Design of Modular Fixture for CNC Machining Center

By

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CERTIFICATION OF APPROVAL

Of Research Project

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MOHD ZUL AKMAL BIN ZAINAL ABIDIN

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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.

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ABSTRACT

The current practice of clamping workpiece for Mazak Variaxis 630 5x II is impractical since different clamping component or fixture was installed repeatedly such as jaw chuck and movable vise to clamp different shape of the workpiece. This practice has increase the setup time of the machine as it covers installing and uninstalling of the fixture. Therefore, in order to reduce the setup time of the machine, a new fixture need be designed to clamp variable shapes and dimensions of the workpiece using the same fixture. Thus, this project objective is to design a fixture with higher flexibility namely modular fixture where it suits with this kind of situation. The first step in designing a fixture was to determine the shapes and dimensions of the workpiece. Then, the external forces were calculated where the cutting force and cutting torque were determined. After external forces are evaluated, the planning to position the equipment such as locator, support and clamps were performed. After fixture planning was done, the design concept was generated by using several methods such as conceptual decomposition, functional decomposition, morphological chart, and lastly Pugh's concept selection to select the best and practical concept. The design was then analyzed especially the clamping force of the clamps. The final phase of this project was to select the required material followed by the final assembly and detailed drawings of each component of the modular fixture. From the analysis performed, it is proven that the developed design is capable to withstand the external forces acting on the fixture.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

A fixture is a device for holding and supporting a workpiece during a manufacturing process. Fixtures are important elements of production processes as they are the reasons for most of the automated manufacturing, inspection and assembly process can be conducted. Fixtures must correctly locate a workpiece in a given position where it should not disturbed the movement of the cutting tools or other devices. This locations must be varied so that the clamp can secure the workpiece in that location for the particular manufacturing operation.

Despite many advancements and changes in cutting tools and production methods, the basice requirement of holding the workpiece has remained the same [Hoffman, 2004]. Every part produced must be constrained its movement while being machined, jointed, or inspected. Thus, whether the operation requires a simple drill press, a multiple-axes computer, or numerically controlled machining center, the workpiece must be accurately located and securely held thorought the operation.

The main purpose of fixture are [Henriksen,1973]:

1. To locate the workpiece quickly and accurately, support it properly, and hold it securely thereby ensuring all parts produced in the same fixture will come out alike within specific limits.
2. Reduce working time in various phases of operation, in the setup and clamping of the work, in adjustment of cutting tool to the required dimensions and during cutting operation itself by allowing heavier feeds due to efficient work support.
3. It serves to simplify complicated operations so that cheaper and unskilled labor may be employed to perform operations previously reserved for skilled mechanics.

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1.2 Problem Statement

Computer Numerical Control (CNC) machining center is a machine that used to perform variable processes such as milling, turning, drilling, etc. To machine a workpiece, CNC machining center needs a fixture to locate, support and hold the workpiece which can be intsalled on the machine bed. There are many type of fixture device have been developed to satisty the manufacturing needs for CNC machining center such as jaw chucks, machine vises, drill chucks, collets, etc.

These fixture have been used for a long time to maintain to the productivity of the CNC machine. However, the current practice using these standard fixtures require setup time where they need to be changed according to the workpiece that need to be machined. For example, vises used to hold a rectangular workpiece during machining then later the vises needs to be uninstalled and replaced by a jaw chuck where the cylindrical workpiece need to be machine next.

This situation will affect the productivity of the machine since the setup time covers the installing and uninstalling of the fixture, resetting the datum of the cutting tool and also loading and unloading the workpiece of the fixture. This will slower the machining process if the workpiece has variable shapes and reduce the productivity of the operator due to higher setup time.

In order to reduce setup time, an appropriate fixture should be made available where it can hold variable shapes of the workpiece. Therefore, a multi-functional fixture should be designed which able to hold rectangular workpieces with variable thickness and also be able to clamp rounded workpieces with variable diameter. The fixture will be able to assist the operator to speed up the machining rates of the CNC machine.

1.3 Objective

To design a modular fixture to clamp variable workpieces for CNC machining center for vertical milling process in order to reduce the setup time of the whole operations.

1.4 Scope of Study

The scope for this project is mainly focussing on developing modular fixture for vertical machining process. The shape of workpieces that can be clamped by this fixture are rectangular, and cylindrical with varible thicknesess and diameters.

1.5 The Relevance of the Project

As a future mechanical engineer, conducting this project will give more understanding in designing process of fixture and study its importance to the manufacturing industry. Take for example of UTP manufacturing lab, the fixtures used were still the common fixtures and it also have time lagging due to variable shapes of workpiece requested which resulted many fixtures need to be used.

1.6 The Feasibility of The Project

This project will use current the current configurations of Mazak Variaxis 630 5x II which located at UTP manufacturing lab at block 16 as a reference to design suitable fixture for this machine . Thus, the project is feasible to be applied in the industry.

CHAPTER 2

LITERATURE REVIEW

This chapter gives an overview of literature review in field of Computer Aided Fixture Design (CAFD), modular fixture, important elements in modular fixture design, Mazak Variaxis 630 5x II machine specifications, material selections and tolerances

2.1 Review of Computer Aided Fixture Design

Fixture design is an important design process as it is critical for the used of computer aided design (CAD) and manufacturing (CAM). Fixture design activities in manufacturing can be divided into three major aspects: setup plannig, fixture planning and fixture configuration design. This is followed by fixture design verification activities as seen in Figure 2.1 shown below:
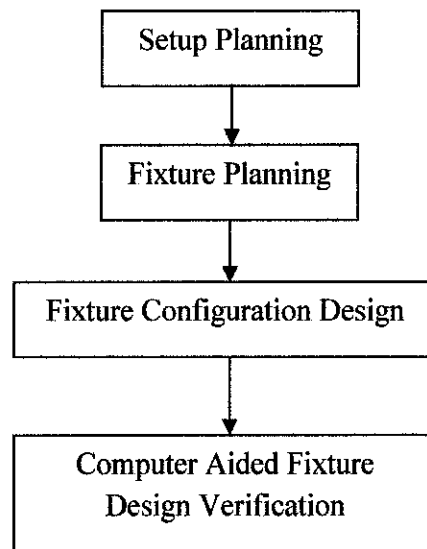
Figure 2.1: Four stages of fixture design [Rong et al., 2003]

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2.2 Modular fixture

History of manufacturing have shown that jigs and fixtures have played important roles in increasing productivity of machined parts. There are two major categories of workholding tool that have been developed over the years which are general purpose workholders and special purpose workholders [Hoffman, 2004]. Evethough both form of fixture covers on every tooling requirements, it is not economically suited for every product. Thus, modular fixturing is invented to fill the gap between general purpose and special purpose fixtures. Modular fixture is a workholding system that uses a series of reusable standard components to build a wide variety of special purpose of workholding devices [Hoffman, 2004]. Modular fixture can be diassembled at the conclusion of the job and reassembled with another job. Modular fixturing system are flexible and consists with a variety of standard fixturing elements such as clamps, locators, base plates etc [Kršulja et al.,2009].

These elements can be assembles without additional machining operations and designed for reused after disassembly. The main advantages of using modular fixtures are their flexibility and the reductions of time and cost to perform its functions. Automation of fixture design is largely based on the concept of modular fixture due to the following characteristics [Andrew Y.C et al.,2004]:

- Predictable and finite number locating and supporting positions which allow heuristics or mathematical search for optimum positions.
- Ease in assembly and disassembly and the potential of automated assembly using robotic devices.
- Relative ease of applying design rules due to the finite number of element combinations.

A typical of modular fixture is shown in Figure 2.2.
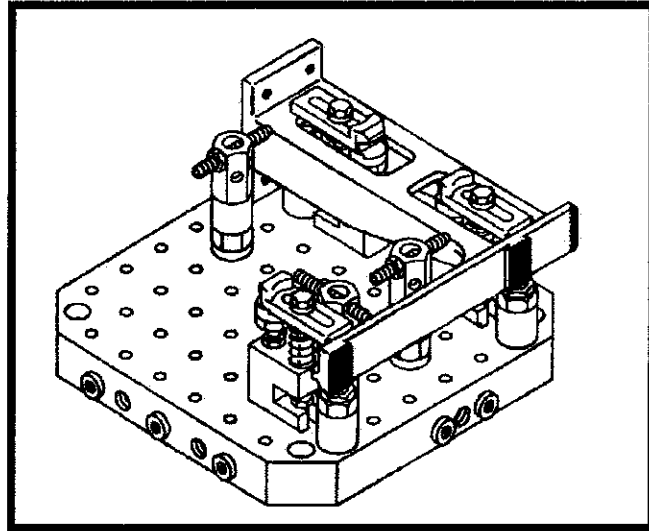
Figure 2.2 : A fixture constructed from modular elements
[Andrew Y.C et al.,2004]

2.3 Elements of Modular Fixture:

2.3.1 Locators

Locators is usually a fixed component of a fixture. It is used to establish and maintain the position of a workpiece in the fixture by constraining its movement . For workpieces of greater variability in shapes and surface conditions, a locator can also be adjustable. [Wang et al., 2001] said that the best fixture with respect to certain performance criterion is constructed by selecting a suitable set of locators such that a significant improvement of the objective-function is registered .

A workpiece is said to be well constrained if the fixture able to constraints all twelve DOFs of the workpiece, six axial degrees of freedom and six radial degree of freedom. Locators are design to hold the workpiece against the cutting force while clamps acts as a support to locators. There are three priciples of locating which are plane, cocentric and radial locating system. Plane locating devices locate a part by its external surfaces. Concentric locators locate a workpiece from a central axis. Radial locators restrict the movement of a workpiece around a concentric areas. Usually, all three locating methods are combined together to locate a workpiece. In applying locator from external surface, supports are the principle devices used for this location. There are three types of supports which are solid, adjustable and equalizing. Solid supports are fixed-height locators meanwhile, adjustable supports

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are variable length locators and equalizing supports are a form of adjustable support used when compensating support is required. Locating from an external workpiece edges is the most common locating method being used [Kršulja et al.,2009].

For planar workpiece, 3-2-1 locating method is commoly used as shown in the Figure 2.3. Primary locating surface is at the bottom with three supports. Based on gemetry principle, three points are needed to fully define a plane. The other two adjacent edges are used to complete the location [Kršulja et al.,2009]. For the secondary and tertiary surface, the face with a larger projected length is used as the secondary plane with two locators and smaller projected is used as tertiary planes with one locator.It is said that, at least three supporting point are required to maintain the stability of the workpiece. These supports must be placed as far as possible such that the mass centre of the workpiece is contained within the triangle formed by three supports. By applying this locating principle, all six degree of freedoms of the workpiece are constrained [Andrew Y.C et al.,2004].
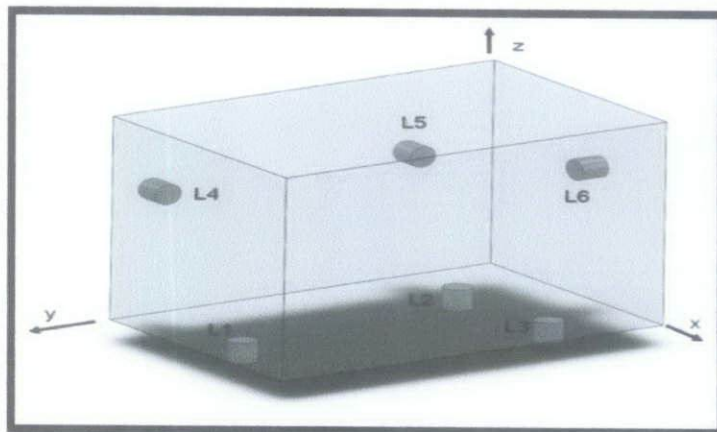
Figure 2.3 : 3-2-1 locating principle

For locating a cylindrical workpiece, vee block is usually used to hold items having a curved outer surface. One vee block, can provide two locating points. If two vee block are used, four locating point is achieved, thus the workpiece can be fully constraint. One advantage of vee locator have than other locators is centralizing feature which the rounded object center point is always placed in the middle of the vee block. It also can locate different diameter of rounded object [Hoffman, 2004].

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2.3.2 Clamps

A clamp is a force actuating mechanism of a fixture. The forces exerted by the clamps hold a part securely in the fixture againts all other external forces. In other words, the process of clamping iduces a locking which, through frictional or some other forms of mechanism, provides a stability of location which cannot be changed until and unless external loading is able to overcome the locking effect. Hence, when a cutting force is producing a load or moment on the workpiece, it is necessary that a sufficient clamping force must be exerted to withstand such actions [Andrew Y.C et al.,2004].

Clamping force is the force required to hold a part againts the locators. Clamping prevents the part from shifting or being pulled from the jig and fixture during the machining operation [Hoffman, 2004]. Clamping forces should be directed towards supporting and locating elements or thin sections of the workpiece. Plus, the force should be transmitted to the rigid sections of the body frame of the fixture [Andrew Y.C et al.,2004]. There are two method of clamping that widely used for holding a workpiece which are top clamp and side clamp. Clamping planning can be summarized as to determined clamping surfaces and points on the workpiece and the clamping components, the magnitude of each clamping force, and the clamping sequence when the stability of workpiece become a concern [Kang, 2009]. It is important that all clamping device should not cause any positional displacement or excessive distortion under the action of the clamping forces.

2.4 Mazak Variaxis 630 5x II

The Variaxis 630-5x II is a built-in tilting rotary table allows to machine workpieces with variables features of parts in small to medium sizes with complex contours that can be finished in a single machine setup. This machine also provide high accuracy and rigidity during machining. Apart from that, with high speed operation up to 12000 rpm, it reduce idle time during machining thus the cycle time is shorter. In this five axis machine tool, X, Y, Z are the linear axis. A axis is the rotational axis around X axis meanwhile C axis is the rotational axis around Z axis [Arda Özgen, 2008].

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Table 2.1 : Mazak variaxis 630-5x II specifications [Arda Özgen, 2008]

Maximum Workpiece Diameter	730 mm
Maximum Workpiece Height	500 mm
X-axis stroke (right and left movement)	630 mm
Y-axis stroke (back and forth movement)	765 mm
Z-axis stroke (up and down movement)	510 mm
A-axis (table tilt) travel amount / indexing 0.0001°	-120 ° to 30 °
C-axis (table rotation) travel amount/ indexing 0.0001°	+/- 360 °
Spindle speed maximum	12000 rpm
Maximum spindle power	30 Hp
Maximum workpiece weight	500kg
Table size	L: 24.800 m x W: 19.690
Maximum feed rate	50 min/s
Magazine capacity	30 tools

2.5 Material Selection Process and Dimensional Tolerance

An incorrectly chosen material can affect not only to failure of the part also to unnecessary life-cycle cost. Also, the properties of the material can be enhanced or diminished by processing and that may affect the service performances of the part. There are enormous amount of materials available to be chosen from and the selection can only be done by simplification and systemization. At the concept level of design, essentially all materials and processes are considered rather broadly. One of the ways to select whether each design concepts will be made from metal, plastics, ceramic, composite, or wood and narrow it down into a group material is by referring to the Ashby charts in Figure 2.4. The material selection methodology and charts developed by Ashby are highly appropriate at this stage since the precision of property data needed is rather low [Dieter, 2001].
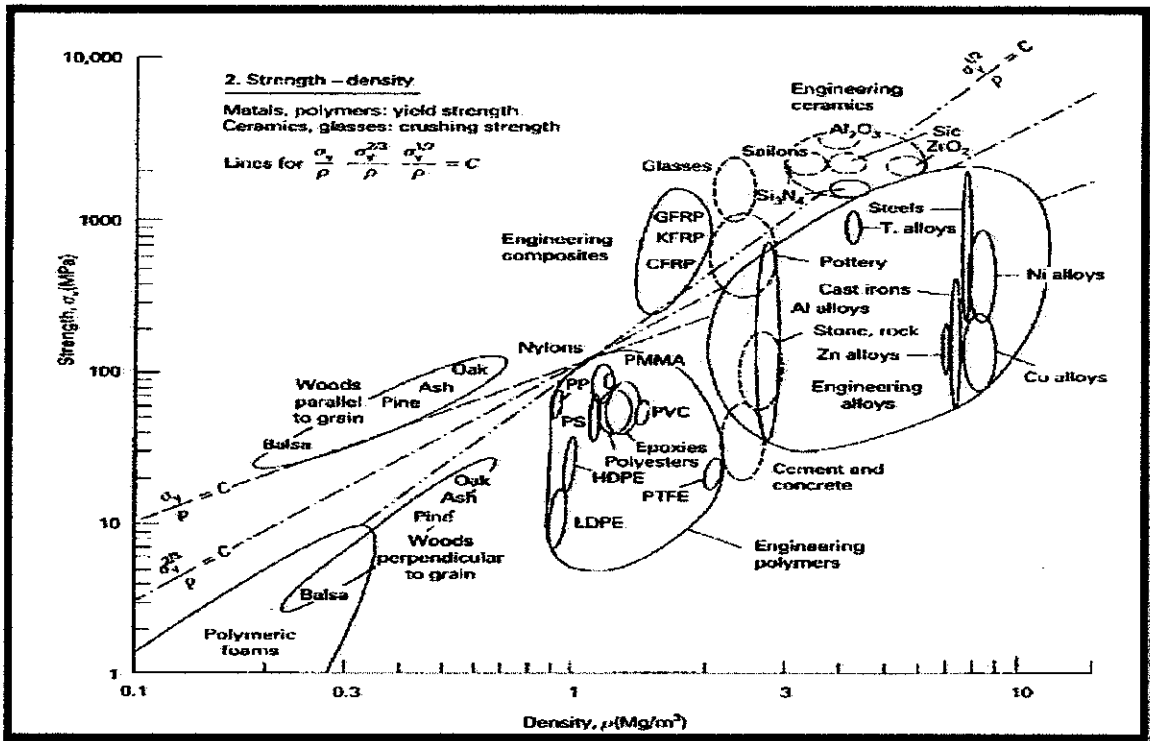
Figure 2.4: Ashby material selection chart: strength vs density [Dieter, 2001]

The figure above plots the strength against density for a variety of materials. Depending on the geometry and type of loading, different $\sigma - \rho$ relationship applies as shown as shown in the Table 2.2.

Table 2.2: Performance indices [Dieter, 2001]

Design objective: minimum weight for different shapes and loadings	To maximize strength	To maximize stiffness
Bar in tension: load. stiffness. length are fixed: section area is variable	σ_f/ρ	E/ρ
Torsion bar: torque. stiffness. length are fixed: section area is variable	$\sigma_f^{2/3}/\rho$	$G^{1/2}/\rho$
Beam in bending: loaded with external forces or self-weight: stiffness. length fixed: section area free	$\sigma_f^{2/3}/\rho$	$E^{1/2}/\rho$
Plate in bending: loaded by external forces or self-weight: stiffness. length. width fixed: thickness free	$\sigma_f^{1/2}/\rho$	$E^{1/3}/\rho$
Cylindrical vessel with internal pressure: elastic distortion. pressure. and radius fixed: wall thickness free	σ_f/ρ	E/ρ
Other design objectives. as stated below	Maximize	
Thermal insulation: minimize heat flux at steady state: thickness given	$1/\kappa$	
Thermal insulation: minimum temperature after specified time: thickness given	$C_p\rho/\kappa$	
Minimize thermal distortion	κ/α	
Maximize thermal shock resistance	$\sigma_f/E\alpha$	

σ_f = failure strength (yield or fracture stress as appropriate to problem): E = Young's modulus: G = shear modulus: ρ = density: C_p = specific heat capacity: α = thermal expansion coefficient: κ = thermal conductivity.

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For simple axial loading, the relationship is $\sigma - \rho$. For solid rectangular under bending, $\sigma^{1/2}/\rho$ applies, for solid cylinder under bending or torsion, the relationship $\sigma^{2/3}/\rho$ applies. Line with these slope are shown in the Figure 2.4. Materials lies near the line are better and materials the farthest are worse [Dieter, 2001].

2.5.1 Shape of Commercially Available Materials

After the material was selected, the material availability is needed to know in terms of shapes and sizes. Generally materials are available in various forms such as castings, extrusions, forgings, bars, plates, sheets, foils, rod, wires and metal powders [Kalpakjian, 2006]. Table 2.3 below shows the availabilty of the shapes of the common materials.

Table 2.3 : Commercially available shapes of material [Kalpakjian, 2006]

Commercially Available Shapes of Materials	
Material	Available as
Aluminum	B, F, I, P, S, T, W
Ceramics	B, p, s, T
Copper and brass	B, f, I, P, s, T, W
Elastomers	b, P, T
Glass	B, P, s, T, W
Graphite	B, P, s, T, W
Magnesium	B, I, P, S, T, w
Plastics	B, f, P, T, w
Precious metals	B, F, I, P, t, W
Steels and stainless steels	B, I, P, S, T, W
Zinc	F, I, P, W

Note: B = bar and rod; F = foil; I = ingots; P = plate and sheet; S = structural shapes; T = tubing; W = wire.
Lowercase letters indicate limited availability.
Most of the metals also are available in powder form, including pre-alloyed powders.

2.5.2 Material Processing

To decide the manufacturing process based on the materials selected, the melting point of the material and its level of deformation resistance and ductility are the main factors to be evaluated. The melting points of the material can be evaluated to determines the casting processes that can be employed. With low melting points, casting processes can applied widely but if the melting poin rises, it limt the available processes. Some material may too brittle for shape creation by deformation processes while others are too reactive to have good weldability [Dieter, 2001]. However this scenario can be avoided by referring to the Table A-3. The table shows the matrix laying out the manufacturing processes generally used with the most common classes

of engineering material [Dieter, 2001].This table then further divided with respect to the quantity of parts needed for economical production.

2.5.2 Dimensional Tolerances

Tolerance is defined as the permissible or acceptable variation in the dimensions of height, width, depth, diameter and angles. Tolerances are unvoidable, because it is virtually impossible to manufacture two parts that have precisely the same dimensions [Kalpakjian, 2006]. To determine the tolerances, there is a general relationship between tolerances and part size like in the Figure 2.5.
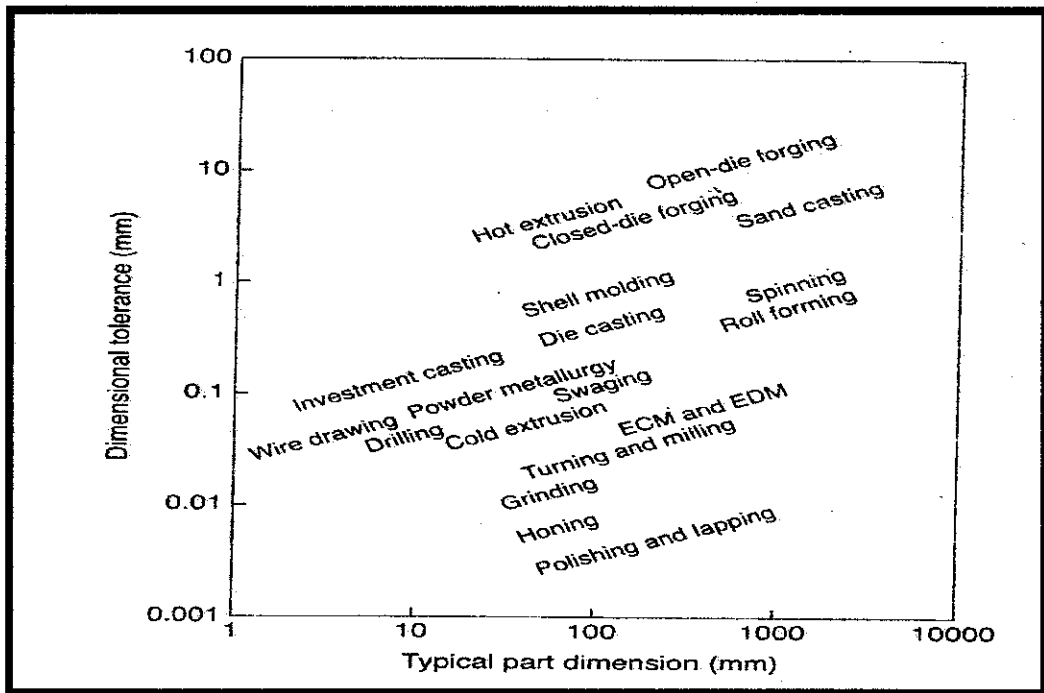
Figure 2.5: Dimensional tolerances as a function of part size for various manufacturing processes [Kalpakjian, 2006]

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CHAPTER 3

METHODOLOGY

3.1 Fixture Planning Model

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┌─────────────────────────────────────────────┐
│ Define shapes and dimensions of workpiece to be │
│                  machined.                    │
└─────────────────────────────────────────────┘
                     ↓
┌─────────────────────────────────────────────┐
│ Check machine specifications including machine │
│              table dimension                  │
└─────────────────────────────────────────────┘
                     ↓
┌─────────────────────────────────────────────┐
│        Evaluate cutting forces and torques     │
└─────────────────────────────────────────────┘
                     ↓
┌─────────────────────────────────────────────┐
│ Identify clamping, locating and supporting faces of │
│                  workpiece                    │
└─────────────────────────────────────────────┘
                     ↓
┌─────────────────────────────────────────────┐
│ Evaluation and analysis of the development of │
│                design concept                 │
└─────────────────────────────────────────────┘
                     ↓
┌─────────────────────────────────────────────┐
│   Designing fixture base, supports and locators │
└─────────────────────────────────────────────┘
                     ↓
┌─────────────────────────────────────────────┐
│      Designing clamping components and        │
│                configuration                  │
└─────────────────────────────────────────────┘
                     ↓
┌─────────────────────────────────────────────┐
│ Calculate clamping force against external force. │
└─────────────────────────────────────────────┘
                     ↓
┌─────────────────────────────────────────────┐
│        Perform material selection process      │
└─────────────────────────────────────────────┘
                     ↓
┌─────────────────────────────────────────────┐
│        Determine manufacturing process         │
└─────────────────────────────────────────────┘
                     ↓
┌─────────────────────────────────────────────┐
│               Detailed design                 │
└─────────────────────────────────────────────┘
                     ↓
┌─────────────────────────────────────────────┐
│               Report writing                  │
└─────────────────────────────────────────────┘
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Figure 3.1 : Flowchart of design and development of modular fixture for CNC machining center

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3.2 Details of Fixture Planning Model

3.2.1 Define shapes and dimensions of workpiece

To design a fixture, the first step taken is to determine the characteristics of the workpiece that need to be fixtured. This is important to valid the functions of the fixture. The assigned task is to hold rectangular and rounded workpiece with variable thickness and dimensions.

After approaching lab instructor Mr. Hafiz at block 16, the instructor explain specifically on the maximum size of workpieces that usually being machined by Mazak Variaxis 630 5x II. The shape that only being machined by this machining center at the lab are rectangular and cylindrical aluminum workpiece. The details of maximum sizes of rectangular and cylindrical workpiece are shown in the figure below:

(a)   (b)
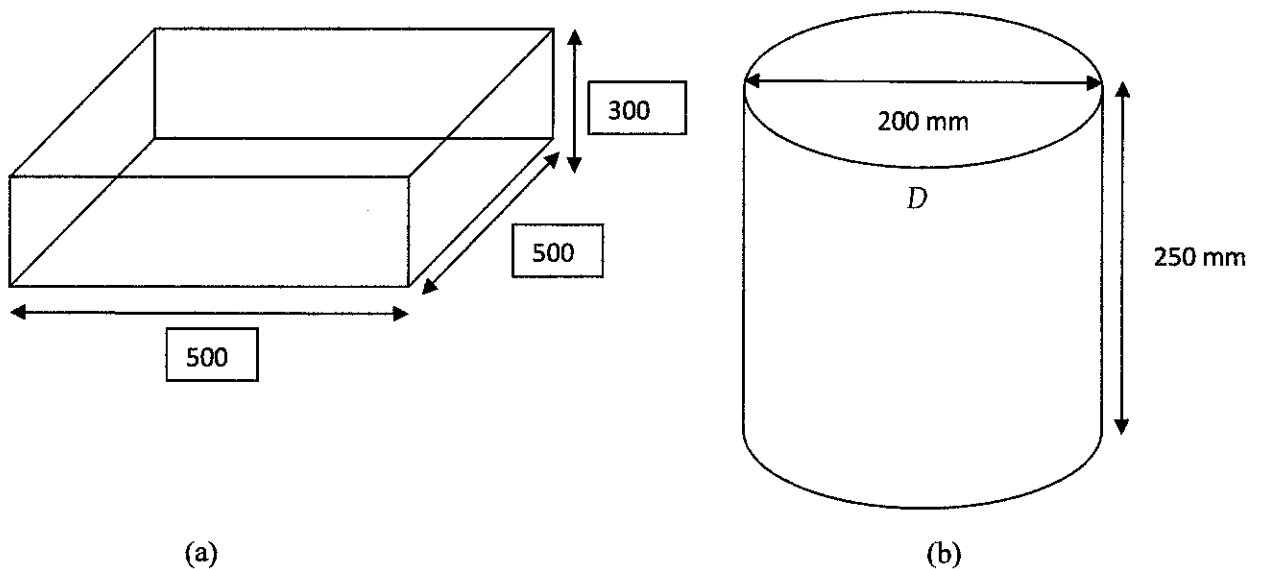
Figure 3.2 : (a) Rectangular wokpiece dimensions. (b) Cylindrical workpiece dimensions.

3.2.2 Check machince specifications including machine table dimensions.

The machine used is Mazak Variaxis 630 5x II. Since the scope of this project is to design a fixture for vertical axis machining, the surfaces to be machined are top and bottom of the workpiece. The machine table dimensions are also determined to ensure the shape and dimension of workpiece can fit to machine bed. The specifications is in literature review sections.

3.2.3 Calculate machining torque and cutting force of cutting tools.

In order to select clamping scheme, the external force must first be determine. The external forces in this context are the cutting force and torque produced during machining process. By determining the external force, suitable clamp can be selected to totally constraint the workpiece.

For this part, the choosen cutting tool is end mill carbide based from Mitsubishi Material General Catalougue. This cutting tool is chosen because of its suitability for machining aluminum alloy material This cutting tool produce medium cut length and have two cutting tooths. The required information to calculate power and torque of the machine are as follows:

Table 3.1 : Feed rate, depth of cut and spindle speed of end milling and side milling carbide cutting tool [Mitsubishi]

Diameter, D	10mm		20mm	
Machining Process	End Milling	Side Milling	End Milling	Side Milling
Feed Rate (mm,min)	1200	1900	970	1500
Depth of Cut (mm)	1D	1D	1D	1D
Spindle Speed, (RPM)	7600	9500	3800	4800

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To calculate the torque of the cutting tools, first determine the material removal rate (MRR) of the work piece from the equation equation (1) [Kalpakjian, 2006]:

$$MRR = wdv \text{ (mm}^3/\text{min)} \tag{1}$$

Where, w = width of the workpiece,

d = depth of cut

v = linear speed of the workpiece or feed rate

From MRR value, the power required can be estimated by using equation (2):

$$Power = Unit\ Power \times MRR \tag{2}$$

Thus, torque is determine from the equation (3):

$$Torque = \frac{Power}{Rotational\ Speed} \tag{3}$$

Cutting force can be calculated from the torque value from equation (3) by using equation (4) below:

$$Torque = \frac{Cutting\ Force \times Cutter\ Diameter}{2} \tag{4}$$

For rectangular wokpiece, the calculations of power, torque and cutting force of cutting tool is shown in the Table 3.2:

Table 3.2 : Calculation process of power, torque and cutting force of 10mm cutting tool for rectangular wokpiece using end milling process.

End Milling process with, **D=10mm**
Material Removal Rate, MRR=wdv
MRR = (500 mm)(10 mm)(1200 mm/min)
MRR = **6 x 10^6 mm^3/min**
Unit Power for aluminum alloy from Table 21.2 [Kalpakjian, 2006] = 1.1 W.s/ mm^3
Power = unit power x MRR
Power = (1.1 W.s/ mm^3) x (6x10^6 mm^3/min) x (1/60) = **110 kW**
Torque = Power/Rotational Speed
Torque = (110 kW)(60 N-m/min.W) / (7600 rpm)(2π) = **138.2 N-m**
Cutting Force = (Torque × 2) / Cutter Diameter
Cutting Force = (138.2 N-m × 2) / 0.01m = **27 640 N**

The result of power torque and cutting force of cutting tool for rectangular and cylindrical workpiece for each process are tabulated in the Table 3.3 and Table 3.4.

Table 3.3 : Results of power, torque and cutting force of 10mm and 20mm diameter cutting tool for rectangular wokpiece for each processes

Diameter, D	10mm		20mm	
Process	End Mill	Side Mill	End Mill	Side Mill
Power (kW)	110	174.17	88.92	137.5
Torque (N-m)	138.2	175.10	223.45	273.5
Cutting Force (N)	27 640	35 020	22 345	27 350

Table 3.4 : Results of power, torque and cutting force of 10mm and 20mm diameter cutting tool for cylindrical wokpiece for each processes

Diameter, D	10mm		20mm	
Process	End Mill	Side Mill	End Mill	Side Mill
Power (kW)	172.79	273.58	139.67	215.98
Torque (N-m)	217.10	275.00	350.98	**429.69**
Cutting Force (N)	43 420	**55 000**	35 098	42 969

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From calculation above, the highest torque is 429.69 N-m for side mill process with tool diameter 20 mm and the highest cutting force also from same process and diameter which is 55 00 N . Thus, the clamping force needed to clamp the workpiece must be higher than the torque and cutting force value to avoid any displacement or movement of workpiece during machining process.

3.2.4 Indentify clamping, supporting and locating surface of the workpiece.

This step require analysis of the workpiece surfaces that suitable to be supported of the fixture. The surface usually is the area that is not be machined. To support the area, candidate points is determine based on the boundary of the edges like circular or linear. For this project, the purpose is to design modular fixture to clamp for cylindrical, rectangular and spherical shape with variables length and diameter. In order to satisfy the purpose, the fixture base must be design wtih modular surface to provide flexibility of the clamps unit. On the other hand, locators is a device used to constraint the workpiece but, it is different from the clamps since the locators does not provide clamping force to the workpiece. For planar workpiece (rectanguar workpiece) commonly used locating principle is 3-2-1 mehtod and for round workpiece, using the princip of four jaw clamping method.

3.2.5 Design concept generation of the fixture (Brainstorming)
3.2.5.1 Conceptual Decompostion

To solve any complex problems, the easier way to solve it is to decompose the problem into smaller parts. In order to divide the system into subsystem, it is important to do it in such a way that the connection of elements in terms of structure and fuctions within the chunks are stronger than those between the chunks. This step typically start with a major product and break into subsidiary subassemblies and components. The figure below shows direct decomposition of the modular fixture.
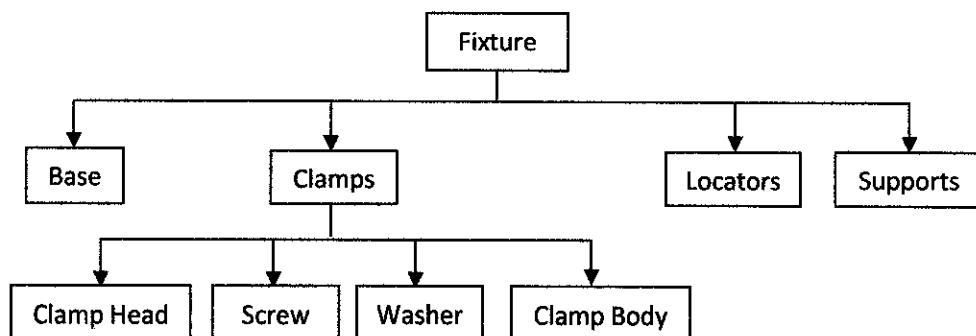
Figure 3.3 :Direct decomposition of a fixture into subassemblies and components

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This step allows the author not too rush in design the fixture wihtout thinking explicitly about the functions each component is created to perform. The great advantage of functional decomposition is that the method facilitates the examination of options that most likely would not have been considered if the author moved quickly to selecting specific physical principles.

### 3.2.5.2 Functional Decomposition

Functional decompositon describes the system's functions as a transformation between an initial state to the desired final state. The functions is considered to be in nature of a physical behaviour or action. Functions will state what the product must perform, while its form or strucutre tells how it will accomplish it. Table 3.5 shows the functionalilty of each part of the fixture.

Table 3.5: Functionality of devices of CNC fixture

Device	Input	Function	Other effects	Output
Base	Mechanical energy	Support fixture elements	Connect fixture to machine bed	Installation of fixture elements to machine bed
Clamps Body	Mechanical energy	Provide force closure to constrain workpiece	Position the workpiece in correct orientation	Clamping force
Locators	Mechanical energy	Provide constrain to the workpiece without force	Hold workpiece in desired location	Workpiece movement is constrained
Support	Mechanical energy	Support the workpiece	Support the clamps	Workpiece and clamps is in desired location
Clamp Head	Mechanical energy	Grip the workpiece	Provide friction to the workpiece	Workpiece movement is constrained
Screw/ Nuts	Mechanical energy	Connect clamps to the supports		Clamps is fixed to the support
Washers	Mechanical energy	Minimize damage to mating material	Increase the force of screw	Ensure tightening

From the Table 3.2, the inputs and outputs to the functional devices are described in terms of energy flow. Functions associated with a flow of energy are classified both by the type of energy and by its action on the system.

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3.2.5.3 Morphological Chart for the Design of CNC Fixture
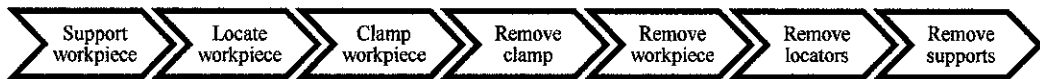
Figure 3.4:Subfunctions of CNC Fixture

The morphological chart arrange the functions and subfunctions in logical order like in the Figure 3.4 and each subfunction lists the possible hows. The meaning of morphology is the study of shape or form. Thus, morphological analysis is a way of creating new forms, i.e., design concepts. The main objective of the method is to uncover combination of ideas that help to build design concept that might ordinarily be generated.

Table 3.6: Morphological chart of CNC fixture

Sub functions	Concepts				
	1	2	3	4	5
1.0 Support workpiece					
1.1 Fixture Base	Modular base	Built in machine table	Built in clamp base	Block	
1.2 Workpiece Supports	Extendable work support	Fixed support	Bolt		
2.0 Locate workpiece					
2.1 Attach locators	Cylinder support	Locating pins	Free Block	Bolt	
2.2 Put workpiece to the fixture	Manual	Robot arm			
2.3 Clamp workpiece	Side Clamp	Strap Clamp	Hydraulic Clamp	Pneumatic clamp	Magnetic Clamp
3.0 Remove clamps					
3.1 Disengage workpiece from clamps	Manual wrench	Motorized Wrench	Robot arm	Allen key	
4.0 Remove workpiece					
4.1 Disengage from fixture	Hand	Robot Arm			
5.0 Remove locators					
5.1 Disengage from fixture base	Hand wrench	Allen key			
6.0 Remove supports					
6.1 Disengage from fixture base	Hand wrench	Allen key			

3.2.5.4 Combining Concepts

To combine the concepts, the number of possible combinations is quite large. Thus, selecting one fragmentary concept for each sub function is preferred. Some may be clearly infeasible or impractical and are not selected. Here are the best options or concept that can be considered:

Concept 1- Design modular base (1), with cylinder shape of supports (3) and cylinder shape of locators (1). Then, the workpiece is clamp by side clamps (1).

Concept 2- Using built in machine table (2), with extandable support (1) and locating pins of locators (2) and clamp by strap clamps (2).

Concept 3- Built in clamp base (3), with extendable work support (2) and using block as locators (3), and the workpiece clamped by hydraulic clamp (3).

Concept 4- Use block as a fixture base (4) and bolt as a support (4), locating pins as locators (2) and pneumatic clamp to clamp the workpiece.

Concept 5- Modular base (1), with extendable support (2), while locating pins as locators (2) and clamp the workpiece by hydraulic clamp.

All the concepts have the potential to be designed, however there are several limitations that need to be considered. Firstly, the height of machine table of Mazak Varia-Axis 630 is quite low where machine cutter cannot fully reach the whole area of workpiece. Thus, the fixture must be added with risers ease the machining process. Secondly, pneumatic clamp and hydaulic clamp are extremely good in clamping or holding the workpiece but it needs an installation of power supply to enables them to function and it is not desirable since it increases the cost of electricity and the cost of maintenance. Plus, these clamps are quite big and it is not suitable to be attached to the machine table which has small in dimensions. It also requires trained personnel to operate. Strap clamp is commonly used by most manufacturers due to its flexibility and have higher clamping force. However, the objective of this project is to hold or clamp workpieces for vertical machining process that means strap clamp is not suitable for this process since it clamps the workpiece at the top surface limiting the reachable point of the cutter. Locators and supports usually chosen based on the shape of the workpiece. Since the shape of the workpiece are cylindrical and rectangular, the most suitable support and locator are

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cylindrical support since it has larger surface area and smooth round shape which can avoid poor surface finish the workpiece due to higher cutting forces. Based on the discussions above, the most suitable concept is concept 1. The modular base can increase the height of the work table so the cutter can reach the workpiece at any points. Plus, modular base adds more flexibility in clamping and supporting the workpiece. Using side clamp is preferable since it clears the top surface for machining. The locators and supports is in cylindrical shape which suitable to hold and support cylindrical and rectangular workpiece. However, this is just the preliminary selection more details step need to be done to evaluate all the concepts to make sure the concept selection is absolutely correct.

3.2.5.5 Pugh's Concept Selection Method

A very good method especially to decide the most suitable and effective design concept at the concept stage is the Pugh's concept selection process. This method is done by compairing each concepts relative to a reference or datum concept. The criteria must be determine first to determine wether the concept is better than, poorer than, or about the same as the reference concept. The selection of concept is shown below.

Table 3.7: Pugh's concept selection of CNC fixture

Criterion	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Standard CNC fixture
Manufacturing cost	S	S	-	-	-	
Increased height	+	S	S	+	+	
Clamping Force	-	-	+	+	+	D
Clamping Area	S	S	-	-	-	A
Mobility	+	S	-	-	-	T
Flexibility	+	+	S	S	S	U
Installation Time	+	+	+	+	+	M
Size	+	+	-	-	-	
Easy to Install	+	+	-	-	-	
Easy to Handle	+	S	+	+	+	
Σ +	7	4	4	4	4	
Σ -	1	2	6	6	6	
Σ S	3	6	2	1	1	

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Study of the concept above shows the concept 1 have the most pluses compared to other concepts. It has only one negative criterion, thus it shows the concept 1 is suitable for desinging modular fixture for CNC machining center.

3.3 Gantt Chart and Key Milestone for FYP II

Table 3.8: Gantt Chart for FYP II

Activities	Weeks										
	6	7	8	9	10	11	12	13	14	15	16
Evaluation and Analysis of The Development of Design Concept											
Designing Fixture Base, Supports and Locators											
Designing Clamping Components and Configuration					▲	▲	▲				
Submission of Progress Report								▲			
Calculate Clamping Force Against External Force						▲					
Perform Material Selection Process											
Determine Manufacturing Process											
Detailed Design					▲	▲	▲	▲			
Preparation of Final Dessertation and Technical Paper											
Oral Presentation									▲		
Submission of Final Dessertation									▲		
Submission of Technical Paper										▲	
Submission of Project Hardbound											▲

▲ = Key Milestone

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CHAPTER 4

RESULT AND DISCUSSION

4.1 Proposed Design

4.1.1Fixture Base

(a)   (b)
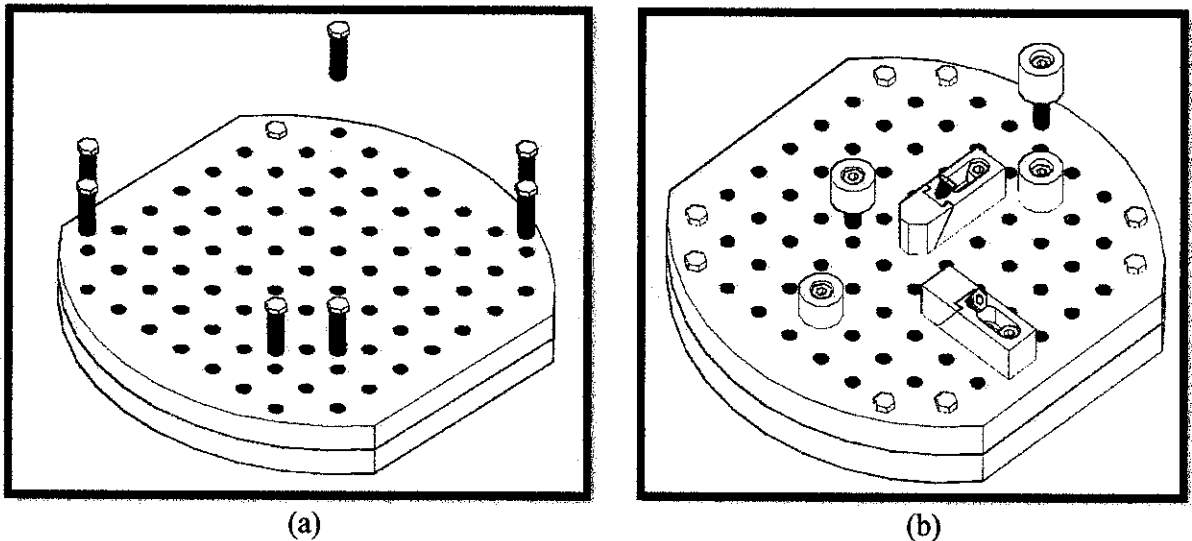
Figure 4.1: (a) Modular fixture base attachment to machine bed. (b) fixture element
attached to fixture base

The fixture base is designed in the same shape and dimension of actual machine table
of Mazak Varia Axis 630 machine to make sure proper alignment between fixture
base and machine table. The fixture base has multiple screw thread holes which
properly aligned like a grid covering the surface of the base. This hole is used to
attach all the fixture equipments such as locators, supports and clamps. The
advantage of using this grid hole is it adds more flexibility to locate all the fixture
equipment into desired location according to the workpiece shapes and dimensions.
Plus, since the machine table is too low which causing the cutting tools cannot reach
at maximum points of the workpiece, this base improve the height of the machine
table and enables the cutter to operate to the maximum points of the workpiece.

4.1.2 Supports

(a)   (b)
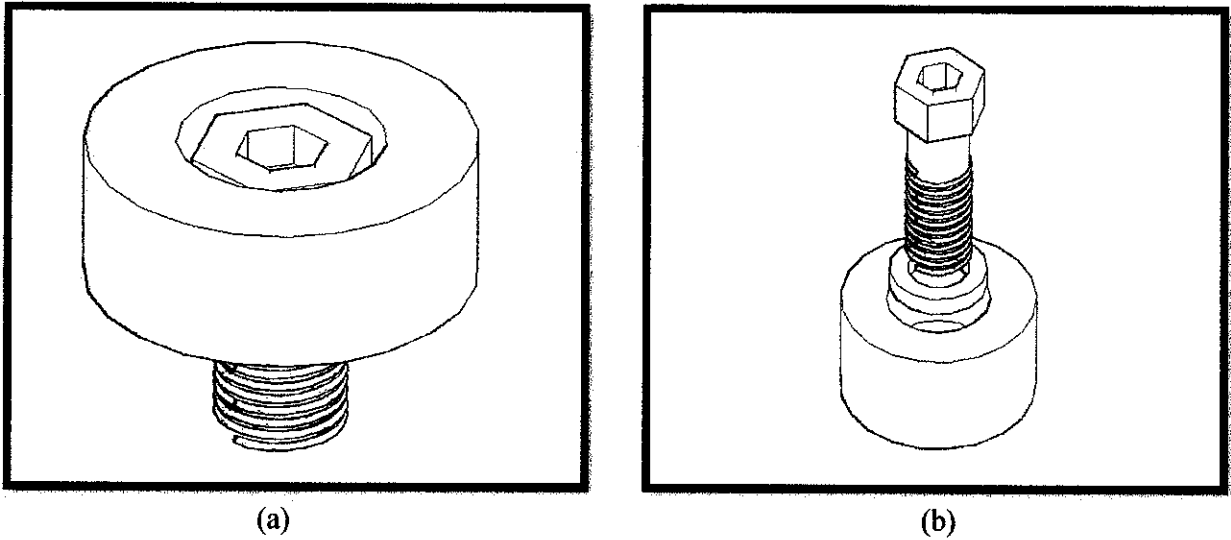
Figure 4.2: (a) Cylindrical supports. (b) Exploded view of support

The purpose of supports is to support the bottom surface of the workpiece. The support will avoid the workpiece from damaging the fixture base and prevent the workpiece from moving while machining. The support is designed in cylindrical shape to avoid any damages of the workpiece since it has no edges.

4.1.3 Locators

(a)   (b)
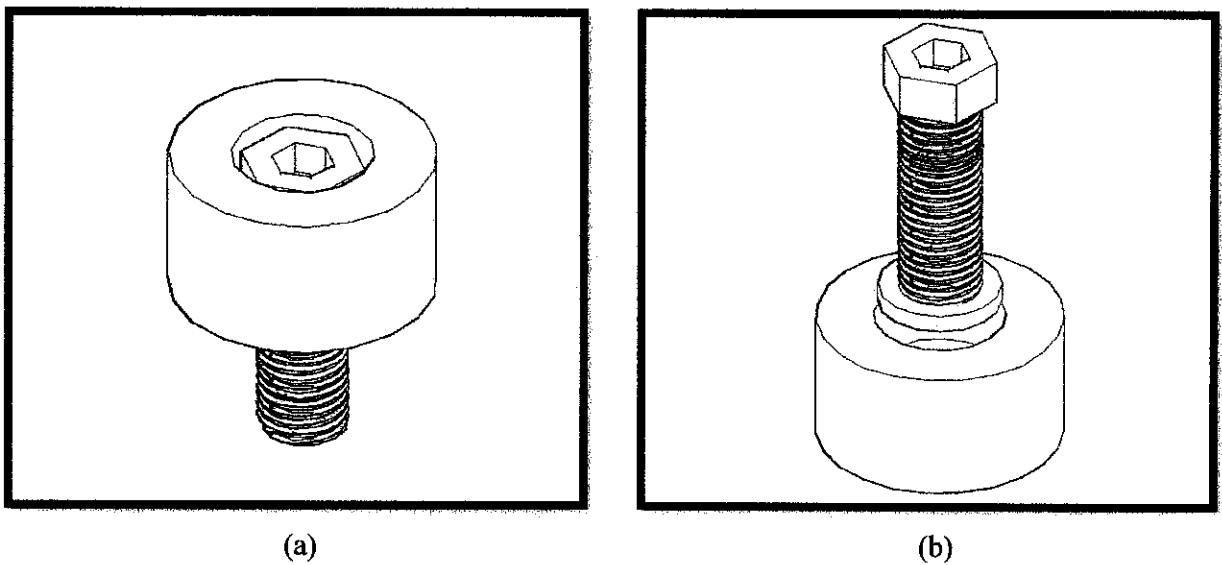
Figure 4.3:(a) Cylindrical locator.(b) Exploded view of cylindrical locator

The purpose of locators is to prevent the movement of the workpiece by reacting to the force exerted from clamps. The locators are designed in the same shape as the supports but slightly higher than the supports. The cylindrical shape of the locators prevents the workpiece from any damages while clamping.

4.1.3 Clamps
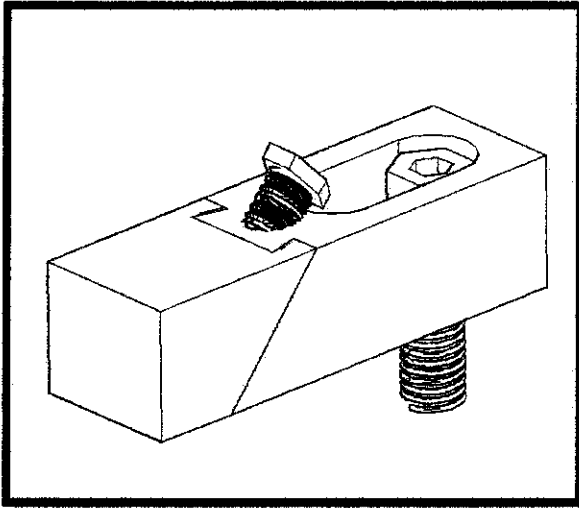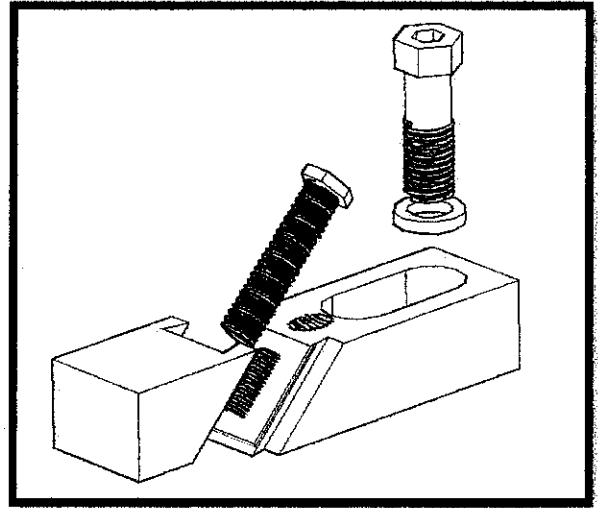
(a)   (b)

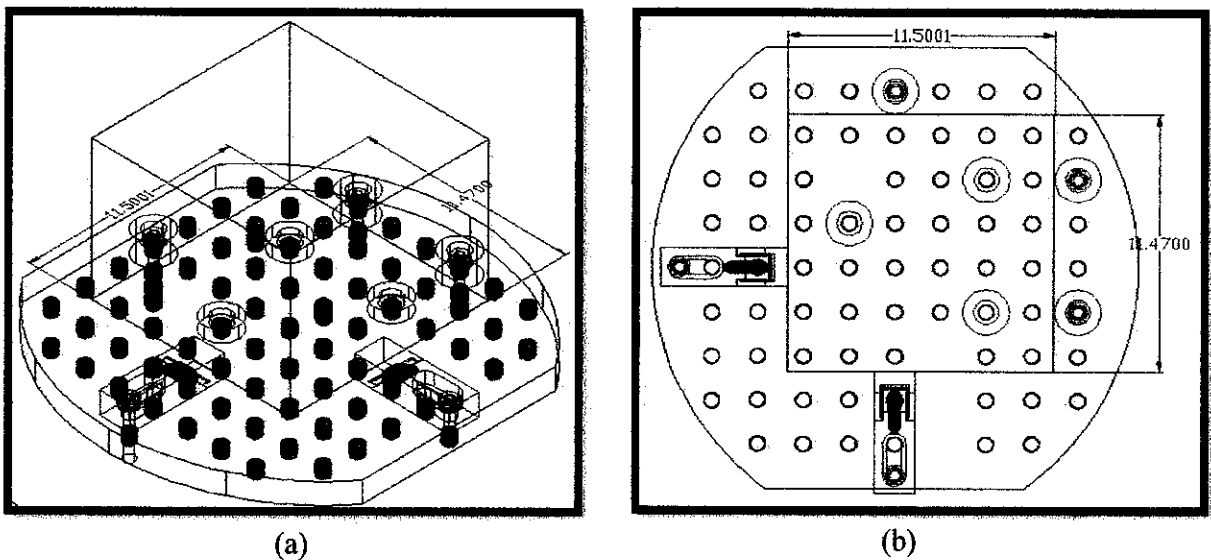**Figure 4.4**: (a) Clamp for rectangular workpiece. (b) Exploded view of clamp for rectangular workpiece
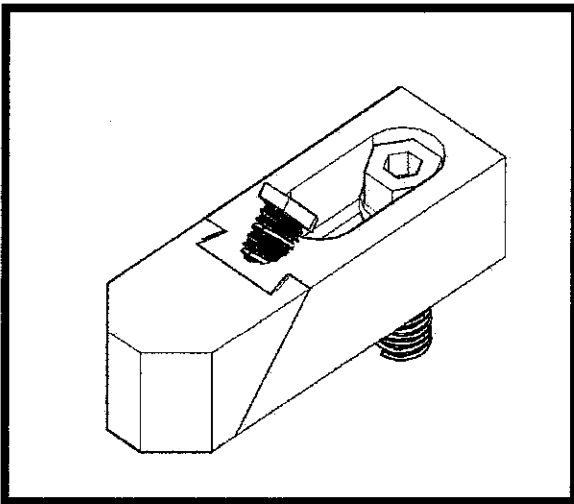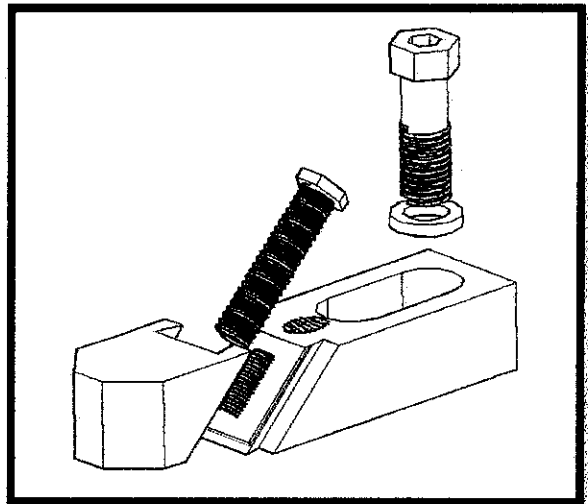
(a)   (b)

Figure 4.5: (a) Clamp for cylindrical workpiece. (b) Exploded view of clamp for cylindrical workpiece

These clamps are designed to clamp the workpiece at the side surface of workpiece. It clears the top surface of the workpiece for machining. Strap clamp is used as a design reference to design this clamp by using screw as a main clamping force. The main difference of the strap clamp and proposed clamp is strap clamp apply force at the top surface of the workpiece. So, the force will be acting downward toward the surface. Thus, to make this clamp able to exert its force to the side, the proposed clamp is design by improvising the strap clamp by adding the clamp head with inclination of 45 degrees to enables the force to be exerted to side as the screw goes downward. With 45 degrees inclination, the force exerted to the side will be the same with the force exerted to the side.

4.1.4 Fixture Layout for Rectangular Workpiece

(a)

(b)

Figure 4.6: (a) Isometric wireframe view and (b) top view of fixture layout for rectangular workpiece
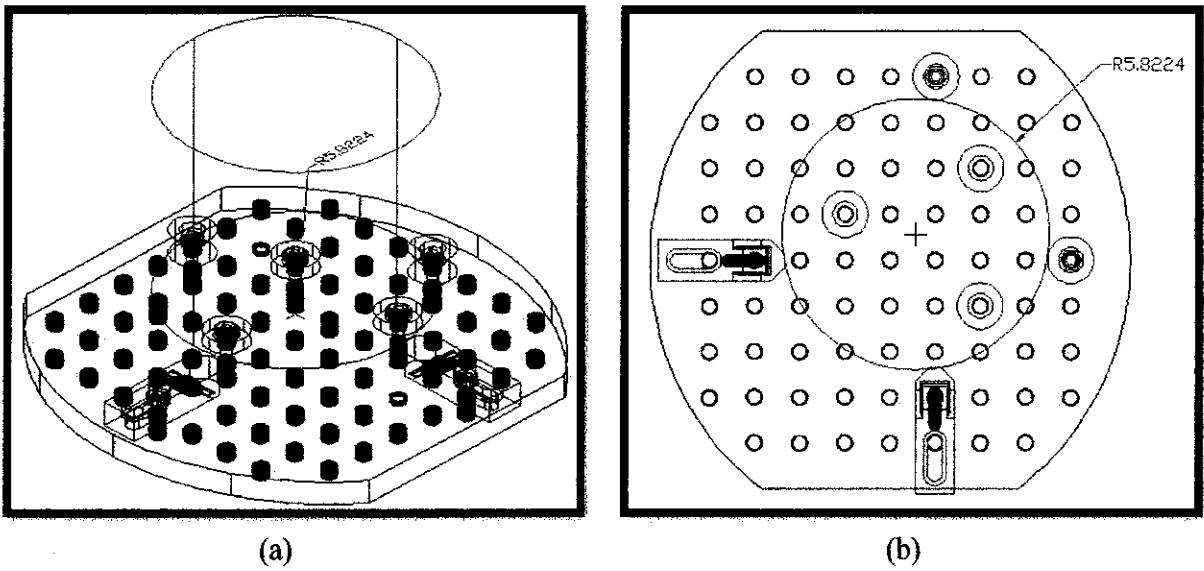
The figure above shows the fixture layout for clamping rectangular workpiece. The layout is based on 3-2-1 clamping method. Primary surface is placed with three supports which at the bottom of the workpiece. Based on gemetry principle, three points are needed to fully define a plane. Then, surface with longer in length will be placed with two locators and shorter surface placed with one locator. The clamps will be positioned against the entire locator one at each side. Thus, all six degree of freedom (DOF) of the workpiece is constrained to avoid any movement during machining. From this layout, the maximum workpiece dimensions are determine by

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applying trial and error using AutoCAD. The maximum dimension that the fixture can clamp the workpiece is 291 mm x 292 mm.
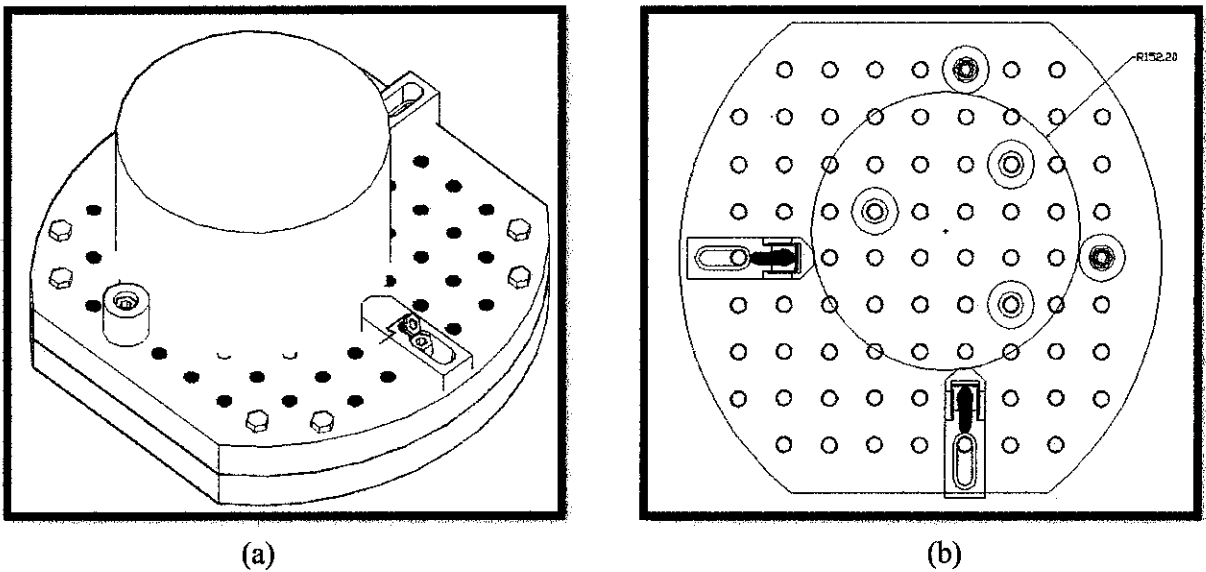

(a)

(b)

(c)

(d)
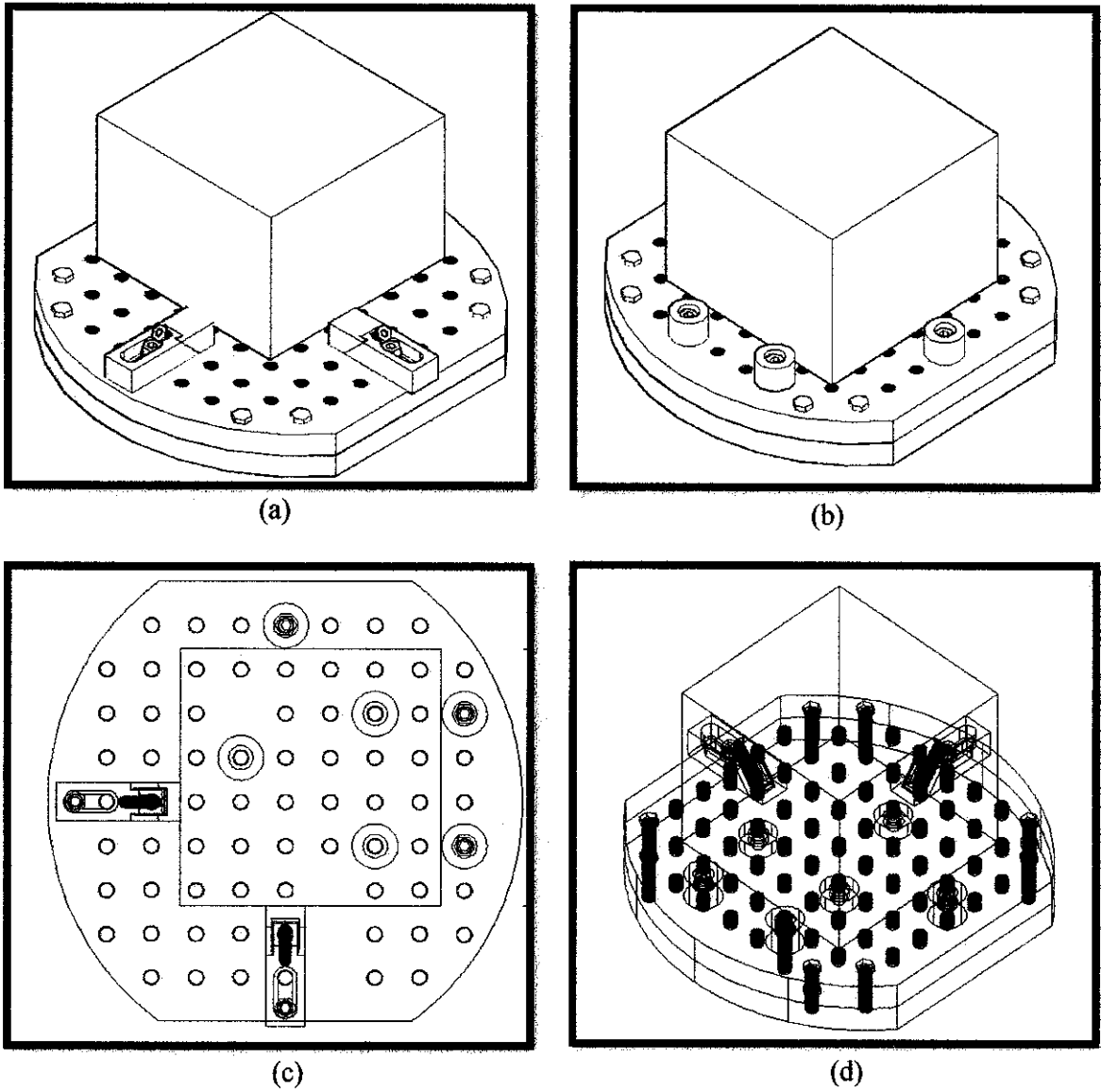
Figure 4.7: (a), (b) Isometric view, (c) top view and (d) isometric wireframe view of fixture layout for rectangular workpiece

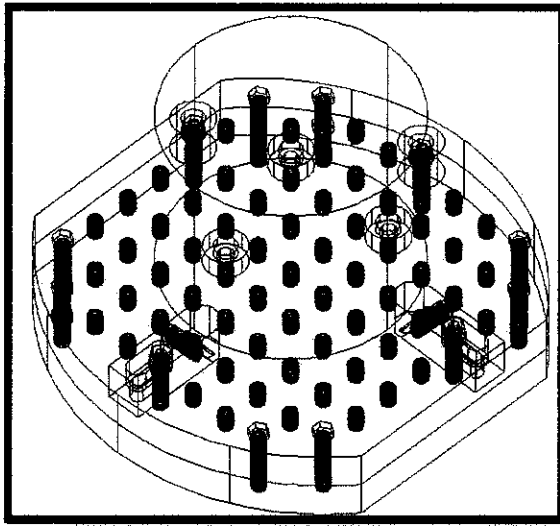### 4.1.5 Fixture Layout for Cylindrical Workpiece

Figure 4.8: (a) Isometric wireframe view and (b) top view of fixture layout for cylindrical workpiece

The figure above shows the clamping layout for cylindrical workpiece. The layout is based on four jaw chuck application. As usual, three supports will be located at the bottom of the surface. Then two locators are located at the side of the workpiece by 90 degrees. Two clamps are positioned opposite the locators to fully constraint the movement of the workpiece. The maximum diameter that this fixture can clamp is 296 mm.

(c)

Figure 4.9: (a)Isometric view, (b) top view and (c) isometric wireframe view of fixture layout for cylindrical workpiece

4.2 Clamping Force Against External Force.

To calculate clamping force of clamps, it depends on the type of the clamps choosen and its position. The minimal clamping force is needed to counterbalance the external load during machining. Therefore, it is essential concern in fixture design to compute or extimate the required clamping magnitude for a given fixture configurations.. Since the main clamping elements of the clamp is bolt and screw, the clamping force of the clamp is the force exerted by the bolt and screw after being tightened. To calculate the force exerted from the screw, the type of screw in terms of diameter must be selected first. Since this fixture deals mainly with steels, the most suitable is M16 x 2 screws where the screw is having nominal major diameter of 16mm and a pith of 2mm. The letter M which precedes the diameter is the clue to the metric designation.

In order to calculate the clamping force of the screw it can be determine from the equation shown below [Budynas, 2008]:

$$F_i = \begin{cases} 0.75\ F_p & \text{For nonpermanent connections, reused fasteners} \quad (5) \\ 0.90\ F_p & \text{For permanent connections} \quad (6) \end{cases}$$

Where: F_i = the clamping force

F_p = proof load

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Proof load can be obtain from the equation (7):

$$F_p = A_T \, S_P \qquad\qquad (7)$$

From equation (7) S_P is the proof strength obtained from Table A-2 and A_T is the tensile stress area is obtained from Table A-1 for screw threads diameter of 16mm. Thus F_p can be calculated as follows:

$$F_p = (157 \text{ mm}^2) \times (600 \text{ N/mm}^2)$$

$$F_p = 94200 \text{ N}$$

Since the fasteners is reused for clamping the workpiece the clamping force can be calculated using equation (5):

$$F_i = (0.75) \times (94200 \text{ N})$$

$$F_i = 70650 \text{ N}$$

To compare the clamping force obtained of the screw, the required clamping force is calculated from the torque of the machine that has been calculated before. The maximum torque of the machine is approximately 429.69 N. Thus, the required clamping force based from equation (8) is:

$$F_{ir} = T/2D \qquad\qquad (8)$$

$$F_{ir} = \frac{429.69}{2 \, (0.02)}$$

$$F_{ir} = 10742.2 \, N$$

From the calculation above the screw clamping force is higher than the required clamping force thus the clamps is able to hold the workpiece properly and avoiding any displacement of the workpiece during machining.

4.3 Material Selection and Manufacturing Process

Material selection for the elements of fixture is performed by referring to the Ashby material selection chart in Figure 2.4. By assuming the elements is made from metals, available material can be selected based on the criteria from Table 2.2.

Since the locators, supports and clamps are subjected to the same force of the screw, all of these elements is made from the same material. From Table 2.2, all of these elements falls on the criteria of the torsion bar which meets the citeria of the elements. Thus, by reffering the to corresponded line which is $\sigma^{2/3}/\rho$ line, the nearest materials are aluminum, titanium alloys and steels. By considering the external forces acting on the elements such as the weight of the workpiece and cutting force of the cutting tool, steels is selected due to higher in strength compared to the other materials.

For fixture base, the criteria selected was plate in bending and falls in the line of $\sigma^{1/2}/\rho$. Based from the line, the nearest material in the metal section was only aluminum. Thus, aluminum is considered to be the fitxture base material.

The availability of steels and aluminum are referred to Table 2.3 and both material which are aluminum and steels are available in almost shapes stated. Thus, the manufacturing process of the fixture is simplified due to both materails availability in various shapes.

4.3.3 Material Processing

Manufacturing procesess can determine from the materials of the part that are going to be processed. For this case, manufacturing process of aluminum and steel can be proposed by referring to the table A-3. The appendix shows the matrix laying out the manufacturing procesess generally used with the most common classes of enigneering material [Dieter, 2001]. The table is divided with respect to the quantity of parts needed for economical production.

From the table given, with the quantity range from 1-100, aluminum and steel can be manufactured using these processess:

- Ceramic mold casting
- Spinning
- Automatic Machining
- Electrical Discharge Machining (EDM)
- Electrical Chemical Machining (ECM)

4.3 Dimensional Tolerance

Based on the Figure 2.5, the tolerance of the fixture elements can be determined. By assuming the manufacturing processess are either ECM and EDM or turning or milling and typical part dimension is in the range of 10mm to 100mm, the dimensional tolerances are between 0.01mm to 0.1mm

4.5 Assembly Drawing of Modular Fixture

Figure below shows the assembly drawing of the proposed modular fixture.

NO	ITEM	QTY
1	BASE	1
2	BASE SCREW	8
3	LOCATORS	3
4	LOCATORS SCREW	3
5	SUPPORT	2
6	SUPPORTS SCREW	2
7	CLAMP BODY	2
8	CLAMP SCREW	2
9	RECTANGULAR CLAMP HEAD	2
10	CYLINDRICAL CLAMP HEAD	2
11	CLAMP HEAD SCREW	2
12	WASHER	16

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DESIGN AND DEVELOPMENT OF MODULAR FIXTURE FOR CNC MACHINING CENTER

Drawing Number: 1 of 1

ASSEMBLY PART DESIGN

ALL PARTS ARE IN millimeter (mm)
Tolerance for each dimensions ±0.1mm

SCALE 1:1   A4

MOHD ZUL AKMAL BIN
ZAINAL ABIDIN M10792

NOTE: This Drawing Is Not To Be Used or Reproduced Without the Permission Of Author
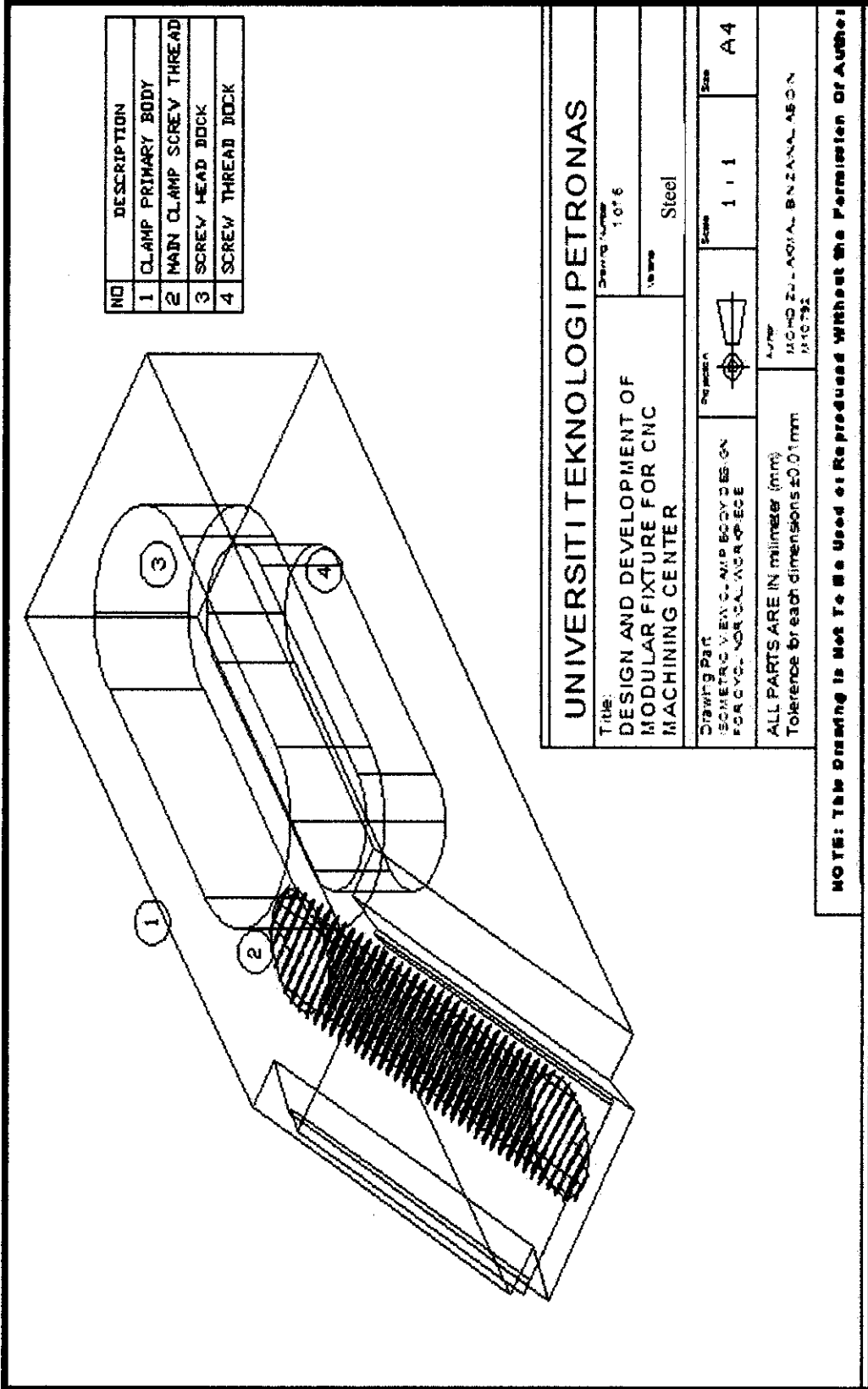
Figure 4.10: Modular Fixture Assembly Drawing

4.6 Detailed Design Of Modular Fixture Elements

Figures below shows the detail design of each components of proposed modular fixture. The dimensional tolerances is selected to be ±0.01mm with fixture base material is aluminum meanwhile locators, support and clamp are made from steel.
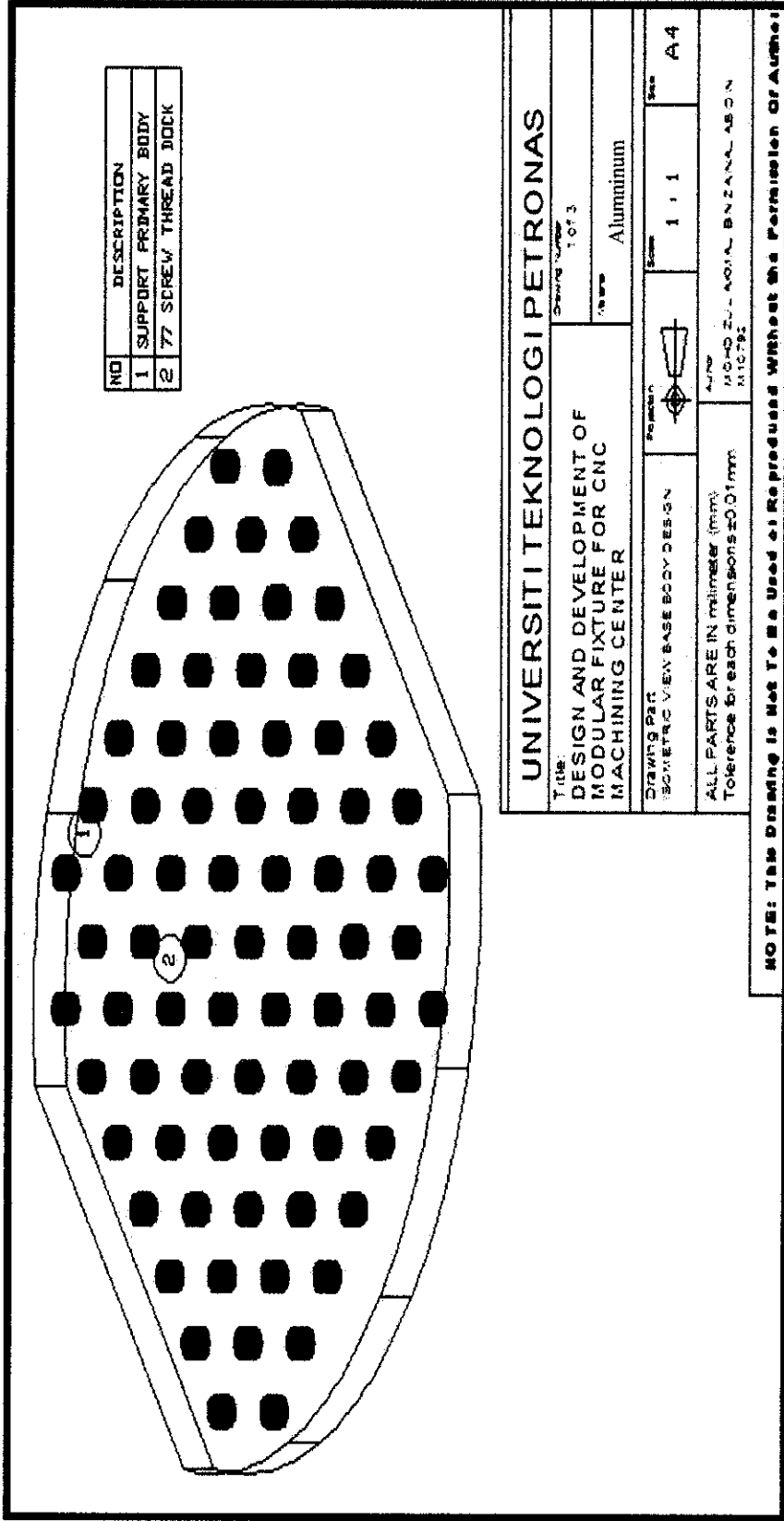
Figure 4.11: Isometric View of Fixture Base

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Title:
DESIGN AND DEVELOPMENT OF
MODULAR FIXTURE FOR CNC
MACHINING CENTER

Drawing Number
3 of 3

Material
Aluminium

Drawing Part:
SIDE VIEW BASE BODY DESIGN

Scale
1 : 1

Size
A4

ALL PARTS ARE IN milimeter (mm)
Tolerance for each dimensions ±0.01mm

Author
MOHD ZUL AKMAL BIN ZAINAL ABIDIN
17907/92

NOTE: This Drawing Is Not To Be Used or Reproduced Without the Permission Of Author

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Figure 4.12: Side View of Fixture Base

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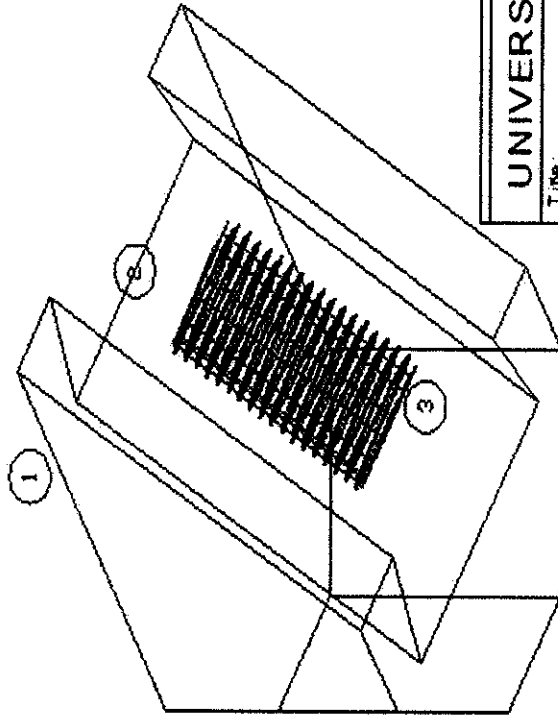| NO	DESCRIPTION
1	CLAMP PRIMARY BODY
2	MAIN CLAMP SCREW THREAD
3	SCREW HEAD DOCK
4	SCREW THREAD DOCK

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Title:
DESIGN AND DEVELOPMENT OF
MODULAR FIXTURE FOR CNC
MACHINING CENTER

Drawing Part
ISOMETRIC VIEW CLAMP BODY DESIGN
FOR CYCLE VERTICAL WORKPIECE

Drawing Number
1 of 6

Name: Steel

Scale 1 : 1

Size A4

Author:
MOHD ZULAKMAL BN ZAINAL ABDIN
18107352

ALL PARTS ARE IN millimeter (mm)
Tolerence for each dimensions ±0.01mm

NOTE: This Drawing is Not To Be Used or Reproduced Without the Permission Of Author!

Figure 4.13: Isometric View of Clamp Body

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113.79

82.55

35.05

21.08

43.94

R12.70

R8.13

R6.35

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Title:
DESIGN AND DEVELOPMENT OF
MODULAR FIXTURE FOR CNC
MACHINING CENTER

Drawing Part:
TOP VIEW CLAMP BODY DESIGN FOR
CYLINDRICAL WORKPIECE

ALL PARTS ARE IN milimeter (mm)
Tolerance for each dimensions ±0.01 mm

Drawing Number
2 of 6

Material
Steel

Projection

Scale
1 : 1

Size
A4

Author
MOHD ZUL AKMAL BN ZAINAL ABIDIN
14072

Figure 4.14: Top View of Clamp Body

39
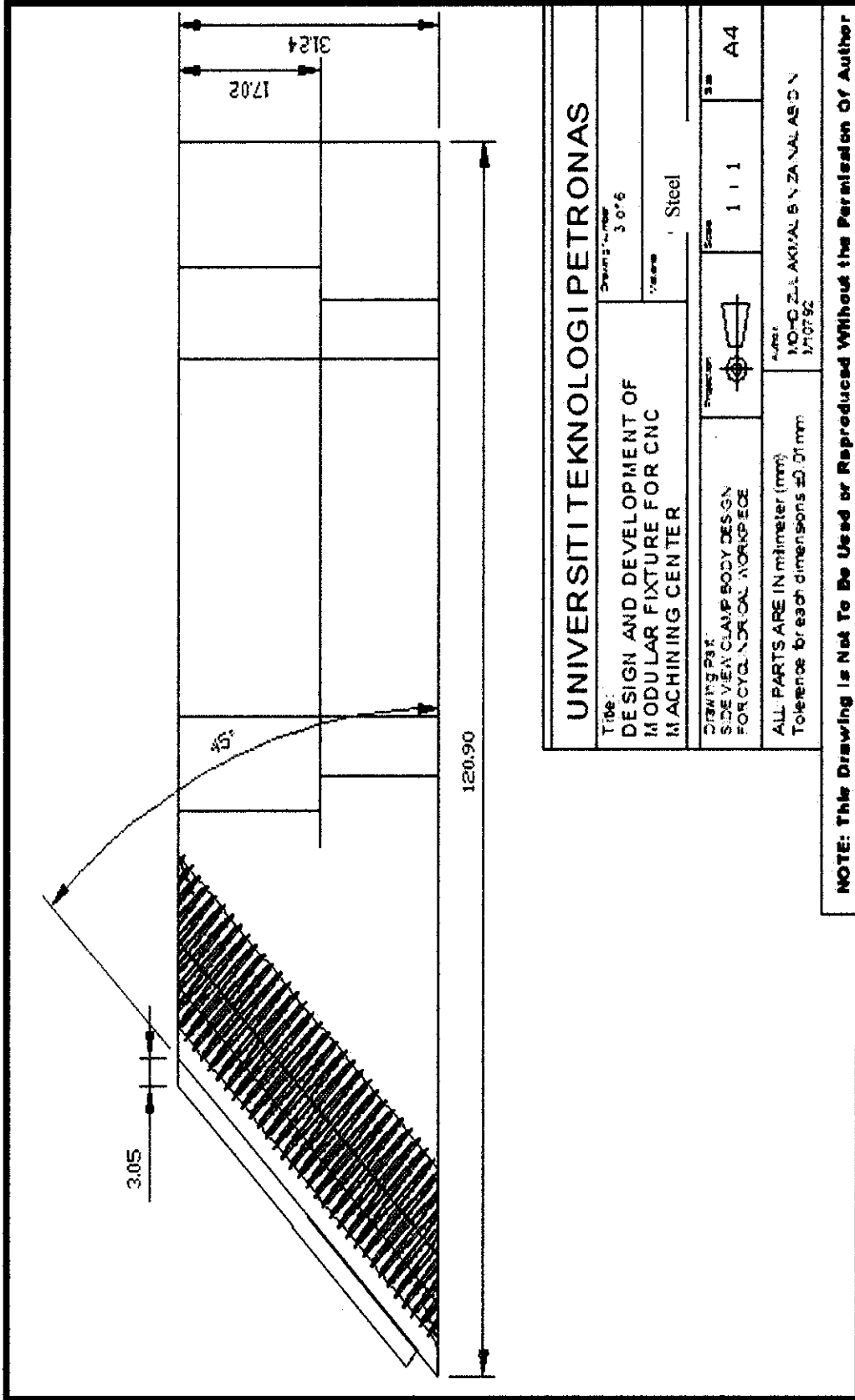
Figure 4.15: Side View of Clamp Body

40

NO	DESCRIPTION
1	CLAMP PRIMARY BODY
2	CLAMP BODY & HEAD FIT SLOT
3	SCREW THREAD DOCK

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Drawing Number
6 016

Title:
DESIGN AND DEVELOPMENT OF
MODULAR FIXTURE FOR CNC
MACHINING CENTER

Material: Steel

Drawing Part:
ISOMETRIC VIEW CLAMP HEAD DESIGN
FOR CUBIC WORKPIECE

Projection

Scale 1 : 1   Size A4

Author:
MOHD ZULAKMAL BIN ZAINAL ABIDIN
12517792

ALL PARTS ARE IN millimeter (mm)
Tolerence for each dimensions ±0.01 mm

NOTE: This Drawing Is Not To Be Used or Reproduced Without the Permission Of Author

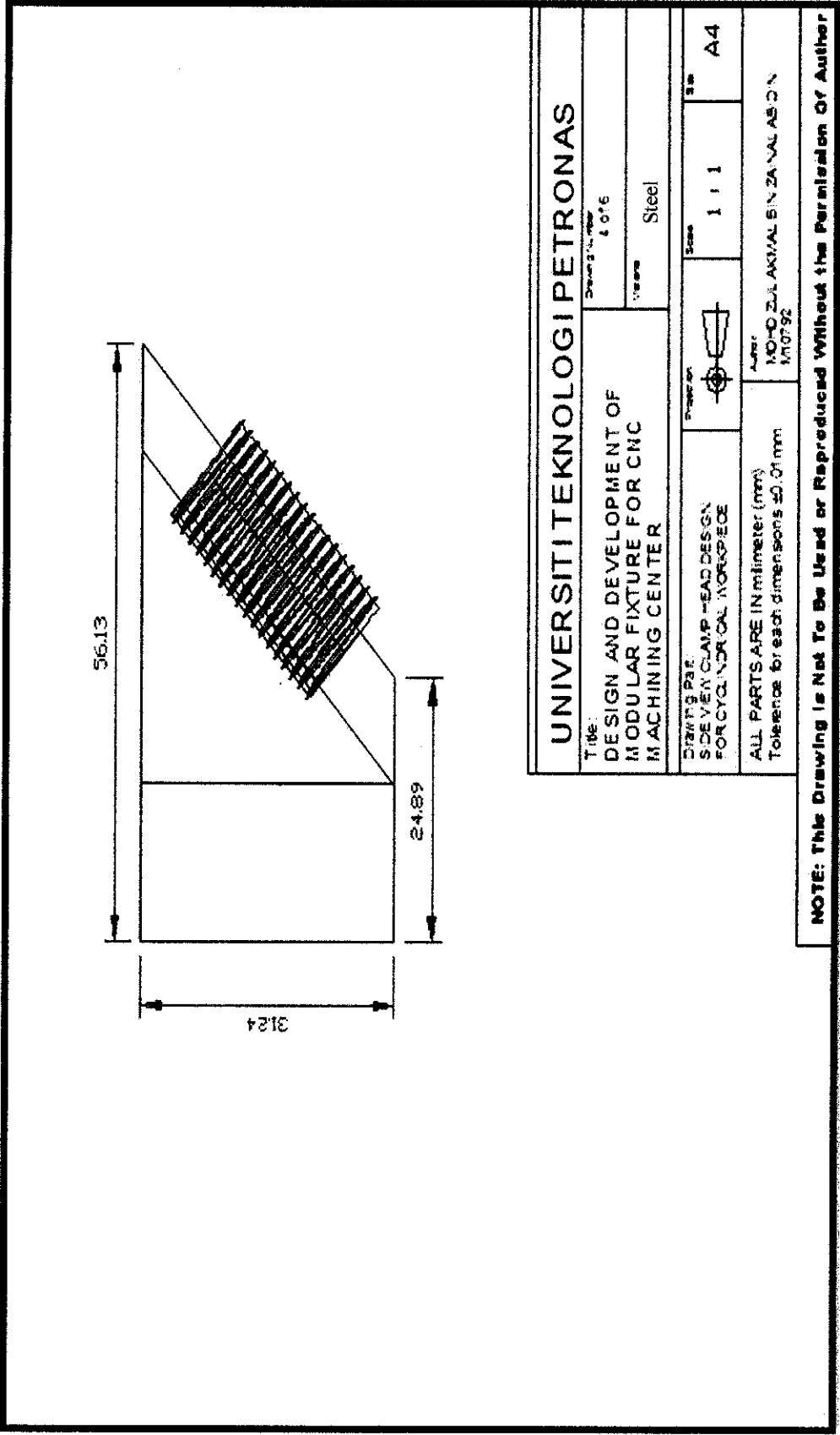**Figure 4.16:** Isometric View of Clamp Head for Rectangular Workpiece

41
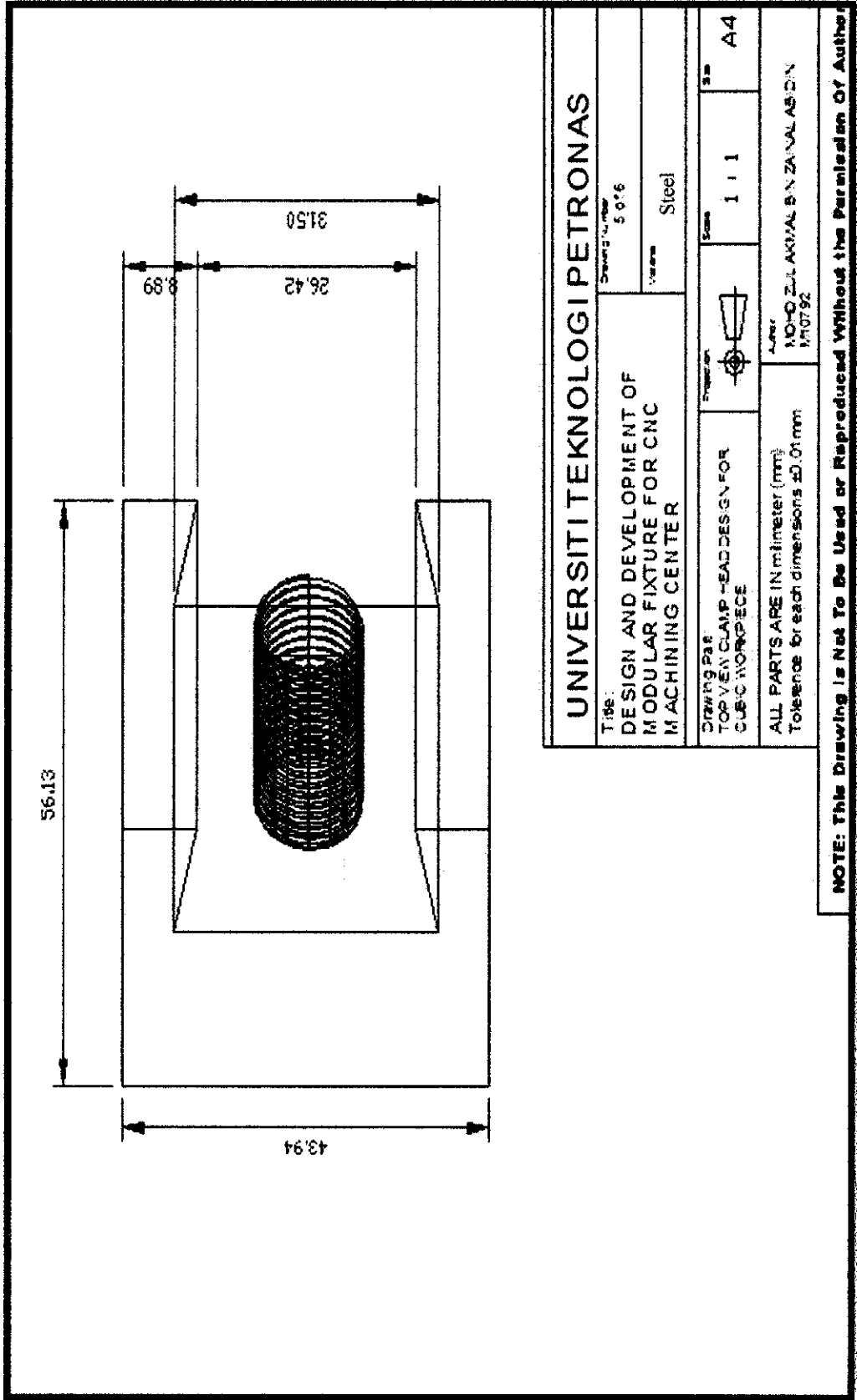
Figure 4.17: Top View of Clamp Head for Rectangular Workpiece

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Title:
DESIGN AND DEVELOPMENT OF
MODULAR FIXTURE FOR CNC
MACHINING CENTER

Drawing Part:
SIDE VIEW CLAMP HEAD DESIGN
FOR CUBIC WORKPIECE

ALL PARTS ARE IN millimeter (mm)
Tolerance for each dimensions ±0.01mm

Drawing Number: 4 of 6

Material: ALUMINUM

Scale: 1 : 1

Size: A4

Author: MOHD ZULAKMAL BIN ZAINAL ABIDIN 11870

56.13

24.89

31.24

NOTE: This Drawing is Not To Be Used or Reproduced Without the Permission Of Author

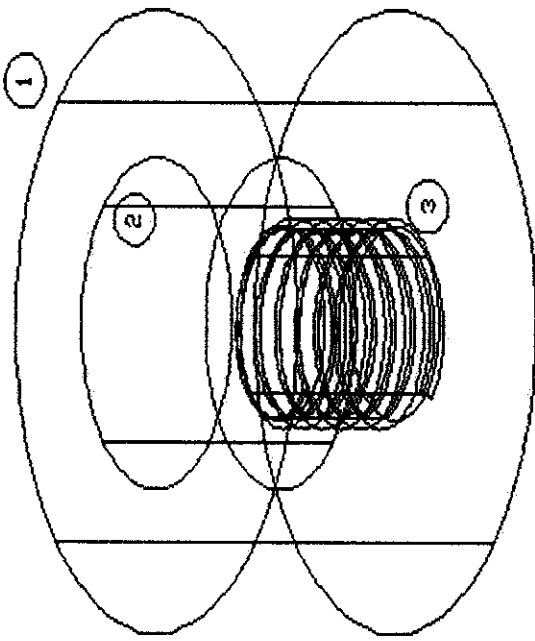Figure 4.18: Side View of Clamp Head for Rectangular Workpiece

43

NO	DESCRIPTION
1	CLAMP PRIMARY BODY
2	CLAMP BODY & HEAD FIT SLOT
3	SCREW THREAD DOCK

UNIVERSITI TEKNOLOGI PETRONAS

Drawing Number: 6 of 6

Title:
DESIGN AND DEVELOPMENT OF
MODULAR FIXTURE FOR CNC
MACHINING CENTER

Material: Steel

Size: A4

Scale: 1 : 1

Drawing Plat.
ISOMETRIC VIEW CLAMP HEAD DESIGN
FOR CYLINDRICAL WORKPIECE

Author:
MOHD. D.A. AKMAL B. V. ZANAL ABIDIN
14107 92

ALL PARTS ARE IN millimeter (mm)
Tolerance for each dimensions ±0.01mm

Figure 4.19: Isometric View of Clamp Head for Cylindrical Workpiece

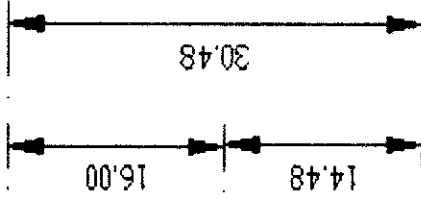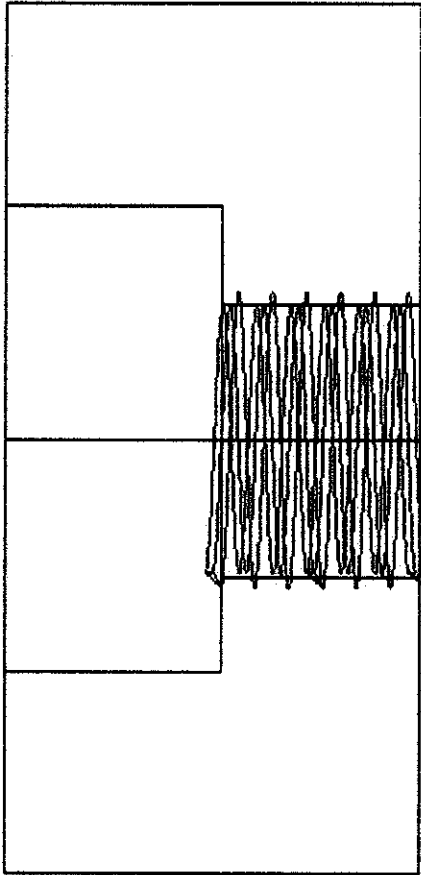**Figure 4.20:** Top View of Clamp Head for Cylindrical Workpiece

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Title:
DESIGN AND DEVELOPMENT OF
MODULAR FIXTURE FOR CNC
MACHINING CENTER

Drawing Number: 5.0*6

Material: Steel

Size: A4

Scale: 1 : 1

Drawing Part:
TOP VIEW CLAMP HEAD DESIGN FOR
CYLINDRICAL WORKPIECE

Author: MOHD ZULAKMAL BIN ZAINAL ABIDIN
11107.92

ALL PARTS ARE IN millimeter (mm)
Tolerance for each dimensions ±0.01mm

NOTE: This Drawing Is Not To Be Used or Reproduced Without the Permission Of Author

Figure 4.21: Side View of Clamp Head for Cylindrical Workpiece

Figure 4.22: Isometric View of Locator Body
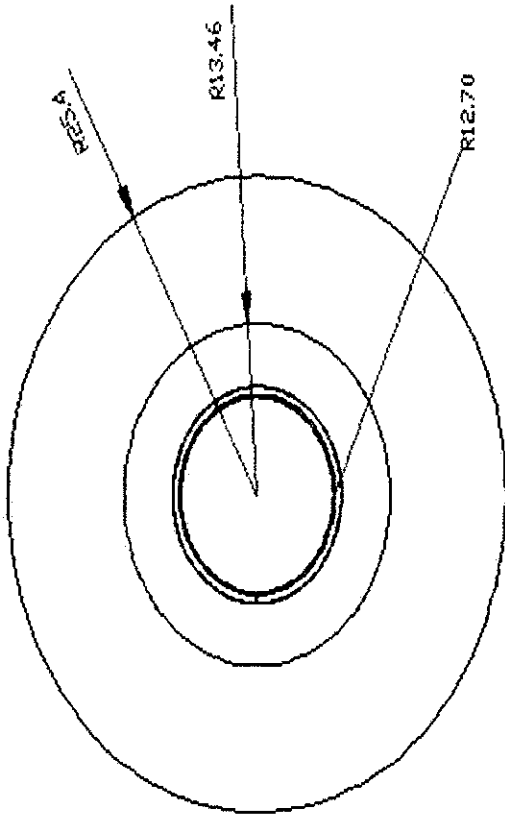
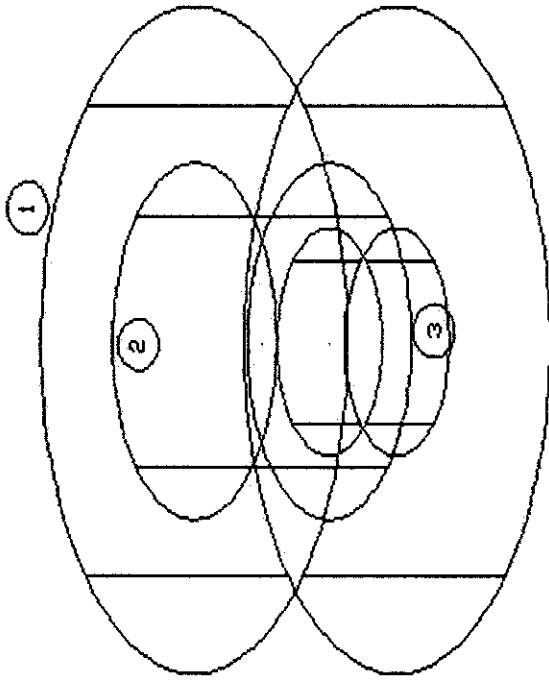| NO	DESCRIPTION
1	SUPPORT PRIMARY BODY
2	SCREW HEAD LOCK
3	SCREW THREAD LOCK

UNIVERSITI TEKNOLOGI PETRONAS

Title:
DESIGN AND DEVELOPMENT OF
MODULAR FIXTURE FOR CNC
MACHINING CENTER

Drawing Number
1 of 3

Name
Steel

Size
A4

Scale
1 : 1

Drawing Part:
ISOMETRIC VIEW LOCATORS BODY
DESIGN FOR ANY WORKPIECE

ALL PARTS ARE IN milimeter (mm)
Tolerence for each dimensions ±0.01 mm

Author
MOHD ZULKAPAL BIN ZAINAL ABIDIN
11467B2

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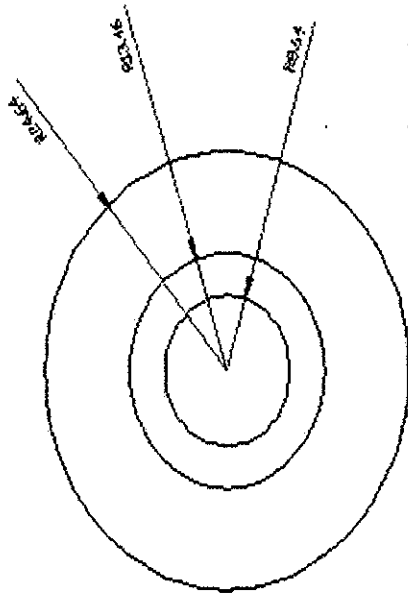
47

R25.4

R13.46

R12.70

UNIVERSITI TEKNOLOGI PETRONAS

Title:
DESIGN AND DEVELOPMENT OF
MODULAR FIXTURE FOR CNC
MACHINING CENTER

Drawing Part:
TOP VIEW LOCATORS BODY DESIGN
FOR ANY WORKPIECE

ALL PARTS ARE IN milimeter (mm)
Tolerance for each dimensions ±0.01 mm

Drawing number			
2 of 3			
Material		Steel	
Scale		Size	A4
1 : 1			
Projection	Author	MOHD ZULAKMAL BIN ZAINAL ABIDIN	
		11079.2	

Figure 4.23: Top View of Locator

48

Universiti Teknologi Petronas

DESIGN AND DEVELOPMENT OF MODULAR FIXTURE FOR CNC MACHINING CENTER

Drawing Part: SIDE VIEW LOCATORS BODY DESIGN FOR ANY WORKPIECE

ALL PARTS ARE IN millimeter (mm)
Tolerance for each dimensions ±0.01 mm

Drawing Number: 3 of 3

Material: Steel

Scale 1:1

Size A4

Author: MOHD ZULAKMAL BIN ZAINAL ABIDIN 9079

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30.48
16.00
14.48
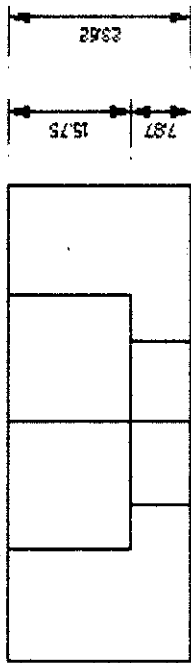
Figure 4.24: Side View of Locator

NO	DESCRIPTION
1	SUPPORT PRIMARY BODY
2	SCREW HEAD LOCK
3	SCREW THREAD LOCK

UNIVERSITI TEKNOLOGI PETRONAS

Title:
DESIGN AND DEVELOPMENT OF
MODULAR FIXTURE FOR CNC
MACHINING CENTER

Drawing Part:
ISOMETRIC VIEW SUPPORT BODY
DESIGN FOR ANY WORKPIECE

ALL PARTS ARE IN millimeter (mm)
Tolerance for each dimensions ±0.01mm

Drawing Number		
1 0f 5		
Material	Steel	
Projection	Scale 1 : 1	Size A4
Author MOHD ZULHAQMAL BNZAINAL ABIDIN 14107BZ		

NOTE: This Drawing is Not To Be Used or Reproduced Without the Permission Of Author

Figure 4.25: Isometric View of Support Body

50
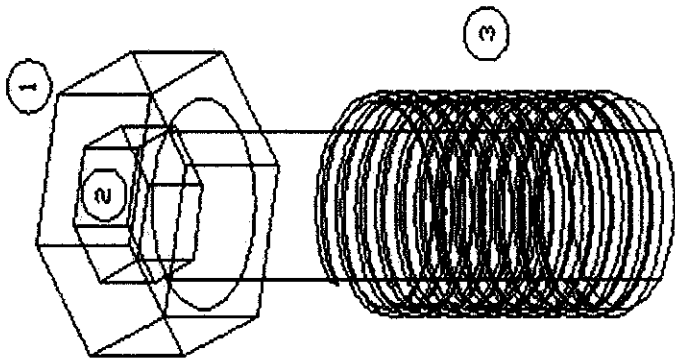
Figure 4.26: Top View of Support Body

51

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Title:
DESIGN AND DEVELOPMENT OF
MODULAR FIXTURE FOR CNC
MACHINING CENTER

Drawing Part:
SIDE VIEW SUPPORT BODY DESIGN
FOR ANY WORKPIECE

ALL PARTS ARE IN millimeter (mm)
Tolerance for each dimensions ±0.01mm

Drawing Number
3 of 3

Material
Steel

Scale
1 : 1

Size
A4

Author
MOHD ZULAKMAL BIN ZAINAL ABIDIN
16079S

NOTE: This Drawing Is Not To Be Used or Reproduced Without the Permission Of Author
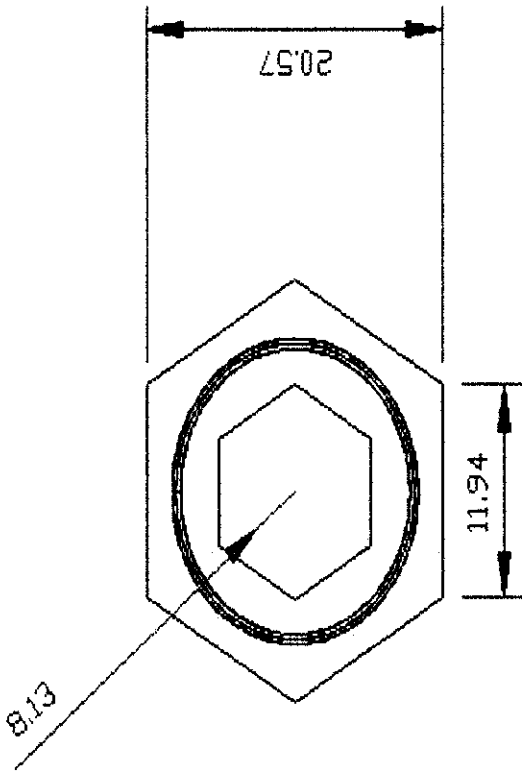
Figure 4.27: Side View of Support Body

52

NO	DESCRIPTION
1	SCREW HEAD
2	ALLENKEY HOLE
3	SCREW THREAD

UNIVERSITI TEKNOLOGI PETRONAS

Title:
DESIGN AND DEVELOPMENT OF
MODULAR FIXTURE FOR CNC
MACHINING CENTER

Drawing Part:
ISOMETRIC VIEW SUPPORT BODY
DESIGN FOR ANY WORKPIECE

ALL PARTS ARE IN milimeter (mm)
Tolerance for each dimensions ±0.01mm

Drawing Number
10°3

Material: Steel

Scale: 1 : 1

Size: A4

Author:
MOHD ZULAQMAL BIN ZANLABSON
14162796

Figure 4.28: Isometric View of Clamp Screw

53

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Title: DESIGN AND DEVELOPMENT OF MODULAR FIXTURE FOR CNC MACHINING CENTER	Drawing Number 2 of 3
	Material Steel
Drawing Part: TOP VIEW SCREW DESIGN	Scale 1 : 1	Size A4
	Author: MOHD ZUL AKMAL B N ZA VALASO N VH0792

ALL PARTS ARE IN milimeter (mm)
Tolerance for each dimensions ±0.01mm

NOTE: This Drawing is Not To Be Used or Reproduced Without the Permission Of Author.

Figure 4.29: Top View of Clamp Screw

54

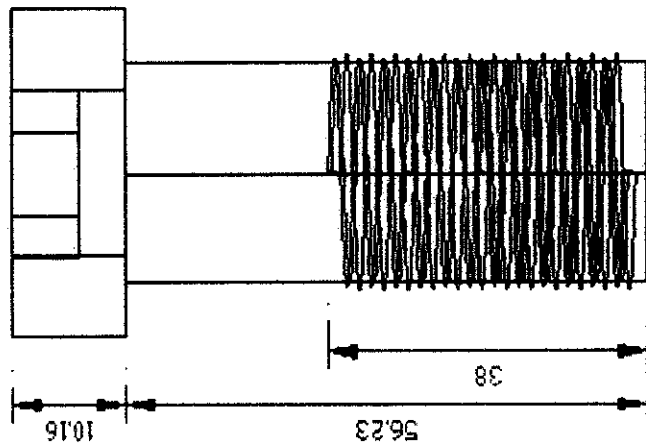UNIVERSITI TEKNOLOGI PETRONAS

Title: DESIGN AND DEVELOPMENT OF MODULAR FIXTURE FOR CNC MACHINING CENTER

Drawing Number: 3 of 3

Material: Steel

Scale: 1:1

Size: A4

Drawing Part: SCREW SCREW DESIGN

ALL PARTS ARE IN millimeter (mm)
Tolerance for each dimensions ±0.01 mm

Author: MOHD ZULAKMAL BIN ZAINAL ABIDIN, 8107.92

10.16   56.23   38

NOTE: This Drawing is Not To Be Used or Reproduced Without the Permission Of Author
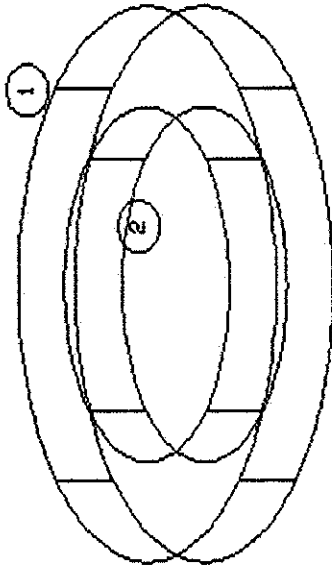
Figure 4.30: Side View of Clamp Screw

NO	DESCRIPTION
1	OUTER DIAMETER
2	INNER DIAMETER

UNIVERSITI TEKNOLOGI PETRONAS

Drawing Number
1013

Title:
DESIGN AND DEVELOPMENT OF
MODULAR FIXTURE FOR CNC
MACHINING CENTER

Name: Steel

Drawing Part
ISOMETRIC VIEW SCREW WASHER
DESIGN

Projection

Author
MOHD ZUL AQMAL BIN ZAINAL ABIDIN
14182

Scale 1 : 1

Size A4

ALL PARTS ARE in millimeter (mm)
Tolerance for each dimensions ±0.01 mm

Figure 4.31: Isometric View of Screw Washer

56

R12.7

R8.13

UNIVERSITI TEKNOLOGI PETRONAS

Title:
DESIGN AND DEVELOPMENT OF
MODULAR FIXTURE FOR CNC
MACHINING CENTER

Drawing number
2 of 3

Material
Steel

Drawing Part
TOP VIEW SCREW WASHER DESIGN

Projection

Scale
1 : 1

Size
A4

Author:
MOHD ZULAKMAL BIN ZAINAL ABIDIN
11079?

ALL PARTS ARE IN millimeter (mm)
Tolerance for each dimensions ±0.01 mm

NOTE: This Drawing Is Not To Be Used or Reproduced Without the Permission Of Author
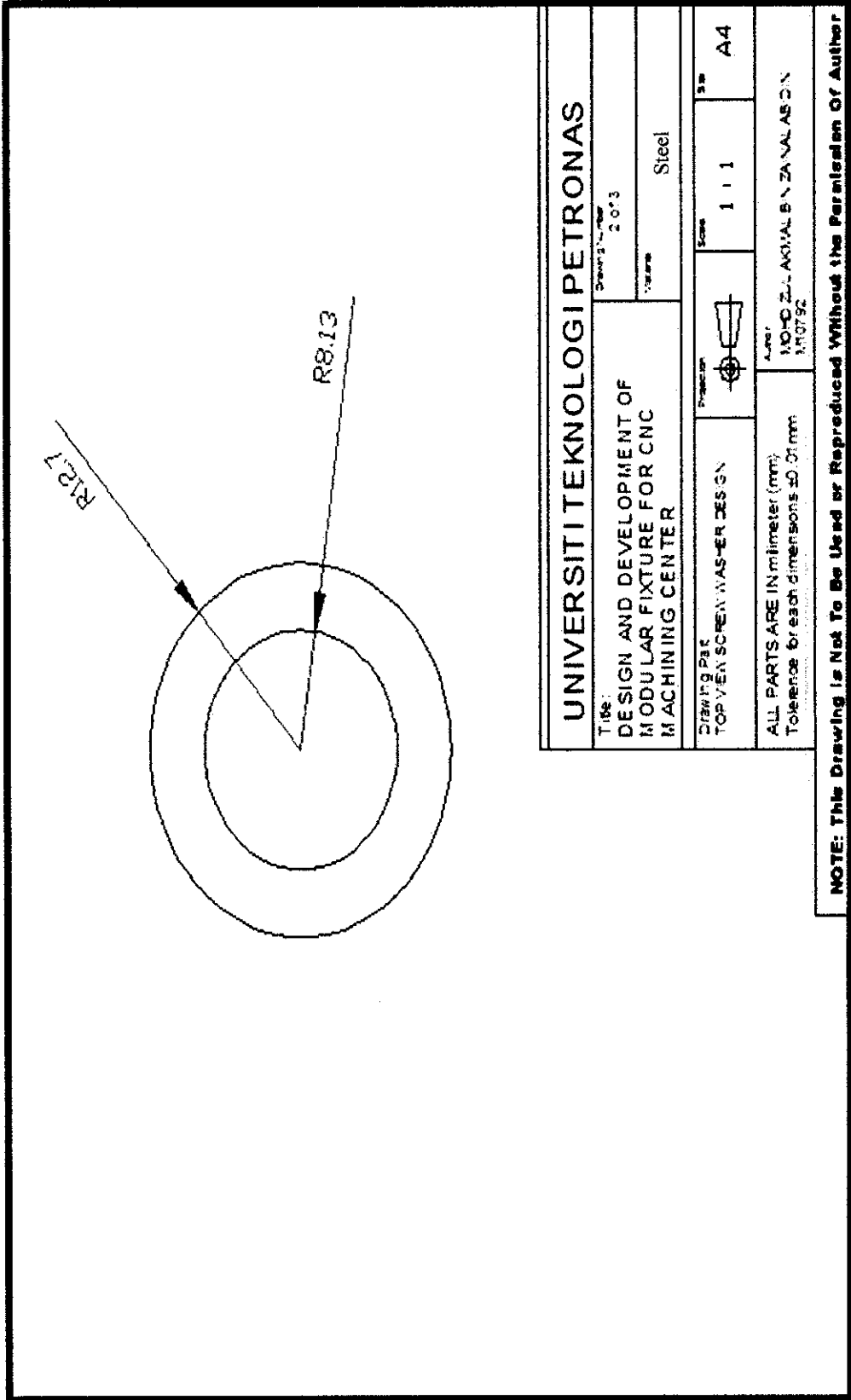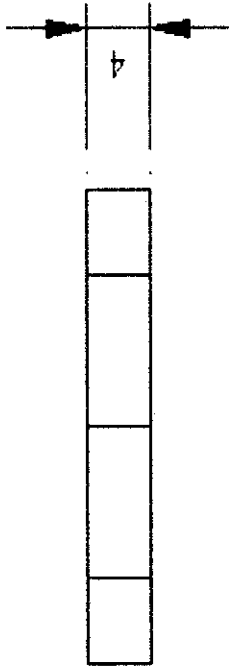
Figure 4.32: Top View of Screw Washer

57

UNIVERSITI TEKNOLOGI PETRONAS

Title:
DESIGN AND DEVELOPMENT OF
MODULAR FIXTURE FOR CNC
MACHINING CENTER

Drawing Part.
SIDE VIEW SCREW WASHER DESIGN

Drawing Number
1 of 3

Material: Steel

Scale 1 : 1

Size A4

Author:
MOHD ZULAKMAL BIN ZAINAL ABIDIN
13092

ALL PARTS ARE IN millimeter (mm)
Tolerance for each dimensions ±0.01mm

NOTE: This Drawing Is Not To Be Used or Reproduced Without the Permission Of Author.

Figure 4.33: Side View of Screw Washer

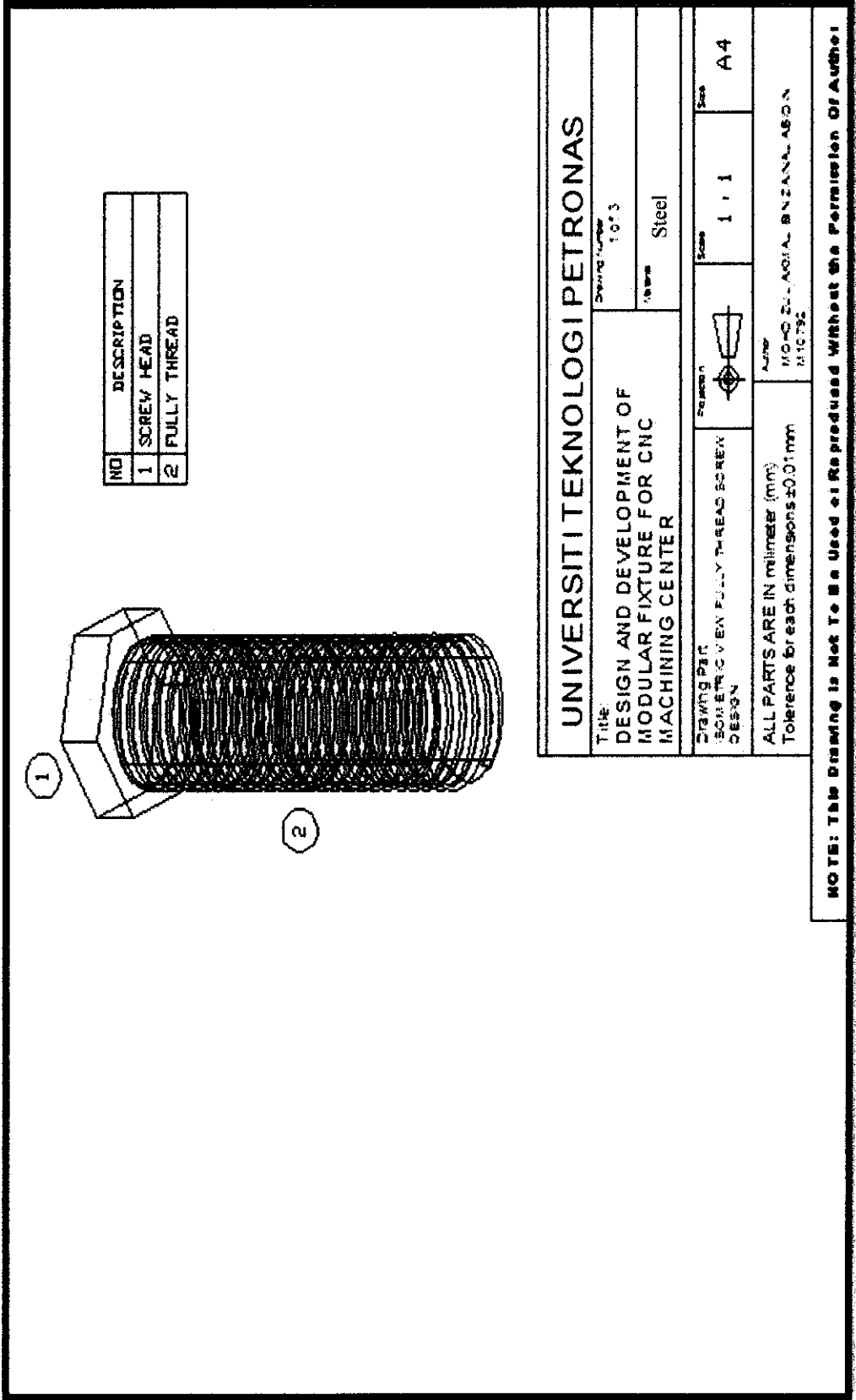| NO	DESCRIPTION
1	SCREW HEAD
2	FULLY THREAD

UNIVERSITI TEKNOLOGI PETRONAS

Title:
DESIGN AND DEVELOPMENT OF
MODULAR FIXTURE FOR CNC
MACHINING CENTER

Drawing Number
1 of 3

Materials: Steel

Drawing Part
ISOMETRIC VIEW FULLY THREAD SCREW
DESIGN

Scale 1 : 1

Size A4

Author
MOHD ZULKARNAIN BIN ZAINAL ABDIN
4810732

ALL PARTS ARE IN millimeter (mm)
Tolerance for each dimensions ±0.01mm

NOTE: This Drawing Is Not To Be Used or Reproduced Without the Permission Of Author!

Figure 4.34: Isometric View of Clamp Head Screw

59

Figure 4.35: Top View of Clamp Head Screw

R6.35

9.906

17.53

9.39
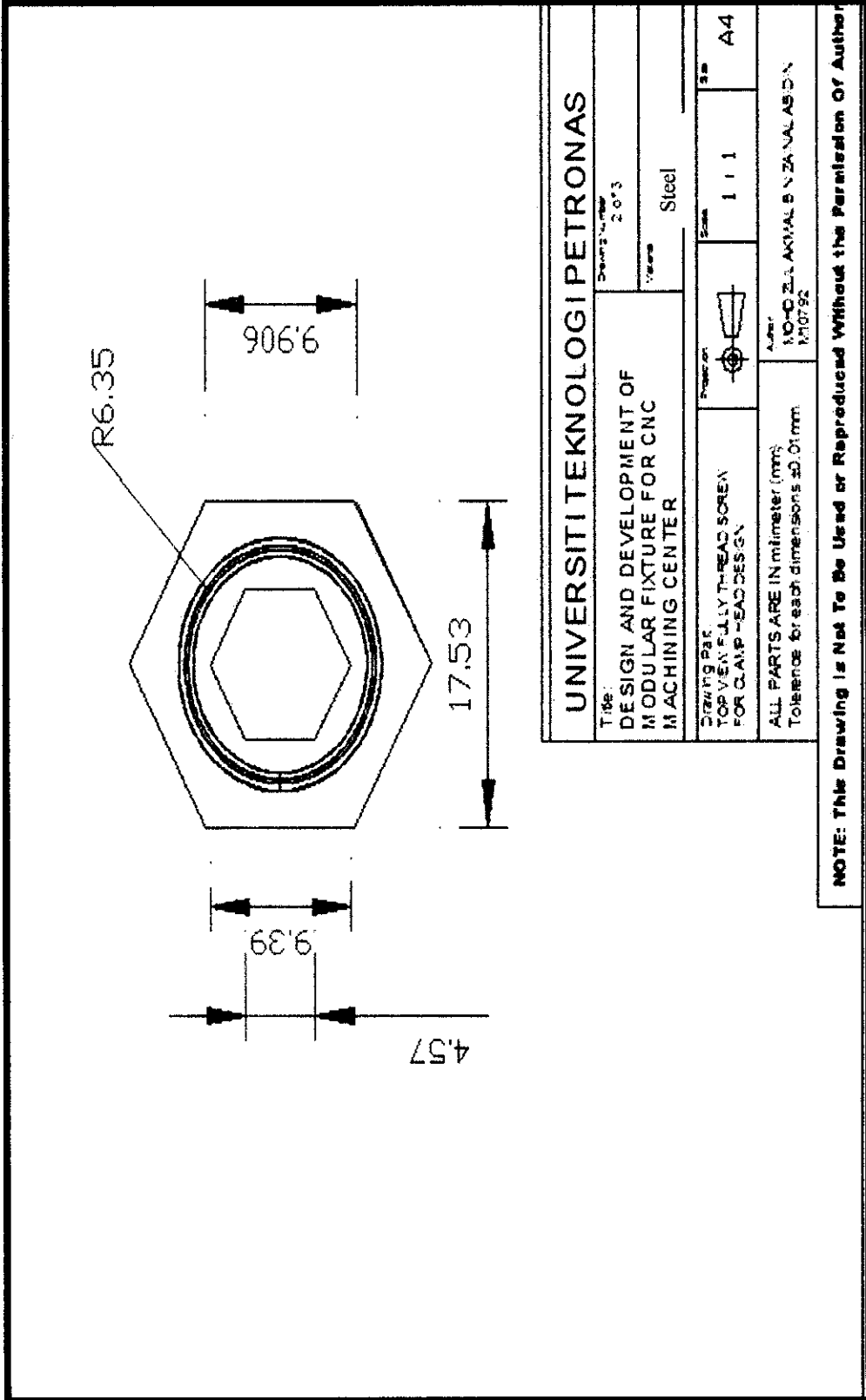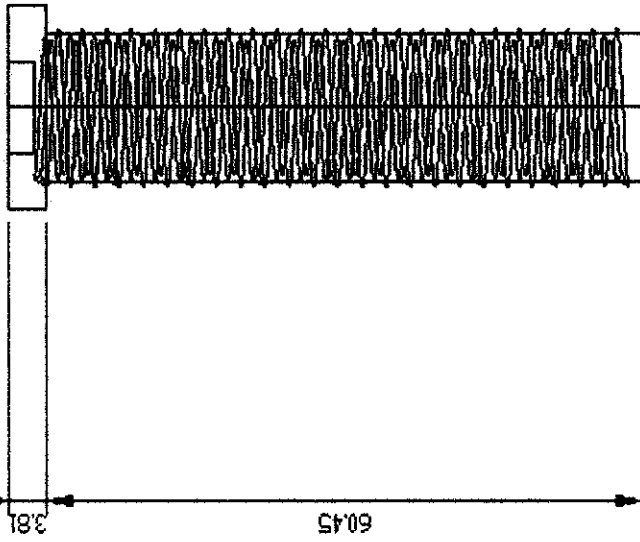
4.57

UNIVERSITI TEKNOLOGI PETRONAS

Title:
DESIGN AND DEVELOPMENT OF
MODULAR FIXTURE FOR CNC
MACHINING CENTER

Drawing Part:
TOP VIEW FULLY THREAD SCREW
FOR CLAMP HEAD DESIGN

Drawing Number:
20 of 3

Material:
Steel

Scale:
1 : 1

Size:
A4

Author:
MOHD ZULAKMAL BIN ZAINAL ABIDIN
M10792

ALL PARTS ARE IN Milimeter (mm)
Tolerance for each dimensions ±0.01mm

NOTE: This Drawing is Not To Be Used or Reproduced Without the Permission Of Author

Figure 4.36: Side View of Clamp Head Screw

CHAPTER 5

CONCLUSION & RECOMMEDATIONS

5.1 Conclusion

The main objective of this project is to design and develop modular fixture for CNC machining center which able to hold variable workpiece in terms of size and shape especially rectangular and cylindrical workpiece. The design was conducted using several tools to generate idea and the design itself such as conceptual decomposition, functional decomposition, morphological chart and Pugh's selection concept.

From the concept generation of the design, the proposed design was produced and several analysis was made such as the postitioning of the fixture equipment like locators, supports and clamp. The main components of this fixture is the clamp since it provide the force to hold the workpiece against external forces. Calculation of the force generated by the clamp has proven the clamp is capable to withstand the external forces acting on the fixture. The clamps also flexible since the clamp head can be changed according to the shape of the workpiece. By simulation using the AutoCAD, the fixture is capable of holding and constrained the movement of the workpiece during machining.

In conclusion, the design of modular fixture have been achieved where all of fixture components is desinged with details especially the dimensions, materials and the tolerances.

5.2 Recommendations

There are findings and challenges faced throughout conducting the research project. Therefore, some recommendations can be implemented so that there will be improvement for further study.

In order to know wether the fixture is capable to perform its functions, simulation need to be done where the distribution of forces initiated by the screw is fully transfered to the workpiece. Also it can help to improve the postitioning of the fixture components.

The determination of materials and tolerances have been made too briefly since time provided is not enough to study the both details. Thus, with deeper analysis specific materials and specific tolerances can be chosen of each components.

If possible the protoype of this fixture should be develop to prove wether the design is suitable for the industry in terms of efficiency, time savings and cost savings.

References

Henrikson, Erik Karl, (1972). Jig and Fixture Design Manual. New York : Industrial Press Inc. ISBN : 0-8311-10980-8.

M. Y. Wang and D. Pelinescu, (2003). "Optimal fixture layout design in a discrete domain," in Proc. 2001 IEEE Int. Conf. on Robotics and Automation, Seoul, Korea, May 2001

Kang, Y., Rong, Y. and Yang, J.C, (2003). "Computer Aided Fixture Design Verification Part 1: The Framework and Modelling", International Journal of Advanced Manufacturing Technologies, pp 827-835.

Andrew Y.C. Nee, Tao Z.J., Kumar A. Senthil, (2004). An Advanced Treatise on Fixture and Design Planning. Series on Manufacturing Systems and Technology-Vol 1.

Hoffman, Edward G, (2004). Jig and Fixture Design. fifth edition. New York : Delmar Learning, 2003. ISBN: 1-4018-1107-8.

Xiumei Kang and Qingjin Peng, (2009) "Recent Research on Computer-Aided Fixture Planning".Recent Patents on Mechanical Engineering 2009, 2, 8-18.

Kršulja, M. Barišić, B. & Kudlaček, J. (2009). "Assembly Setup for Modular Fixture Machining Process". Advanced engineering 2009. ISSN 1846-5900.

Arda Özgen, (2008). "Cutting Strategies For Forging Die Manufacturing On Cnc Milling Machines". A Thesis Submitted To The Graduate School Of Natural And Applied Sciences Of Middle East Technical University.

Serope Kalpakjian, Steven Schimdt, (2006). Manufacturing Engineering and Manufacturing Technology fifth edition. ISBN: 0-13-197639-7.

George E. Dieter, (2001). Engineering Design third edition. ISBN: 0-07-366136

Richard G. Budynas, J. Keith Nisbett. Shingley's Mechanical Engineering Design eight edition. ISBN: 978-007-125763-

APPENDIX

Table A-1: Diameters And Areas Of Coarse-Pitch And Fine-Pitch Metric Threads

Nominal Major Diameter d mm	Coarse-Pitch Series			Fine-Pitch Series		
	Pitch p mm	Tensile-Stress Area A_t mm^2	Minor-Diameter Area A_r mm^2	Pitch p mm	Tensile-Stress Area A_t mm^2	Minor-Diameter Area A_r mm^2
8	1.25	36.6	32.8	1	39.2	36.0
10	1.5	58.0	52.3	1.25	61.2	56.3
12	1.75	84.3	76.3	1.25	92.1	86.0
14	2	115	104	1.5	125	116
16	2	157	144	1.5	167	157
20	2.5	245	225	1.5	272	259
24	3	353	324	2	384	365
30	3.5	561	519	2	621	596
36	4	817	759	2	915	884
42	4.5	1120	1050	2	1260	1230
48	5	1470	1380	2	1670	1630
56	5.5	2030	1910	2	2300	2250
64	6	2680	2520	2	3030	2980
72	6	3460	3280	2	3860	3800
80	6	4340	4140	1.5	4850	4800
90	6	5590	5360	2	6100	6020
100	6	6990	6740	2	7560	7470
110				2	9180	9080

Table A-2 : Metric Mechanical-Propety Classes for Steel Bolts, Screw and Studs

Property Class	Size Range, Inclusive	Minimum Proof Strength, Mpa	Minimum Tensile Strength, Mpa	Head Marking
4.6	M5-M36	225	400	4.6
4.8	M.16-M16	310	340	4.8
5.8	M5-M24	380	520	5.8
8.8	M16-M36	600	830	8.8
9.8	M1.6-M16	650	900	9.8
10.9	M5-M36	830	1040	10.9
12.9	M1.6-M36	970	1220	12.9

Table A-3: Pima Selection Matrix Showing Which Materials And Processes Are Usually Used in Practice

Note: The PRIMA selection matrix cannot be regarded as comprehensive and should not be taken as such. It represents the main common industrial practice but there will always be exceptions at this level of detail. Also, the order in which the PRIMAs are listed in the nodes of the matrix has no significance in terms of preference.

QUANTITY \ MATERIAL	IRONS	STEEL (carbon)	STEEL (tool, alloy)	STAINLESS STEEL	COPPER & ALLOYS	ALUMINUM & ALLOYS	MAGNESIUM & ALLOYS	ZINC & ALLOYS	TIN & ALLOYS	LEAD & ALLOYS	NICKEL & ALLOYS	TITANIUM & ALLOYS	THERMOPLASTICS	THERMOSETS	FR COMPOSITES	CERAMICS	REACTIVE METALS	PRECIOUS METALS
VERY SMALL 1 TO 100	[1.5][1.7] [3.6][4.M] [3.1][5.6]	[1.5][1.7] [3.6][4.M] [3.1][5.6]	[1.1][1.7] [3.6][4.M] [5.1][5.6]	[1.7][3.6] [4.M][5.1] [5.6][5.6]	[3.5][1.7] [3.6][4.M] [5.1]	[1.5][1.7] [3.6][4.M] [5.1][5.6]	[1.6][1.7] [3.6][4.M] [5.1][5.6]	[1.1][1.7] [3.6][4.M] [5.5]	[1.1][1.7] [3.6][4.M] [5.5]	[1.1][1.6] [4.M][5.5]	[1.5][1.7] [3.6][4.M] [5.1][5.6][5.6]	[1.1][1.6] [4.M][5.1] [5.6][5.6]	[2.3] [2.5]		[2.6]	[5.6]		[5.5]
SMALL 100 TO 1,000	[1.2][1.3] [1.5][1.6] [1.7][4.M] [5.3][5.4][5.6]	[1.2][1.3][1.5] [1.7][3.6] [4.M][5.1] [5.3][5.4][5.6]	[1.1][1.7][3.6] [4.M][5.1] [5.3][5.4] [5.6][5.6]	[1.2][1.7] [3.6][4.M] [5.1][5.3] [5.4][5.2]	[1.2][1.3][1.5] [1.7][1.8][3.3] [3.6][4.M][5.1] [5.3][5.4]	[1.2][1.3][1.5] [1.7][1.8][3.6] [4.M][5.3] [5.4][5.6]	[1.3][1.6] [1.7][1.8] [3.6][4.M] [5.5]	[1.1][1.3] [1.7][1.8] [3.6][4.M] [5.5]	[1.1][1.3] [1.7][1.8] [3.6][4.M] [5.5]	[1.1][1.3] [1.8][3.6] [4.M][5.5]	[1.2][1.3][1.5] [1.7][3.6] [4.M][5.1] [5.3][5.4][5.6]	[1.1][1.6] [4.M][3.1] [5.4][5.6] [5.6]	[2.2] [2.5] [2.5]	[2.2]	[2.2] [2.6]	[5.6]		[5.5]
SMALL TO MEDIUM 1,000 TO 10,000	[1.2][1.3] [1.5][1.6] [1.7][3.7] [4.4][5.2]	[1.2][1.3][1.5] [1.7][3.1][3.2] [3.7][4.A][3.2] [5.3][5.4][5.5]	[1.2][1.3][1.5] [3.2][3.7][4.A] [5.2][5.3] [5.4][5.5]	[1.2][1.7][3.1] [3.2][3.7][4.A] [3.2][5.3] [5.4][5.5]	[1.2][1.3][1.4] [1.6][1.8][3.1] [3.2][3.7][4.A] [5.2][5.3][5.4]	[1.2][1.3][1.4] [1.5][4.M][3.1] [3.2][3.7][4.A] [5.3][5.4][5.5]	[1.3][1.4] [1.6][1.8] [3.1][3.2] [4.A][5.5]	[1.3][1.4] [1.8][3.2] [4.A][5.5]	[1.3][1.4] [3.2]	[1.2][1.4] [3.8]	[1.2][1.3][1.5] [1.7][3.1][3.2] [3.7][4.A][3.8] [5.3][5.4][5.5]	[3.1][3.7] [4.A][5.2] [3.3][5.6] [5.6]	[2.1] [2.2] [2.3] [2.4]	[2.2]	[2.4]	[5.2]		[5.5]
MEDIUM TO HIGH 10,000 TO 100,000	[1.2][1.3] [3.7][4.A]	[3.1][3.2] [3.3][3.7] [3.8][4.A] [5.5]	[3.2][3.3] [3.8][4.A] [4.2]	[3.1][3.2] [3.3][3.7] [3.8][4.A]	[1.2][1.4] [3.1][3.2] [3.3][3.7] [3.8][4.A]	[1.2][1.4] [3.1][3.2][3.3] [3.7][3.8] [4.A][5.5]	[1.3][1.4] [3.1][3.2] [3.3][3.8] [4.A]	[1.4][3.2] [3.8][4.A]	[1.4][3.2] [3.8]	[1.2][1.4] [3.8]	[3.3][3.7] [3.8][4.A] [5.2][5.5]	[3.7][3.8] [4.A][5.2] [5.5]	[2.1] [2.3] [2.4] [2.7]	[2.1] [2.2] [2.7]	[2.2] [2.7]	[3.7]		[3.5]
HIGH 100,000+	[1.2][1.3] [3.7]	[3.1][3.2] [3.3][3.8] [4.A]	[1.1][1.6] [3.4][3.5]		[1.2][3.2] [3.3][3.7] [3.8][4.A]	[1.2][1.3] [3.4][3.2] [3.3][3.8] [4.A]	[1.2][1.4] [3.1][3.8] [4.A]	[1.4][3.2]		[1.4][3.2]			[2.1] [2.4] [2.7]	[2.1] [2.2] [2.7]	[2.2] [2.7]	[3.7]		[3.5]
ALL QUANTITIES	[1.1]	[1.1][1.6] [3.4][3.5]	[1.6]	[1.1][1.6] [3.4][3.5]	[1.1][1.6] [3.4][3.5] [5.5]	[1.1][1.6] [3.4][3.5]	[1.1][3.4] [3.5]	[3.4][3.5]		[1.4][3.2]	[1.1][1.6] [3.4][3.5]	[3.4][3.5]				[5.5][3.5]	[1.6][1.6]	[1.6]

KEY TO MATRIX:

[1.1] SAND CASTING
[1.2] SHELL MOLDING
[1.3] GRAVITY DIE CASTING
[1.4] PRESSURE DIE CASTING
[1.5] CENTRIFUGAL CASTING
[1.6] INVESTMENT CASTING
[1.7] CERAMIC MOLD CASTING
[1.8] PLASTER MOLD CASTING

[2.1] INJECTION MOLDING
[2.2] COMPRESSION MOLDING
[2.3] VACUUM FORMING
[2.4] BLOW MOLDING
[2.5] ROTATIONAL MOLDING
[2.6] CONTACT MOLDING
[2.7] CONTINUOUS EXTRUSION (PLASTICS)

[3.1] CLOSED DIE FORGING/ UPSET FORGING
[3.2] COLD FORMING
[3.3] COLD HEADING
[3.4] SHEET METAL SHEARING
[3.5] SHEET METAL FORMING
[3.6] SPINNING
[3.7] POWDER METALLURGY
[3.8] CONTINUOUS EXTRUSION (METALS)

[4.A] AUTOMATIC MACHINING
[4.M] MANUAL MACHINING
(THE ABOVE HEADINGS COVER A BROAD RANGE OF MACHINING PROCESSES AND LEVELS OF CONTROL TECHNOLOGY. FOR MORE DETAIL, THE READER IS REFERRED TO REFERENCES ON THE INDIVIDUAL PROCESSES.)

[5.1] ELECTRICAL DISCHARGE MACHINING
[5.2] ELECTROCHEMICAL MACHINING
[5.3] ELECTRON BEAM MACHINING
[5.4] LASER BEAM MACHINING
[5.5] CHEMICAL MACHINING
[5.6] ULTRASONIC MACHINING

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