DESIGN OF MINIATURE WATERJET MACHINE

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Report submitted in partial fulfillment of the requirements
for the award of the degree of
Bachelor of Engineering in Manufacturing Engineering

Faculty of Manufacturing Engineering
UNIVERSITI MALAYSIA PAHANG

June 2016

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SPECIAL DEDICATION

Dedicated To My Beloved Parents

MAZELAN BIN AMAT

AZIZAH BINTI AMAT

And

My Supervisor

DR. MOHD AZMIR BIN MOHD AZHARI

ACKNWOLEDGEMENT

In the name of Allah Most Gracious and Most Merciful.

Firstly, thanks to God throughout all His Almighty kindness and loveliness for letting me to finish my final year project. Secondly, I wish to hand a million thank to my final year project supervisor Dr. Mohd Azmir Bin Mohd Azhari for his encouragement, guidance and consistent support in finishing this project.

I would like to extend my thank you to UMP associates that contribute in the project either directly or indirectly. My great thanks to my family especially my beloved parents who give a very good support to me to complete this project. For all of that, I am very thankful to the cooperation and contributions from everyone that has driven me to accomplished of this project especially my friends. Lastly, thank you for everything. May Allah bless all of you.

ABSTRACT

The waterjet machine has found wide acceptance and applications in the industries for the past few decades. It is proven to be sufficient for many cutting problems. The present work focuses on the design of miniature waterjet machine. The design of the waterjet machine was conducted based on various stages of product development process. All necessary systematic approaches in a product design based on VDI-guideline 2221 are presented in the present work. The main approaches begin with understanding the specification of the task in developing the miniature waterjet machine. It is then followed with evaluation of the conceptual design of the machine. Finally, the development of the final design of the miniature waterjet machine is presented.

ABSTRAK

Penggunaan mesin jet air di dalam industri telah ditemui meluas sejak beberapa dekad yang lalu. Ia telah terbukti bersesuaian sebagai solusi terhadap pelbagai masalah pemotongan. Kajian terkini telah dilakukan dalam memberi focus kepada reka bentuk mesin jet air bersaiz mini. Kajian telah dilakukan berdasarkan pelbagai peringkat proses dalam pembangunan produk. Segala pendekatan yang sistematik telah dilakukan berdasarkan garis panduan iaitu "VDI-guideline 2221" yang telah dibentangkan sepanjang projek ini. Pendekatan utama bermula dengan memahami spesifikasi tugas dalam membangunkan mesin jet air bersaiz mini. Ia kemudian diikuti dengan penilaian konsep reka bentuk mesin. Akhirnya, pembangunan reka bentuk mesin bersaiz kecil yang terakhir telah dibentangkan.

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LIST OF ABBREVIATIONS

CNC	Computer Numerical Control
HAZ	Heat Affected Zone
VDI	Verein Deutscher Ingenieure (Association of German Engineers)
DSM	Design Structure Matrix
NPD	New Product Development
EDM	Electrical Discharge Machine
PERT	Program Evaluation and Review Technique
CPM	Cost per Mille
CAD	Computer Aided Design
FEA	Finite Element Analysis

CHAPTER 1

INTRODUCTION

1.1 RESEARCH BACKGROUND

Nowadays waterjet cutting is one of a method that is widely used in most of industrial applications because its ability to cut material either hard or soft by using water stream. The cutting process can be done by applying a pure water to cut soft materials such as foam or by adding abrasive to the stream to cut hard materials such as metals effectively. The operating principle of this process is by forcing a large volume of water through a small hole in the cutting head. The small hole or either known as orifice is place at the upper part of nozzle to reduce the cross sectional area to achieve a high velocity of water by maintaining a constant volume travelling through the cutting head. The high velocity of water will accelerate when going out the nozzle to cut the materials.

Typically in a larger manufacture industry the stream of water produced under the pressure of 276 MPa up to 414 MPa (Hashish, Steelers, & Bothelli, 1997). During the cutting process the material is placed on the bed and the CNC controller is programmed. Once the process start the nozzle will move around the bed to cut the material. A typical waterjet machine consist of controller, cutting head, pump, system and machine table. The movement of cutting head is controlled by a computer. When the computer has been properly programmed, the cutting head will move around the bed of a machine as per instructed. The cutting head will move all over the area of machine's bed to get the desired cut. The cutting head of a waterjet machine allow the water to enter at the inlet and will be left through a small orifice located at the bottom part of cutting head. In the case of abrasive cutting, the high velocity exits the small orifice to create a suction effect to pull in abrasive particles in the nozzle. Most importantly the waterjet machine works with various types of high pressure pump. The high pressure pump provides designated flow rates of water at a consistent high pressure. Finally, a waterjet machine table is where the material to be cut is placed. The maximum area that the XY motion control system can move is by determine the length and the width of the machine table (Hashish et al., 1997).

As the popularity of waterjet has grown, there are several reasons why waterjet has become the recent versatile and flexible machining tool. The combination of water and abrasive in material cutting allow waterjet to cut with a wide-ranging variety of material. The materials are included copper, brass, aluminium, brittle materials and flammable materials. Not only that there is no heat affected zone (HAZ) on materials because the little heat formed by the waterjet is absorbed by the water and passed into the catch tank (Hace & Jezernik, 2004). Moreover waterjet machine is one kind of cutting process that is more environmentally friendly. Typically, the abrasive use for abrasive waterjet is garnet where garnet is a non-reactive mineral that is biologically inert (Hace & Jezernik, 2004).

1.2 PROBLEM STATEMENT

Waterjet machine used in industrial application nowadays only use in larger size. The cost of producing one waterjet machine depends on the size of the bed which will indicates the cost of the waterjet machine itself. Meanwhile the cost of purchasing one whole set water jet machine may ranges from hundred thousand up to half a million. Considering to its industrial size, once the waterjet machine is being placed, it is fixed and difficult to move and consuming many space to be installed. Thus the problems mentioned are common therefore this project is carried out to develop a miniature waterjet machine for university used with expected result to minimize the size of waterjet machine and able to make the waterjet moveable.

1.3 OBJECTIVES

This purpose of this study are as follows

1.3.1 To design a miniature waterjet machine by using product design and development concept.

1.3.2 To develop a low cost miniature waterjet machine.

1.4 PROJECT SCOPE

This project is related in developing a waterjet machine for the universities used that will comes in smaller size and minimum production cost. This project will focus on main components of waterjet machine which are the pump, pipe and cutting head, machine bed and CNC controller. Thus to achieve the purpose on developing miniature waterjet machine, the type of components that will be reduced in size are the pump, machine bed and CNC controller. However this product development process will be done according to VDI guidelines 2221 (VDI, 2004). This product development guideline divides into four main phases that contain several work stages that have to be worked out. Therefore, at the end of these phases the design of the product will be carried out.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

These review of previous research that have been made is provided related to waterjet machine system, product life cycle and product design and development guidelines. This chapter also involves a review on research studies on waterjet machine parameter that involves the parameter of waterjet components. Related literature has been studied on the types of nozzle used and high pressure water pump. This review has been well elaborated to cover the product development guideline about product design and development. A study has been made in order to help classifying the proper way to develop a product that involved product selection and cost comparison. The review is properly detailed so that the present research effort can be properly followed to add to the current body of the literature as well as to justify the scope.

2.2 PRODUCT DEVELOPMENT

2.2.1 Product Development Decision.

In the development decisions concept it is offer the life cycle services and after sale supplies where the concept will not only cover the product specifications and the product's basic physical configuration (Krishnan & Ulrich, 2001). According to Krishnan and Ulrich there are five basic decisions to be made. With the help of questionnaire such as; what are the target values of the product attributes? What will the product concept be? What variants of the product will be offered? What is the product architecture? And, what will be the overall physical form and industrial design of the product? A suitable representation of a product is a course of attribute such as speed, price, reliability and capacity (Krishnan & Ulrich, 2001). They anticipate attributes to refer to both customer needs which can also be known as customer attributes or customer requirements and engineering characteristics or technical performance metrics or product specifications. A comprehensive discussion of the issues related with evaluating and using customer needs that provided. A conjoint analysis is a designed approach to optimally regulate the target values of these attributes by using given a representation of a product as a set of attributes. This attribute-based methods is kind of limited methods to be able to represent the overall demand of products, especially those for which aesthetics and other universal product attributes are important. A journal offer a cross methodology in which attribute-based methods are complemented by the use of representative physical samples to stimulate consumer liking information. Ample of the research on setting attribute values is also target on take full advantage of customer satisfaction or market share, and does not openly consider design and production costs or overall effectiveness. In addition, the research on setting attribute values that have been done in the context of packaged goods are often assumes that random combinations of specifications are possible. While it may be possible to provide any combination of “crunchiness” and “richness” in a chocolate cookies, it is not possible to offer a random combination of “compactness” and “image quality” in a camera. Attributes are an idea of a product. Concept development also makes best of the embodiment of these attributes into some kind of technological approach where they call a core product concept. The decision of which technological approach to follow is often sustained by two more focused activities which are the concept generation and concept selection. Most of the textbooks which regard on the design and development discuss are also focus on concept generation.

2.2.2 Product Development Process Modelling

The five categories of process modelling are the sequencing and planning simulations, disintegration simulations, stochastic lead time simulations, design review timing simulations, and parallelism simulations (Smith & Morrow, 1999).

2.2.2.1 Sequencing and scheduling.

Sequencing and scheduling design tasks covered when the product development is separate from many activities with project-like theme, in that iteration and rework are commonplace. A difficulty to fine the appropriate orderings occur with the presence of iteration. Firstly, by using design structure matrix (DSM) method take on that each design task can be displayed as an information processing task to use and create information. The final information from one task will becomes the initial information for another task. The final/initial relationships may (in all likelihood) include cycles, which specify the need for iteration. The DSM formulation is represent a matrix form that includes these relationships. Tasks in the matrix may be re-organised, which helps identify repeated and acyclical tasks.

2.2.2.2 Breaking down large systems into subsystems.

The decomposition of a larger systems, an important task within product development management the large design projects should be divided into smaller fundamentals. This decision is hard, imperative, and responsive to formal analysis, and has therefore been the target of several simulations. Decomposition of large systems is beneficial either to assign the work among multiple designers or design teams, or also to suggest a disintegration of the technical object that will minimize intersecting between subsystems. Decompositions therefore help to increase speed of the design process and also help to create higher performance design outcomes.

2.2.2.3 Iteration of product development and delays.

To determine the effects of stochastic intervals on product development lead time, the effect that is possibly important to product development that are not captured in PERT/CPM models of product development is the need for iteration as well as the potential delays in product development because of line up delays. The simulations in this subsection recognize that product development projects do not occur in segregation, but instead there are several simultaneous projects that are competing for the same limited resources. The inadequate availability of resources might causes delay in the overall project that can unpleasantly affect overall project lead time.

2.2.2.4 Simulation and activities for product effectiveness.

Determining the timing of design reviews/product release, another class of simulations concerns the effectiveness of activities that are related to the design process, but are not design tasks themselves where the activities covered design reviews and product release.

2.2.2.5 Sequential scheduling in design process

Determining the amount of parallelism. A simulation is described to indicate that there are valid reasons for maintaining some amount of sequential scheduling in the design process as a method to lower the costs and reduce the size and difficulty of the organization required to support design activity.

2.2.3 Modeling of a Product Development

To measure a product development cycle time, the use of dependent variables in this research which are called new product development (NPD) times collected in a standard format across firms. The generating of raw data is the start times for each of a series of product development stages and the product introduction date where for the product introduction date will allocate the date of first creation for sale from the manufacturing facility. The product development cycle times are calculated from these raw data. There is no one ‘right’ number or description of stages. The stages in this research were defined to highest probability of that conclusive dates could be associated with the start of each stage in the paper trajectories of the projects (Griffin, 1997). According to Abbie Griffin, the start times of five product development stages were required for each project. First stage is concept generation that begins when the product idea first come out. Second stage is project evaluation where the evaluation of a project starts when the strategy and target market have been recommended and the project has been given a permission to develop specifications.

Sticking down exact times for the starts of stages first and second is sometimes quite hard because an idea may have been arose in the marketing or development group at the first place for a long time even though no action has been taken. The startup point of other projects may be acknowledged clearly in communications when proposing the idea or in the case of a project which is commenced to meet a competitor's offering, by the date the other product was declared to the market. When conclusive dates were not available from records, the data are treated as missing and excluded from the analysis. Stage three of the development starts with the first spending of money on research and development to physically developing the product. Stage four is proceeding with the manufacturing development where it will starts with the documentation of process development. Stage five or the last stage is the commercialization. The commercialization begins with manufacturing production trials.

2.2.4 Structuring Product Development Process

This journal talked about implementation of restructuring product development process methodologies for a product design (Ahmadi, Roemer, & Wang, 2001).

2.2.4.1 Collection of product data base.

The construction of a product according to development process, a data base of all applicable and important design activities and design parameters along with their interrelationship.

2.2.4.2 Establishment of requirement.

A questionnaire stimulated the basic information on every design activity. The design activities and parameters will be evaluated by development project personnel, and then the establishment of information requirements and exchanges activities. Based on this input, a graphical design consisting of design activities were built. The proposed methodologies is applied to construct the ideal structure of design activities and their completion time were determined.

2.2.4.3 Breaking down parameters into conceptual design.

In line to the exclusive nature of the design activities and parameters, the limitation of the presentation of the results is measured to a small subset of conceptual design activities. The first activity of the design is to iterate among the activities of the practical areas to achieve overall energy balance.

2.2.4.4 Determination of product requirement.

Proceed to the second stage of development where the determination of the size, dimension, and location of each stage is conducted. These two stages is used to interact each other to decide potential encounters. The remaining stages that are left contain a single design activity each.

2.2.4.5 Analyzing and evaluating product design.

These remaining stages basically analyze and evaluate the early design activities to ensure the intersection of the design specifications and customer requirements. The critical information id obtained from the design activities in the first two stages provided which regards to the size and potential expertise needed to form the design team.

2.3 WATERJET DEFINITION

2.3.1 Waterjet- An innovative tool for manufacturing.

Recently one of the fastest growing machine process is waterjet technology where the machine can cut almost any materials. The utilizations of water stream only is enough to cut a material, but in order to get higher material removal rate an abrasive is added to the water stream (Folkes, 2009). Besides the components of the machine system have become more reliable. Firstly pump technology with high pressure had been introduced to the market. This high pressure pump makes the waterjet machine to be able to cut a whole range of materials to become more reliable (Folkes, 2009). But then in order the waterjet to be able to operate with minimal maintenance and accurate performance, a head and nozzle component is designed. The design of this component that consist of orifice allows the water inside to accelerate once leaving the nozzle. This orifice can be ruby, sapphire and diamond that act as small hole that being placed on the upper part of the nozzle. Study shows that among these orifice, a ruby is commonly used in abrasive waterjet cutting. Not to mention there are two types of waterjet cutting which are the abrasive cutting and pure water cutting. The abrasive waterjet machine is the most commonly used for cutting process. The abrasive which is garnet is specifically the most common in waterjet cutting. A study also shows that abrasive cuts most materials with a good surface finish and processing time. Moreover waterjet can do various kind of process which are cutting, drilling, milling, surface preparation, cleaning, coating removal, peening and forming. To conclude here waterjet is one of versatile tool where it can cut almost any materials and competes with other technologies since there is no minimal force, no heat damage and it is environmentally friendly process.

2.3.2 Process and tool developments in industrial waterjet applications.

In the most current of non-traditional methods in machining process to cut material is waterjet machine. There are two types waterjet machine which are pure waterjet and abrasive waterjet. Pure waterjet initially the first cutting process that used up only water to cut soft materials such as paper and foods. While abrasive waterjet is the new version of waterjet that added abrasive to speed up the waterjet cutting ability (Kulekci, 2002). Moreover abrasive waterjet is used to compliment other cutting system and may be integrated with cutting process such as flame cutting, routing, plasma cutting or EDM-ing (Kulekci, 2002). To be compared to other cutting abrasive waterjet has a higher damage-free cut rate. In this journal, the study focused on main parts of the waterjet system. Generally abrasive waterjet cutting system consist of four major parts.

2.3.2.1 Intensifier Pumps

They are the intensifier pump that provides pressurized water. The intensifier is an amplifier that converts the energy from the low pressure hydraulic fluid into ultra-high pressure water. An attenuator works to fluctuate pressure from the intensifier to deliver constant and steady stream of ultra-high pressure water to the cutting element.

2.3.2.2 Cutting Head

A cutting head that provides pure water or abrasive water jetting. This cutting functions to change the pressurized water to become a cutting element. The cutting head is one of the effector in this system that helps to maintain the pressurized water is supplied to perform the cutting process. To enhance the performance of this cutting head, the efficiency of mixing and particle entrance is increased.

2.3.2.3 Computer Numerical Control (CNC)

A computer controlled manipulator that helps to effectuates the desired motion of the cutting head. Nowadays the commercialized computer controlled for waterjet motion has varied in its system. This component consist of software and hardware that is easy to handle compared to the oldest version of computer controlled manipulator. Moreover the software of this component has comes with compensation mixing chamber wear, bending of jet stream for specific materials and variation in cutting speeds neededfor corers and curves.

2.3.2.4 Water catcher

Lastly a catcher that dissipates the remaining water jet energy after cutting process. After the water jet passes through the material that need to be cut, most of the initial energy of the jet may retained but in the case of no material on the bed the jet will reaches this catcher with full energy. Hence in order to maintain a long life span of the catcher, the catcher must be sturdy and reliable. Thus in order to meet these characteristics a moveable catcher must consist of small container that build from energy absorbent material or in other the container must be filled with water. Besides the catcher size will define the maximum motion of the cutting head. Lastly the water jet process is environmentally friendly compared to other process.

2.4 PRESSURE ON WATERJET CUTTING

2.4.1 A model of water jet cutting system for low pressure

The aim of the paper is to demonstrate the concept of water-jet cutting systems and empower the research activities and cost-reduction methods to promote the use of the same in India. A water jet machine is a mechanism that is capable to slice a metal or other materials by using a jet of water at high velocity and pressure (Mehta, Wadgaokar, Khatal, & Chavan, 2013). Its most significant attribute as an accurate cold cutting process allows it to cut metals without leaving a heat affected zone. The system uses a jet of pure water at high velocity and pressure or a mixture of water and an abrasive substance. There are basically two types of water-jet machines:

a) Pure Water-Jet Machine.
b) Abrasive Water-Jet Machine. As a part of this project, the researchers have successfully developed a working model of pure water-jet cutting system. The system utilizes a pump of capacity 2000 psi and 140 bar pressure as compared to 60,000 psi and 4000 bar pressure in present industrial use. Such pressure pumps are usually used in garages for car washing. In actual cutting systems, the pressure is intensified by double acting intensifier, whereas we have obtained the intensification with the help of piston movements.
c) Project observations:

Pump Specifications: 140 bar 2000psi

Orifice size: zero degree, 1mm

Table 2.1: Cutting Speed Result for Materials 1

Sr. No	MATERIAL	THICKNESS (mm)	CUTTING SPEED (mm/min)
1	P.O.P	2	59.1
2	TYRE	2	3008.78
3	FOAM	12	5179.89

Table 2.2: Cutting Speed Result for Materials 2

SR.NO	MATERIAL	THICKNESS (mm)	CUTTING SPEED (mm/min)
1	RUBBER	2	27000
		10	11500
		20	2200
2	SYNTHETIC MATERIAL	2	22500
		5	8900
		10	3400
3	FOAMED MATERIAL	10	27500
		100	5500

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Methodology is a method that refer more than one method sometimes accompany by training, worksheet and diagramming tools. It is including documents that record all the phases of the product development such as requirement, designs, development, assembly, testing and maintenance. Methodologies also include diagramming notation for documenting the result of the project whether it is acceptable.

3.1.1 Flow chart

Table below shows a plan to work on development of waterjet machine according to VDI 2221 guideline.

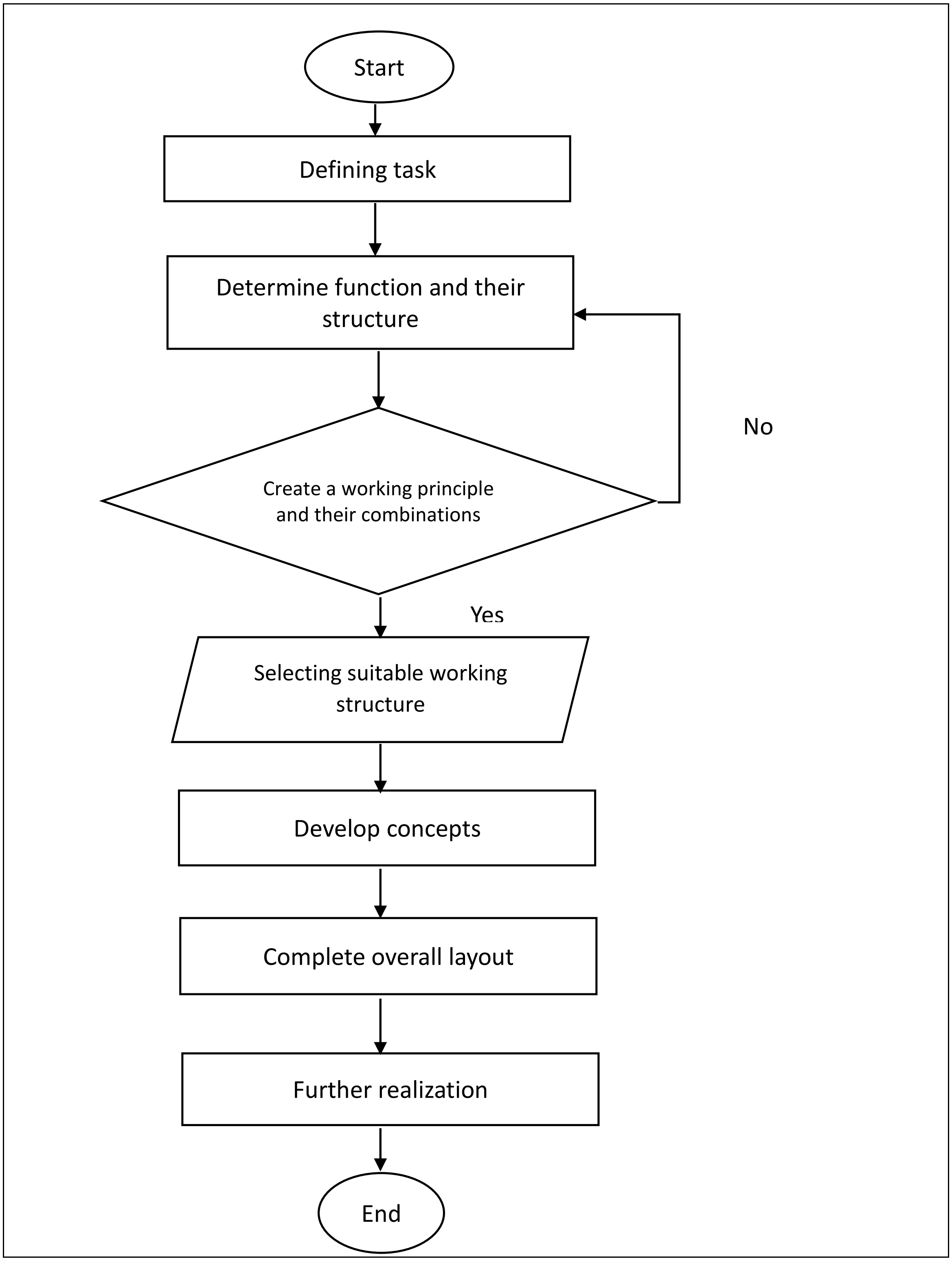


Figure 3.1: Flow chart

3.2 PRODUCT DEVELOPMENT PROCESS.

The development of miniature waterjet machine has used produt design and development guideline to help to go through this project this guideline which consist of 4 main phases according to Pahl and Beitz and they are the clarification of the task, conceptual design, embodiment design and detail design (Pahl & Beitz, 2007). Going down this phases there are stages that need to be carried out.

Figure 3.2 below generally shows how the phases being done. At a certain cases a product design will undergoes these stages once, or there will a repetitive concept while finish off the stages regarding the specific task. For the project as the task require to develop a miniature waterjet machine there are four components that will be focused to. Necessarily there are major components that will develop this machine system. They are the high pressure pump, CNC controller, cutting head and table (Kulekci, 2002). During this product development, all the stages above will be done repeatedly.

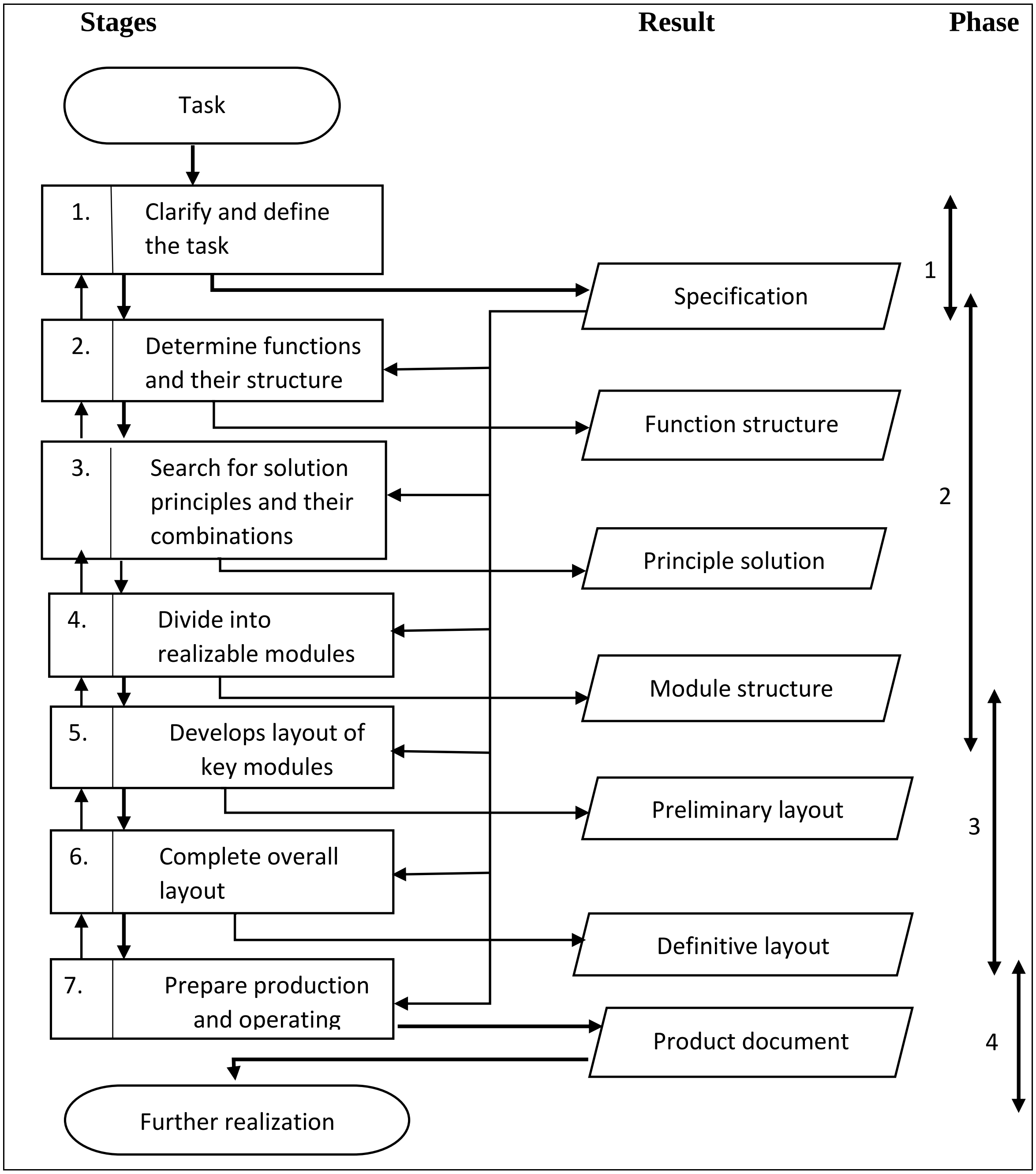


Figure 3.2: Product development according to VDI 2221 guideline (Vdi, 2004)

3.2.1 Clarification of the task

Task clarification phase (or well known as development phase). This phase involves planning the initial product by collecting information about customer requirement and by generating initial product ideas (Pahl & Beits, 2007). It culminates in the drawing up and elaboration of a detailed requirement list (design specification) (Pahl & Beits, 2007). During this phase it is necessary to clarify and define the requirements of the task requested by the customer. After the task is given, the clarification and definition of it builds the essential part of the development phase. Hence the information gaining about the product requirements and the existing conditions and their importance is the most important operation.

3.3.1.1 Stage 1-Clarify and define the task.

The first stage of this product development is to define and clarify the task requested by the customer or the product planning department. In this project, a task has been assigned to develop a waterjet machine in miniature figure to improve the facility of university's laboratory. The establishment of essential requirements for the waterjet machine where the throughput of this machine are the waterjet system, external dimension and production cost. The steps to be taken in this stage are; first step is to check the external requirement of the product. Secondly, if necessary the additional requirement will put on the list. And lastly the essential design requirement will be reformulates and structuring it back. The result from the stage will come up with the specification of the product. Working guideline to build a list of requirements for a product is according to Table 3.1.

Table 3.1: List of main characteristics to find requirement (Pahl & Beitz, 2007)

Main headings	Examples
Geometry	Size, height, breadth, length, diameter, space requirement, number,
	arrangement, connection, extension
Kinematics	Type of motion, direction of motion, velocity, acceleration.
Forces	Direction of force, magnitude of force, frequency, weight, load
	deformation, stiffness, elasticity, inertia forces, resonance.
Energy	Output, efficiency, loss, friction, ventilation, state, pressure,
	temperature, heating, cooling, supply, storage, capacity, conversion.
Material	Flow and transport of material. Physical and chemical properties of
	the initial and final product, auxiliary materials, prescribed material
Signal	(food regulation etc)
Safety	Inputs and ouputs, form, display, control equipment.
Ergonomics	Direct safety systems, operational and environmental safety.
	Main-machine relationship, type of operation, operating high, clarity
Production	of layout, sitting comfort, lighting, shape compability.
	Factory limitations, maximum possible dimensions, preferred
Quality control	production methods, means of production, achieveable qualtity and
	tolerances, wastage.
Assembly	Possibilities of testing and measuring, application of special
Transport	regulations and standards.
	Special regulations, installation, siting, foundation.
Operation	Limitation due to lifting gear, clearance, means of transport (height
	and weight), nature and conditions of dispatch.
Maintenance	Quietness, wear, special uses, marketing are, destination (for
Recycling	example sulphurous atmosphere, tropical condition)
Costs	Servicing intervals (if any), inspection, exchange and repair,
	painting, cleaning.
Schedule	Reuse, reprocessing, waste disposal, storage.
	Maximum permissible manufacturing costs, cost of tooling,
	investment and depreciation.
	End of date development, project planning and control, delivery
	date.

After gathering the requirement, the list will divided into demand (D) and wishes (W). Those requirements marked with “D” it must be fulfilled in any way while the requirements marked with “W” it can be fulfilled if possible.

As mentioned earlier at section 3.2 the main parts to build a waterjet are the high pressure pump, cutting head, catcher and CNC controller. Next the fundamental is defined which are the geometry of each parts, the energy, signals, safety, ergonomics, assembly, maintenance, costs and schedule. Hence a Table 3.2 is constructed to show the requirement of each part for miniature waterjet machine.

Table 3.2: List of requirement

		Requirement specification of high waterjet machine	Sheet: 1 Page:1
Change	D W	Requirement	Respon.
			Arina
	D	Water pump with minimum pressure of 100 bar.	
	D	Cutting table :	
		Length : ± 1000mm	
		Width : ± 1000mm	
	D	CNC guide	
	D	PC based programmable controller (CNC	
	D	controller)	
	D	"X/Y" carriage	
	W	Motorized "Z" axis	
	D	Catch tank	
	D	Cutting table	
		Workpiece support material	
	W		
	W	Pressure intensifier	
	D	Abrasive removal system	
	W	Cutting nozzle	
		Chiller	
	D		
		Cost estimation	
		➢ >RM50 000	

Table above shows the requirement list for miniature waterjet machine. After the requirement is gathered, there divided into demands with label 'D' and wishes with label 'W'. This can be seen in the column left to the requirements. By doing this, the requirements list is finalized for this stage. That means that the product specification is at hand and the next phase can be initiated.

3.3.2 Conceptual design

The conceptual design phase is where the requirement list that has been worked out is reduced to the main requirements. According to Pahl/Beitz, during this phase there are several matters that will work on; abstracting to find the essential problems, establish function structures, searching for working principle, combining working principle into working structure and selecting a suitable working structure and firming up into a principle concept[6]. Figure 3.3 shows the work flow for conceptual phase.

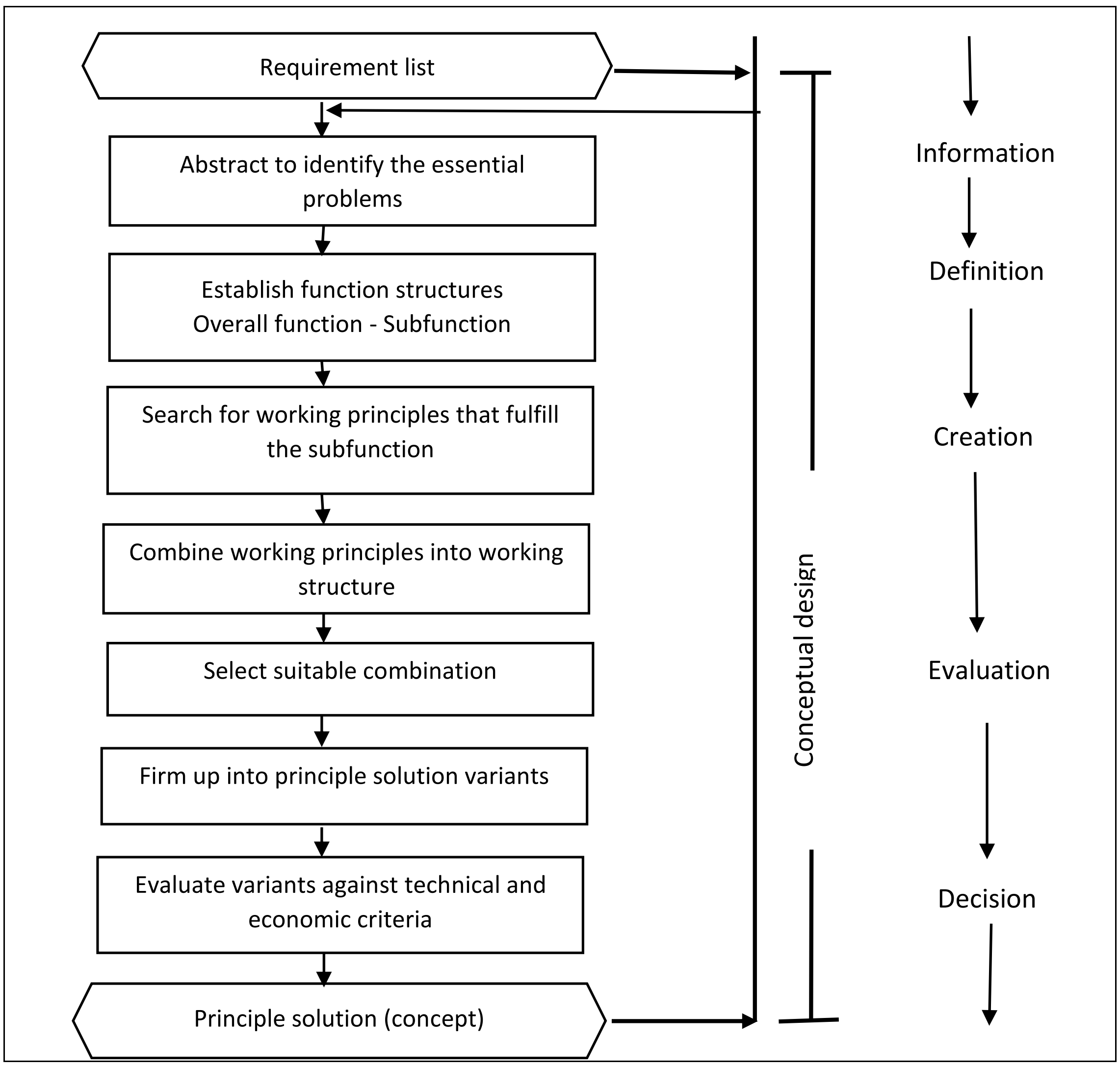


Figure 3.3: Steps of conceptual design (Pahl & Beitz, 2007)

3.3.2.1 Stage 2- Determine the function and their structure

After the requirement of a product is worked out, the function of a product is determine after the main conversion and the essential auxiliary conversion have been defined. The main conversion and auxiliary conversion is present in the form of function structure (block diagram) as result of this stage.

First of all, the main conversions for the miniature waterjet cutting system are the pressurized water, cutting element and catch tank. For the auxiliary conversion is the motion controller of the cutting element. Then the input and output for this system is the water supply and material cutting. After that the establishment of the overall function is define from the main conversion which is the waterjet machine. From the overall function the sub-function will be built to describe the basic structure function.

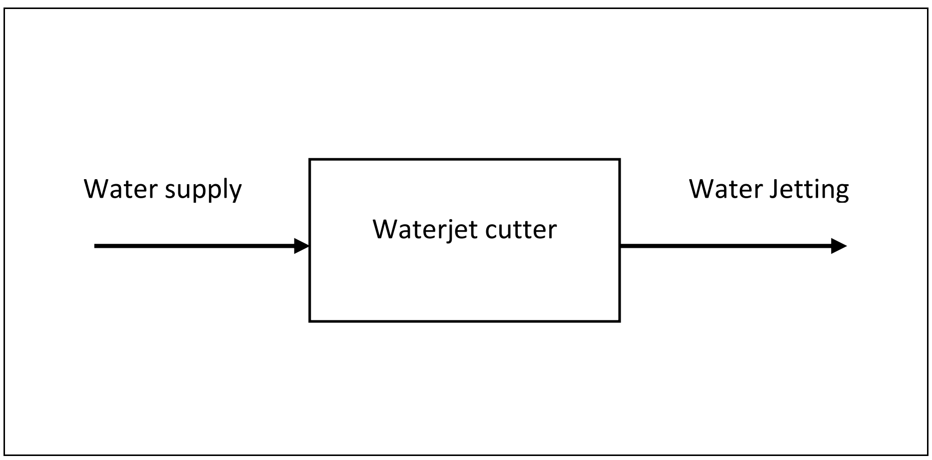


Figure 3.4: Overall function for waterjet

The input of the system is the water supply. For the waterjet to cut a material, water is needed to be pressurized first and then a constant volume and pressure will go through the system to be able to cut the material. Hence the input and input of this is connected by the waterjet machine itself. So the overall function is the water supply as the input and the material cutting as the output.

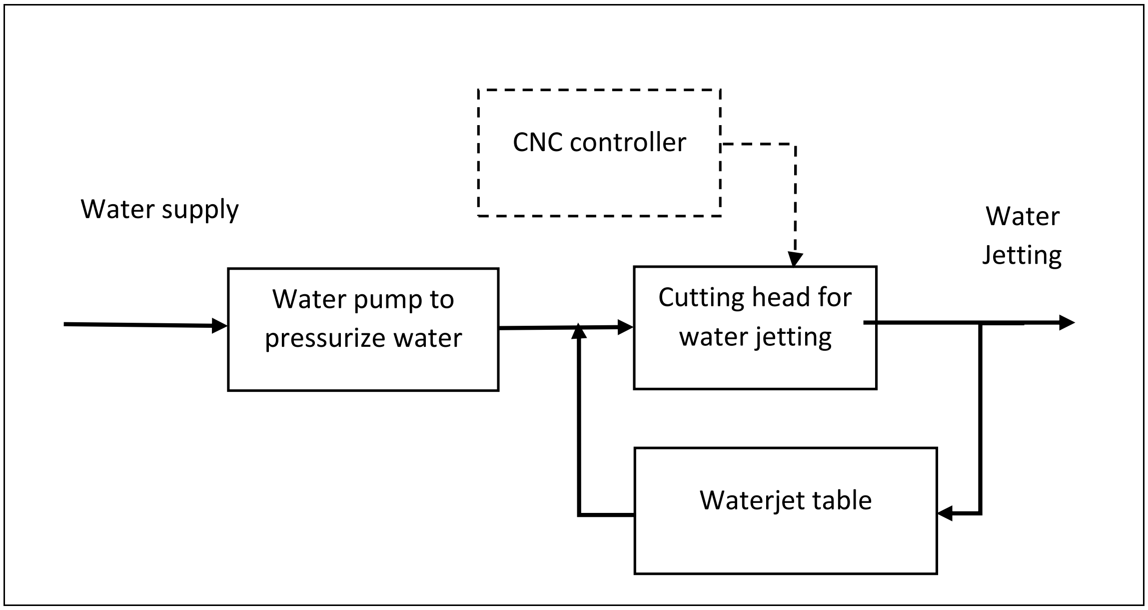


Figure 3.5: Sub-function structure for waterjet

After the overall function is built, the function then is breaking down into sub-function of the waterjet. The sub-function of this waterjet are the water pump to pressurize the water, cutting head for water jetting, waterjet table and CNC controller. The input and output of this system remain the same. Besides there is an addition to the function of this system that needs to mention. The auxiliary function is the motion controller for cutting head to get the material (output) to be cut into a desired shape.

3.3.2.2 Stage 3- Search for solution principle and their combination.

After the various functions of various levels are known, it is a must to search for solution principle or in the term of working principle for each of the functions and sub-functions. A solution principle is based on the flows of materials, energy and information within each function (Yousef, 2003).

The *first step* to search for possible working principle is to develop concepts for each function. A working principle contains the physical effect and the geometrical and material characteristics necessary to fulfill the functions. To develop concepts for the function there are two activities that are similar to each other. Firstly, for each function, develop as alternatives options functions as possible. Secondly, for each sub-function the goal is to develop as many means of accomplishing the function as possible. For an example, there are various type of pump to deliver water in high pressure. By all means, one can list out the types of pumps as the options to deliver water. But if there is a very limited option, a person may be has made the fundamental assumption early (Vdi, 2004).

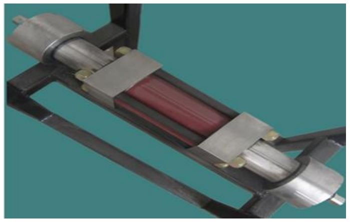
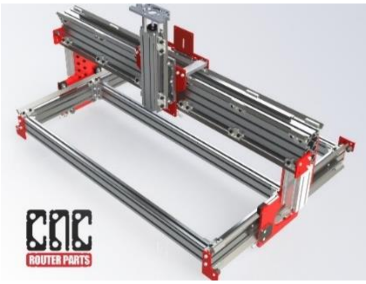
The *second step* is to define for each function or functions and to list the means or methods to be used. During this step there will be resulting in abstracting a solution or method to a function. This abstracting solution can be expressed in rather general terms, but it is probably better if they can be identified as real devices or subcomponents (VDI, 2004). For an example, if I want to maintain the pressurized water is delivered to cutting head in a constant high pressure, I might want to use an attenuator as the solution. But the solution might not only contain the known component. It is either will be presented as new or unconventional method.

The *third step* to develop a working principle is to draw up a chart containing all the possible solutions. The best method to use is to draw up a morphological chart. This type of chart is a table that build from the functional analysis (Yousef, 2003). On the left side of the chart are the listed functions while on the right side will show different mechanisms which can be used to come up with different ideas.

Table 3.3: A morphological chart (Yousef, 2003)

	Option 1	Option 2	Option 3	Option 4	Option 5
Function 1	C_{11}	C_{12}	:	:	:
Function 2	C_{21}	C_{22}	:	:	:
Function 3	C_{31}	C_{32}	:	:	:
Function 4	C_{41}	C_{42}	:	:	:
Function 5	C_{51}	C_{52}	:	:	:

Table 3.4: Scope of possible solution.

Solution Principle Subfunctions	1	2	3
1. Water pump	 Direct drive pump Pressure : 206.8 Bar Weight : 6.35 kg Price : RM 1288.47	 Centrifugal pump Pressure : pressurized water for housing (high) Weight : 6.80 kg Price : RM 472.41	 Intensifier pump Pressure : 3800 bar Weight : 75 kg Price : RM 34360.40
2. Cnc Router (waterjet table)	 Axis : 4 axis Table dimension : 750mm×450mm Weight : 51.98 kg Price : RM 7271.43	 Axis : 4 axis Table dimension : 736.6mm×711.2mm×609.6mm Weight : 36.42 kg Price : RM 9302.65	 Axis : 4 axis Table dimension : 647.7mm×1308.1mm×304.8mm Weight : Price : RM 11875.81

3. Cutting head	 Size : 17cm x 12cm x 12cm Price : RM2552.33	 Weight : 0.5 kg Machining: CNC Machining Price: 3,096.07	
4. CNC controller	 Types : 4 axis machine CNC controller Compatibility : G-code and CAM software (CAD drawing) Price : RM 8976.65		

According to table 3.4 it shows the scope of possible solution for waterjet machine. From the table, the left column contains the subfunctions of the function structure. For each of those functions several possible solutions are shown in the columns in the right side of the table.

The *fourth step* is to identify possible combinations. A list of concepts or the alternatives will be generated from the previous chart. To complete a conceptual designs the individual concept is combined. Be selecting one option for one from each function, a single designed is formed.

Table 3.5: Selecting concept combination

	Option 1	Option 2	Option 3	Option 4	Option 5
Function 1	C_{11}	C_{12}	:	:	:
Function 2	C_{21}	C_{22}	:	:	:
Function 3	C_{31}	C_{32}	:	:	:
Function 4	C_{41}	C_{42}	:	:	:
Function 5	C_{51}	C_{52}	:	:	:

By looking at the selection concepts combination on the morphological chart, those following options were chosen for the different functions which govern the mechanism.

Table 3.6: Combination of working principle

Solution principle / Sub-function	**1**	**2**	**3**
Water pump (To supply pressurizes water)	Direct drive pump Pressure : 206.8 Bar Weight : 6.35 kg Price : RM 1,288.47 A1 A2	Centrifugal pump Pressure : pressurized water for housing (high) Weight : 6.80 kg Price : RM 472.41	Intensifier pump Pressure : 3800 bar Weight : 75 kg Price : RM 34,360.40 A3 A4
CNC router (Hold the workpiece and cutting head)	Axis : 4 axis Table dimension : 730mm x 520mm x 500 mm Weight : 31 kg Price : RM 13,162.7	Axis : 4 axis Table dimension : 1575mm x 1650mm Weight : 40 kg Price : RM 15,015.92	Axis : 4 axis Table dimension : 647.7mm×1308.1mm×304.8mm Weight : 35 kg Price : RM 11,875.81
Cutting head (To increase velocity of pressurized water)	Size : 17cm x 12cm x 12cm Price : RM2,552.33	Weight : 0.5 kg Machining: CNC Machining Price: 3,096.07	
CNC controller (Ability to control the movement of cutting materials)	Types : 4 axis machine CNC controller Compatibility : G-code and CAM software (CAD drawing) Price : RM 8,976.65	Types : High-end Gantry type CNC Cutting Controller Compatibality : Windows operation system, CAD support system Price : RM 4,418.53	

Table shows that there are 4 alternatives combinations found in this project. Those are marked with A1 to A4 and are tagged with different types of arrows. All combinations starts with the first sub-function stated in the left column. So the first step is to choose a suitable solution for the function “ pump water from water supply”. The one that seems most satisfying is a “ direct drive pump with pressure of 206.8 bar”. Starting with this solution, combinations with the next sub-function has to be made. It seems like two out of three options might be compatible with the first solution and therefore two combinations are shown. For the second function, the one with most satisfying solution is a “CNC router with dimension of 647.7mm×1308.1mm×304.8mm”. as the next two function on require one possible solution, thus the possible solution of function “cutting head and “ CNC router” is selected. These combinations or working principle are called working structures. As there are 2 combinations which are A1 and A2 might be possible to select, thus the most preferable ones must be selected to get to a principle solution.

3.3.2.3 Selecting suitable working structure.

This selection for suitable working structure is built by using decision matrices to evaluate each concept with respect to a set of selection criteria. The chosen criteria are used to decide which alternative can be used as a principle solution to proceed later on. This process is done by using concept-scoring matix by Karl T.Ulrich. The purpose of this matrices is to narrow the number of concepts quickly and to improve the concepts if needed. Table 3.7 shows the decision list and the results for the different alternatives.

Table 3.7: Decision list for the waterjet machine.

		Concept							
		Alt 1		Alt 2 (Reference)		Alt 3		Alt 4	
Selection criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Ease of handling	14.29%	2	0.2858	2	0.2858	2	0.2858	2	0.2858
Compatible with the definition of the task.	14.29%	2	0.2858	2	0.2858	2	0.2858	2	0.2858
Water pump with minimum pressure of 100 bar.	14.29%	2	0.2858	2	0.2858	2	0.2858	2	0.2858
Dimension of ±1 square per meter.	14.29%	2	0.2858	2	0.2858	1	0.1429	1	0.1429
Readability of setting.	14.29%	2	0.2858	2	0.2858	2	0.2858	2	0.2858
Portability.	14.29%	2	0.2858	2	0.2858	1	0.1429	1	0.1429
Cost estimation >RM50 000	14.29%	1	0.1429	2	0.2858	1	0.1429	1	0.1429

	Total score	1.8577	2.0006	1.5719	1.5719
	Rank	2	1	3	3
	Continue?	No	Yes	No	No

Table 3.8: Rating for Relative Performance

Relative Performance	Rating
Worse than reference	1
Same as reference	2
Better than reference	3

Regarding to Table 3.7 the concept of scoring matrix is prepare and a reference concept is identified. As there are two alternatives are most preferable to select, Alt 2 is chosen as the reference for this scoring concept. Next, the left column of the matrix contains the criteria for the decision making. After those criteria are entered, the importance weights is added to the matrix. There are several ways to value the weight but in this case a range of percentage from 1 to 100 is allocate in the weight column. The points assigned is divided equally among criteria as all the criteria are equally importance.

The procedure is then proceed by adding rating to each of the alternative. Generally, it is easiest to rate all of the concepts with respect to one criterion at a time. A scale is used to rate the concept to the desired alternatives by referring the Table 3.8. Alt 2 is then being chose again as the reference to be used for the comparative ratings. However, Alt 1 is also can be used as the reference as both Alt 1 and Alt 2 are being mentioned in the combination of working principle. Rating 2 is used for all the criteria with respect to Alt 2. The other Alt received an evaluation of 1, 2 or 3 (“worse than,” “same as,” or “ better than”) than the stated reference. Next the concepts are ranked by weighted score. Each concept is given a rank corresponding to its total score.

The first alternative (Alt 1) has only one negative result (“worse than,”). Even though most of the criteria for Alt 1 are same with Alt 2 but considering to the total cost of all components Alt 2 received the minimum cost compared to all Alts’. Thus the total score for Alt 1 is below than Alt 2. Like the first alternate, the third and fourth one also received ‘1’ (“worse than,”) throughout the scoring matrix. Both alternatives received same total score, thus they have been going down to third rank from fourth. As the targeted cost for the waterjet machine is below than RM 50,000, both Alt 3 and Alt 4 have exceeded the estimation. Not only regarding to size and portability criteria, Alt 2 has better compatibility with criteria compared to Alt 3 and Alt 4, thus Alt 2 is rank as number 1 and is consider to continue for further realization.

3.3.3 Embodiment design (Sketching)

Embodiment design phase (or design phase) is the part of the design process in which, a design is develop with the help of technical and economic criteria and with the provided further information where the starting is from the principle solution or concept of a technical product to the point where succeeding detail design can lead directly to production. Before determine the embodiment design, the earlier concept is structured first into assemblies and parts. This project is take as an example, the pump, cutting head, CNC controller and working table will determine the overall layout.

A preliminary layout will be developed at the end of this stage where the arrangement of assemblies and individual part drawings are defined. As the product evolves, a detail of individual components develops. The drawings are made using computer aided design (CAD) such as CATIA. All the dimensions and technical calculation is made. Those parts drawings are then is assembled to finalize the parts dimension, and connecting procedure. This phase will concentrates on the preparation of detail drawings, part and assembly drawings, including part list. The results is a complete set of product documents for the manufacture and operation of the product.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter will present the result and final product that obtained by carrying out the process described in the Chapter 3 (methodology). The objectives of these studies are to study the characteristic between microstructure and mechanical properties on the medium carbon steel. The mechanical properties evaluated through the hardness test and impact test. Microstructure studies conducted to examine, viewed from microstructure of the specific changes due to heat treatment. Fracture analysis due to impact test also has been analysis. Figure 4.1 shows the outline of chapter 4.

4.2 3D MODELLING OF WATERJET MACHINE

Regarding to the function of waterjet machine, the machine is presented in 3D drawing by using Inventor. Therefore, all the components of waterjet machine is drawn up and all the dimensions is ensured. Figure 4.1 and figure 4.2 show the drawing of the machine.

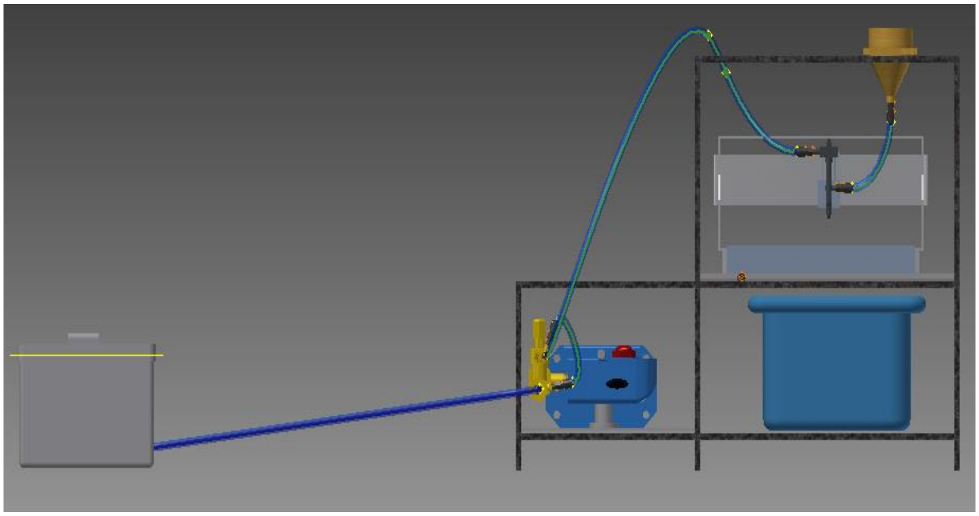


Figure 4.1: Front view of Waterjet Machine

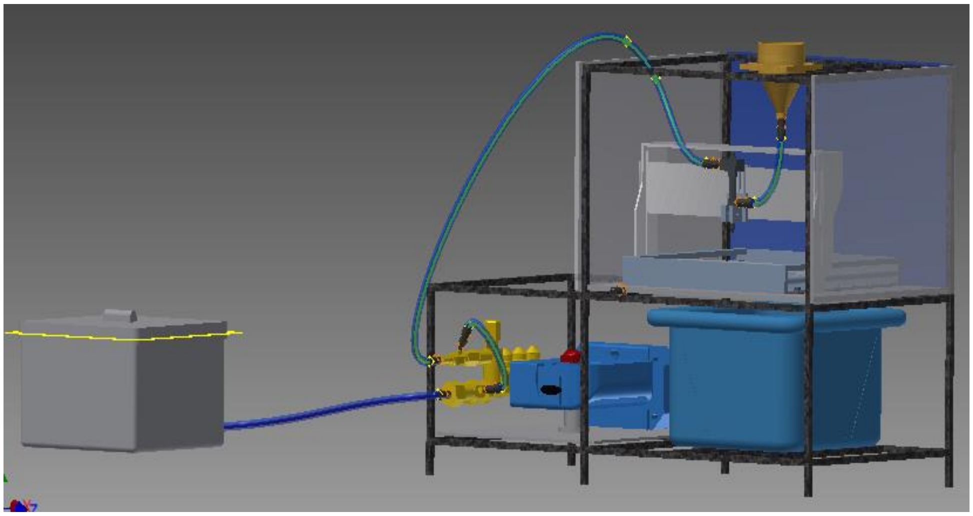


Figure 4.2: Isometric View of Waterjet Machine

According to the drawing of the water jet, the overall dimensions shall be 1007mm x 490mm x 743mm. The length and width result simply show that the drawing of this machine has meet the requirement list which is for length and width in ± 1000mm range. Thus the size of the waterjet machine is smaller and the further realization of waterjet machine will be in miniature size.

4.3 DETAILS DESIGN

Details design of waterjet machine will give the details of the parts function. Therefore a closer look on the design is necessary. To make this part easier, the waterjet machine is divided into different function carriers.

4.3.1 Frame of the waterjet machine.

The function of the frame is to carry most of the weight of the component attached to it and to stabilize it. Regarding how the waterjet will be built, the weight should not be a big problem if the frame is dimensioned right away. An analysis on the frame will be done to select the materials with good strength and lower cost. Figure 4.3 shows the frame of the waterjet machine.

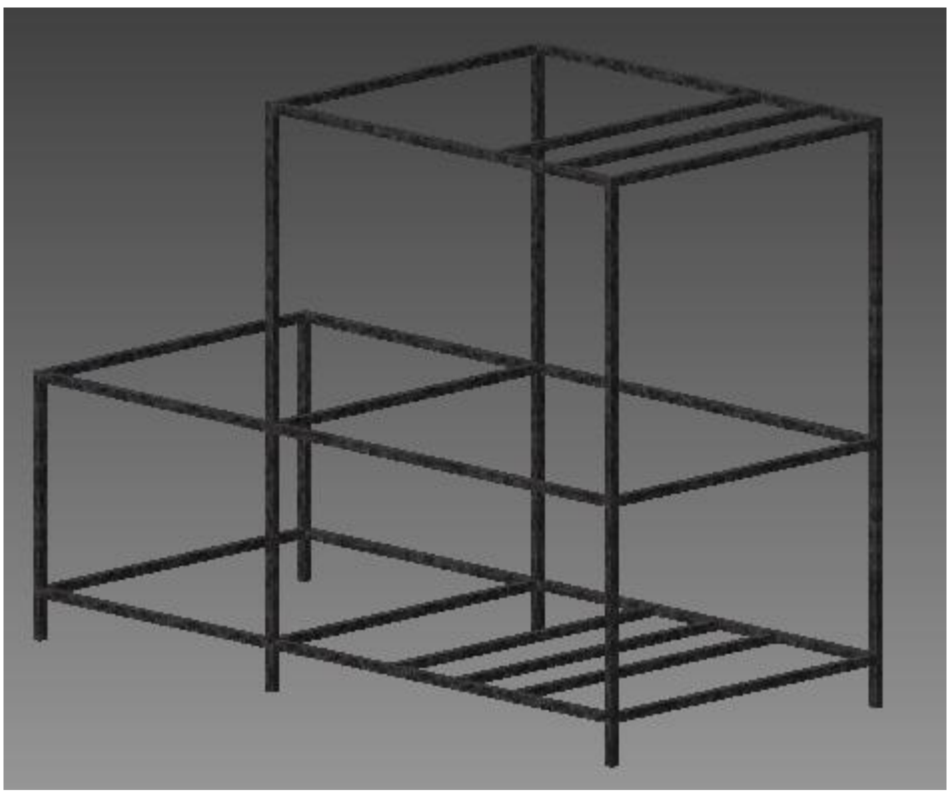


Figure 4.3: Frame of Waterjet Machine

For this frame, the budget has been taken into consideration. Increasing in beams leads to more material needed. Thus this frame has been evaluated if the benefit is worth the money to spend later on. It has been cleared and has already been considered in the design for its dimension.

4.3.2 Router

Precisely, a cutting head is moved around the cutting table which is placed at the bottom part of router to make the desired materials cuts. A router movement is supported and controlled by a computer where it is function to move in x, y and z direction. When a computer is properly programmed, it can instruct the cutting head to move to any area of the cutting table while performing the cutting process. The dimension of the frame is followed by the dimension of the router. The smaller size of router resulting to the development of miniature waterjet machine. It has been mentioned in chapter 3 the type and cost selected for desired router. Figure 4.4 shows the router of waterjet machine.

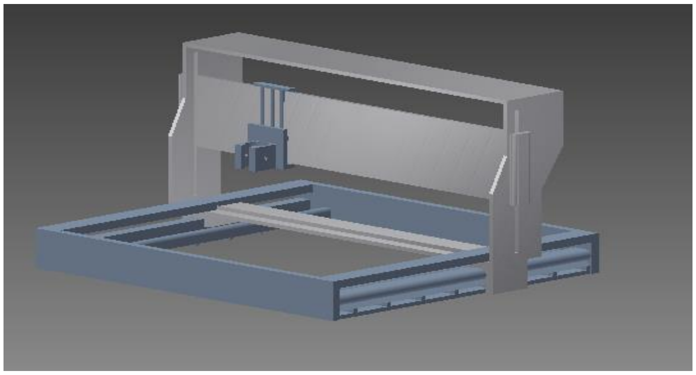


Figure 4.4: Router for Waterjet Machine

Figure 4.5: Router in selected working principle

As mentioned in chapter 3 an alternative method to select working principle has been done. The smaller router with lower cost is selected to be the model for router in 3D drawing. The real dimension is 647.7mm×1308.1mm×304.8mm whilst for the router drawn with inventor has been in 380.0mm×422.1mm×245.9mm dimension.

4.3.3 Water Pump

In the function structure, water pump played as one of the important role in the waterjet machine. Pump helps to deliver pressurize water from water tank. Study shows minimum pressure with 100 bar is enough to cut soft material such as paper. With small diameter of outlet from the pump increase the water velocity thus higher the pressure. The high pressure water is designed to supply and provide sufficient water flow rates at a specific high pressure to supply single or multiple cutting head as required consistently. As the waterjet machine that will be built in miniature size, a minimum amount of pressure as mentioned earlier is required to supply water for single cutting. There various type of high pressure pump but direct drive pump is chosen instead while the pump size and pump horsepower has been taken into consideration. Figure 4.6 and 4.7 show the water pump of waterjet machine.

Figure 4.6: Real Waterjet Pump

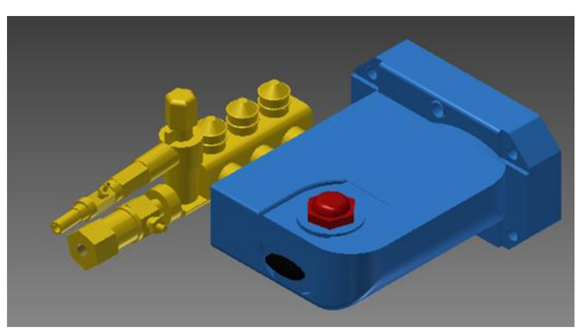


Figure 4.7: Water pump Drawn in 3D Drawing

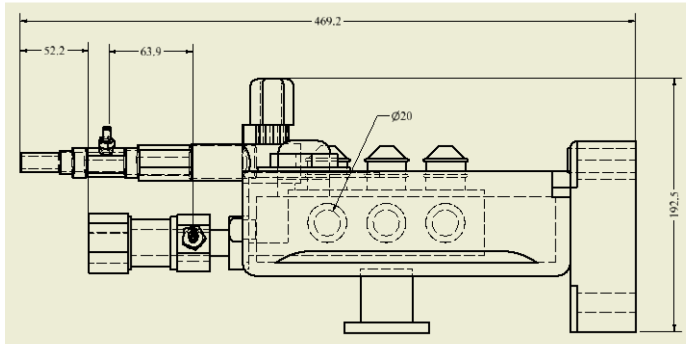


Figure 4.8: Side view of water pump's dimension

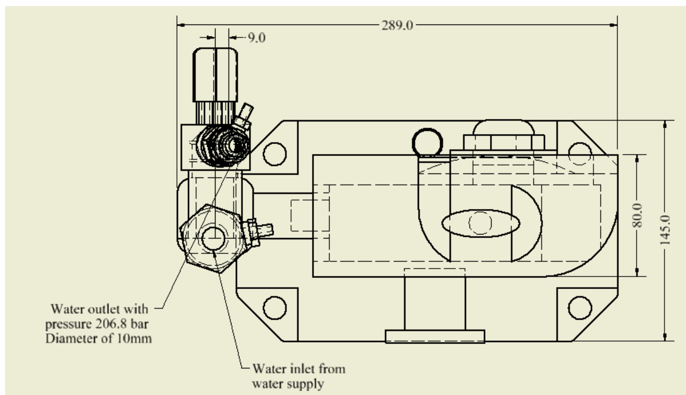


Figure 4.9: Front view of water pump's dimension

While Figure 4.8 and 4.9 show dimension of water pump with its inlet and outlet. The pump in Figure 4.7 has been drawn exactly from the real one. This gives advantageous for the given dimensions of the water pump. The size of the pump with 289.0mm×469.2mm×192.5mm has been clearly shown in figures.

4.3.4 Cutting Head

An essential requirement for waterjet machine is that the water must be in high pressure and can be mixed with abrasive particles. That is among the main purpose of the waterjet to be built and therefore it has to make sure that it is fulfilled. It has been decided that the cutting head contains 3 inlets which are water supply, abrasive and pneumatic purposes. The pressurized water supply will need energy for cutting materials. Hence the amount of energy required is obtained from the pressurized water to ultrahigh pressure and will form an intense cutting stream by streaming this high speed water through a small orifice. For both water only and abrasive jets is applicable into this waterjet cutting process.

Moreover for the abrasive cutting, the abrasive particles is fed into the abrasive mixing chamber where the mixing chamber is part of the cutting head body. Figure 4.10 and Figure 4.11 show real cutting head to be compared and cutting head that has been drawn in 3D way.

Figure 4.10: Real cutting Head

Figure 4.11: Cutting Head Drawn in 3D modelling

4.4 FRAME ANALYSIS ON WATERJET MACHINE.

Analysis on waterjet machine frame has been done to select best material with designated thickness. The strength of the frame need to be analyzed to see maximum load of the frame can withstand. The result will included maximum displacement, stress distribution, bending stress and safety factor. The source of following graphs and tables are from Dynamic Simulation and Finite Element Analysis (FEA) for Inventor Professional 2015. The selection of materials that have been taken into account are chose regarding to their cost and the ability to be processed by using existing equipment.

4.4.1 Static Result Summary for Aluminium with 5mm Thickness.

Table 4.1: Static Result Summary

Name		Minimum	Maximum
Displacement		0.000 mm	5970.884 mm
Forces	Fx	-92088.119 N	92066.430 N
	Fy	-42019.221 N	68690.311 N
	Fz	-63166.360 N	90581.141 N
Moments	Mx	-5786953.783 N mm	4056958.900 N mm
	My	-2230302.757 N mm	4070782.983 N mm
	Mz	-1201494.239 N mm	1201489.630 N mm
Normal Stresses	Smax	-536.574 MPa	66581.824 MPa
	Smin	-69072.194 MPa	-5.060 MPa
	Smax(Mx)	0.001 MPa	67815.865 MPa
	Smin(Mx)	-67815.865 MPa	-0.001 MPa
	Smax(My)	0.000 MPa	47704.488 MPa
	Smin(My)	-47704.488 MPa	-0.000 MPa
	Saxial	-1415.330 MPa	986.974 MPa
Shear Stresses	Tx	-2157.807 MPa	2158.315 MPa
	Ty	-1609.929 MPa	984.825 MPa
Torsional Stresses	T	-11265.021 MPa	11265.065 MPa

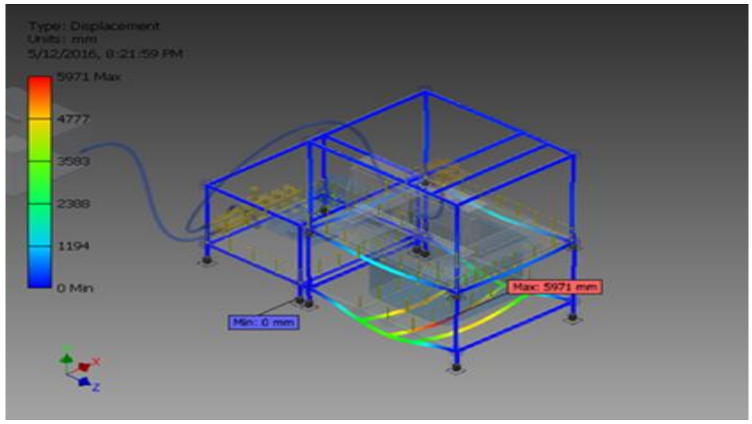


Figure 4.12: Effect on displacement when 797 N (maximum load) is applied.

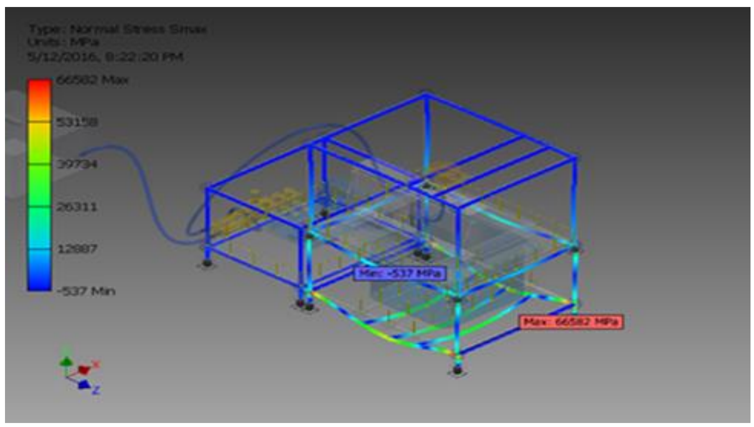


Figure 4.13: Normal Stress Distribution when 797 N (maximum load) is applied

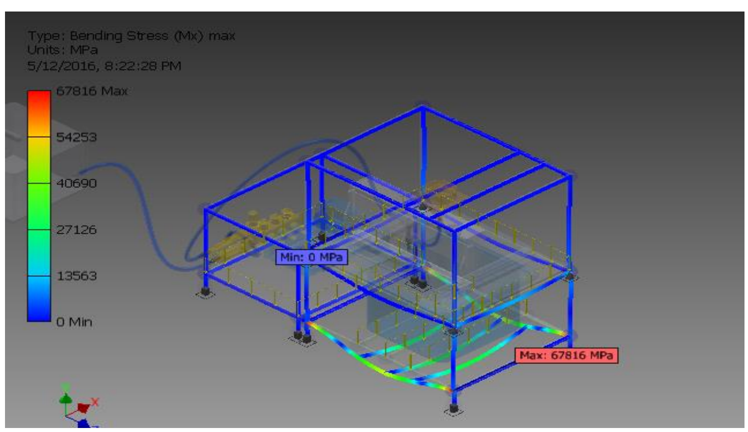


Figure 4.14: Bending Stress Distribution when 797 N (maximum load) is applied

The Frame Analysis modal for the structure is created. The material properties of AISI 1018 Aluminium 6061 with 5 mm thickness is defined and added into engineering data as new material. Force is applied with maximum load 797 N. Next, the simulation solution is added into the project model. Once the calculation is completed, the Frame Analysis postprocessor gain stress distribution output which are in form of displacement output and von misses stress. From the figure the orange region is highest load can be applied while the dark blue region is vice versa. From Figure 4.12 through Figure 4.13 the frame can still support the maximum load applied.

4.4.2 Static Result Summary for Aluminium with 8mm Thickness.

Table 4.2: Static Result Summary

Name		**Minimum**	**Maximum**
Displacement		0.000 mm	5970.884 mm
Forces	Fx	-92088.119 N	92066.430 N
	Fy	-42019.221 N	68690.311 N
	Fz	-63166.360 N	90581.141 N
Moments	Mx	-5786953.783 N mm	4056958.900 N mm
	My	-2230302.757 N mm	4070782.983 N mm
	Mz	-1201494.239 N mm	1201489.630 N mm
Normal Stresses	Smax	-536.574 MPa	66581.824 MPa
	Smin	-69072.194 MPa	-5.060 MPa
	Smax(Mx)	0.001 MPa	67815.865 MPa
	Smin(Mx)	-67815.865 MPa	-0.001 MPa
	Smax(My)	0.000 MPa	47704.488 MPa
	Smin(My)	-47704.488 MPa	-0.000 MPa
	Saxial	-1415.330 MPa	986.974 MPa
Shear Stresses	Tx	-2157.807 MPa	2158.315 MPa
	Ty	-1609.929 MPa	984.825 MPa
Torsional Stresses	T	-11265.021 MPa	11265.065 MPa

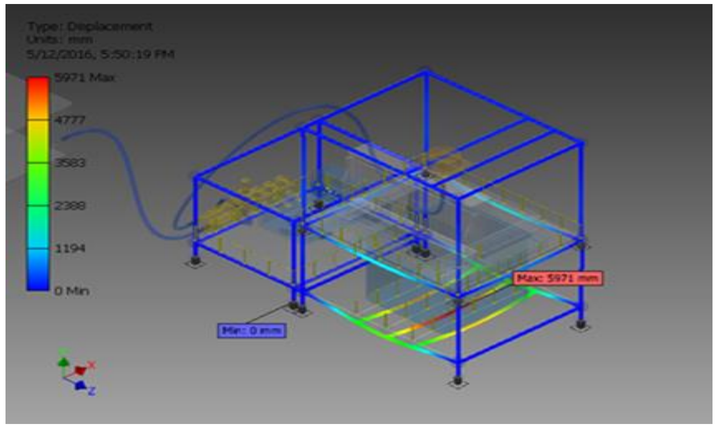


Figure 4.15: Effect on displacement when 797 N (maximum load) is applied

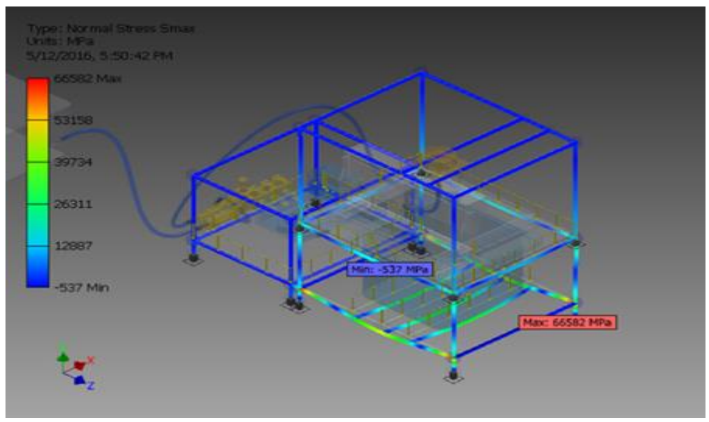


Figure 4.16: Normal Stress Distribution when 797 N (maximum load) is applied

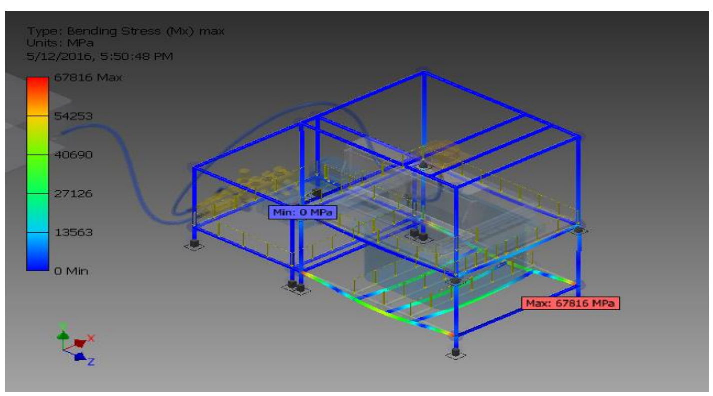


Figure 4.17: Bending Stress Distribution when 797 N (maximum load) is applied

Next the material properties of AISI 1018 Aluminium 6061 with 8 mm thickness is defined and added into engineering data as new material. The same force is applied with maximum load 797 N. Next, the simulation solution is added into the project model. From Figure 4.15 through Figure 4.17 the frame can still support the maximum load applied regarding to the material maximum strength.

4.4.3 Static Result Summary for Aluminium with 12mm Thickness.

Table 4.3: Static Result Summary

Name		Minimum	Maximum
Displacement		0.000 mm	1201.060 mm
Forces	Fx	-90868.220 N	96291.550 N
	Fy	-90868.220 N	96291.550 N
	Fz	-9164.979 N	83887.788 N
Moments	Mx	-4196956.277 N mm	5911773.007 N mm
	My	-4112106.037 N mm	5911773.007 N mm
	Mz	-1207775.057 N mm	1207775.057 N mm
Normal Stresses	Smax	-138.172 MPa	19951.679 MPa
	Smin	-21116.787 MPa	-16.749 MPa
	Smax(Mx)	0.007 MPa	20526.990 MPa
	Smin(Mx)	-20526.990 MPa	-0.007 MPa
	Smax(My)	0.001 MPa	20526.990 MPa
	Smin(My)	-20526.990 MPa	-0.001 MPa
	Saxial	-582.554 MPa	63.646 MPa
Shear Stresses	Tx	-1003.037 MPa	946.544 MPa
	Ty	-1003.037 MPa	946.544 MPa
Torsional Stresses	T	-3355.245 MPa	3355.245 MPa

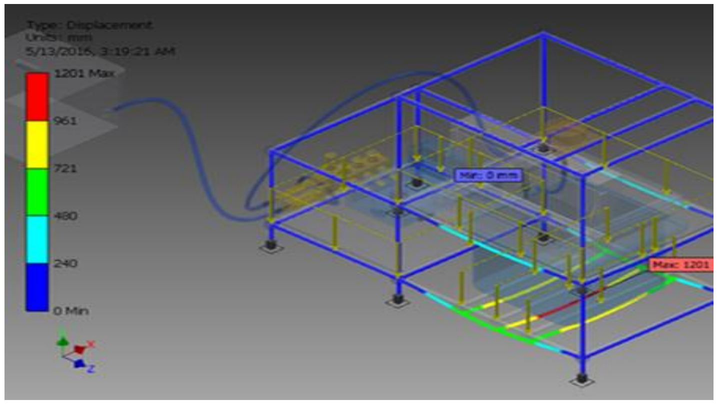


Figure 4.18: Effect on displacement when 797 N (maximum load) is applied

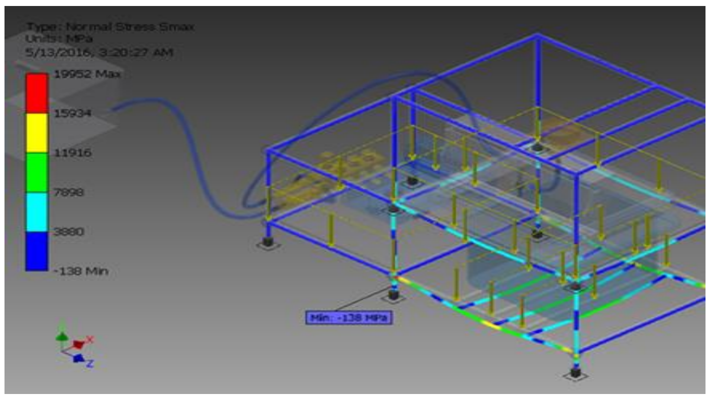


Figure 4.19: Normal Stress Distribution when 797 N (maximum load) is applied

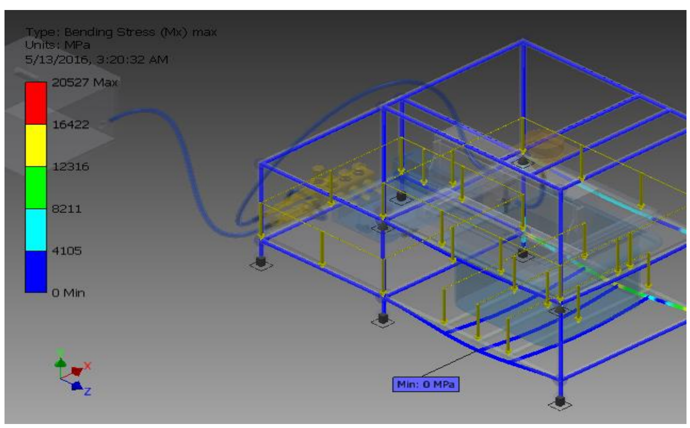


Figure 4.20: Bending Stress Distribution when 797 N (maximum load) is applied

Lastly the material properties of AISI 1018 Aluminium 6061 with 12 mm thickness is defined and added into engineering data as new material. The same force is applied with maximum load 797 N. Next, the simulation solution is added into the project model. From Figure 4.18

through Figure 4.20 the frame can still support the maximum load applied regarding to the material maximum strength.

4.4.4 Static Result Summary for Stainless Steel with 5mm Thickness.

Table 4.4: Static Result Summary

Name		**Minimum**	**Maximum**
Displacement		0.000 mm	2817.016 mm
Forces	Fx	-37967.276 N	73220.852 N
	Fy	-285533.513 N	296470.141 N
	Fz	-71487.597 N	564009.212 N
Moments	Mx	-26538724.033 N mm	18234417.567 N mm
	My	-3394294.028 N mm	5848954.443 N mm
	Mz	-2045772.804 N mm	2235093.135 N mm
Normal Stresses	Smax	-4418.066 MPa	124753.837 MPa
	Smin	-127314.268 MPa	835.465 MPa
	Smax(Mx)	0.045 MPa	124400.269 MPa
	Smin(Mx)	-124400.269 MPa	-0.045 MPa
	Smax(My)	0.553 MPa	87734.317 MPa
	Smin(My)	-87734.317 MPa	-0.553 MPa
	Saxial	-7050.115 MPa	893.595 MPa
Shear Stresses	Tx	-1372.891 MPa	711.886 MPa
	Ty	-5558.815 MPa	5353.753 MPa
Torsional Stresses	T	-20654.892 MPa	18905.349 MPa

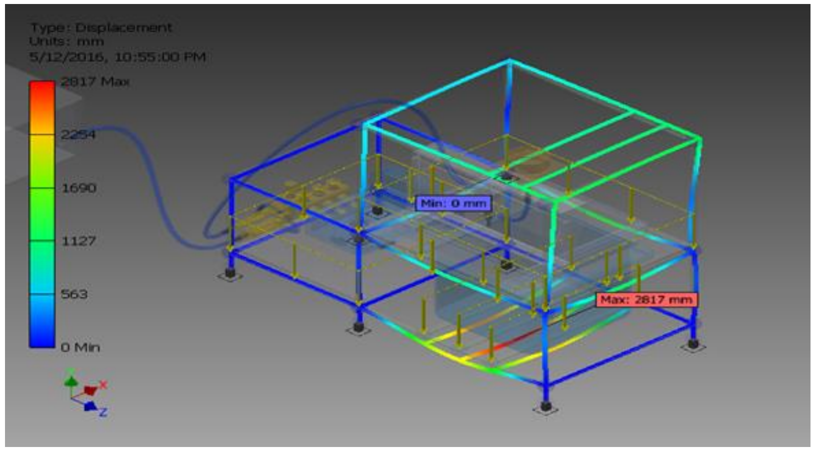


Figure 4.21: Effect on displacement when 797 N (maximum load) is applied

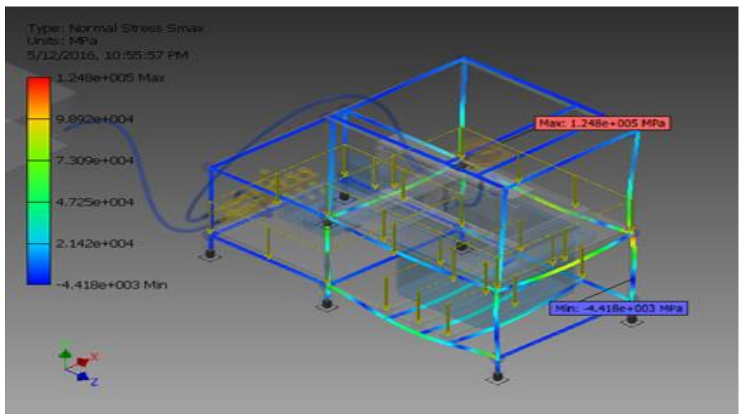


Figure 2.22: Normal Stress Distribution when 797 N (maximum load) is applied

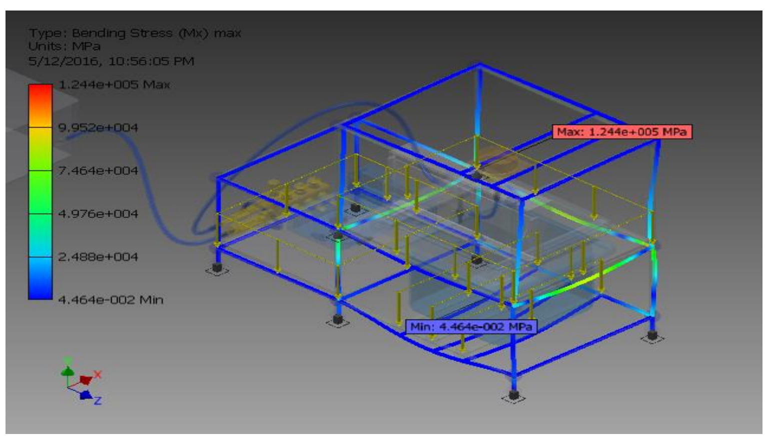


Figure 2.23: Bending Stress Distribution when 797 N (maximum load) is applied

After that the material properties of AISI 1018 Stainless Steel is proceed with 5 mm thickness is defined and added into engineering data as new material. The same force is applied with maximum load 797 N. Next, the simulation solution is added into the project model. From

Figure 4.21 through Figure 4.23 the frame can still support the maximum load applied regarding to the material maximum strength.

4.4.5 Static Result Summary for Stainless Steel with 8mm Thickness.

Table 4.5: Static Result Summary

Name		**Minimum**	**Maximum**
Displacement		0.000 mm	5970.884 mm
Forces	Fx	-92088.119 N	92066.430 N
	Fy	-42019.221 N	68690.311 N
	Fz	-63166.360 N	90581.141 N
Moments	Mx	-5786953.783 N mm	4056958.900 N mm
	My	-2230302.757 N mm	4070782.983 N mm
	Mz	-1201494.239 N mm	1201489.630 N mm
Normal Stresses	Smax	-536.574 MPa	66581.824 MPa
	Smin	-69072.194 MPa	-5.060 MPa
	Smax(Mx)	0.001 MPa	67815.865 MPa
	Smin(Mx)	-67815.865 MPa	-0.001 MPa
	Smax(My)	0.000 MPa	47704.488 MPa
	Smin(My)	-47704.488 MPa	-0.000 MPa
	Saxial	-1415.330 MPa	986.974 MPa
Shear Stresses	Tx	-2157.807 MPa	2158.315 MPa
	Ty	-1609.929 MPa	984.825 MPa
Torsional Stresses	T	-11265.021 MPa	11265.065 MPa

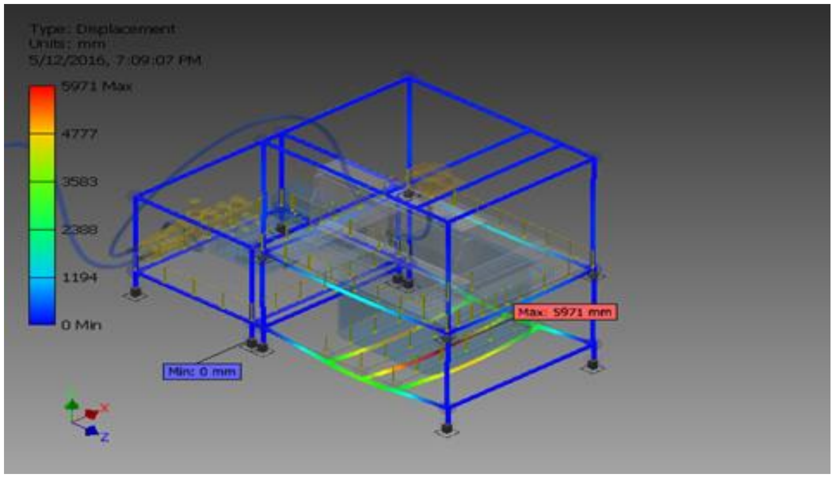


Figure 2.24: Effect on displacement when 797 N (maximum load) is applied

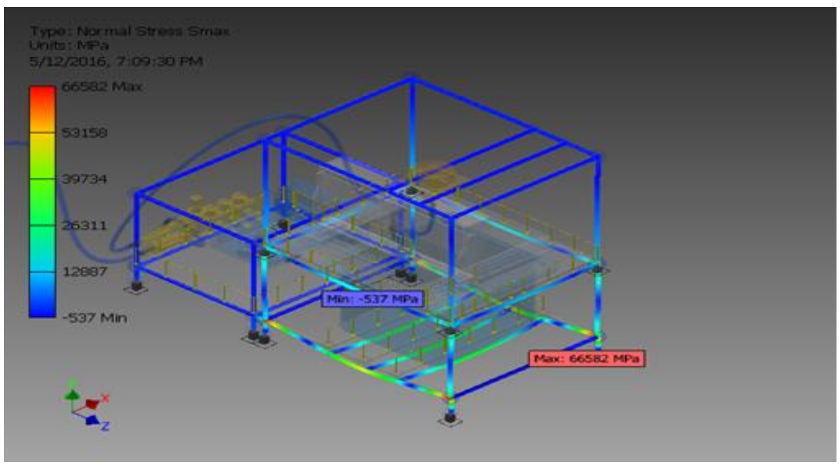


Figure 2.25: Normal Stress Distribution when 797 N (maximum load) is applied

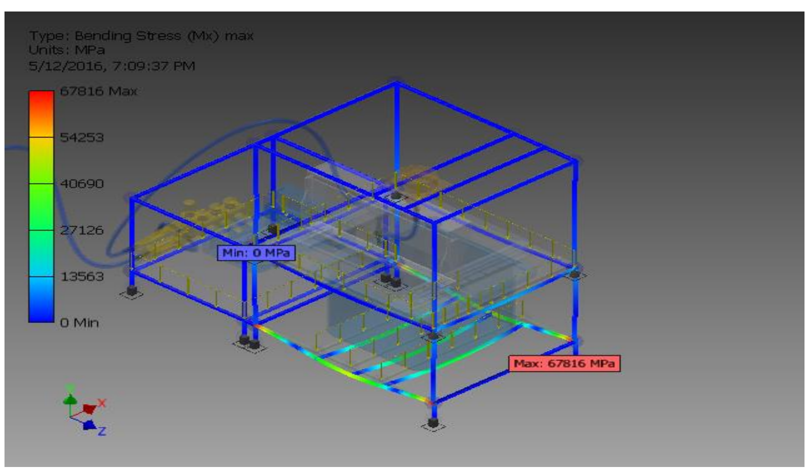


Figure 2.26: Bending Stress Distribution when 797 N (maximum load) is applied

Next the material properties of AISI 1018 Stainless Steel is proceed with 8 mm thickness is defined and added into engineering data as new material. The same force is applied with maximum load 797 N. Next, the simulation solution is added into the project model. From Figure 4.24 through Figure 4.26 the frame can still support the maximum load applied regarding to the material maximum strength.

4.4.6 Static Result Summary for Stainless Steel with 12mm Thickness.

Table 4.6: Static Result Summary

Name		**Minimum**	**Maximum**
Displacement		0.000 mm	427.883 mm
Forces	Fx	-96300.880 N	96300.880 N
	Fy	-24776.007 N	25137.070 N
	Fz	-9167.672 N	83896.390 N
Moments	Mx	-2258494.216 N mm	1425216.717 N mm
	My	-4197365.388 N mm	5912306.822 N mm
	Mz	-1225433.628 N mm	1225433.628 N mm
Normal Stresses	Smax	-136.325 MPa	19953.768 MPa
	Smin	-21118.995 MPa	-16.620 MPa
	Smax(Mx)	0.004 MPa	7841.994 MPa
	Smin(Mx)	-7841.994 MPa	-0.004 MPa
	Smax(My)	0.000 MPa	20528.843 MPa
	Smin(My)	-20528.843 MPa	-0.000 MPa
	Saxial	-582.614 MPa	63.664 MPa
Shear Stresses	Tx	-1003.134 MPa	1003.134 MPa
	Ty	-261.844 MPa	258.083 MPa
Torsional Stresses	T	-3404.301 MPa	3404.301 MPa

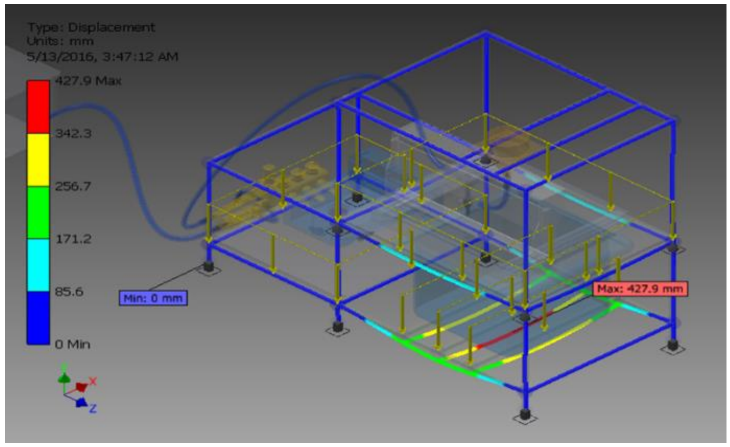


Figure 4. 27: Effect on displacement when 797 N (maximum load) is applied

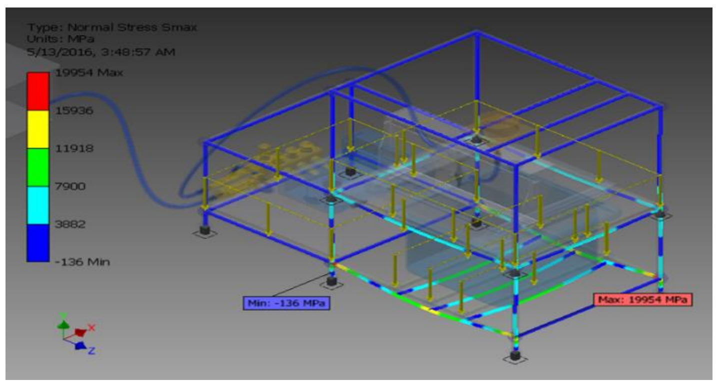


Figure 4.28: Normal Stress Distribution when 797 N (maximum load) is applied

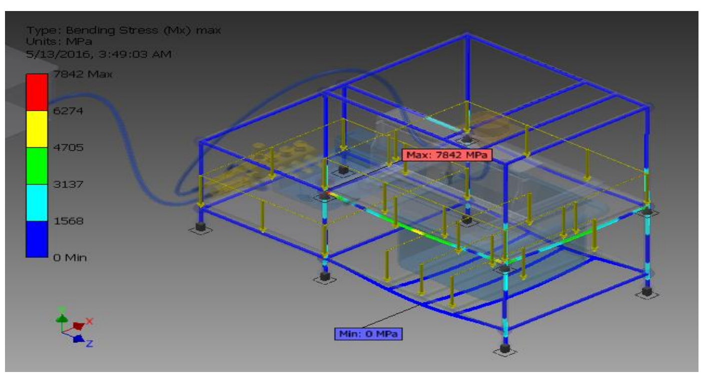


Figure 4.29: Bending Stress Distribution when 797 N (maximum load) is applied

Lastly for Stainless Steel the material properties of AISI 1018 is proceed with 12 mm thickness is defined and added into engineering data as new material. The same force is applied with maximum load 797 N. Next, the simulation solution is added into the project model. From Figure 4.27 through Figure 4.29 the frame can still support the maximum load applied regarding to the material maximum strength.

4.4.7 Static Result Summary for Concrete with 5mm Thickness.

Table 4.7: Static Result Summary

Name		**Minimum**	**Maximum**
Displacement		0.000 mm	2817.016 mm
Forces	Fx	-37967.276 N	73220.852 N
	Fy	-285533.513 N	296470.141 N
	Fz	-71487.597 N	564009.212 N
Moments	Mx	-26538724.033 N mm	18234417.567 N mm
	My	-3394294.028 N mm	5848954.443 N mm
	Mz	-2045772.804 N mm	2235093.135 N mm
Normal Stresses	Smax	-4418.066 MPa	124753.837 MPa
	Smin	-127314.268 MPa	835.465 MPa
	Smax(Mx)	0.045 MPa	124400.269 MPa
	Smin(Mx)	-124400.269 MPa	-0.045 MPa
	Smax(My)	0.553 MPa	87734.317 MPa
	Smin(My)	-87734.317 MPa	-0.553 MPa
	Saxial	-7050.115 MPa	893.595 MPa
Shear Stresses	Tx	-1372.891 MPa	711.886 MPa
	Ty	-5558.815 MPa	5353.753 MPa
Torsional Stresses	T	-20654.892 MPa	18905.349 MPa

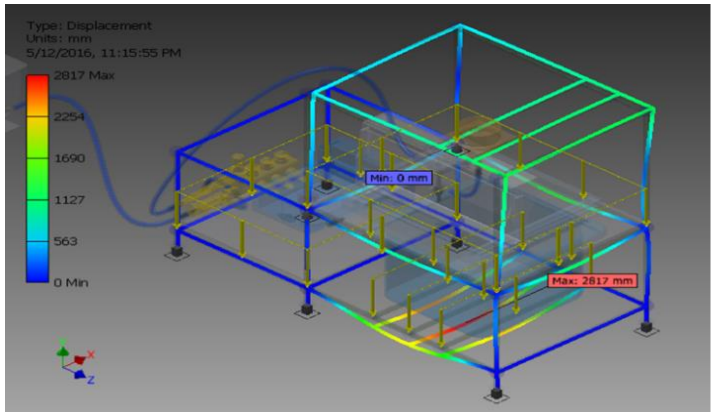


Figure 4.30: Effect on displacement when 797 N (maximum load) is applied

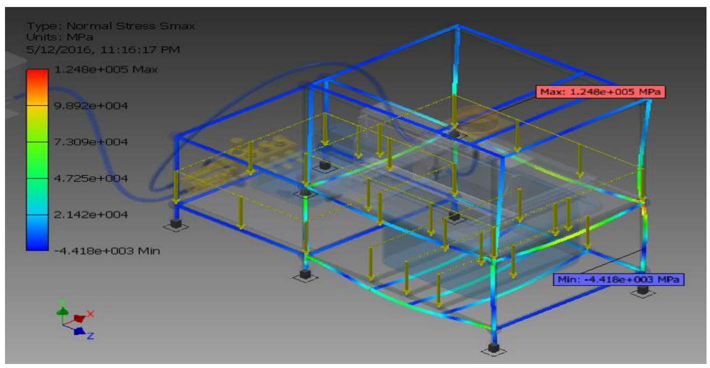


Figure 4.31: Normal Stress Distribution when 797 N (maximum load) is applied

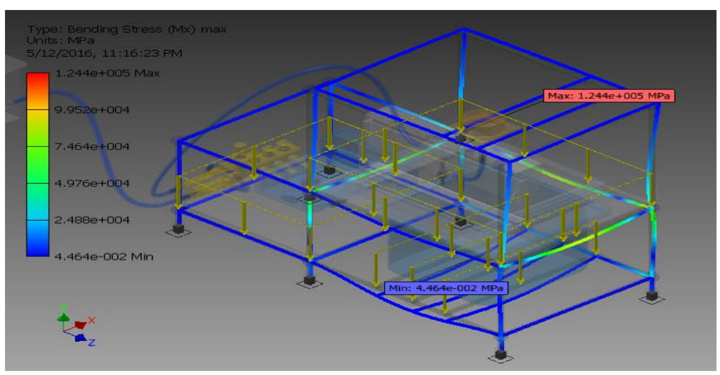


Figure 4.32: Bending Stress Distribution when 797 N (maximum load) is applied

For the last material selection, concrete is added as the material properties of AISI 1018 with 5 mm thickness is defined and added into engineering data as new material. The same force is applied with maximum load 797 N. Next, the simulation solution is added into the project model. From Figure 4.30 through Figure 4.32 the frame can still support the maximum load applied regarding to the material maximum strength.

4.4.8 Static Result Summary for Concrete with 8mm Thickness.

Table 4.8: Static Result Summary

Name		**Minimum**	**Maximum**
Displacement		0.000 mm	5970.884 mm
Forces	Fx	-92088.119 N	92066.430 N
	Fy	-42019.221 N	68690.311 N
	Fz	-63166.360 N	90581.141 N
Moments	Mx	-5786953.783 N mm	4056958.900 N mm
	My	-2230302.757 N mm	4070782.983 N mm
	Mz	-1201494.239 N mm	1201489.630 N mm
Normal Stresses	Smax	-536.574 MPa	66581.824 MPa
	Smin	-69072.194 MPa	-5.060 MPa
	Smax(Mx)	0.001 MPa	67815.865 MPa
	Smin(Mx)	-67815.865 MPa	-0.001 MPa
	Smax(My)	0.000 MPa	47704.488 MPa
	Smin(My)	-47704.488 MPa	-0.000 MPa
	Saxial	-1415.330 MPa	986.974 MPa
Shear Stresses	Tx	-2157.807 MPa	2158.315 MPa
	Ty	-1609.929 MPa	984.825 MPa
Torsional Stresses	T	-11265.021 MPa	11265.065 MPa

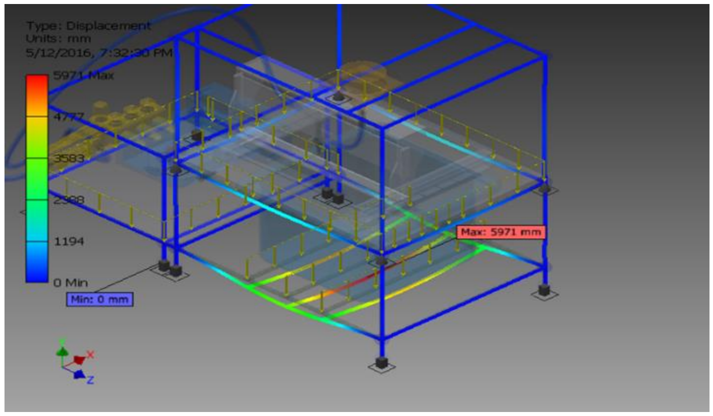


Figure 4.33: Effect on displacement when 797 N (maximum load) is applied

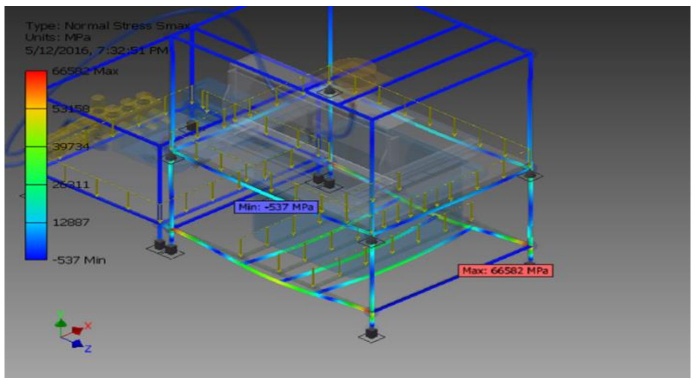


Figure 4.34: Normal Stress Distribution when 797 N (maximum load) is applied

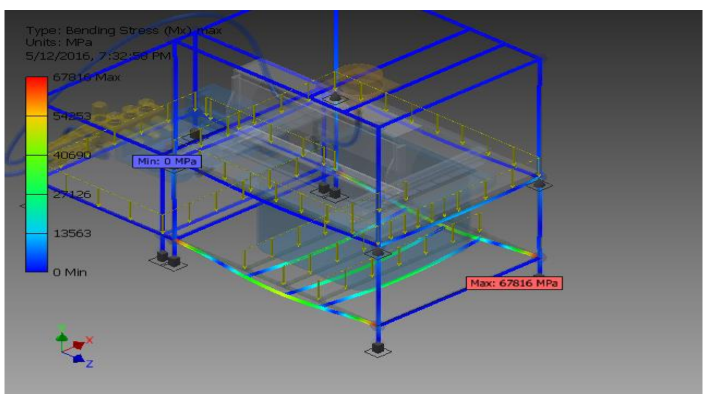


Figure 4.35: Bending Stress Distribution when 797 N (maximum load) is applied

Next 8 mm Concrete is added as the material properties of AISI 1018 and defined into engineering data as new material. The same force is applied with maximum load 797 N. Next, the simulation solution is added into the project model. From Figure 4.33 through Figure 4.35 the frame can still support the maximum load applied regarding to the material maximum strength.

4.4.9 Static Result Summary for Concrete with 12mm Thickness.

Table 4.9: Static Result Summary

Name		Minimum	Maximum
Displacement		0.000 mm	3514.494 mm
Forces	Fx	-96291.035 N	96291.035 N
	Fy	-90867.761 N	25134.703 N
	Fz	-9164.831 N	83887.313 N
Moments	Mx	-1837164.748 N mm	3614900.925 N mm
	My	-4112086.791 N mm	5911743.528 N mm
	Mz	-1310058.644 N mm	1310058.644 N mm
Normal Stresses	Smax	-128.711 MPa	19953.334 MPa
	Smin	-21118.435 MPa	-16.790 MPa
	Smax(Mx)	0.012 MPa	12551.739 MPa
	Smin(Mx)	-12551.739 MPa	-0.012 MPa
	Smax(My)	0.000 MPa	20526.887 MPa
	Smin(My)	-20526.887 MPa	-0.000 MPa
	Saxial	-582.551 MPa	63.645 MPa
Shear Stresses	Tx	-1003.032 MPa	1003.032 MPa
	Ty	-261.820 MPa	946.539 MPa
Torsional Stresses	T	-3639.393 MPa	3639.393 MPa

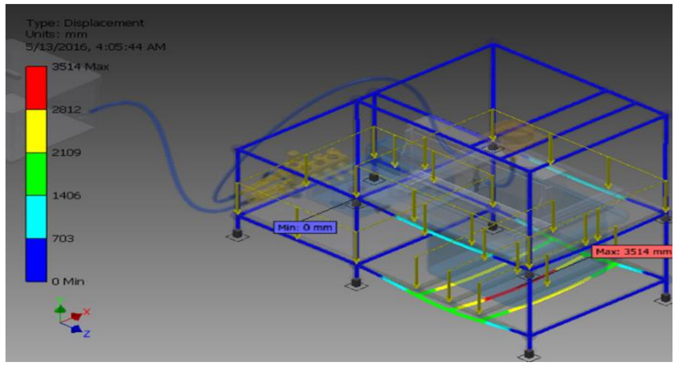


Figure 4.36: Effect on displacement when 797 N (maximum load) is applied

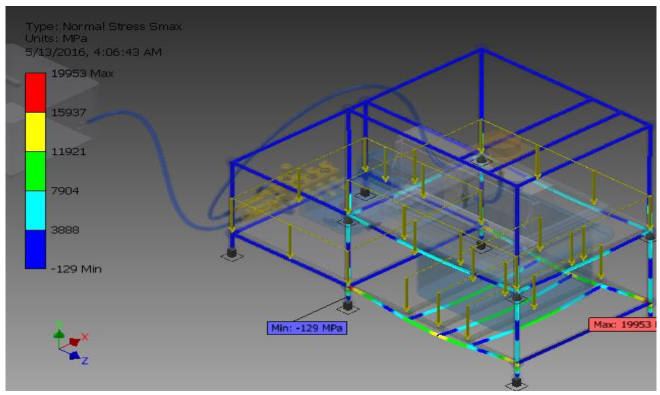


Figure 4.37: Normal Stress Distribution when 797 N (maximum load) is applied

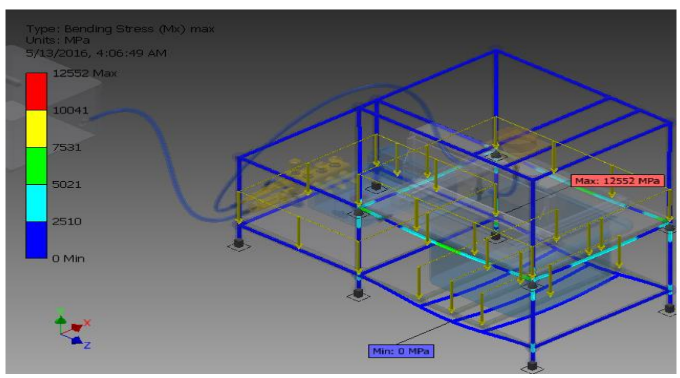


Figure 4.38: Bending Stress Distribution when 797 N (maximum load) is applied

Lastly 12 mm Concrete is added as the material properties of AISI 1018 and defined into engineering data as new material. The same force is applied with maximum load 797 N. Next, the simulation solution is added into the project model. From Figure 4.36 through Figure 4.38 the frame can still support the maximum load applied regarding to the material maximum strength. Overall analysis shows that each material with designated thickness can support maximum loads applied to the beams. While for elongation from displacement analysis result, most of the beams show highest elongation region.

4.5 COST

Cost for materials selection is important to determine which materials for frame can reduce the cost to develop waterjet machine.

Total dimensions = 1007 mm x 490 mm x 743mm

	Beams
724 mm x 12 mm x 12 mm	4 x 2
336 mm x 12 mm x 12 mm	8 x 2
400 mm x 12 mm x 12 mm	8 x 2
460 mm x 12 mm x 12 mm	5 x 2
Total	50

Materials required = 2(1920 mm x 2500 mm)

Roughly the size of the plate/sheet metals is about 1920 mm x 2500 mm. As the quantity of the beams require are twice each, the amount of materials needed is doubled.

Table 4.10: Cost for Aluminium 6061 (Flat bars)

Thickness of Aluminium sheet/plate	Price per unit	Quantity (pcs)	Total
1000 mm x 1225 mm x 12 mm	RM335.52	5	RM1677.60
1000 mm x 1000 mm x 5 mm	RM380.40	8	RM3043.20
1000 mm x 1000 mm x 8 mm	RM380.40	8	RM3043.20

Table 4.11: Cost for Stainless Steel (Flat bars)

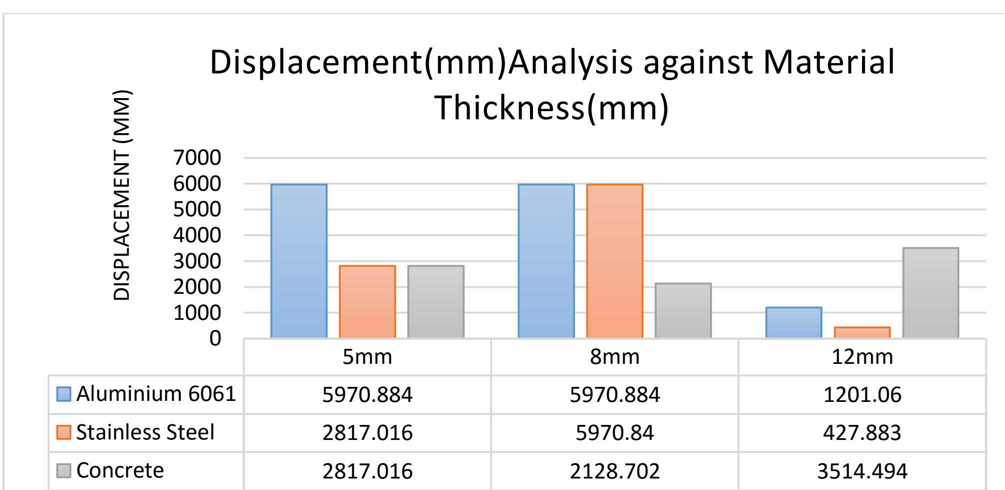
Thickness of Stainless Steel sheet/plate	Price per unit	Quantity (pcs)	Total
1000 mm x 1225 mm x 12 mm	RM277.26	5	RM1386.30
600 mm x 1800 mm x 5 mm	RM327.27	12	RM3927.24
200 mm x 1450 mm x 8 mm	RM327.27	14	RM4581.78

Table 4.12: Cost for Epoxy Concrete (Round bars)

Term	Price per unit	Quantity	Total
Cement (50 kg)	RM16.00	1 bag	RM16.00
Graded sand	RM40.00	1 yard	RM40.00
Fine sand	RM45.00	1 yard	RM45.00
Acrylic-epoxy coating	RM186.64	2 litres	RM373.28
		Total	RM474.28

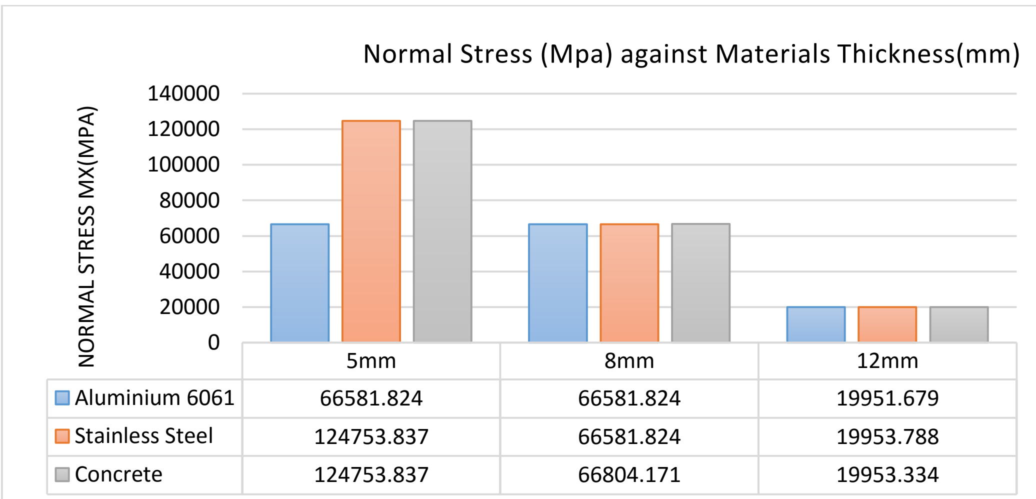
4.6 DISCUSSION

It is common preparation to use approximate solutions of differential equations as the basis for frame analysis. This has been usually done using numerical approximation techniques and the most commonly used numerical approximation in frame analysis is finite element method. While stress analysis is to determine the stresses in materials and structures subjected to forces and loads. For this waterjet machine frame, the weight distribution among beams of the frame is at its maximum amount and constant. The total load of 797 N has been applied to the beams where 62N is distribute among beams that support water pump. While 343N is a total load for router and 392 N is a load has been distributed for been that support catch tank. Then, the stress distribution was used to identify the high stress region for introduction of the initial crack. The total deformation, stress and strain distribution for both loads are compared. The result for materials has been compared in the form of graph.



Graph 4.1: Displacement (mm) Analysis against Material Thickness (mm)

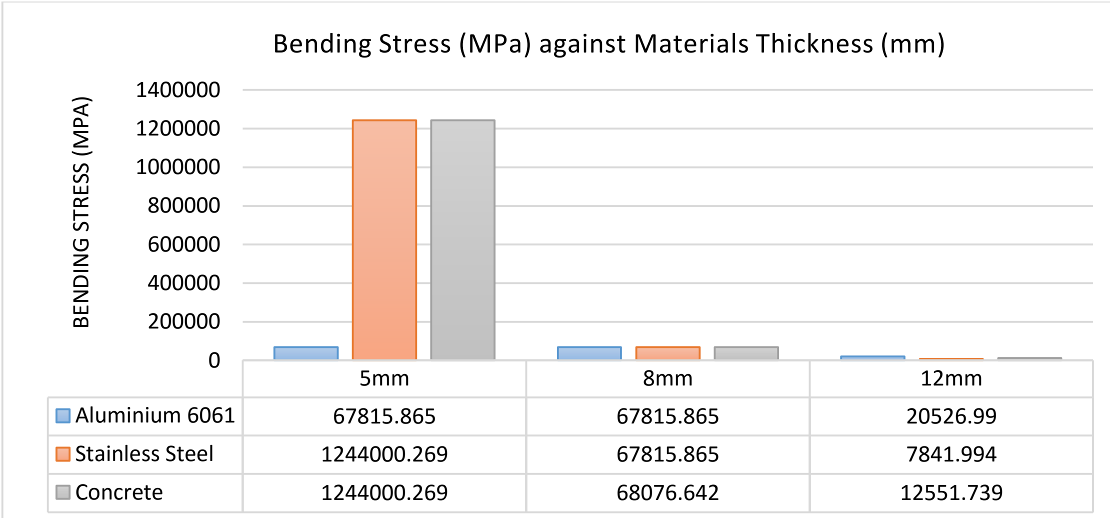
Graph 4.1 shows the result for frame analysis for Aluminium, Stainless Steel and Concrete with thickness 5mm, 8mm and 12mm. The computation of displacement analysis, which contribute to the flexibility of materials has been figured out. The numbers show the maximum value of each materials and certain thickness. The smallest amount of displacement indicates the higher stiffness of materials which is best to select. Thus regarding to displacement analysis Stainless Steel with 12mm in thickness shows the best result hence it is selected to be considered.



	5mm	8mm	12mm
Aluminium 6061	66581.824	66581.824	19951.679
Stainless Steel	124753.837	66581.824	19953.788
Concrete	124753.837	66804.171	19953.334

Graph 4.2: Normal Stress (Mpa) against Materials Thickness (mm)

Next Graph 4.2 shows the computation of stress analysis on different types of materials on different thickness for the maximum allowable stress. The maximum allowable stress means that it is the highest stress applied to the red region under the same load applied and the minimum stress for different loads applied is constant which is in the blue regions. This concluded that higher load applied, the higher the maximum stress construct of the stress distribution. From the results the lowest maximum value of normal stress resulting from the same loads shows the better for the material to withstand a great amount of loads. The wider the area the greater the strength of materials thus 12mm of Aluminium, Stainless Steel and Concrete are taken into consideration.



Graph 4.3: Bending Stress (MPa) against Materials Thickness (mm)

From Graph 4.3 to determine the adequacy of the frames, when a member of the frame is being loaded a bending stress (or flexure stress) will result. The analysis used to identify where the greatest amount of bending takes place. From the graph the 12mm of materials shows the lowest amount of bending in a frame thus shows the better result of the materials strength. Hence, 12mm of Aluminium, Stainless Steel and Concrete are taken into consideration.

Table 4.13: Decision list of material for frame for waterjet machine

Alternative Materials	Compatible with the definition of the task	Requirement of the req. list fulfilled	Chance to realize it	No additional effort	Lower Cost of Material	Easy to realize with the use machine in the laboratory	Notes	Decision
Concrete	+	+	?	-	+	?	Mold means additional effort; quite difficult to realize regarding the construction of the frame.	-
Aluminium 6061	+	+	+	?	+	+	Additional work after every test.	+
Stainless Steel	+	+	+	?	+	+	Easier for construction.	+

The left column contains the alternatives materials. Next to that column, criteria for the decision making are listed where it meets the criteria from the requirement list. Some of these criteria should be used for every possible solution. Those are the fulfillment of the requirements in the requirements list, the chance of its realization and the effort to realize it. The '+' sign shows that materials has fulfilled the criterion, '-'is vice versa and '?' means it is cannot be predicted. From the cost decision making, even though concrete has resulted in lower cost but it will need more work to do it where it will increase the cost even more. From the analysis and decision list, a 12mm Stainless Steel is chosen. The definition of easier for construction tells the capability to produce by using the equipment provided to construct the machine are present and the raw cost for steel is RM1386.30 is the lowest amongst others.

CHAPTER 5

CONCLUSION AND RECOMMENDTION

5.1 INTRODUCTION

Through this chapter, the summarization for the whole project will be concluded. Improvement on research methodology can be done as some recommendation will be write up next.

5.2 CONCLUSION

In conclusion, all the objectives for the "Development of Miniature Waterjet Machine" has achieved. The main purpose of this project is to develop a machine in miniature size. As the further realization of development of waterjet machine needed longer time inclusive purchasing and developing, the waterjet machine has been developed in virtual form. Through this project, the waterjet machine has been successfully presented in 3D modelling including its detailing for dimension and costing.

First and foremost, the first objective of developing waterjet cuter is to the machine in smaller size as the term of miniature is mentioned in the title. Firstly the function structure of waterjet is developed first. After that to determine the size for the whole machine, a study on types of router with its size has taken into account. The waterjet machine firstly is drawn in sketches. With exact dimension of 1007mm x 490mm x 743mm, the waterjet machine has been translated into 3D modelling with addition of specific materials. While the total raw cost for this project is RM. Hence the second objective is achieved which is to developed a miniature waterjet machine with reduce minimize cost.

Above all, as the waterjet machine is developed virtually, the title of this project has been modified into "Virtual Development of Miniature Waterjet Machine". By the information from this research, this project can be reduce by using other method for costing study and analysis.

5.3 RECOMMENDATION

There are always rooms for further improvements for every study and researches that has been done. For further improvement, there are several suggestions that could be implanted when running this project next time:

a) The next researches can use ANSYS WORKBENCH 16.0 for analysis where they can use structural analysis on waterjet frame. The load applied will be automatically distributes accurately rather that frame analysis where the load distribution are define by the user.
b) The study on factor of safety is included so that we know the durability and capability of the elements.

REFERENCE

Ahmadi, R., Roemer, T. a., & Wang, R. H. (2001). Structuring product development processes. *European Journal of Operational Research*, *130*(3), 539–558. http://doi.org/10.1016/S0377-2217(99)00412-9

Folkes, J. (2009). Waterjet-An innovative tool for manufacturing. *Journal of Materials Processing Technology*, *209*(20), 6181–6189. http://doi.org/10.1016/j.jmatprotec.2009.05.025

Griffin, A. (1997). Modeling and measuring product development cycle time across industries. *Journal of Engineering and Technology Management*, *14*(1), 1–24. http://doi.org/10.1016/S0923-4748(97)00004-0

Hace, A., & Jezernik, K. (2004). Control system for the waterjet cutting machine. *IEEE/ASME Transactions on Mechatronics*, *9*(4), 627–635. http://doi.org/10.1109/TMECH.2004.839045

HAIK, Yousef (2003). Engineering Design Process. United State of America, USA: Bill Stenquist

Hashish, M., Steelers, D. E., & Bothelli, D. H. (1997). MACHINING WITH SUPER-PRESSURE (690 MPa) WATERJETS. *Int. J. Math. Tools Manufact*, *37*(4), 46–479.

Krishnan, V; Ulrich, K,T: Product development decision- A review of the literature. Management Science, Pages 1-21, Januanry 1, 2001.

Kulekci, M. K. (2002). Processes and apparatus developments in industrial waterjet applications. *International Journal of Machine Tools and Manufacture*, *42*(12), 1297–1306. http://doi.org/10.1016/S0890-6955(02)00069-X

Mehta, J. N., Wadgaokar, R., Khatal, a, & Chavan, M. (2013). Working Model of Water Jet Cutting System on Low, *1*(April).

Pahl, G; Beitz,W;Feldhusen,J;Grote,K,H (2007). Engineering Design: A Systematic Approach-3rd edition. London : Springer.

Smith, R. P., & Morrow, J. a. (1999). Product development process modeling. *Design Studies*, *20*(3), 237–261. http://doi.org/10.1016/S0142-694X(98)00018-0

Ulrich, K,T; Eppinger, S,D (2004): Product Design and Development Fifth Edition. Boston, MA: McGraw-Hill/Irwin.

Vdi. (2004). Methodisches Entwerfen technischer Produkte Systematic embodiment design of technical products VDI 2223, (Januar).