials are analyzed to select the best material for the application.

Table 3-3: Selection of the candidate materials

Properties	**Weightage**	**Material**			
		Stainless Steel (430)	**Carbon Steel (1010)**	**Aluminum Alloy (1100-H14)**	**Copper Alloy (C11000)**
Density ($\frac{lb}{in^3}$)	2	DATUM	+	+	-
Yield Strength (MPa)	5		+	-	+
Elongation (%)	3		+	-	-
Hardness (HV)	4		-	-	-
Machinability Index	1		-	+	-
Price per Pound	5		+	+	+
Weightage Score			10	-4	0

3.1.2.4 Development of design data.

Based on the decision matrix, carbon steel is the most suitable material to be used to be chosen. The material is relatively light, posses high yield strength, able to absorb high impacts or loadings, easy to machine and cheap.

Galvanized steel is one type of carbon steel covered with a layer of zinc by hot dipping. In Malaysia, galvanized steel is found abundantly used for household applications, e.g: furniture, as well as grills or gates. This material inherits all properties of carbon steel but with an added feature: corrosion resistance. Thus, it is best to select galvanized steel as the final material to fabricate the base as well as other major components of the prototype.

3.1.3 Relevant Calculations

Calculations governing the design are identified. These will determine the sustainability of the design.

3.1.3.1 Tolerance between prototype's base and pipe surface

One of the limitations for the device is the fixture on Nominal Diameter 6": Schedule 40 pipes. Thus, it is important to develop a proper calculation of the tolerance so that the device's base is not in contact with the steel pipe's surface while operating. Basic trigonometry functions were used to develop the calculations;

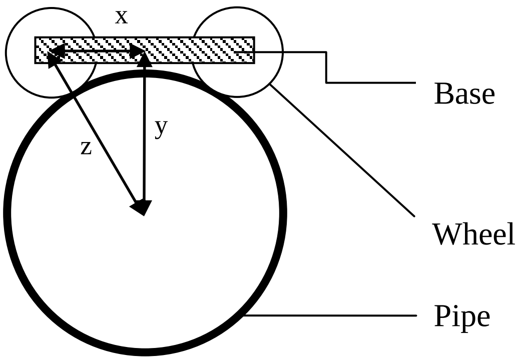


Figure 3-5: Wheel design calculation

The diameter of all purchased wheels is 5". Thus, the value of z is wheel radius, r_{wheel}, plus radius of outer diameter, r_{outer}, of ND 6": Sch 40 pipe (Appendix III);

$$z = r_{wheel} + r_{outer} \qquad [3.1]$$

The x value is set as 4", thus, the value of y can be calculated using trigonometry function;

$$y = \sqrt{z^2 - x^2} \qquad [3.2]$$

∴ The tolerance between base and pipe $= y - {}^{1}/_{2}\, t_{bar} - r_{outer}$ [3.3]

A structural design (*Figure 3-6*) of the prototype is then produced when the tolerance value is positive, fulfilling all design requirements mentioned in the introduction part of this report.

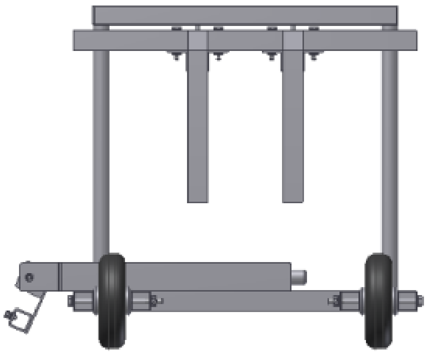
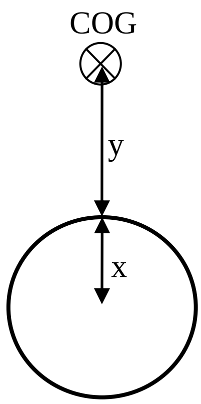


Figure 3-6: Structural design

The determination of center of gravity (COG) is then possible. The center of gravity is not only considering the geometric factor of the prototype design but also the weight.

3.1.3.2 Selection of actuator for vertical circular motion

In order to calculate the velocity of the prototype, the distance between COG and the center of pipe must be known.



Variable	Height
x	3.3125 inch
y	7.6820 inch

Figure 3-7: Distance between center of gravity to the center of pipe

Radius of motion, r_{motion}, is:

$$r_{motion} = x + y \qquad [3.4]$$

The angular velocity, ω_{motion}, can be determined by setting how much revolution should the prototype perform in a period of time;

$$\omega_{motion} = \frac{x\text{−}revolutions}{time} \times \frac{2\pi\ radian}{1revolution} \qquad [3.5]$$

The velocity of motion, v_{motion}:

$$v_{motion} = r_{motion}.\omega_{motion} \qquad [3.6]$$

Each wheel will experience same v_{motion}. Thus, ω_{wheel} can be determined later.

In order for the prototype not to slide down the incline, there must be friction between the wheel and pipe surface. It is friction, f that is producing the torque. Hence, the torque required to counteract the friction is;

$$T_{req} = f.r_{wheel} \qquad [3.7]$$

To select the proper actuator, consideration has to be put when the prototype is not only on an incline, but accelerating up it:

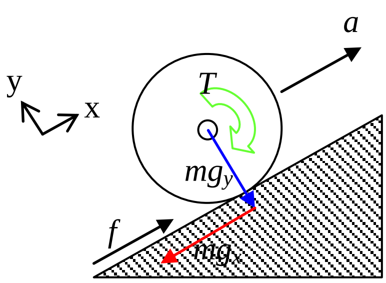


Figure 3-8: Forces acting on wheel

Note that all forces are along the x and y axes. The forces in x-direction:

$$\sum F_x = ma = -mg_x + f \qquad [3.8]$$

$$ma = -mgsin\theta + \frac{T_{req}}{R_{wheel}} \qquad [3.9]$$

Rearranging the equation:

$$T_{req} = (a + g\sin\theta).m.r_{wheel} \qquad [3.10]$$

The torque value shows the total torque required for the prototype to move up an incline. Since the project is adopting vertical circular motion, the torque value may also represent the torque needed to move down an incline. The total required power, P_{req} is:

$$P_{req} = T_{req}.\omega_{wheel} \qquad [3.11]$$

Where ω is obtained from:

$$v_{motion} = r_{wheel} . \omega_{wheel} \qquad [3.12]$$

Maximum current requirement, I_{max} is obtained from:

$$P_{req} = I_{max} . V \qquad [3.13]$$

3.1.3.3 Selection of Actuator for Translational Motion

It is essential to calculate the torque to move the end-effector from one point to another and return back to initial position.

The mean diameter, d_m, is delivered from major diameter of power screw, d, minus the half of pitch, p:

$$d_m = d - {}^{p}/_{2} \qquad [3.14]$$

The lead, l, is a product thread number, n, and pitch, p:

$$l = np \qquad [3.15]$$

The torque required, Treq, to turn the screw against the load is:

$$T_{req} = \frac{F d_m}{2} \left(\frac{l + \pi f d_m}{\pi d_m - f l} \right) \qquad [3.16]$$

Where F is the force exerted and f is the friction factor. Equation [3.11], [3.12] and [3.13] are then applied to calculate the desired power.

3.2 Fabrication Phase

The fabrication process of the prototype is divided into 3 phases based on the physical decomposition diagram (*Figure 3-3*). Phase 1 includes the fabrication of prototype's *base* and the assembly of 5 inch tires. Phase 2 involves the fabrication of *chains fixer*. The chain fixer functions to tighten or loosen the gripping of chains onto steel pipe. Phase 3 entails the manufacturing of *end-effector* that holds and moves the marker to mark steel pipe surface.

3.2.1 Fabrication Sequence

The fabrication sequence functions to steer the progress of fabrication phase. The sequence must correlates with the project scheduling.

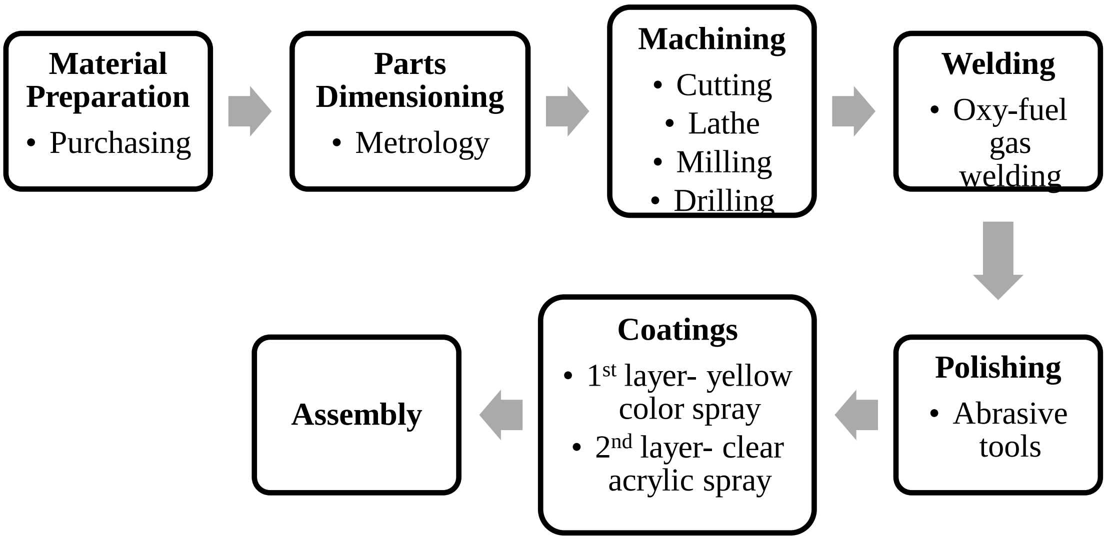


Figure 3-9: Fabrication sequence

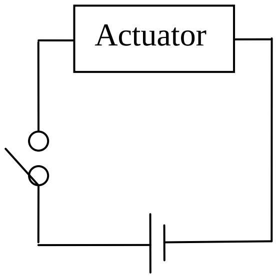
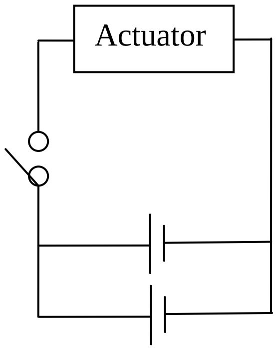
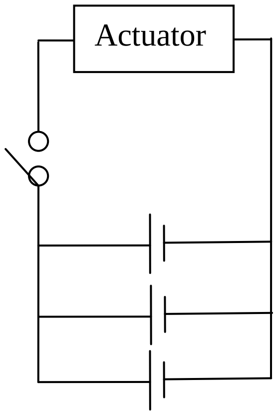
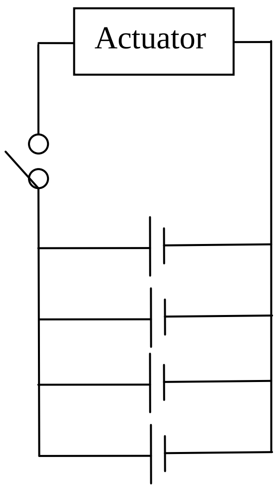
3.3 Testing Phase

Tests were done on the circulating mechanism of the prototype. Simple series and parallel circuits were set up to evaluate the capability of the prototype to travel across the surface of workpiece as well as the translational motion of the end-effector.

Parallel circuits were developed to test the motion of the prototype circulating across pipe surface. The rationale of the experiments is to ensure enough current flow into the circuit for the test. These will provide the desired power rating needed to actuate the motion.

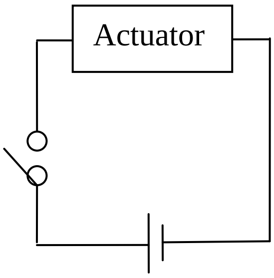
Rechargeable batteries were used to test the circuit. It is known that current flow from rechargeable batteries is not consistent since the current draw is dependent on rechargeable time. *Table 3-4* lists configurations of series and parallel circuits used to do the testings.

Table 3-4: Parallel circuit arrangement for circulating motion

Parallel Circuit	**Voltage**	**Current**
	$V_{total} = V_1$ $= 12V$	$I_{total} = I_1$ $= 1.3A$
	$V_{total} = V_1 = V_2$ $= 12V$	$I_{total} = I_1 + I_2$ $= 3.45A$
	$V_{total} = V_1 = V_2 = V_3$ $= 12V$	$I_{total} = I_1 + I_2 + I_3$ $= 5.6A$
	$V_{total} = V_1 = V_2 = V_3 = V_4$ $= 12V$	$I_{total} = I_1 + I_2 + I_3 + I_4$ $= 8.55A$

Testing of translational motion was done by connecting the actuator with battery cell in series connection.

Table 3-5: Series circuit arrangement and power output

Series Circuit	Voltage	Current
	$V_{total} = V_1$	$I_{total} = I_1$ $= 0.564A$

CHAPTER 4: RESULT AND DISCUSSION

4.1 Design Outcome

4.1.1 Relevant Calculations

Several calculations were done to design the base of the prototype and to select actuators for both vertical circular and translational motions..

4.1.1.1 Base tolerance

The prototype shall at least provide a tolerance of 0.5 inch to avoid collision between prototype base and pipe surface.

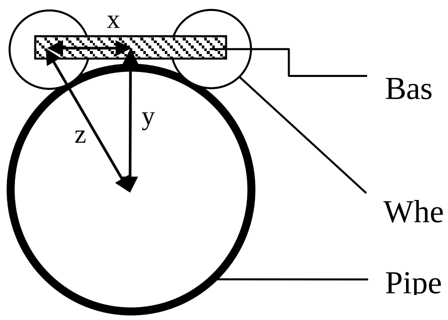


Figure 4-1: Tolerance calculation

The diameter of all purchased tires is 5”. Thus, the value of z is tire radius plus outer diameter of ND 6”: Sch 40 pipe;

z $=2.5'' + 3.3125'' = 5.8125''$

The x value is set as 4”, thus, the value of y can be calculated using trigonometry function;

y $= \sqrt{5.8125''^2 - 4''^2} = 4.217''$

The tolerance between base and pipe = $4.217'' - .5''(thickness) - 3.3125'' = 0.5''$

0.5 inches tolerance is sufficient to operate the prototype. The tolerance value increases with bigger pipe diameter. The prototype may also be used for nominal pipe diameter of 6 inch and above. However, number of chains needs to be added to fit various pipe diameters.

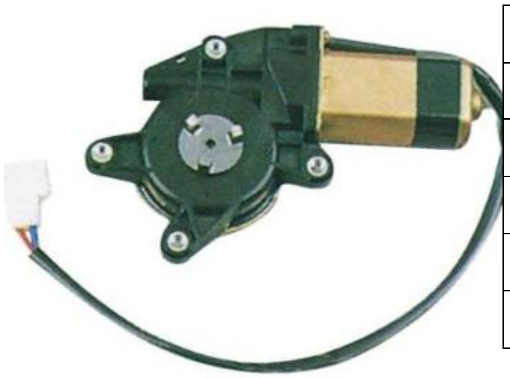
4.1.1.2 Vertical Circular Motion

Based on equation [3.4], [3.5], [3.6], [3.7], [3.8], [3.9], [3.10], [3.11], [3.12], and [3.13], the desired power of the actuator can be calculated.

Table 4-1: Summary of vertical circular motion calculated

Parameter	Value
Motion radius, r_{motion}	0.279m
Revolution	1turn
Time taken	1second
Motion angular velocity, ω_{motion}	6.283185rad/s
Motion velocity, v_{motion}	1.753009m/s
Sprocket radius, $r_{sprocket}$	0.0381m
Sprocket angular velocity, $\omega_{sprocket}$	46.01073rad/s
Friction factor, f	2
Torque required, T_{req}	2.232Nm
Power required, P_{req}	102.6959W

The actuator selected must work with at least 103W of power, have a torque of 2.3Nm and possess an output speed of 440 rpm. Figure below shows a selected motor found suitable for the task.



Parameter	Value
Working voltage	12V
Stall current	24A
Maximum power	288W
Load self-lock	50kg
Maximum Speed	500rpm

Figure 4-2: Power window motor [18]

Power window motor is used majorly in automobile industry. This type of motor is known for its durability to perform high load lifting. It has a self-locking mechanism that circumvents backlash of loading. . The mechanism is possible with the attributes of worm gears set in the power window motor.

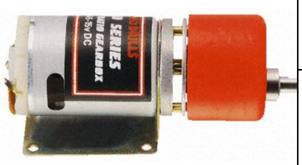
4.1.1.3 Translational Motion

The selection of actuator for translational motion is dependent on equation [3.11], [3.12], [3.13], [3.14], [3.15], and [3.16]. Several additional requirements were added to meet the expected performance from the actuator. With the given parameters, the actuator should complete 75 revolutions below 30 seconds. 75 revolutions of the power screw is equivalent to a completion of one-way direction of the translational motion. Thus, for two-ways directions, the actuator shall do its job in less than 1 minute.

Table 4-2: Summary of translational motion calculated

Parameter	**Value**
Pitch, p	0.003m
Friction coefficient, f_c	0.08
Major diameter, d	0.01m
Force exerted, F	19.62N
Mean diameter, d_m	0.0085m
Thread number, n	2
Lead, l	0.006m
Torque required, T_{req}	0.258716Nm
Revolutions of screw	75turns
Time taken	30s
Angular velocity, ω	15.70796rad/s
Power required, P_{req}	4.063896W
Current, I	0.507987A

The actuator selected must work with at least 4W of power, have a torque of 0.25Nm and possess an output speed of 150 rpm. Figure below shows a selected motor found suitable for the task.



Output Speed	316rpm
Output Torque	0.294Nm
Type	Ironcore Motor/ Spur Gearhead
Voltage	4.5 → 15Vdc

Figure 4-3: Industrial dc motor [18]

The isometric design configuration of the prototype is as shown below:

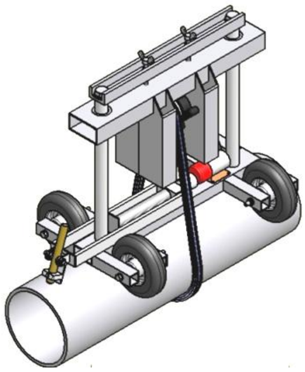


Figure 4-4: Isometric view

For detailed design of the prototype, please refer to Appendix VIII. The design embedded the selected actuators.

4.2 Fabricated Components

The outputs from designing stage assist fabrication processes. Redesigns of the prototype were carried out during the fabrication phase. This was severely affected by the availability of materials in the market.

Some dimensional errors were committed while producing the parts. Mostly were associated by human errors and thermal expansion of the material. Parallax errors were the major contributors of measuring and machining processes, while the latter was due to welding activities conducted. Dimensional errors were then mitigated by replacing defected components and surface finish. The bill of materials for the prototype is shown in the table below:

Table 4-3: Bill of material

Item	Quantity	Description
Pipe	1	ND 6" Sche: 40
Base	1	
DC Motor	1	RS Motor 1500 RPM
Pillar	2	
Chain Fixer	1	
Power Window Motor	1	
Shaft	1	
Roller Chain	1	
Sprocket	1	No. of Teeth: 16
KS B 1005 - M 8 x 80	2	Wing bolts
SKF Series EE - EE 3	1	Deep Groove Ball Bearings
Top Bar	1	
Coupler	1	
Power Screw	1	
End Effector	1	
ISO 4035 - M8	8	Hexagon thin nuts (chamfered) - Product grades A and B
ISO 7092 - ST 8 - 140 HV	8	Plain washers-Small series-Product grade A
AS 1111 - M8 x 120	4	ISO metric hexagon commercial bolts and screws
Marker Holder	1	
Marker	1	
JIS B 1180 - C M8 x 16	2	Hex-Head Bolt
Tire	4	Rhombus 5" Diameter with Inner Bearings

The fabricated components and the manufacturing processes involved to fabricate them can be referred in Appendix VII. The costing is prepared in Appendix IX.

The final assembly of the prototype is as per shown in the figure below:

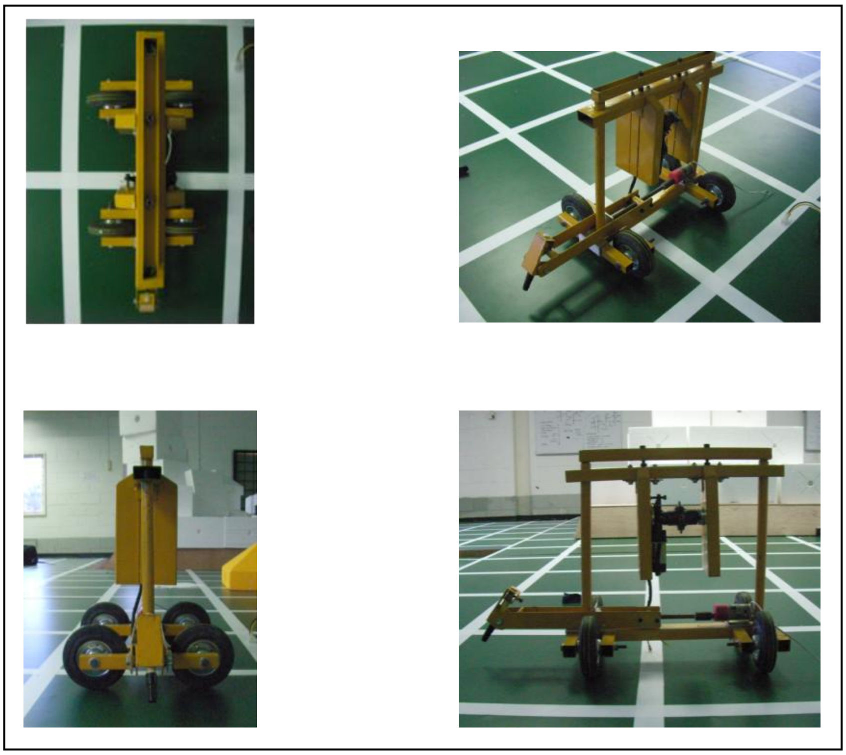


Figure 4-5: Final assembly of the prototype

The completed assembly of the prototype is found to be capable of performing the intended purpose of the project. The circulating motion is possible with the application of sprocket-chain mechanism. Translational motion is controlled by an industrial DC motor, applying power screw mechanism.

4.3 Tests Conducted

Tests are conducted to verify vertical circulating and translational motions.

4.3.1 Vertical Circulating Motion

A parallel circuit was designed to provide 12V and 8.55A producing 102.6W. The prototype was able to perform its task as per designed. In one of the motion captured video of the prototype, the prototype has completed 3 revolutions circulating a ND 6” pipe. This is the fastest speed that the prototype can perform with the selected actuator.

4.3.2 Translational Motion

Simple series circuit was built to test translational motion of the end-effector. Table 16 inscribes number of test runs done and the time taken for each run. The average time taken to complete one direction of translational motion is 27.4 seconds.

Table 4-4: Test run

Test Run	Time Taken
1	27 seconds
2	26 seconds
3	27 seconds
4	29 seconds
5	28 seconds

Various times taken to complete one direction of translational motion were recorded. This is due to inconsistencies of current draw from rechargeable battery used during the test. Table below shows the result of one of the tests recorded in a video.

Table 4-5: Time taken to complete one-way direction of translational motion

Parameter	Value
Current, I	0.564A
Power produced, P	4.515W
Angular velocity, ω	17.456rad/s
Revolutions of screw	75turns
Time taken	27s

The current draw is 0.564A, thus producing 4.515W of power. Increase in power affects the performance of the actuator. The power induced to the actuator is still in safe power rating, so it does no damage to the actuator. With increased current, the time taken to complete 75 revolutions is 27 seconds, 3 seconds faster than initial design.

The prototype should also reach 6.626 inch of displacement as the number indicates the furthest point for 45° and 90° pipe angle of joint. The translational motion was designed to move more than it has to be so that the prototype can perform with better workspace. Figure below depicts maximum reach of the prototype compared to the actual requirement of linear displacement of the end-effector.

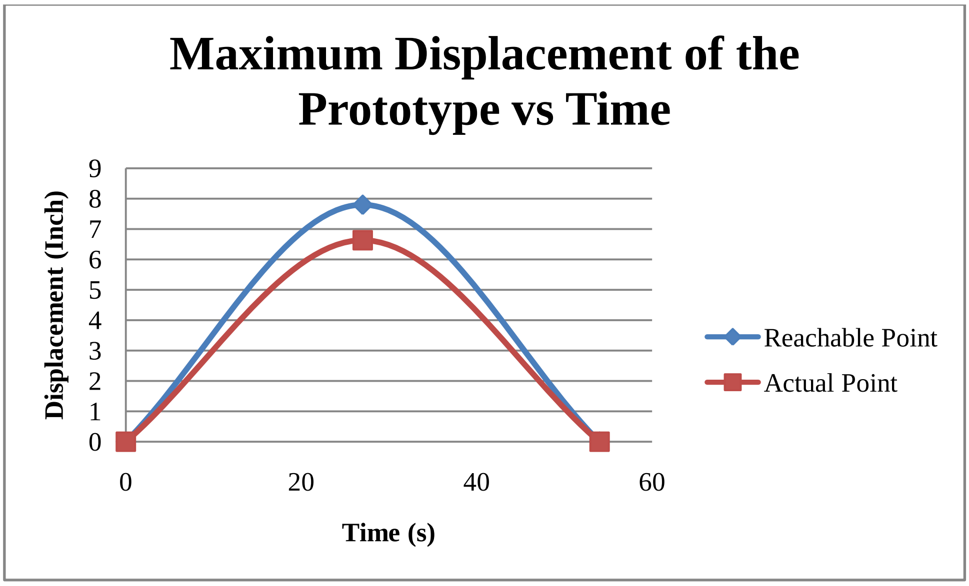


Figure 4-6: Maximum displacement of the translational motion

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Completed design has achieved the requirement and limitation of the prototype. Stress analysis done on identified important components assist designing process, thus improving structural integrity of the selected components. The detailed drawing of the prototype is available in Appendix-VII.

The prototype was constructed in fabrication phase. 90% of the components were fabricated manually. Assembly of components was done in accordance to the design specifications.

Tests conducted prove that the prototype can perform its intended functions and purpose. Circulating motion is made possible by using the selected power window motor while translational motion is controlled by power screw mechanism.

As a conclusion, this project has completed the designing phase of the steel pipe marking profiler prototype with relevant calculations. Fabrication the prototype based on design specifications and dimensioning was completed within schedule. Results from testing of vertical circulating and translational motions by implying simple circuit configuration prove the workability of the prototype.

5.2 Recommendations

The recommendations made are based on the findings after the prototype is being utilized during the tests phase. The modifications are as but not restricted to the follows:

1. The prototype is developed based on minimum requirement and does not include a microcontroller circuit board to sequence the circulating and translational motions.
2. Bicycle chain should be replaced by a conveyor chain as the latter has a flat surface thus providing more contact surface between chain and pipe surface.
3. Small battery packs should be placed on the prototype instead of having external power source via wire connection. This is to avoid entanglement of wires.
4. Braking mechanism shall be installed to lock the tires during fixation process.

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APPENDIX I- FYP I Gantt Chart

Action Plan	Semester July 2009													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Problem Definition														
Project Planning			■	■										
Literature Review	■	■	■	■	■	■	■	■	■	■				
Conceptual Design														
Produce Conceptual Composition					■	■	■	■						
Selection of Design								■	■	■				
Fabrication Process														
Fabrication of custom made components									■	■	■	■	■	■
Assembly of components											■	■	■	■
FYP I														
Submission of Preliminary Report				■										
Submission of Progress Report								■						
Seminar								■						
Submission of Interim Report Final Draft													■	
Oral Presentation														■

APPENDIX II- FYP II Gantt Chart

Action Plan	Semester Jan 2010													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Problem Definition														
Literature Review	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Fabrication Process														
Fabrication of custom made components	■	■	■	■	■	■	■	■	■	■	■			
Assembly of components	■	■	■	■	■	■	■	■	■	■	■			
Electronic System Development														
Input/Output configuration							■	■	■	■	■	■		
Programming							■	■	■	■	■	■		
Testing														
Simulation Test #1										■	■	■	■	
Simulation Test #2										■	■	■	■	
FYP II														
Submission of Progress Report I				■										
Submission of Progress Report II								■						
Seminar								■						
Poster Exhibition										■				
Submission of Project Dissertation (soft bound)													■	
Oral Presentation														■
Submission of Project Dissertation (hard bound)														■

APPENDIX III- Nominal Pipe Size Chart

Table III-1: Nominal pipe size chart [16]

Nominal	O.D. (In.)	PIPE SCHEDULES WALL THICKNESS							
		5s	5	10s	10	20	30	40s & Std	40
1/8	.405		.035	.049	.049			.068	.068
1/4	.540		.049	.065	.065			.088	.088
3/8	.675		.049	.065	.065			.091	.091
1/2	.840	.065	.065	.083	.083			.109	.109
3/4	1.050	.065	.065	.083	.083			.113	.113
1	1.315	.065	.065	.109	.109			.133	.133
1 1/4	1.660	.065	.065	.109	.109			.140	.140
1 1/2	1.900	.065	.065	.109	.109			.145	.145
2	2.375	.065	.065	.109	.109			.154	.154
2 1/2	2.875	.083	.083	.120	.120			.203	.203
3	3.500	.083	.083	.120	.120			.216	.216
3 1/2	4.000	.083	.083	.120	.120			.226	.226
4	4.500	.083	.083	.120	.120			.237	.237
4 1/2	5.000							.247	
5	5.563	.109	.109	.134	.134			.258	.258
6	6.625	.109	.109	.134	.134			.280	.280
7	7.625							.301	
8	8.625	.109	.109	.148	.148	.250	.277	.322	.322
9	9.625							.342	
10	10.750	.134	.134	.165	.165	.250	.307	.365	.365

APPENDIX IV- Metric Screw Thread

Table IV-1: Metric screw thread [17]

Nominal Diameter, d (mm)	Pitch, p (mm)	
	Coarse-Pitch Series	Fine-Pitch Series
1	0.25	
1.2	0.25	
1.4	0.3	
1.6	0.35	
1.8	0.35	
2	0.4	
2.5	0.45	
3	0.5	
3.5	0.6	
4	0.7	
5	0.8	
6	1	
7	1	
8	1.25	1
10	1.5	1.25 or 1
12	1.75	1.5 or 1.25
14	2	1.5
16	2	1.5
18	2.5	2 or 1.5
20	2.5	2 or 1.5
22	2.5	2 or 1.5
24	3	2
27	3	2
30	3.5	2
33	3.5	2
36	4	3
39	4	3
42	4.5	3
45	4.5	3
48	5	3
52	5	4
56	5.5	4
60	5.5	4
64	6	4

APPENDIX V- Graphical Representation of Stress Analysis

Autodesk Inventor Professional Stress Analysis was used to simulate the behavior of a mechanical part under structural loading conditions. ANSYS technology generated the results presented in this report. So far, stress analysis was conducted for 2 important components; pillar/column and top bar, both attached to the base of the prototype.

Stress Analysis on Pillar Component

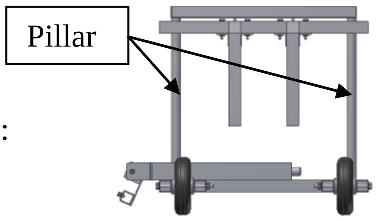


Figure V-1: Pillar

The following material behavior assumptions apply to this analysis:

- Linear - stress is directly proportional to strain.
- Constant - all properties temperature-independent.
- Homogeneous - properties do not change throughout the volume of the part.
- Isotropic - material properties are identical in all directions.

Table V-1: Material data for pillar

Young's Modulus	2.2e+005 MPa
Poisson's Ratio	0.275
Mass Density	7.86e-006 kg/mm³
Tensile Yield Strength	207.0 MPa
Tensile Ultimate Strength	345.0 MPa

The following loads and constraints act on specific regions of the part. Regions were defined by selecting surfaces, cylinders, edges or vertices.

Table V-2: Load an constraint definition for pillar components

Name	Type	Magnitude	Vector
Force	Surface Force	100.0 N	-100.0 N -1.225e-014 N 0.0 N
Fixed Constraint	Edge Fixed Constraint	0.0 mm	0.0 mm 0.0 mm 0.0 mm

Table V-3: Constraint reactions for pillar components

Name	Force	Vector	Moment	Moment Vector
Fixed Constraint	100.0 N	100.0 N 3.678e-008 N 1.144e-007 N	1.778e+004 N·mm	-1.005e-004 N·mm 1.778e+004 N·mm 1.326e-005 N·mm

The table below lists all structural results generated by the analysis. The following section provides figures showing each result contoured over the surface of the part.

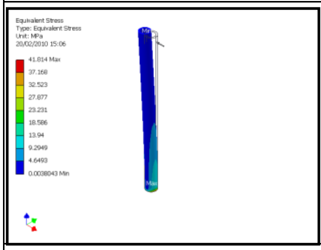
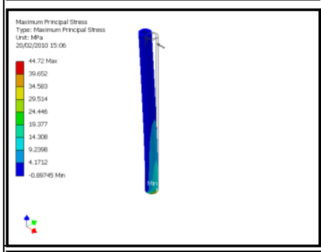
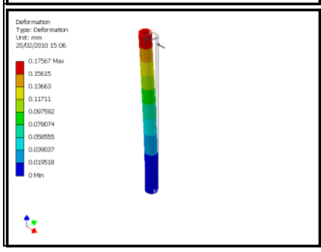
Safety factor was calculated by using the maximum equivalent stress failure theory for ductile materials. The stress limit was specified by the tensile yield strength of the material.

Table V-4: Structural result for pillar components

Name	Minimum	Maximum
Equivalent Stress	3.804e-003 MPa	41.81 MPa
Maximum Principal Stress	-0.8974 MPa	44.72 MPa
Deformation	0.0 mm	0.1757 mm

Graphical result representations for stress analysis done on pillar components can be viewed as below:

Table V-5: Graphical stress analysis result

Figure	**Description**
	Equivalent Stress
	Maximum Principle Stress
	Deformation

Stress Analysis on Top Bar Components

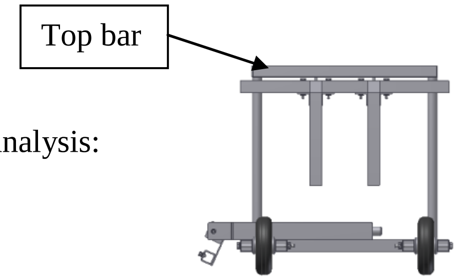


Figure V-5: Top bar

The following material behavior assumptions apply to this analysis:

- Linear - stress is directly proportional to strain.
- Constant - all properties temperature-independent.
- Homogeneous - properties do not change throughout the volume of the part.
- Isotropic - material properties are identical in all directions.

Table V-6: Material data for top bar component

Young's Modulus	2.2e+005 MPa
Poisson's Ratio	0.275
Mass Density	7.86e-006 kg/mm³
Tensile Yield Strength	207.0 MPa
Tensile Ultimate Strength	345.0 MPa

The following loads and constraints act on specific regions of the part. Regions were defined by selecting surfaces, cylinders, edges or vertices.

Table V-7: Load and constraint definition for top bar component

Name	Type	Magnitude	Vector
Force 1	Edge Force	100.0 N	0.0 N -100.0 N 0.0 N
Fixed Constraint 1	Surface Fixed Constraint	0.0 mm	0.0 mm 0.0 mm 0.0 mm

TableV-8: Constraint reactions for top bar component

Name	Force	Vector	Moment	Moment Vector
Fixed Constraint 1	99.92 N	-2.069e-008 N 99.92 N -1.676e-009 N	2.871e-005 N·mm	3.179e-006 N·mm 2.931e-006 N·mm 2.839e-005 N·mm

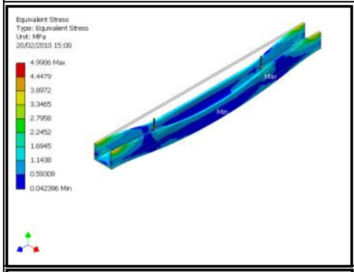
The table below lists all structural results generated by the analysis. The following section provides figures showing each result contoured over the surface of the part.

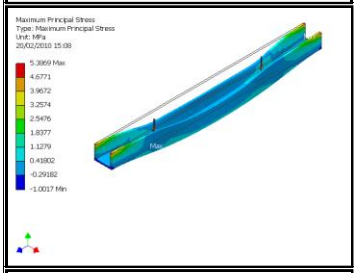
Safety factor was calculated by using the maximum equivalent stress failure theory for ductile materials. The stress limit was specified by the tensile yield strength of the material.

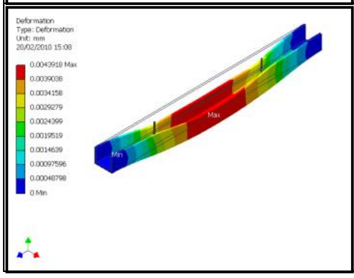
Table V-9: Structural result for top bar component

Name	Minimum	Maximum
Equivalent Stress	4.24e-002 MPa	4.999 MPa
Maximum Principal Stress	-1.002 MPa	5.387 MPa
Deformation	0.0 mm	4.392e-003 mm

Table V-10: Graphical result representations for stress analysis done on pillar components

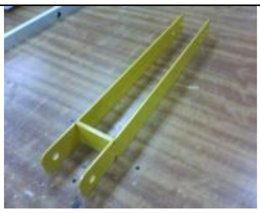
<table>
<tr><th>Figure</th><th>Description</th></tr>
<tr><td>


</td><td>Equivalent Stress</td></tr>
<tr><td>


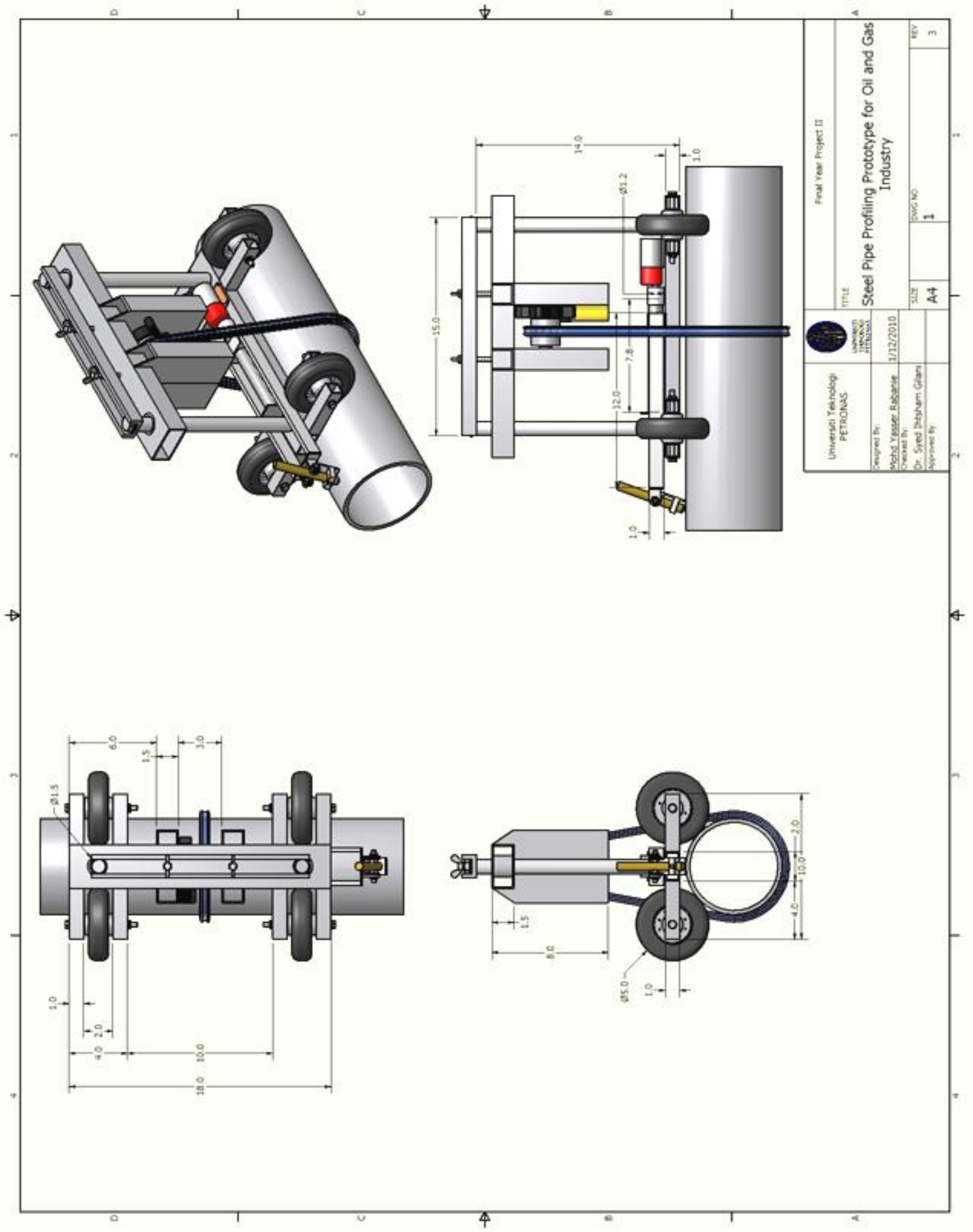
</td><td>Max Principal Stress for Top Bar</td></tr>
<tr><td>


</td><td>Deformation for Top Bar</td></tr>
</table>

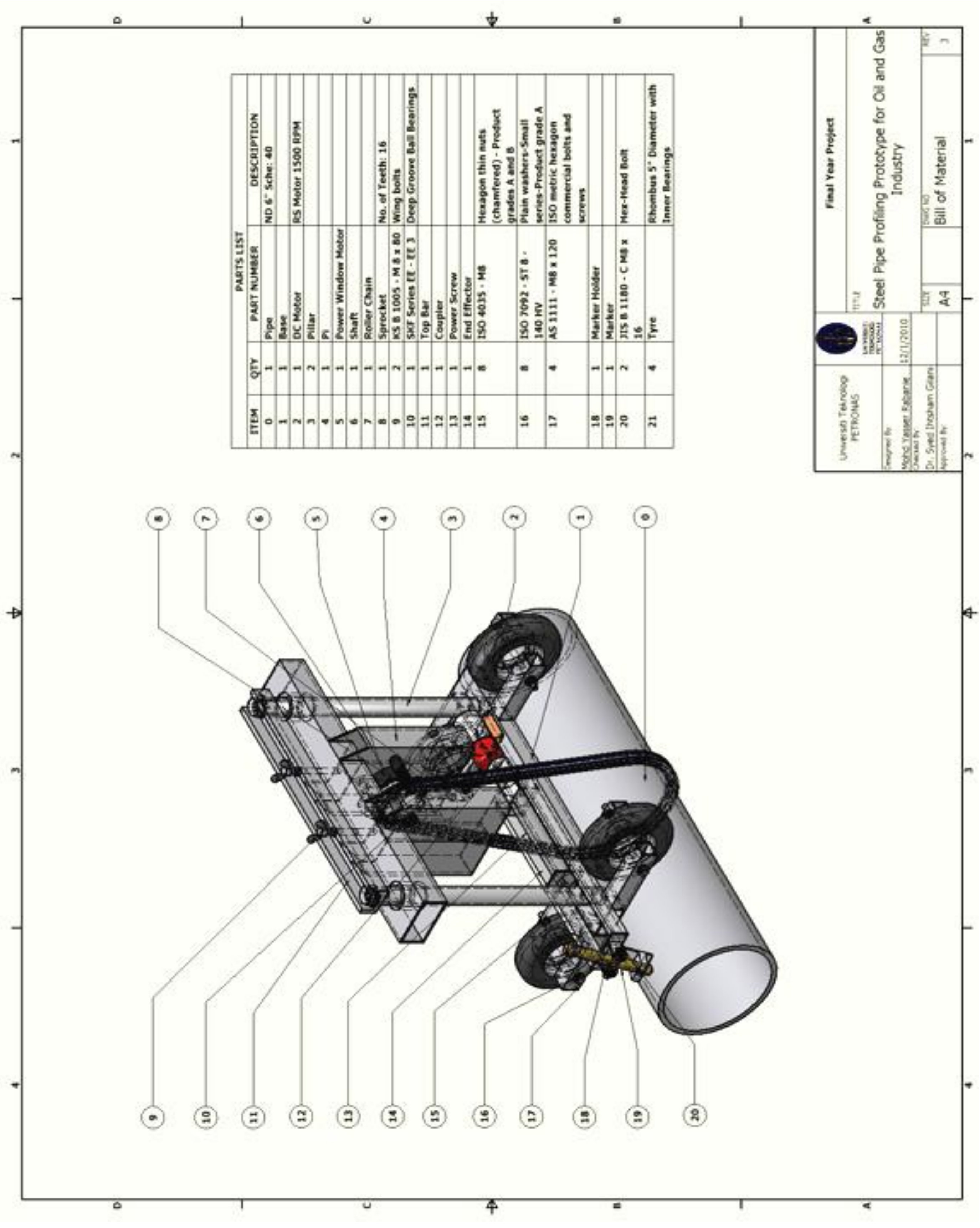
APPENDIX VII- Fabricated Components

Item	Figure	Fabrication Method
Sprocket and shaft		• Cutting • Milling • Turning • Welding
Chain fixer-power window/ bearing holder		• Cutting • Welding
Chain fixer-height adjustor		• Cutting • Welding
Base		• Cutting • Welding
Base-top bar		• Cutting • Welding
Marker holder		• Cutting • Welding
End-effector		• Cutting • Welding

APPENDIX VIII- Orthographic Drawing of the Prototype



APPENDIX VIII- Bill of Materials



PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
0	1	Pipe	ND 6" Sche: 40
1	1	Base	
2	1	DC Motor	RS Motor 1500 RPM
3	2	Pillar	
4	1	Pi	
5	1	Power Window Motor	
6	1	Shaft	
7	1	Roller Chain	
8	1	Sprocket	No. of Teeth: 16
9	2	KS B 1005 - M 8 x 80	Wing bolts
10	1	SKF Series EE - EE 3	Deep Groove Ball Bearings
11	1	Top Bar	
12	1	Coupler	
13	1	Power Screw	
14	1	End Effector	
15	8	ISO 4035 - M8	Hexagon thin nuts (chamfered) - Product grades A and B
16	8	ISO 7092 - ST 8 - 140 HV	Plain washers-Small series-Product grade A
17	4	AS 1111 - M8 x 120	ISO metric hexagon commercial bolts and screws
18	1	Marker Holder	
19	1	Marker	
20	2	JIS B 1180 - C M8 x 16	Hex-Head Bolt
21	4	Tyre	Rhombus 5" Diameter with Inner Bearings

APPENDIX IX- Costing

The estimated cost for a single unit of the prototype is per shown in the table below:

Table IX-1: Estimated Cost

Item	Cost per unit	Quantity	Total Price (RM)
Galvanized steels	2.17 per kg	5	10.85
DC Motor	65	1	65
Power Window Motor	40	1	40
Mild Steel	1.50 per kg	1	1.50
Roller Chain	10	1	10
Sprocket	5	1	5
SKF Series EE - EE 3	35	2	70
Power Screw	15	1	15
Bolts and Screws	NA	32	10
Tire	5	4	20
		TOTAL COST	247.35

The actual cost differs from estimated cost due to availability of some components in labs, as well as additional labor cost to weld certain parts of the prototype.

Table IX-2: Actual Cost

Item	Cost per unit	Quantity	Total Price (RM)
Galvanized steels	2.17 per kg	5 kg	10.85
DC Motor	65	1	Borrow
Power Window Motor	40	1	Borrow
Mild Steel	1.5 per kg	1 kg	1.5
Roller Chain	10	1	Borrow
Sprocket	5	1	Borrow
SKF Series EE - EE 3	35	2	70
Power Screw	15	1	15
Bolts and Screws	NA	32	10
Tire	5	4	20
Labor Cost	NA	NA	100
		TOTAL COST	227.35