Design and Development of Fixture for Lathe Machine to Perform Milling Operations

A thesis submitted by

TIGIST ALEMAYEHU

For the Partial fulfillment of the

Requirement for the award of degree

Of

Master of Science

In

Manufacturing Engineering

Under the Supervision & Guidance of

Dr. Perumalla Janaki Ramulu (PhD)

Associate Professor& Director for CoE-AME

Mr. Dufera Bulto (MSc)

Lecturer

Mechanical Design & Manufacturing Engineering Program

School of Mechanical, Chemical and Materials Engineering

Adama Science and Technology University

Adama, Ethiopia

May 2018

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

School of Mechanical, Chemical and Materials Engineering

Design and Development of Fixture for Lathe Machine to Perform Milling Operations

By

TIGIST ALEMAYEHU

ID No: GSR 1486/08

Approved by Board of Examiners

______________________	________	______
Chairman, Department Graduate Committee	Signature	Date
______________________	________	______
Major Advisor	Signature	Date
______________________	________	______
Co-Advisor	Signature	Date
______________________	________	______
Internal Examiner	Signature	Date
______________________	________	______
External Examiner	Signature	Date

DECLARATION

I hereby declare that the project entitled "***Design and development of fixture for Lathe machine to Perform milling operations***" for the Master's Degree is my original work and the project has not formed the basis for the award of any degree, associate ship, fellowship or any other similar titles.

All examiners' comments are duly incorporated.

Name: Tigist Alemayehu

Signature of the student______________________

Place_____________________________________

Date of submission: ____________________________________

This thesis has been submitted for examination with my approval as a university advisor.

Dr. Perumalla Janaki Ramulu

Advisor's Name Signature

Mr. Dufera Bulto (MSc)

Co-Advisor's Name Signature

ACKNOWLEDGMENT

First of all, I would like to thank the almighty God who helps me from the beginning to the end. I want to offer my appreciation to my advisor **Dr Perumalla Janaki Ramulu** for his insightful direction and Guidance throughout the project. His supports have been invaluable in realizing and completing this project. I would like to give my gratitude to **Mr. Dufera Bulto** for his support and time.

Ato Dawit for his kind cooperation and professional advice that was appreciable in design concepts. I am truly appreciated for **Ato Shewatatek** for his full guidance in the manufacturing process and reviews on my thesis. It has been a great learning experience. It gives me immense pleasure to express my deep sense of gratitude to **Ato Tsege** and **Ato Samuel** (Machinist) for their contribution in Hibret manufacturing and machine building industry (HMMBI) to the successful completion of fabrication process.

In addition, my parents who have offered me a tremendous amount of support and love. I am truly fortunate and happy to have such a wonderful support.

ABSTRACT

In the small-scale manufacturing industries, the purchasing of machineries is a challenge to survive in the current market competition. The under developed and developing countries needs more attention on small scale manufacturing industries where machineries are limited. These industries play a vital role with respect to economy, employment and entrepreneurs etc. to any kind of nation. From the needs and deeds of small-scale manufacturing industries, the objective of the thesis is aimed to design and fabricate the fixture that has major impact in performing multiple operations on a single machine. The study had been included a detail design analysis of components, complete fabrication process and feasibility study of the fixture. The design methods used were based on the design concepts and stress analysis. Modeling was done using CatiaV5 and Solid works, Master CAM for manufacturing and TESA RUGOSOFT for feasibility study. The study was focused on the geometrical configuration and surface roughness tests. Face milling and keyway milling operations on Aluminum alloy workpiece were carried out on vertical milling machine and conventional lathe machine to check the practicability of the fixture. The machining was done within three stages of standard cutting parameters, feed, depth of cut and spindle speed. The test was recorded forty-eight times by adjusting cutting parameters. By taking the average value of each step, the optimal value for the best surface finish has been determined at 0.01m/min feed, 2mm depth of cut and 630rpm spindle speed. From the experimentations, it is observed that surface roughness increases with an increase in feed rate and depth of cut. From the optimal parameters, the best result of surface roughness for the workpiece manufactured by milling machines is R_a=1.4217 and for workpiece manufactured by fixture is R_a=1.6585 which are relatively similar. Also the geometrical configuration test of the keyways proved that the fixture can perform similar work as that of milling machine.

Keywords: *Attachment; Fixture; CNC machine center, turret lathe; Milling; keyways; Aluminum alloy; surface roughness.*

Contents **Page No**

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND SYMBOLS

Z	Flute length
l	Length of the cutter
L	flute length
D	Tool diameter
w	Width of the cutter
k	Lead angle
γ	Rake angle
α	Clearance angle
a_e	Axial depth of cut
a_c	Radial depth of cut
fz	Feed per tooth
F/rev	Feed per revolution
k_t	Tangential force equation
k_r	Radial force equation
t_{cave}	Average chip thickness
t_{uc}	Uncut chip thickness
t_{max}	Maximum chip thickness
Fc	Total cutting force
n	Spindle speed
σ	Normal stress
τ	Shear stress
σ_s	Slip stress
σ_b	Bearing stress
M	Bending moment
R_a	Roughness average
R_z	Average maximum height of the profile
R_q	Root mean square (RMS) roughness
R_t	Maximum height of the profile
N	Economic life
D	Depreciation charge

P Initial purchase price

S Salvage value

NC Numerical control

CNC Computer numerical control

RPM Revolution per minute

MPM Millimeter per minute

HSS High Speed Steel

SMEs Small and medium scale

VMM Vertical milling machine

MLM Modified lathe machine

HMMBI Hibret Manufacturing and machine building factory

EELPA Ethiopian Electricity and Light Power Agency

CHAPTER ONE

1. INTRODUCTION

1.1 INTRODUCTION AND BACKGROUND OF STUDY

Lathe and milling operations are the most common machining operations that are used to make different tools and components. Lathe has always been the mother of all machines before the invention of Computer Numerical Control (CNC) machines. The turning operation on lathe is most frequently performed operation that has done at the beginning of circular tools, and then it is transferred to milling, grinding or other machining processes to get the required shape of the workpiece and surface finish. The required time to perform this is generally huge and loading and unloading of job causes human fatigue. Thus, combining different operations on single machine would benefit and led to think multiple operations to be processed on one machine. There are different types of attachments on lathe machine that can perform many kinds of machining operations.

Now a day in Ethiopia, there are many number of small scale industries which involved in engineering works. The manufacturers in Ethiopia produces their products by a limited number of machineries by which production rate become small. Mostly, these industries are highly dependent on conventional machining techniques. Eventhough, the process is conventional, the cost of these machines is very high. These small-scale industries are purchasing and importing the machines at high cost. Specially, used lathe and milling machines are purchasing with a cost of 250,000 birr and 350,000 birrs. Due to this high cost, these industries have limited number machines i.e. only lathe machines and have no or have a single milling machine. Therefore, the production is become time consuming. The main aim behind this research is to develop the milling fixture for lathe machine to reduce the number of machines required to perform the desired work by working those operations in one machine. Most milling operations like keyways, slots, flat surfaces, grooves and finishing the edge of workpieces are made by end mill cutter. Here after these can be processed on the conventional lathe machine without waiting for milling machine. Though the developed lathe machine with additional fixture is kept common for lathe and milling operations. If necessary, the fixture can be disassembled to do the lathe operation. So, it is essential to design and manufacture this fixture in order to reduce the problems occurred in production processes.

In Ethiopia, there are more than 40 governmental technological universities under Ministry of Science and Technology (MOST) and Ministry of Education (MOE). These universities were divided in to three generation as first, second and third generation universities. The second and the third-generation universities have engineering schools but don't have organized laboratories and workshops. Especially mechanical workshops are not fully organized but lathe and grinding machines are available. Most of these workshops don't have milling machines. Consequently, these universities take their students to other universities for 15 days of lab work in their semester breaks. So, students are requested to prepare a report from their lab work they had observed in workshop which is not effective and efficient for engineering schools to gain practical knowledge efficiently. Therefore, this limit the universities to meet their goal in creating competitive intellectual students. For such cases this kind of fixtures can help students to know common milling operation by working on the available lathe machine in their university.

1.1 Statement of problem

Ethiopia is following the policy of industry based development that promote many small and medium scale industries to enter in to the manufacturing business that produce different kinds of tools, spare parts and automotive parts. Universities that don't have milling machine in their workshop are also facing a problem of giving integrated knowledge for their students. But, in this dynamic world, small scale industries are facing very tough competition from large scale industries which is difficult for them to survive with an option of having one or two machines. Most machining operations done on lathe machine should wait until the milling machine is free to do the milling operation. Otherwise they need to transport semi-finished products to other industries.

This causes

- Extra labor cost
- High transportation cost
- Long process time from raw materials to finished product
- Delayed due date

By selecting a way of maximizing capacity of available machines through adding fixtures, a small-scale industrial can save huge amount of time, energy, and money hence forth increasing the overall efficiency and effectiveness of the industry and the country.

1.2 Objectives

1.2.1 General Objective

The main objective of the project is to design and fabricate the milling fixture for a conventional lathe machine to perform milling operations.

1.2.2 Specific Objectives

The specific objectives of the thesis are:

- Designing and Fabricating of milling fixture for a conventional lathe machine
- Performing end milling and keyway using the fabricated fixture
- Testing of geometrical configuration and surface finish of the workpiece produced by fabricated fixture
- Investigating the workability of the workpiece

1.3 Significance of the project

The following benefits can be achieved through designing and developing milling attachment on lathe machine for the industry.

- Reduce dependency on milling machine
- Provide locally available attachment with low cost
- Delivers supplemental milling machine for conventional lathe which is effective and easily maintained
- Benefit small and medium scale industrial sectors to achieve profit by using small man power and reduce unnecessary costs
- Benefit new universities that don’t have milling machines in their workshop
- Facilitate the production process as per customer specification and delivery date

1.4 Scope of the project

The scope of the study is to perform milling operations done by end mill cutters for soft materials like Aluminum and brass, on the conventional lathe machine. The work mainly focuses on improving the process of keyway and irregular shape milling operation on lathe machine.

1.5 Methodology

The methodology activities include

- Referring to documents related to fixture design (literature review)
- Choosing & modifying a better design

- Design analysis and material selection
- Fabricating a milling fixture using different manufacturing processes
- Testing the fixture

1.6 Limitations

Due to time limitations components are not analyzed by ANSYS static structural analysis. And manual technique was used to determine the optimal cutting conditions.

1.7 Organization of the thesis

This study is consisting of six chapters;

Chapter One describes a general introduction of the Thesis or the project. Chapter Two presents' literatures review about jig and fixture for lathe machine to perform additional processes. Chapter Three Materials and methods of the design and fabrication process of the critical components. Chapter Four presents experiments to test the product made by the designed fixture on lathe machine. Chapter five covers results and discussion from the experiment. Finally, Chapter Six give a short recommendation and conclusions.

CHAPTER TWO

2. LITRETURE REVIEW

2.1 Introduction

A literature review was performed to understand the use of jig and fixture systems for different kinds of machining operations. Much research had been done on the different attachments on lathe machine to study the configuration and uses of adding fixtures for many purposes. These studies reveal a great insight into various fixturing schemes. Since, Manufacturing industries are in intense global competition, and stricter demands for reduction in cost and total in-process time while the competition with large industries increase year after year. As a result, the production system that can produce a wide variety of components in small lot sizes in response to fluctuations in demand with small floor space requirements is strongly demanded. Aguilar *et al.* (2013) stated that to fulfill the demand for different kinds of obstacles one way was using jig and fixtures.

2.1.1 Introduction to Jig and fixture

Jigs are defined as the device which holds and positions the work piece, which locates or guides the cutting tool related to the workpiece and usually are not fixed on the machine table.

Fixtures are special devices designed to hold workpiece for specific operations more efficiently than standard work holding devices and useful when large numbers of identical parts are being produced. However, when the numbers of parts are large enough to justify its cost, a fixture is generally used for holding and locating the work. A typical fixture contains a base plate, locators, clamps and guiding elements. The goal of a fixture is to provide the constrained workpiece with a quasi-equilibrium environment throughout an entire machining operation which includes setup and material removal.

Campbell (2005) described utilization of fixtures minimizes the time for loading, locating, clamping and unloading. The term work-holder embraces all devices that hold, grip, or chuck a work-piece in a prescribed manner of firmness and location within a manufacturing operation. Fixture are required in various industries according to their application. This can be achieved by selecting the optimal location of fixturing elements such as locators and clamps. The fixture setup for component was done manually. For that more cycle time required for loading and unloading the material. So, there is need to develop system which can help in improving productivity and time. Fixtures reduce operation time and increases productivity and high quality of operation was possible. Fang (2009) discussed the functions of fixture during a material removal process. The work-holder was identified as a machining fixture or simply called fixture. The specific functions of a fixture within a machining process were as a support for the work-piece in a precise location and orientation. The physical characteristics of a workpiece such as material properties, size, shape, and weight govern the overall structural integrity of a fixture. A fixture must be able to provide tool path clearance to enable tool access into the machining surfaces. A fixture should allow access in loading and unloading of the work-piece efficiently. This was very critical for a high production volume environment. The fixture provides the safety to all users by containing all components from being dislocated during a machining process. In additional, the costs of a fixture should be economical. Fang also discussed in his paper that the two methods of designing a machining fixture that were cut-and-try and analytical approach.

The cut-and-try method involves building a fixture and trying out the proposed machining operation. The analytical approach determining the magnitudes and directions of the cutting forces, and then following a step-by-step determination of designing a fixture that can withstand the cutting forces. The analytical approach is not widely used in the industry due to the extensive time required. The analytical approach might not be practical because the calculation results might require having fasteners of different diameter at each attachment point to match the anticipated load. This creates difficulties for installation and maintenance. Tool designers usually apply the analytical approach mentally without any mathematical computations. However, the analytical approach must always predominate to ensure proper structural integrity of a fixture. Though this project tries to design the fixture using this analytical approach.

2.1.2 Elements of Jigs and Fixtures

The element of Jig and fixture are locating elements; to position workpiece accurately. Clamping elements; to hold workpiece securely and tool guiding and setting elements to aid guiding or setting of the tools in correct position with respect to the workpiece. Locator and clamping elements are discussed below in detail referring from different authors.

A. Locators

There are six requirements for choosing the locating points within a fixture each point of contact between the locators of a fixture and workpiece should eliminate one degree of freedom up to six points for total of six degree of freedom (Fang (2009)). This will determine the proper placement of locating points. The conditions of the locating surface should be considered. A finished surface of a work-piece may be acceptable to have a full 360° locating surface. When the surface of a workpiece is a non-finished surface, more than three points in a plane do not improve locating purposes, but may promote stability and give extra support (Kaya (2006)). The shape of a work-piece affects both the shape and location of locators. The location of the machining surface governs the locating points within a fixture. The locating supports should be as close to the machining surface as possible for maximum support.

B. Clamps

Fang (2009) discussed the purpose of clamping is to firmly hold a work-piece against the locating points or surfaces and to secure a workpiece against all cutting forces. A clamp must direct and maintain a force onto the workpiece. There are four main considerations of choosing clamps. These are size of the clamping force is affected by the type and positions of the locators, the availability of clamping surfaces, the conditions of clamping surfaces and the directions and magnitude of cutting forces. The clamping forces applied against the work-piece must counteract the cutting forces. The clamping pressure should not be large enough to change the dimension of a work-piece. The source and size of the force which is available for actuating the clamp will determine the type and size of a clamp. In the industry, the clamps can be tightened manually using a torque wrench. Shailesh and Laukik (2014) stated that there were many kinds of fixtures that were different with their applications. They were classified by the machine or by the process. Such as Milling fixtures, Lathe fixtures, Grinding Fixtures, Surface grinding fixtures, Cylindrical grinding fixtures, Boring fixtures, Broaching fixtures and Sawing fixtures.

2.1.3 Consideration in the Design of Jig and Fixture

In the design of Jig and fixture, there were many considerations that the designer should give focus for the work. These are general, machine, process and product considerations. In general considerations cost vs. benefit, fixture required an economics are considered. On the other side machine considerations are machine tool information from the international guides, Condition of workpiece: which one should move, what should be the weight and size of the work piece, and selecting of proper tool for the Job, from the standard cutters. In Process Considerations, the best and fast method for the operation is certain and holding vs. cutting forces are calculated. Lastly Product Considerations emphases on what does the product allow? Location and clamping surfaces, areas to machine and precision and changes earlier rather than later.

2.2 Attachments

Attachments are used in various fields and machines depending upon the needs to be fulfilled and mode of operation. It eliminates the purchasing of a new unit which serves the same purpose. Each general purpose conventional machine tool is designed and used for a set of specific machining work on jobs of limited range of shape and size. But often some unusual work also need to be done in a specific machine tools, e.g. milling in a lathe, tapping in a drilling machine, gear teeth cutting in shaping machine and so on. Under such conditions, some special devices or systems are additionally used being mounted in the ordinary machine tools which is called attachments.

2.2.1 Conditions and places suitable for application of attachments in machine tools

Some attachments are occasionally still being used on non-automatic general-purpose machine tools in some small and medium scale machining industries especially in developing countries where:

- Machining facilities are very limited
- Production requirement is small
- Frequently product changes as per job order
- Repair work under maintenance, especially when spare parts are not available
- When CNC machine tools and even reasonable number of conventional machine tools cannot be afforded

Therefore, use of aforesaid attachments is restricted to manufacture of unusual jobs in small quantities under limited facilities and at low cost. There are many kinds of attachments on lathe machine. The one which is most popular is milling attachment.

2.2.2 Milling attachment on lathe machine

Milling attachment is a major type of attachment to perform different kinds of milling operation fixed on lathe machine. Such as cutting of grooves or keyways and gears. The attachment for cutting grooves or keyways is one type of attachment that fits to the lathe machine carriage which is used for milling of slots, flats, or keyway cuttings on lathe mounted work-pieces. Here, the workpiece is held on the cross slide by using a special attachment and the end milling cutter is held in the chuck. Then the feed is given by a vertical slide provided on the special attachment. The other attachment for cutting multiple grooves and gear using a milling head, comprising a motor, a small gear box and a spindle to hold the milling cutter, mounted on the saddle after removing the cross slide etc. The workpiece is held stationary between centers. Grooves are made on the periphery of the workpiece by rotating the work piece.

2.3 Historical review of different attachments

Many researchers had conducted many experiments and tried to studies the effect and advantages of processing different operations on single lathe machine. These researchers had done many experiments and detect the effects of type of material for workpiece and cutter, process parameters and machine tool while doing those operations on lathe machine that can work additional operations. Ahn *et al.* (2006) done side-milling on an automatic lathe to show how different machining process can be produced in single machine. The study investigated cutting characteristics of side-milling which was proposed as a more efficient way to manufacture worms of higher accuracy than form-threading and planetary milling. Chip thickness, cutting force and surface roughness were simulated using the calculated tool-tip trajectories. The effects of various errors in the real cutting such as run-out errors of a tool axis, tool setup errors and work-piece deflection due to cutting forces were investigated and optimal cutting conditions and the tool tip run out were determined in the paper.

Nagae *et al.* (2012) discussed the history and structure of multi-tasking machine tools and how they are used recently. Their work showed that using of this machine tool reduce the total production lead time from supply of raw material to the finished product. Therefore, as long as there continues to be strong customer demands for higher efficiency, the evolution of multi-tasking machines will continue in the future resulting in further improvements in productivity. Aguilar *et al.* (2013) demonstrated satisfactorily the reconfiguration characteristics of modularity, integrality, and convertibility by developing, designing and prototyping a new lathe-mill reconfigurable machine tool. It documented the design, refinement, and implementation of a reconfigurable machine tool that provides a flexible platform for turning and milling. The study recommended that advances in the design and capabilities of machine tools is a drive to modern industry. In fact, the expanding capabilities of the machines permit economic changes in the manufacturing and design of products. Albua (2013) approached with the idea of roughing of the helical flanks of the worms with frontal-cylindrical milling tools on numerical control lathe machine. The work found the milling position and determined on the basis of the contact between the toroid surface of frontal-cylindrical milling tool and a helical surface, so that it remains the desired addition of processing. He positioned the milling perpendicular to the axis of symmetry of the half-product to obtain different diameters, with the different mill position. The study concluded that the processing can be done with mono-block mills or with milling tools with removable plates, by positioning the tool according to the calculations made using the program by viewing the tool position. Albua and Bolos (2014) experimented and conducted the possibility of processing the worms on machine tool CNC in small series can be made by milling using mono block frontal cylindrical milling tools or milling heads with removable plates. In this case worm roughing using milling heads with removable plates has much smaller cost.

Grinding attachment for lathe machine was proposed by (Partik *et al.* (2015)) and described an attempt to decrease the time in loading and unloading of workpiece with desired surface finish. The attachment was fabricated and mounted successfully according to the proposed design. In the research the attachment was mounted and a considerable reduction in the human effort required in loading and unloading the workpiece was obtained. Which also led to reduction in the lead time. By using the attachment the researchers found an accuracy of up to 20 microns with fine surface finish. Kumar (2015) conducted a research on grinding attachment. The cylindrical grinding process yields out to be a low-cost operation. He used the regression equations for surface roughness and variable process parameters under dry and wet condition to reveals that cylindrical grinding attachment was very useful for finishing the cylindrical shafts on lathe, up to 0.1µm. So, by applying regression analysis under dry and wet conditions he found the optimal input (speed, feed rate and depth of cut) values for good surface finish. Kumar (2016) designed and fabricated gear cutting attachment for lathe to machine a spur gear. Which results an output of cost effectiveness in spur gear manufacturing as compared to other gear cutting attachments. The medium duty center lathe of standard power 2.5kW which is capable of cutting spur gears up to a diameter of 30mm and module between 1 and 2 can be generated. The paper proved that the profile quality obtained was comparable to milling which will be helpful to small and medium industry. The Milling attachment was an effective tool for modern industrialization which helped to improve the productivity and quality of keyway operation. Shedbale (2017) described milling attachment to easy operation of keyways. By using this attachment, located the exact center of keyway and found fine surface roughness which was good for soft materials like, Brass, Aluminum and rough surface roughness for material like mild steel. The research revealed that the time of changing for the job from one machine to another for keyway operation was reduced.

Summary of Literature Review

All of the research publication mentioned above gives different approaches towards operating additional operation on lathe machine and benefits of having different fixture on lathe machine. Various researchers developed and fabricated the fixtures and showed how fixtures can improve manufacturing technology. Most of the papers basically focused on the design and fabrication of fixtures to benefits various organizations. This review has categorically given sufficient information to direct this thesis research. So, this research work will add all datas related to design and manufacturing process in the small and medium scale industries and benefits of the country.

CHAPTER THREE

3. Design and cost analysis

3.1 Introduction

This chapter discuss all the methods and materials to complete the objective of this thesis. The design of a milling fixture for lathe machine requires the careful implementation of a product development methodology. Therefore, the methodology applied to the development of this machine tool was based on the two main stages named as design and development. The first stages starts from design calculation of each parts using strength of material and machine element concepts. Here material is selected and production drawing is done as per the design. Modeling software's like CATIA and Solid work software's were used.

After the design, the fabrication process was conducted in Hibret Manufacturing and machine building factory (HMMBI) precision shop. The fabrication process was done by using CNC milling machine, conventional lathe machine and radial drill machines for the several machining processes needed in the fabrication of the fixture components. MASTER CAM software was used for the manufacturing process on CNC machine.

After the fixture was fabricated the conventional lathe machine was modified by assembling this fixture and milling operation were done on Aluminum material. The experiment done were surface roughness test and geometrical configuration test of products. The milling operations experimented by the fixture were keyway, slotting and face milling. All the methods used to perform this work was shown in the process flow chart Fig. (3.1).

3.2 Design of fixture component

3.2.1 Conceptual design and description of the fixture

The objective of this project is to design and fabricate locally a milling fixture for lathe machine that can provide milling operation with an ease of flexibility and low cost to improve production process in the manufacturing sector. Therefor the first step to fulfill this objective was creating the conceptual design.

The conceptual design for the fixture shown in Fig. 3.2 led to the following key elements:

- Aluminum workpiece and HSS cutting tool
- Left and right column supports which carries the upper and lower clamping jaws
- Upper and lower clamping Jaws to hold the workpiece
- Fixture base to carry the assembled fixture and mounted on lathe cross slide
- Lead screw to slide left column supports over the right column
- Reinforcements to join column supports with the fixture base

3.2.2 Flow chart

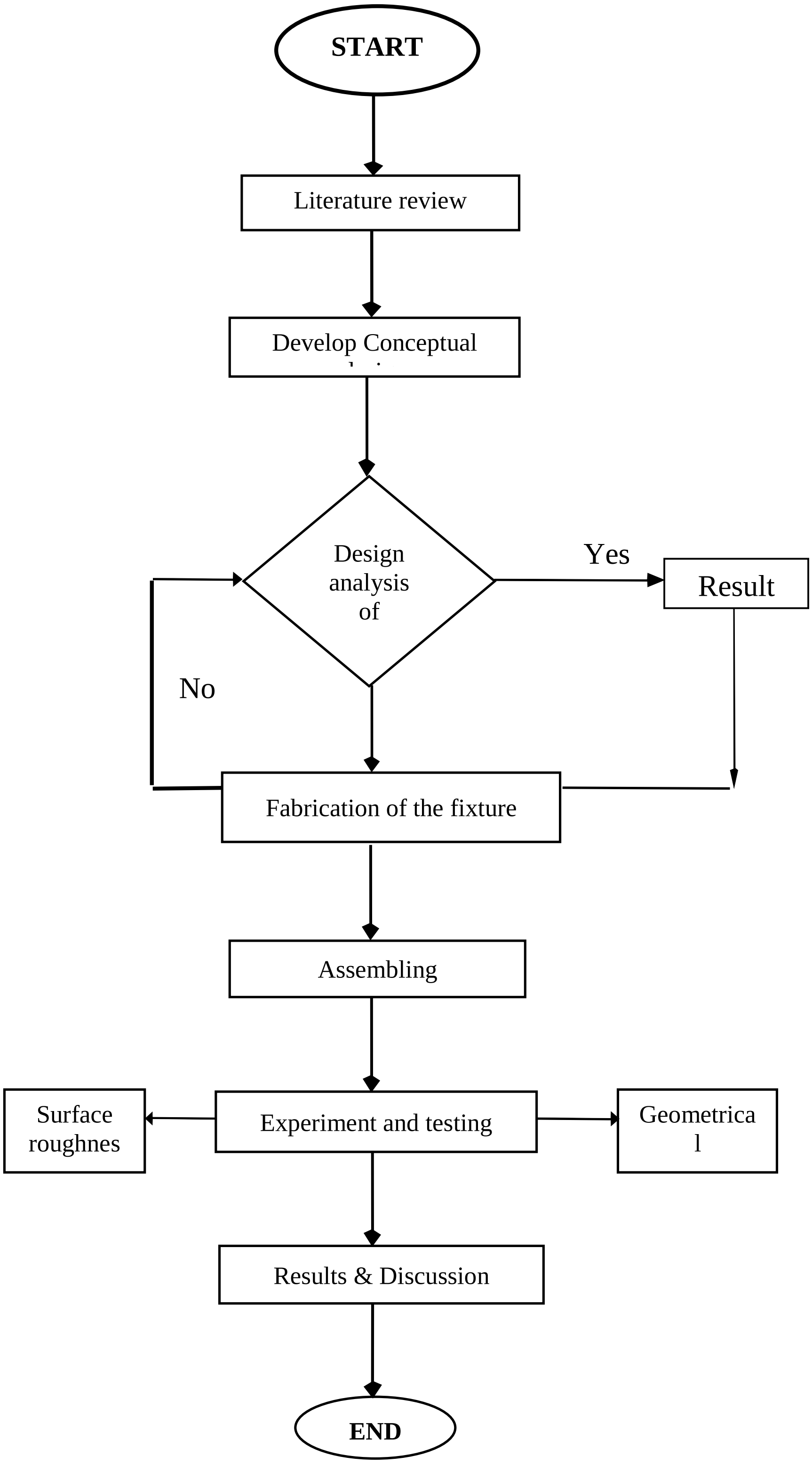


Figure 3-1 Processes flow chart of the project

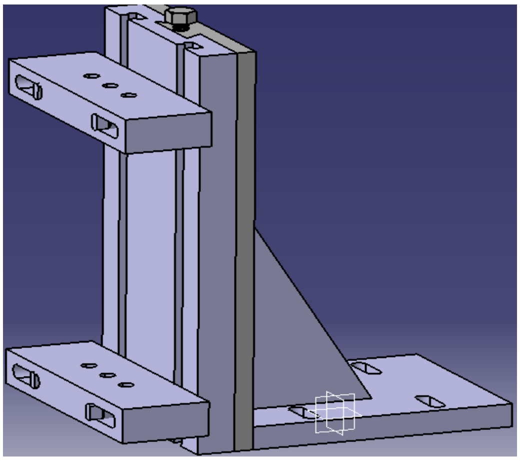


Figure 3-2 Conceptual design of the fixture

One of the most significant departures from the conceptual design was the circular hole of the base part was changed to elongated holes. This makes the fixture flexibly attached for different type lathe machines.

3.2.3 Cutting force analysis

After the completion of conceptual design, force calculation was analyzed to determine the loads acting on the fixture as shown in figure 3.3 due to cutting operation of end mill cutter.

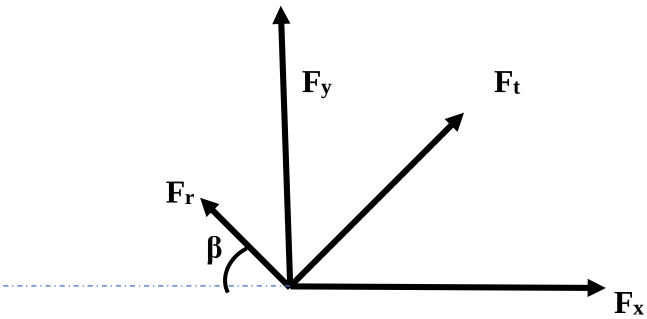


Figure 3-3 Free body diagram of forces

These force analyses were critical to the execution of all subsequent machine element and structure calculations. A mathematical model proposed by different authors provides a reasonable estimate of the machining forces for this project. Accurate modeling of cutting forces was required to predict the cutting forces, vibration, surface quality and stability of machining processes. A number of different methods to predict these cutting forces were developed over the last fifty years. These models are classified into three major categories: empirical, analytical and mechanistic methods (Newby (2005)).

In the empirical model, a number of machining experiments were performed and performance measures such as cutting force, tool life and tool wear were measured. This method often requires a lot of experimentation and have limited extrapolative value.

Analytical model the uses physical mechanisms that occur during cutting. However due to complex mechanisms such as high strain rates, high temperature gradients and combined elastic and plastic deformations this model is unable to completely characterize the phenomena that occur on rake and flank face of the cutting insert.

Mechanistic model predicts the cutting forces assuming to be proportional to the chip cross sectional area. Traditionally, the calibration of the cutting force model is performed by running tests at different combinations of spindle seed, feed rate and depth of cut. In face milling, these tests were conducted using a single cutting insert to avoid the effects of run out. In addition, they were conducted on a workpiece with no surface discontinuities to simplify the correlation of the cutting forces with the angular position of cutting insert. From these models' empirical model was selected for analysis of cutting force in this project.

I. Cutting Tool Geometry

A milling cutter has different terminologies such as rake angle, lead angle, clearance angle, cutter diameter, width and number of flutes. Unlike lathe, milling cutter does not give a continuous cut, but begins with a sliding motion between the cutter and work. Then follows a crushing movement and a cutting operation by which the chip is removed. The cutter should fulfill specific requirements (Julia (2014)), such as cutting tool should have high hardness to resist high stresses developed during machining, cutting tool should have good thermal conductivity to minimize thermal gradients and thermal shock, cutting tool should have toughness and fatigue resistance to withstand the chip segmentation process and lastly cutting tool should have high compressive, tensile, and shear strength.

Based on previous studies, carbide and high carbon steel are the best suitable tool materials for machining Aluminum alloys. A three number of flute end mill cutting tool was chosen for this study because it is commonly used cutter in milling processes of sticky material like Aluminum. Three flute cutters provide enough chip flow. In the present work, an investigation of cutting forces is undertaken in order to check its effect on stability in end milling process and milling fixture with its predictive model from machining parameters.

II. Workpiece material: Aluminum

Aluminum alloy (7075-T6) was well known with very low machinability due to the specific material properties which were chosen for this project. The material properties of Aluminum and its alloys are light weight, excellent corrosion resistance, strong at low temperatures, easy to work, good heat conductor and easy surface treatment (Songmene *et al.* (2010)).

Manufacturers use Aluminum alloy to make most of structural, aeronautic and automotive components that are expected to demonstrate superior quality and enhanced functional performance. Most Aluminum products within manufacturing industries are produced by turning and milling processes. Both turning and milling offer best tolerance requirements at most economical cost (Sheasby and Pinner (2001)). This machinability quantifies machining performance and may be defined for a specific application by various criteria, such as tool life, surface finish, chip evacuation, material removal rate and machine-tool power. It has been shown that chemical composition, structural defects and alloying elements significantly influence machinability. Thus, with similar chemical compositions, machinability of alloys can be improved by different treatments. One is heat treatment, which increase hardness and reduce the built-up edge (BUE) tendency during machining (Songmene *et al.* (2010)).

Juilia (2014) conducted experiment to investigate the effect of tool geometry and cutting conditions (type of milling, feed rate, and depth of cut) on machining performance during end milling of Aluminum alloy. The study revealed that improper geometry may result in enhanced tool costs or a loss in production. Cutting force is just one among several parameters to be considered for a full assessment of machinability in metallic alloys, with the others being tool life, surface finish, cutting energy and chip formation mode. In their work, different authors addressed the machinability of Aluminum alloys from several points of view, including cutting forces, chip formation and segmentation and metallic particle emission. In addition, the geometry of cutting tool is very critical in terms of heat dissipation during machining. In ideal conditions, cutting edge of the tool is constant and has no tool wear. Tool wear would result in built-up during machining of Al alloys. The built-up edge causes poor surface finishes and increases the magnitudes of cutting forces. This increment may cause deflection within the workpiece (Songmene *et al.* (2010)). The mechanical properties and chemical composition of the workpiece material Aluminum 7075 T6, selected for this work have ultimate tensile strength of 570MPa,ultimate shear stress of 331MPa and hardness of 150.

III. Calculation of cutting force

The mathematical analysis of cutting force starts from analyzing different kinds of mathematical modeling of cutting force found from different literatures.

Parameters

Material selected for end mill cutting tool is High Speed Steel (HSS). And each input parameters are selected from the standards tables found in the appendixes. Table 3.2 discuss each parameters needed for the evaluation of cutting speed, chip thickness and feed per tooth found from the standard specification for HSS.

Allowable cutting speed

Allowable cutting speed for HSS cutter to cut Aluminum material is in the range between V = 25 m/min – 65 m/min and for steel materials V = 17 m/min – 33 m/min. Newby (2005)

$$n = \frac{v}{\pi D} \qquad \text{Eq (3.1)}$$

Let's select a cutting speed of 45m/min for Al considering its sticky property.

V =45m/min,

D= diameter of the cutter= 20mm

Spindle speed of the lathe can be calculated

$$n = \frac{1000v}{\pi D}$$

$$= \frac{45000}{\pi x 20} = 683.57\text{rpm}$$

Where this result meets the allowable spindle speed for Aluminum materials on lathe machine (300-3000rpm).

Table 3-1 Selected parameter for cutting force analysis

S.No	Parameters	Notation	Units	Values
1	Number of flute	z	-	3
2	Flute length	l	mm	30
3	Tool diameter	d	mm	20
4	Length of the cutter	l	mm	90
5	Width of cut	w	mm	15
6	Lead angle	k	degree	90
7	Rake angle	γ	degree	12
8	Helix	Ø	degree	45
9	Clearance angle	α	degree	12
10	Axial depth of cut	a_p	mm	20
11	Radial depth of cut	a_e	mm	2
12	Feed per revolution	f/rev	m/min	0.003-0.03
13	Chip size per tooth	f/tooth		0.003-0.01
14	Feed	f		0.08

Feed per tooth (f_z)

A milling cutter's performance is limited by its maximum chip load. Since commonly used speed and feed calculators show only feed per tooth, expressed as f_z, the terms "chip load" and "f_z" tend to be used interchangeably. This common misconception can lead to significant error, (Nemes *et al.* (2001)). Always remember that chip load refers to chip thickness not f_z. Rather, f_z is the increment of feed that takes place by one insert in one revolution of milling cutter.

Since standard feed per revolution value of Al materials is given in the specification in appendix E. Let's take 0.004 inch = 0.102mm feed per revolution (Bolsunovskya *et al.* (2013)).

$$Feed/revolution = \frac{feed\ speed\ (Vf)}{spindle\ speed\ (n)} \qquad \text{Eq (3.2)}$$

Feed speed value obtained from the above equation

$f_z = \frac{Vf}{Nn}$ where V_f= feed speed

N = Number of teeth

n = spindle speed

There for feed speed $V_f = f/\text{rev} \times n$

Where feed/rev for Al work piece 0.003 - 0.03 or 0.004 – 0.01 for HSS and carbide tools respectively. Let's take feed per revolution = 0.02

V_f = 0.02 (683.57)

= 13.67 m/min

By rearranging the above equation and substitute the values of feed speed 13.67 m/min and three number of teeth the result for feed per tooth found as 6.66×10^{-3} m/min.

The feed/tooth (f_z) is then $f_z = \frac{Vf}{Nn}$

$= \frac{13.67}{3 \times 683.57}$

$= 6.66 \times 10^{-3}$ m/min

Average chip thickness (t_{cave})

Average chip thickness is amount taken by each insert as it advances through the arc of the cut. The metal removed by a single pass of one insert looks like a very thin crescent. It is the thickness of the crescent anywhere along its arc, which makes its thickness vary from zero to a maximum, usually equal to the f_z. In calculating average chip thickness first uncut chip thickness and maximum chip thickness values should be found.

Three assumption needs to be considered are

- Path of the tool (assumed to be circular)
- Cutter tool run out is very small
- Chip thickness differs on entry and exit b/n 0 and 180°.

The engagement angle (β) where depth of cut for 20mm diameter tool was selected as 2mm, spindle speed 683.57 rpm. The engagement angle obtained as then 36.8° (Wang (2001)).

$$\cos \beta = 1 - \frac{2\,ae}{D} \qquad \text{Eq (3.3)}$$

$\beta = \cos^{-1}(1- \frac{2(2)}{20})$

$= \cos^{-1}(0.8)$

$= 36.8°$

Uncut chip thickness of the workspace (t_{uc}) and Max chip thickness (t_{max}) are obtained as 0.00401m and 0.00399m respectively from the formula stated in equation 3.4 and 3.5 below.

Chip load (f_z) or feed/tooth 0.0067m, standard lead angle (K) for sticky materials is 90° and engagement angle (β) found from equation 3.3 was 36.8°.

- ❖ All these parameters are used to find the value of uncut chip thickness 4.01×10^{-3}m
- ❖ Maximum chip thickness 3.99×10^{-3} m.

There for Average chip thickness (t_{cave}) becomes 2.11mm which was calculated in equation 3.6. (Huang *et al.* (2016))

$$t_{uc} = f_z \sin k \sin \beta \qquad \text{Eq (3.4)}$$

$$= 0.0067\text{m} \sin 90 \sin 36.8$$

$$= 4.01 \times 10^{-3}\text{m}$$

$$t_{max} = \frac{\text{vf} \sin \beta}{\text{NT}} \qquad \text{Eq (3.5)}$$

$$= \frac{13.67 \sin 36.8}{3 \times 683.57}$$

$$t_{max} = 3.99 \times 10^{-3} \text{ m}$$

$$= 3.99\text{mm}$$

$$t_{cave} = f_z \sqrt{\frac{ae}{D}} \qquad \text{Eq (3.6)}$$

$$= 0.0067 \sqrt{\frac{0.002}{0.02}}$$

$$= 2.11 \times 10^{-3} \text{ m}$$

$$= 2.11\text{mm}$$

Machining time (CT) and Material removal rate (MRR)

Cutting Time. Here several situations must be considered, these include:

1. Tool Not Fully Engaged with W<D/2

$$L_A = L_o \sqrt{W(D - W)}$$

2. Tool not Fully Engaged but W> D/2

$$L_A = L_o = \frac{D}{2}$$

3. Tool Fully Engaged, Roughing Pass -- Doesn’t require “Full Wipe”

$$L_A = L_o = 0.5(\sqrt{(D^2 - W^2)})$$

4. Tool Fully Engaged, Finishing Pass -- requires “Full Wiping Action”

$$L_A = L_o = \frac{D}{2}$$

In this case the tool is not fully engaged but width is greater than half of the diameter. So to find the cutting time the second case should be taken in to the consideration.

$$CT = \frac{L + LA + Lo}{Vf} \qquad \text{Eq (3.7)}$$

Where

L: Length of pass or cut =50mm

L_A: Approach Length =10mm

L_O: Length of "Over Travel" =10mm

V_f: Table (machine) Feed =13.67m/min

$$CT=\frac{(0.05+0.01+0.01)\ mm}{13.67m/min}$$

$$=\frac{0.07mm}{13.67m/min}$$

$$=0.0048min$$

Metal Removal Rate: Material removal rate (MRR) is the volume of material removed per unit time (mm3/min or in3/min)

$$MRR=\frac{vol\ removed}{CT}$$

$$=\frac{L*W*t}{CT} \qquad \text{Eq (3.8)}$$

Where L: Length of pass or cut =50mm

W: Width of cut (may be full cutter or partial cutter)

t: depth of cutter engagement

$$=\frac{(0.05*0.02*\ 0.002)mm}{0.0048min}$$

$$MRR = 4.16x10^{-4}\ mm^3/min$$

Cutting force (F_c)

In milling, cutting forces shown in figure 3.3 exerted in three planes to deform and shear away material in the form of a chip. Tangential cutting forces are forces overcome the resistance of rotation and account for 70 percent of the total force unlike feed forces account for 20 percent of the total force. Radial forces tend to push away the tool and account for 10 percent of the cutting forces. Newby (2005) While calculating for conventional end milling operation which was manual and time taken, there are some parameters to be considered.

Tangential and radial forces (F_t and F_r)

For tool diameter between 3.175mm – 25.4mm lower feed per tooth is less than 0.1. Newby (2005) found the formula of tangential force equations (K_t) and (K_r) for Al 7075 in his experiment.

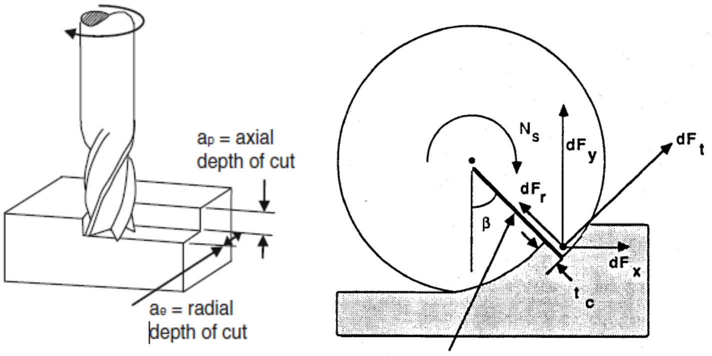


Figure 3-4 Tangential and radial forces (Ft and Fr) (Serope (2000))

Experimentally obtained Newby (2005) value of tangential force equations (K_t) for Al 7075 was 569.14 $(t_{ave})^{0.283}$N/mm^3 and radial force equation (K_r) for Al 7075 was 0.1468 $(t_{ave})^{0.364}$ N/mm^2. By substituting the value of t_{ave} obtained in equation 3.6, K_t and K_r can be calculated as follows.

$$K_t = 569.14\,(t_{ave})^{0.283}\ (tave)^{0.283}\ \text{N/mm}^2$$
$$= 569.14\,(3)^{0.283}\ \text{N/mm}^2$$
$$=417\ \text{N/mm}^2$$
$$K_r = 0.1468\,(t_{ave})^{0.364}\ .\text{N/mm}^2$$
$$= 0.1468(3)^{0.364}\ .\text{N/mm}^2$$
$$= 0.098\ \text{N/mm}^2$$

Since tangential and radical force equations are attained one can calculate for tangential and radical forces applied to the end mill cutter using equation 3.9 (Newby (2005))

$$\left.\begin{aligned} F_t &= K_t\, a_e\, t_{cave} = K_t\, A_c \\ F_r &= K_r\, F_t = K_r\, K_t\, A_c \end{aligned}\right\} \qquad \text{Eq (3.9)}$$

By substituting the values of engagement angle (β), radical depth of cut (A_c) and average chip thickness (t_{cave}) in the above equations, the value of tangential and radial force becomes

$$F_t = 569.14(3)^{0.283}(2mm)$$
$$=2502\text{N}$$
$$F_r = 0.1468(3)^{0.364}(2mm)$$
$$=245.2\text{N}$$

Total cutting force (Fc)

Total cutting force applied on the workpiece is the combination of those three forces applied in X, Y and Z direction. The value of elemental force in x direction F_x, in Y direction F_y and in Z direction F_z are obtained from the formulas below (Yangui1 *et al.* (2010)).

$$\left.\begin{aligned} F_x &= F_t \cos\beta - F_r \sin\beta \\ F_y &= F_t \sin\beta + F_r \cos\beta \\ F_z &= F_t \end{aligned}\right\} \qquad \text{Eq (3.10)}$$

Then these three forces are

$$F_x = 2502 \cos 36.8° - 245.2 \sin 36.8°$$
$$= 1856.7 \text{ N}$$
$$F_y = 2502 \sin 36.8° + 245.2 \cos 36.8°$$
$$= 1695 \text{ N}$$

F_z = 2502N where F_Z is the same as tangential force.

There for total cutting force becomes 3.547 kN is then determined by a formula of

$$F_c = \sqrt{Fx^2 + Fy^2 + Fz^2} \qquad \text{Eq (3.11)}$$
$$= \sqrt{1856^2 + 1695^2 + 2502^2}$$
$$= 3.547 \text{ kN}$$

3.2.4 Design of the fixture and material selection

While designing this work, a good number of literature and titles written on the subject by renowned authors are referred. All findings and conclusions obtained from the literature review and the interaction with fixture designers are used as guide to design the present research work. Additionally, a fundamental and well-known engineering principle should be considered: the functional requirements and their associated constraints should be the first input to any design process. Various areas related to design of fixture like machining fixture knowledge, optimizing workpiece setups, modeling of forces, improving workpiece location and high efficiency tools are already been very well described by various renowned authors.

The fixture designing and manufacturing is considered as complex process that demands the knowledge of different areas, such as geometry, tolerances, dimensions, procedures and manufacturing processes. The specifications & limitations of the machine limits the ideas of designing. To design a fixture and a collet, a designer must know manufacturing procedures. One must be able to visualize exactly how the workpiece is to be made (Wang (2010)). A mastery of drafting techniques is an essential to the tool designer as ability to read and write. Hunter *et al.* (2006) proposed the methodology for design of a fixture which includes the realization of two stages.

An important characteristic of a workpiece-fixture system that locators are passive elements and can only react to clamping forces and external loads, whereas clamps are active elements and apply a predetermined normal load to the surface of workpiece to prevent it from losing contact with the locators. Li *et al.* (1999) developed a theoretical model for forces in milling based on a predictive machining theory and the mechanics of milling. In the model, the action of a milling cutter was considered as the simultaneous work of a number of single-point cutting tools, and milling forces were predicted from input data of the workpiece material properties, cutter parameters and tooth geometry, cutting condition and the types of milling. The commonly used material properties of fixture components are hardened steel with Young's Modulus of 201 GPa and Poisson Ratio of 0.296.

Here the obtained cutting force (3.547 kN) was the major input for the power requirements, machine element selection and structural analysis of the fixture. The fixture was designed for the family of soft materials like Aluminum and brass materials to make end milling process and keyways and on lathe machine to benefit small and medium scale manufacturing industries.

3.2.4.1 Upper and lower clamping jaw design and analysis

This fixture has two clamping jaws connected to column support by T bolts, hold the workpiece tightly during machining operation. These two parts should resist the cutting force coming from end mill cutter. The upper and lower clamping jaws were affected by the cutting force equally. The cutting force components in equation 3.12, exerted on clamping jaws is shown in Fig, 3.5 (Golenko (2010)).

$$Fc = F_{xi} + F_{yj} + F_{zk} \quad \text{Eq (3.12)}$$

Figure 3-5 Upper and lower clamping jaws

From equation 3.10 F_{xi}= 1856.6N, F_{yj} = 1695N, F_{zk}=2502N these three forces create different kinds of stresses in three directions. Slip stress occurs due to force in x direction and z direction (F_x, F_z). Normal stress occurs due to Force in y direction. According to Maximum Principal or Normal Stress Theory (Rankine's Theory), the failure or yielding occurs at a point in a member when the maximum principal or normal stress in a bi-axial stress system reaches the limiting strength of the material in a simple tension test.

Since the limiting strength for ductile materials is yield point stress and for brittle materials (which do not have well defined yield point) is ultimate stress, therefore according to the above theory, taking factor of safety (*F.S.*) into consideration, the maximum principal or normal stress (σ_t) in a bi-axial stress system is given by the equation found below (Beer *et al. (*2006)).

$$\left.\begin{aligned} \sigma_t &= \frac{\sigma y}{F.S} \text{ for ductile materials} \\ \sigma_t &= \frac{\sigma u}{F.S} \text{ for brittle materials} \end{aligned}\right\} \qquad \text{Eq (3.13)}$$

Where σ_{yt} = Yield point stress in tension as determined from simple tension test and σ_u =Ultimate stress. Since the maximum principal or normal stress theory is based on failure in tension or compression and ignores the possibility of failure due to shearing stress, therefore it is not used for ductile materials.

Slip stress (σ_s)

Using the contact area of clamping Jaw where F_x and F_z forces are exerted and resultant load slip stress can be found. Including ductility factor of material 0.2 slip stress on the jaw calculated as follows.

Jaw dimensions t= 30mm, w= 70mm, l= 220mm

Contact area (A) = 2250mm^2

Resultant force in x and z direction (Beer *et al. (*2006))

$$F_{zx} = \sqrt{Fx^2 + Fz^2} \qquad \text{Eqn (3.14)}$$

$$= \sqrt{1856.6^2 + 1695^2}$$

$$= 2513.95\text{N}$$

$$\text{Slip stress } \sigma_s = \frac{\text{Fzx}}{A} \qquad \text{Eqn (3.15)}$$

$$\sigma_s = \frac{3115.2\text{N}}{2520mm^2}$$

$$= 1.426 \text{ MPa}$$

Allowable slip stress can be obtained from the above designed slip stress and factor of safety. Where factor of safety for shock load in steel material obtained in the range 12-16 from the standard table found in appendix B.

Therefor so let's choose F.S=15

$$\sigma_{all} = 1.23 \text{ MPa x } 15$$

$$\sigma_{all} = 18.45 \text{ MPa}$$

Since shear stress and slip stress are half of normal and yielding stress the yield stress becomes

$$\sigma_y = 18.45 \text{ MPa x } 2 = 36.9 \text{ MPa}$$

Normal (bending) stress σ_b

In case of pure bending the neutral passes through the centroid of the cross section. Moment of inertia or section modulus of the cross section with respect to centroidal axis perpendicular to the couple from the elastic flexural formulas $\sigma_s = \frac{Mc}{I}$ this normal stress can be tensile when $\sigma_s > 0$, $y > 0$, M=+ve, and compressive when $\sigma_s < 0$, $y <0$, M=-ve. Since the section modulus $S = \frac{I}{c}$ depend on the geometry it should be as large as possible for high resistance. This normal stress occurs due to normal force acting on the Jaw.

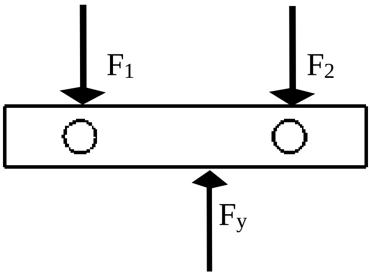


Figure 3-6 Forces applied on the jaw

This force in Y direction. F_1 and F_2 are force that occurs in the left and right side of the jaw which are equal but opposite of the force coming from the y direction.

$$F_1=F_2 = \frac{1}{2} F_y$$

$$= \frac{1}{2} (1695N)$$

$$= 847.5N$$

From bending moment and shear force diagram, bending stress and shear stress on clamping jaws moment (couple) shown from the Figure 3.6 calculated as

$$\Sigma M_y = 0$$

$$-M-F_2x=0$$

$$M= -F_2x=-V_x$$

$$= -847.5N \times 60mm$$

$= -50850Nmm$ –ve sign shows the stress is compressive stress

Since cross section is rectangular and neutral axis passes through the centroid.

$$I= \frac{1}{12} bh^3 = \frac{1}{12} (70)(30)^3$$

$$= 157500 \text{ mm}^4$$

$$\sigma = \frac{MI}{C} = \frac{(50850)(157500)}{15}$$

$$= 534 \text{ MPa}$$

Summation of force in Y direction

$$\Sigma Fy = 0,$$

$$V - Fy = 0$$

$$Fy = V$$

Shear stress (τ)

The area covers thickness and width of the jaw cross section and reduce diameter of the bolt. (Beer *et al. (*2006))

$$\tau = \frac{V}{A} \qquad \text{Eq (3.16)}$$

Where A=thickness x width = t x w (w-d), where w = (width-diameter of the bolt)

= (30) (70-16) = 1620mm^2

$$\tau = \frac{847.5N}{1620mm^2}$$

$$= 0.5234 \text{ MPa}$$

$$\tau_{all} = \tau \text{ x F.S}$$

$$= 0.523 \text{ x } 15$$

$$= 7.845 \text{ MPa}$$

$$\tau_{max} = \frac{\sigma\, yield}{2}$$

$$= 7.845 \text{ x } 2$$

$$= 15.69 \text{ MPa}$$

By comparing these three designed stresses slip stress, normal stress and shear stress, using maximum stress material for the upper and lower clamping jaws was selected.

$$\tau_{max} = 15.69 \text{ MPa}$$

$$\sigma_b = 534 \text{ MPa}$$

$$\sigma_y = 36.9 \text{ MPa}$$

From the above result a material selected from material property table shown in the appendix K for the upper and lower jaws is AISI No.1050 hot rolled.

3.2.4.2 Left column supports design and analysis

The column supports classified as left and right column supports for this project are major components of the fixture. The left side column support carries two clamping jaws that slides over its T slot guiding way and bolt and nut connection by using as shown in the Fig. 3.7.

The force comes from upper and lower jaws is distributed to the whole area of column support. This force from Z direction (F_z) creates bearing stress between jaws and left column support surface. And also force comes from x direction (F_x) cause bending stress on the two grooves.

The third force from y direction F_y creates slip stress between bolt surface and column support surface.

Figure 3-7 Left column support

Bearing stress (σ_{br})

The stress that occurs between jaws and left column surface F_{Z1} and F_{Z2} are forces in left and right side of the jaw which are equal in magnitude but opposite to force in z direction.

$$F_{Z1} = F_{Z2} = \frac{1}{2}(F_z) = 1251\text{N, Surface area (A) } 5400\text{mm}^2$$

When these two forces act on column surface area the bearing stress develop is then

$$\sigma = \frac{F}{A} = \frac{1251N}{5400mm^2}$$

$$= 0.23\text{MPa}$$

Allowable stress σ_{all} with factor of safety 15 is 3.5 MPa and bearing stress is half of yielding stress. (Beer *et al.* (2006))

$$\sigma_{br} = \frac{\sigma\, yield}{2} \qquad \text{Eq (3.17)}$$

$$\sigma_{yield} = 2\text{x } \sigma_{br}$$

$$\sigma_{yield} = 2\text{x } 3.5$$

$$= 7 \text{ MPa}$$

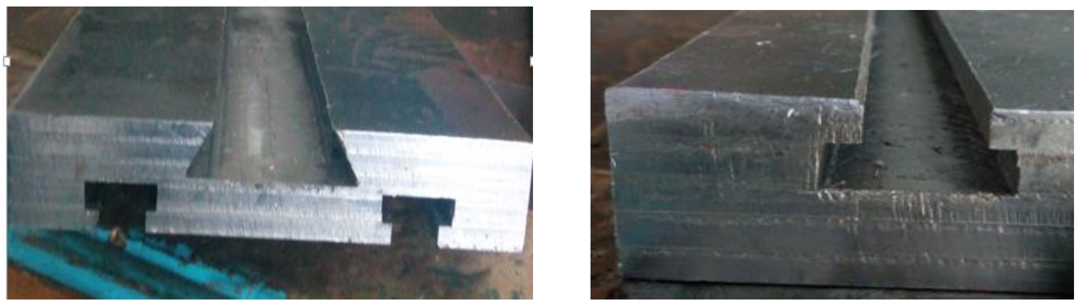


Figure 3-8 Grooves in column support

Normal stress occurs on the flange of T slot shown in the Figure 3.8 when column support tries to hold Jaws joined using bolts. For this design calculation T slot can be considered as cantilever beam to see the effect of stress easily. $\sigma_x = \frac{Fx}{A}$ since the cross section has two rectangular sections. Total area will be the sum of two individual areas A_1 = 5600 mm^2 and A_2 =7700mm^2.

Stress at x direction is then calculated from the total area and force at x direction.

$$\sigma_x = \frac{Fx}{A}$$

$$= \frac{1856.6N}{13300mm^2}$$

$$= 0.14\text{MPa}.$$

Slip stress between bolt and column support

While the bolt is connected through the slot to hold the jaw properly there will be a slip between bolt surface and wall of slot contact area this slipping create the slip stress in between.

Contact area is the product of bolt width, number of bolt and slot width. Where Slot width the difference between total depth of T slot and minor depth which is 22-16= 6 mm as shown in the Figure 3.8 by assuming bolt width 4mm and two number of bolt we have here. (Beer *et al.* *(*2006))

The contact area is then A= 6mm x 4mm x 2 = 48mm^2.

$$\sigma_{slip} = \frac{Fy}{A} \qquad \text{Eqn (3.18)}$$

$$= \frac{1695N}{48mm^2}$$

$$= 35.3\text{MPa}$$

$$\sigma_y = \sigma_{slip} \text{ x } 2 \text{ x F.S}$$

$$= 1050\text{MPa}$$

Yield stress becomes 1050 MPa, the highest stress will be selected. From the above result a material selected from material property table shown in the appendix K is AISI No.1080 hot rolled.

3.2.4.3 Design of right column support

This component is a right column support shown in Figure 3.9 connects the left column support shown in Figure 3.7 and the fixture base Figure 3.10 together and is a major part to slide the left vertical support and to make the milling operation.

From the principal plane and principal stress theory, stress in x, y and z direction is developed. By taking a small cubic element we can determine the stress of the plate. Where σ_x, σ_y and σ_z describes normal stress exerted on the plate face. τ_{xy}, τ_{yz} and τ_{zx} defines shear stress exerted on same element. By assuming plane stress (the two faces are free from any stress) if x axis is chosen perpendicular to these face σ_y, σ_z, and τ_{zy} are found on any surface of all machine components are subjected to bi- axial stresses. In this case z and x $\tau_{xy} = \tau_{zy}$.


Figure 3-9 Right column support

In this right column support we have forces that cause three stresses. Therefore, maximum shear and average normal stress can be found from these three different stress shown below (Beer *et al. (*2006)).

$$\sigma_y = \frac{Fy}{A} \qquad \sigma_z = \frac{Fz}{A} \qquad \tau_{zy} = \frac{Fzy}{A} \qquad \text{Eq (3.19)}$$

Using the above formulas of normal stress at y direction, normal stress at z direction and shear stress from x direction are determined and used to evaluate the maximum shear stress as follows. By taking some part of the column shown in the Figure 3.9, this area where all the three stresses occur are the same. Width and length is 30mm area will be 900mm^2. The normal stress develops due to force in Y direction 1695N becomes 1.88MPa. The second normal stress develops due to force in Z direction 2502N in the same area becomes 2.78MPa.

The shear stress occur due to combination forces in Z and Y directions (F_{zy}) and A= 900mm^2

$$F_{zy} = \sqrt{2502^2 + 1695^2}$$

$$= 3022\text{N}$$

By substituting the values of F_{zy} and A in the equation 3.19 for shear stress

$$\tau_{zy} = \frac{3022}{900}$$

$$= 3.35 \text{ MPa.}$$

According to maximum principal stress theory and According to maximum shear stress theory

$$\sigma_{max} = \frac{\sigma y + \sigma z}{2} + \sqrt{\left(\frac{\sigma y - \sigma z}{2}\right)^2 + \tau zy^2} \qquad \text{Eq 3.20)}$$

$$= \frac{1.88+2.78}{2} + \sqrt{\left(\frac{1.88-2.78}{2}\right)^2 + 3.35^2}$$

$$= 5.73 \text{ MPa}$$

$$\sigma_{min} = \frac{\sigma y + \sigma z}{2} - \sqrt{\left(\frac{\sigma y - \sigma z}{2}\right)^2 + \tau zy^2} \qquad \text{Eq (3.21)}$$

$$= \frac{1.88+2.78}{2} - \sqrt{\left(\frac{1.88-2.78}{2}\right)^2 + 3.35^2}$$

$$= -1.07 \text{ MPa}$$

Tensile stress or positive stress and compressive stress or negative stress under selected factor of safety are 85.95 MPa and -16.05 MPa respectively. According to maximum shear stress theory, maximum shear (3.4MPa) and yielding stress (104MPa) formulated as follows

$$\tau_{max} = \sqrt{\left(\frac{\sigma y - \sigma z}{2}\right)^2 + \tau zy^2} \qquad \text{Eq (3.22)}$$

$$= \sqrt{\left(\frac{1.88-2.78}{2}\right)^2 + 3.35^2}$$

$$= 3.4\text{MPa}$$

By rearranging the yielding stress

$$\tau_{max} = \frac{\sigma\, yield}{2\, F.S}$$

$$\sigma_{min} = \tau_{max}\, x\ 2\ F.S$$

$$= 3.4\text{x}2\text{x}30 = 104 \text{ MPa}$$

From the above results slip stress 1050MPa, tensile stress 85.95 MPa and shear stress 104MPa. The material selected for right column support from material property is AISI No.1080 hot rolled.

3.2.4.4 Base design and analysis

Fixture base is the last component that carries two clamping jaws and two column supports. It is mounted on lathe machine cross slide with bolt and nut. In the view of the loads applied different stresses were developed and evaluated. By using these stresses, the material selection was carried out. The cross section of the base shown in Figure 3.10 is length 210mm, width 180mm and 20mm thickness.

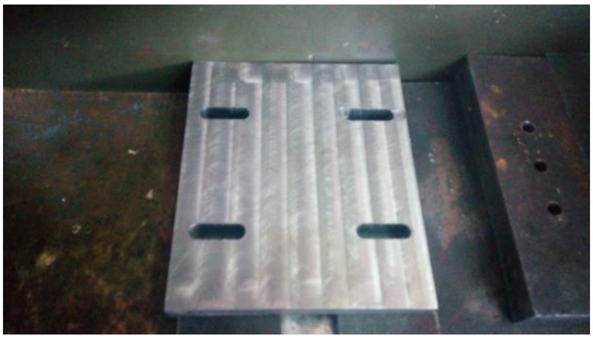


Figure 3-10 Base of the fixture

The force acting on X axis creates bending stress when it fits to lathe machine cross slide at the corners. Considering this and in determining stresses the reaction forces acting on the bolts are equal but opposite in direction to the force in x direction F_x (Beer *et al. (*2006)).

$$R_1 = R_2 = \frac{1}{4} Fx \qquad \text{Eq (3.23)}$$

$$R_1 = \frac{1}{4}(1856\text{N})$$

$$= 464.15 \text{ N}$$

Since the beam has triangular shape, the area for this kind of shapes is given as $A = \frac{1}{2} bh$ where b is breadth (15) and h is height (16) is= 120mm^2.

Designed bending stress value is then

$$\sigma_b = \frac{R1}{A}$$

$$= \frac{464.15}{120} = 3.86 \text{ MPa}$$

The allowable bending stress is then 115.8 MPa.

$$\sigma_{all} = \text{designed bending stress x 2 x F.S}$$

From the above result a material selected from table shown in the appendix K for fixture base is AISI No.1018 hot rolled.

3.2.4.5 Lead screw design and material selection

The lead screws purpose is to convert rotary motion produced by servo motors to linear motion of the axes. Lead screw major parts are pitch, major diameter and minor diameter. For the designed fixture a square thread lead screw was used because of its high efficiency (>90%) in dynamic motion, in contrast with the low efficiency (30%) of an ACME screw. (Beer *et al. (*2006))

Figure 3-11 Lead screw for right column support

Handle screw used to slide left column support over the right column support is selected based on the following data's

Axial load = force exerted on screw head by an operator is assumed to be 100N (average man) and Nominal diameter (d) of the screw is selected as 20mm. For this lead screw minor diameter, mean diameter, pitch and depth of nut calculated from the standard equation are found below. The selected major diameter for lead screw is 20mm and pitch is 2. Using the following formulas mean diameter, core diameter and lead are 19mm, 18mm and 4.

$$d_m = d - \frac{p}{2} \qquad d_r = d - p \qquad l = n \times p$$

The lead screw must have adequate strength to withstand axial load and applied torque.

Torque to raise or to lower the load

The torque is a product of force F and mean radius $\frac{dm}{2}$. T_R is the torque required for two purposes: to overcome thread friction and to raise the load. The torque required to lower the load, is required to overcome a part of friction in lowering the load. It may turn out, in specific instances where lead is large or friction is low, that the load will lower itself by causing the screw to spin without any external effort. In such cases, the torque T_L will be negative or zero. When a positive torque is obtained from this equation, the screw is said to be self-locking. Thus, the condition for self-locking is $\pi f dm > l$. (Beer *et al. (*2006))

$$Tr= \frac{Fdm}{2}\left(\frac{l+\pi f dm}{\pi dm-fl}\right) \qquad \text{Eq (3.24)}$$

$$Tr= \frac{Fdm}{2}\left(\frac{\pi f dm-l}{\pi dm+fl}\right) \qquad \text{Eq (3.25)}$$

From the above two equations and given parameters torque is require to raise the load becomes 140. 41Nm and torque to lower the load becomes 12.27 Nm. The overall efficiency of the screw in raising the load calculated with the equation 3.26 obtained as 65%. This efficiency can be increased by proper lubrication and heat treatment process.

Based on the obtained torque, the stress that are developed due to these loads must be checked and appropriate material should be selected (Beer *et al. (*2006)).

$$e=\frac{Fl}{2\pi TR} \qquad \text{Eq (3.26)}$$

Stress developed on the screw

Direct compressive stress (σ), Torsional shear stress and Shear stress of screw due to axial load are stresses developed on the screw. These three stresses are direct compressive stress (σ), occurs due to axial load applied by the operator that depends up on core diameter of the screw.

The load applied on this handle screw is vertical direction and creates compressive stress (Beer *et al. (*2006)).

$$\sigma = \frac{W}{Ac} \qquad \text{Eq (3.27)}$$

$$= \frac{4F}{\pi dr^2}$$

W= axial load= 100N

A_c= area corresponds to minor or core diameter.

Core area for 20 mm bolt is 18mm (coarse series).

$$\sigma= \frac{4F}{\pi dr^2} = \frac{4x100}{\pi 18^2} = -392\text{MPa}$$

It gives the compressive axial stress of -392MPa. The minus sign indicates that the screw alone is not self-locking and would rotate under the action of load except for the fact that the collar friction is present and must be overcome, too. Thus, torque required to rotate the screw with the load is less than is torque necessary to overcome collar friction alone.

Torsional shear stress (*T_R*): - The body shear stress τ due to torsional moment T_R at the outside of screw body. Since the screw is subjected to twisting moment, therefore torsional shear stress is induced which was obtained by considering minimum cross section of the screw.

From table 3.3 let's take coefficient of friction μ= 0.14 = tan Ø

$$\tan\alpha= \frac{P}{\pi d}$$

$$= \frac{10}{\pi x 25}$$

$$= 0.1273$$

Torque transmitted by screw obtained

$$T=15000\text{N x } \left(\frac{0.1273+0.14}{1-(0.1273x0.14)}\right)$$

$$=4082.2\text{Nmm}$$

To find the torsional shear stress from the torque transmitted by screw, rearrange the equation below. Beer *et al. (*2006)

$$T= \frac{\pi}{16}\tau dc^3 \qquad \text{Eq (3.28)}$$

$$\tau = \frac{\pi dc^3}{16T}$$

$$=\frac{\pi x 25^3}{16x\ 4082.2} = 122\text{MPa}$$

Torsional shear stress is then 122MPa with factor of safety 6,

$$\tau_y= 2\tau \text{ x F.S}$$

$$=732\text{MPa.}$$

Since the screw is subjected to both direct stress and torsional shear stress then the design must be based on maximum shear stress theory, according to which maximum shear stress on minor diameter section.

Table 3-2 Coefficient of friction, source (Beer et al. (2006))

No	Condition	Average coefficient of friction	
		Starting	Running
1	High grade materials and workmanship and best running conditions	0.14	0.10
2	Average quality of material and workmanship and average running condition	0.18	0.13
3	Poor workmanship or very slow and in frequent motion with indifferent lubrication or newly machined surface	0.21	0.15

Maximum shear stress is then

$$\tau_{max} = \frac{1}{2}\sqrt{\sigma c^2 + 4\tau^2} \qquad \text{Eq (3.29)}$$

$$=\frac{1}{2}\sqrt{-392^2 + 4x732^2}$$

$$=757.78 \text{ MPa}$$

From the above result of material selection shows that AISI No.1006 hot rolled is the material for the screw.

3.2.4.6 Design of bolt and nut material selection

Bolts are machine components used to connect and fasten parts together temporary for easy maintenance. In this design, the column supports are joined by means of welding with fixture base and bolted to lathe cross slide, also upper and lower jaws are bolted to left column support. When a connection is desired that disassembled without destructive methods and strong enough to resist external tensile loads, moment loads, and shear loads or a combination of these, then simple bolted joint is a good solution. The material of the nut must be selected carefully to match that of the bolt. The nut material can be steel which is same strength as the bolt or weaker material as cast iron and aluminum alloy.

a. Design of Bolt for base plate

The fixture base was bolted with a lathe cross slide using four T bolts. From the design of the base, force acting on X axis creates bending stress when it fits to lathe machine cross slide at the corners. Considering this and determining stresses in analysis.

The reaction forces acting on the bolts are equal but opposite in direction to the force in x direction F_x. This force is equally distributed through the four bolts.

Therefore, applied force in each bolt is quarter of the reaction (tangential) force

$$F_b = R_1 = R_2 = \frac{1}{4} Fx.$$

$$= \frac{1}{4} (1856N)$$

$$= 464.15 \text{ N}$$

Using maximum shear stress theory Beer *et al. (*2006)

$$\tau_{max} < 0.5 \quad \frac{\sigma y}{n} \text{.................................} \quad \text{Equ (3.30)}$$

Where τ_{max} - is the maximum shear stress, σ_y - is yield strength of bolt and n is factor of safety, by taking n =8, the bolt with high yield strength is low or medium carbon steel (Property class 5.8) from table 3.4 having yield strength of σ_y = 520MPa.

$$\tau = 0.5x520/8$$

$$= 32.5 N/mm^2$$

$$\text{Thus } \tau = \frac{Fb}{A}$$

Table 3-3 Strength specifications for different property classes of metric steel bolts, screws, and studs (Beer et al.(2006))

Property class	Nominal size range in mm	Proof strength (MPa)	Yield strength (MPa)	Tensile strength (MPa)	Material
4.6	5-1000	225	240	400	Low or medium carbon steel
4.8	1.6-16	310	340	420	Low or medium carbon steel fully or partially annealed
5.8	5-24	380	420	520	Low or medium carbon steel cold work
8.8	Up to 400	660	640	800	Medium carbon steel quenched and tempered

Where F_b – is force applied on bolt = 464.15 N.

A –stress area on bolt $=\frac{\pi d^2}{4}$ whered is diameter of the bolt

$$\tau = \frac{4Fb}{\pi d^2}$$

$$d^2 = \sqrt{\frac{4Fb}{\pi\tau}}$$

$$= \sqrt{\frac{4(464.4)}{\pi 32.5}}$$

$$= 7.55mm$$

Therefore AISI No.1050 hot rolled M10 is the material for the bolt. Material for nut based on the bolts material selected as steel. And height of the nut is same as nominal diameter of the bolt though for 8mm bolt height of the nut= 8 mm.

b. Design of square (T) Bolt for left column support

The upper and lower clamping jaws were bolted with a left column support by using four bolts. From the design of column support the third force from y direction (F_y) creates slip stress between bolt surface and column support surface. Considering this and stresses analysis continuous. The reaction forces acting on bolts are equal but opposite in direction to the force in Y direction F_y. This force is equally distributed through four T bolts.

Therefore the force applied in each bolt is quarter of the tangential force

$$F_b = R_1 = R_2 = \frac{1}{4} Fy.$$

$$= \frac{1}{4}(1695N)$$

$$= 423N.$$

Using maximum shear stress theory and taking factor of safety 10. From the table 3.4 the bolt that has high yield strength is low or medium carbon steel (Property class 5.8) having yield strength of

σ_y = 520MPa from data books.

$$\tau = 0.5x\ \frac{520}{10}$$

$$= 26N/mm^2$$

Thus $\tau = \frac{Fb}{A}$

Where F_b – is force applied on bolt = 423 N.

A –stress area on bolt $= \frac{\pi d^2}{4}$ where d is diameter of the bolt (Beer *et al.(*2006))

$$\tau = \frac{4Fb}{\pi d^2} \qquad \text{Eqn (3.31)}$$

$$d^2 = \sqrt{\frac{4Fb}{\pi\tau}}$$

$$= \sqrt{\frac{4(423)}{\pi(26)}}$$

$$= 8.06 \text{ mm}$$

There for M12 is safe.

3.2.4.7 Design of welded joints

Welding is the process of joining two pieces of metal by creating a strong metallurgical bond between them by heating or pressure or both. It is distinguished from other forms of mechanical connections, such as riveting or bolting, which are formed by friction or mechanical interlocking. It is one of the oldest and reliable methods of joining. Welding offers many advantages over bolting and riveting. Welding enables direct transfer of stress between members eliminating gusset and splice plates necessary for bolted structures. Hence, the weight of the joint is minimum. In the case of tension members, the absence of holes improves the efficiency of the section. It involves less fabrication cost compared to other methods due to handling of fewer parts and elimination of operations like drilling, punching etc. and consequently less labor leading to economy.

Welding offers air tight and water tight joining and hence is ideal for oil storage tanks, ships etc. Welded structures also have a neat appearance and enable the connection of complicated shapes. Welded structures are more rigid compared to structures with riveted and bolted connections. A truly continuous structure is formed by the process of fusing the members together. Generally welded joints are as strong as or stronger than the base metal, thereby placing no restriction on the joints. Stress concentration effect is also considerably less in a welded connection.

Fusion Welding

Most weld joints are fusion welded where the processes use heat to melt the base metals. In many fusion welding operations, a filler metal is added to the molten pool to facilitate the process and provide bulk and strength to the welded joint.

Welding for reinforcements

These guiding supports are 10mm steel plates that used to connect the vertical and horizontal part of the right-angle support component. The material for these supports is selected mild steel with allowable shear stress. Since the cross section of all welds shown in the Figure below are the same, the weld size will be equal.

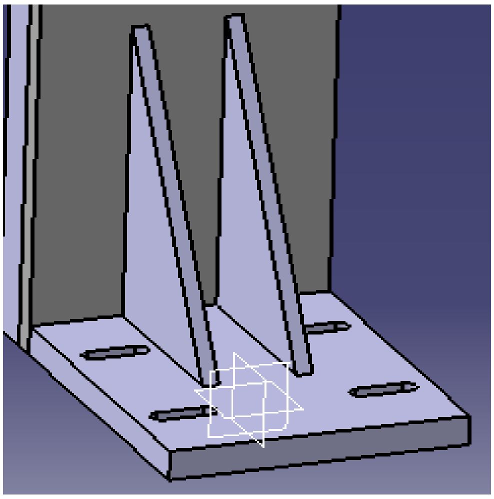



Figure 3-12 Reinforcements welding

Let S_y and S_z are the weld sizes in vertical and horizontal direction as shown in the Figure above. These guiding supports are subjected to resultant force comes from Y and Z direction. Using the given and known parameters weld size for each side can be calculated.

Resultant force

$$F_{zy} = \sqrt{Fz^2 + Fy^2}$$

$$Fzy = \sqrt{2502^2 + 1695^2} = 3022\text{N}$$

Since we have two guiding supports the resultant force is divided to the base

$$P = \frac{Fzy}{2}$$

$$= \frac{3022N}{2}$$

$$= 1511\text{N}$$

Direct primary shears due to axial load (F_{zy})

Shear stress due to axial load is

$$\tau_1 = \frac{P}{A}$$

$$= \frac{\text{Fzy}}{\text{A}}$$

Where l=233.2mm, b=10mm and e=116.1mm

$$\tau_1 = \frac{P}{A}$$

$$= \frac{\text{Fzy}}{2(0.707)\text{s}\times\text{l}}$$

$$= \frac{1511N}{2(0.707)\times 233.2\text{mm}}$$

$$= \frac{4.58\ \text{N/mm}^2}{s}$$

$= \frac{4.58}{s}$ MPa

Shear stress due to turning moment (T)

This shear stress occurs due to turning moment (t)

$T = p \times e = F_{zy}$ x e

Where e=116.1mm

l= 233.2mm

b= 10mm

T=1511N x 116.1 mm

= 175427Nmm

From mathematical equation based on the Figure 3.13

$$\tau_2 = \frac{\mathrm{Ter2}}{\mathrm{J}} \qquad \text{Eq (3.32)}$$

Where r_2 and J need to calculate

$\text{Cos } \theta = \frac{r2}{r1}$

$r_2 = \sqrt{AB^2 + GB^2}$

$GB = r_2 \cos \theta = l/2$, $AB = b/2$

$r_2 = \sqrt{5^2 + 116.1^2} = 116.2\text{mm}$

$\cos \theta = \frac{GB}{r2} = \frac{5}{116.2} = 87.5°$

$r_2 = \sqrt{5^2 + 116.1^2} = 116.2\text{mm}$

$\cos \theta = \frac{GB}{r2} = \frac{5}{116.2} = 87.5°$

From the table for polar moment of inertia (J) (in appendix I)

$J = \frac{t1\,(3b^2 + l^2)}{6}$

$J = \frac{1.414\text{sx}233.2\,(3x10^2 + 233.2^2)}{6}$

$J = 9.02 \text{ x } 10^6 \text{ mm}^4$

Shear stress is then

$\tau_2 = \frac{\mathrm{Ter2}}{\mathrm{J}}$

$\tau_2 = \frac{175427\text{Nmmx } 116.1\text{x}116.2\text{mm}}{\text{Sx } 700\text{x}10^6\text{mm}^4}$

$\tau_2 = \frac{262.4\text{N/mm}^2}{s}$

$= \frac{262.4\text{MPa}}{s}$

Resultant shear stress

$$\tau_A = \sqrt{\tau1^2 + \tau2^2 + 2\tau1\tau2\cos\theta} \qquad \text{Equ (3.33)}$$

$$\tau_A = \sqrt{\left(\frac{4.58}{s}\right)^2 + \left(\frac{262.4}{s}\right)^2 + \left(\frac{4.58}{s}\right)\left(\frac{262.4}{s}\right)\cos 87°}$$

$$\tau_A = \frac{262.5}{s}$$

Where $\boldsymbol{\tau_A}$ maximum shear stress of the plate material 45MPa.

$$\text{Therefore S} = \frac{262.5}{\frac{262.4}{s}}$$

$$=5.83 \text{ mm} = 6\text{mm}$$

Since the allowable weld size for 10 mm thickness from the standard table is 6mm.

3.3 Fabrication of fixture components and Assembly process

Fabrication process of this milling fixture components were produced in Hibret manufacturing and machine building industry (HMMBI), precision factory using different machines and equipment's discussed in the above sections. The fabrication includes different machining and joining processes such as milling, turning, drilling and grinding operations and welding for the joining purpose.

3.3.1 Manufacturing process

Each part must be designed carefully as per the design requirements and specifications, so it can be manufactured easily and economically. Manufacturing process is the part of production process which is directly concerned with the change of form or dimensions of the part being produced. It is usually carried out as a unit operation, which means that it is a single step in the sequence of steps required to transform starting material into a final product. The broad categories of processing methods for materials are: Casting (expansion mold and permanent mold), Forming and Shaping (rolling, extrusion, drawing, sheet forming, powder metallurgy, and molding), Machining (turning, boring, drilling, milling), Joining (welding, brazing, soldering, diffusion bonding, adhesive bonding and mechanical joining), Finishing operations (polishing, burnishing, honing, surface treating, coating, and painting).

Selection of a particular manufacturing process depends not only on the shape to be produced but also on other factors.

General steps to manufacture components of the fixture are: -

- Select the material for each component according to design specification.
- Mark the selected material to the recommended dimensions by proper measuring tool (layout)
- Select the appropriate machine or tool to prepare the blank size.

- Perform the machining operation within the measured dimensions for each part.
- Assembling by joining operation (welding, bolt & nut)
- Finishing operation (polishing, painting)

After fixture fabrication process is finished setting up the lathe machine and testing of the fixture have carried out. Since manufacturing process is series of operation in which components are manufactured in their sequential order.

Manufacturing operations can be divided into two basic types Processing operations and Assembly operations.

A processing operation transforms a work material from one state of completion to a more advanced state that is closer to final desired product. It adds value by changing the geometry, properties, or appearance of the starting material. In general, processing operations are performed in discrete work-parts, but certain processing operations are also applicable to assembled items (e.g. painting a spot-welded car body). Processing operation is done by using operation sheet which is the best & simplest way of showing how the part is manufacture through different steps to complete the work. Therefore, process operation of this project is explained by using operation sheet.

3.3.2 Machines and equipment's

Different kinds of machines and equipment's were used in manufacturing processes were vertical CNC milling machine, lathe machine and radial drilling machine. Lathe machine and drilling machines were used to make turning operation of lead screw and radial drill machine for the drilling operations in the desired positions.

3.3.2.1 Vertical CNC milling machine

Most milling operations done here in the fabrication process were manufactured by this vertical milling machine. The machines specification such as allowable size, allowable load, degree of freedom, number of tools and time to change these tools and overall dimension are all given in table 3.5.

Figure 3-13 CNC milling machine for machining of fixture components

Figure 3-14 Conventional lathe machine

Table 3-4 Technical data for DMTG vertical CNC milling machine

Table	Table size	800mmx420mm
	T slot dimension	3x14x110 b/t slots
	Load on the table	500kg
Table travel	X,Y,Z axis	450mm,350mm,380mm
Feeds	Feed rate	1-10000mm/min
	Rapid traverse	24/24/24m/min
Spindle	Spindle power	7.5-11r/min
	Spindle speed	Max 8000rpm
	Height of spindle face from table top	150-670mm
Automatic tool changer	Number of tools	20-24Nose
	Maximum tool diameter	All pockets full 80mm
		Alternate pockets empty 125mm
	Maximum tool length	250mm
	Maximum tool weight	7kg
	Time of Tool change	6-8sec
Overall dimension		2310x2040x2337mm
Net weight		4800kg

Not only vertical milling machine was used but conventional lathe machine and drill machines were used. These two machines helped the fabrication process in make turning operation for the lead screw and radial drill machine for the drilling operations.

3.3.3 Operation sheet for fixture components

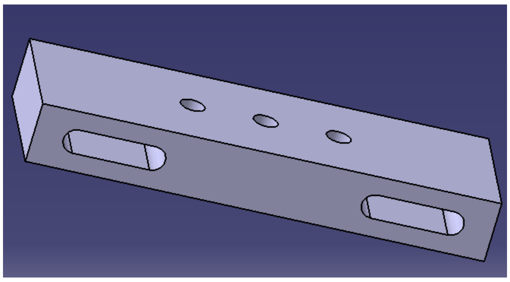
A. Operation sheet for upper and lower clamping jaws

These are 30 mm thick steel used to hold the workpiece using three 12 mm diameter bolts and it is connected with T bolts.

Material------------ **AISI No.1080 hot rolled.**

Blank size---------220x30x70 mm

Quantity------------02



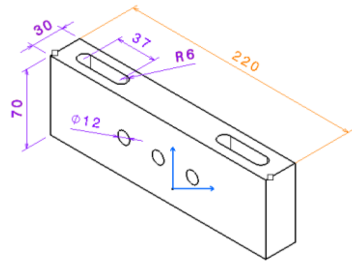


Figure 3-15 Upper and lower clamping Jaws

Table 3-5 Operation sheet for upper and lower clamping Jaws

Op No	Operation description	Feed in mm/ min	Spindle speed in RPM	Depth of cut	Planned time in minutes			Tools	Measuring tools
					Set up time	Machine time	Total time		
0.05	Mill the rectangular profile 240x70x30mm	0.3	318	2	30min	30min	60min	End mill	V.C
0.010	Contour the two profiles 12x37x70mm depth	0.3	318	2	1hr	1hr	2hr		
0.015	Drill three holes Ø12x30mm depth from edge to center distance 35x75mm length		318	6	30min	1:30hr 1:15hr	2hr	Drill bit Ø12	V.C
0.020	Make a thread M12x1.75 with 30mm depth				30min	1:30hr	2hr	Tap M12	

B. Operation sheet for right vertical support

It is a 30mm thick steel used to hold and slide the left column support and join with reinforcement by welding.

Material------------ **AISI No.1080 hot rolled.**

Blank size---------350 x 30 x 180 mm

Quantity------------01

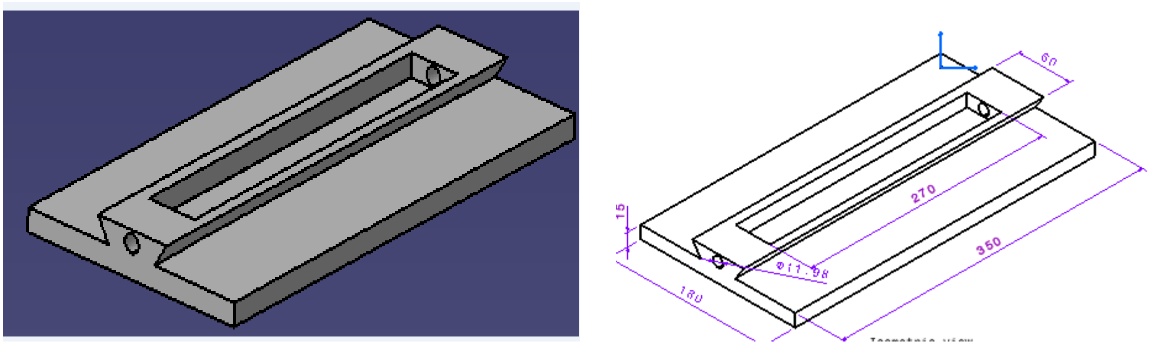


Figure 3-16 Right column support

Table 3-6 Operation sheet for right column support

Op No	Operation description	Feed (mm/ min)	Spindl e speed Rpm	Depth of cut	Planned time in minutes			Tools	Measur ing tools
					Set up time	Machine time	Total time		
0.05	Mill the rectangular profile 350x180x30mm	0.3	318	2mm	30min	1:30	2hr	Carbide end mile Ø14	v-caliper
0.010	Mill the dovetail profile 350x40x15 with angle 56.31°	0.2	318	2mm	30min	1hr	1:30	Carbide dovetail cutterØ14	v-caliper
0.015	Mill 2 T-shape profile 16x350x6.5mm per the drawing	0.2	318	2mm	30min	1:15hr	1:45hr	End mill	V.C
0.020	Mill 25x350x7.5mm depth from edge distance 30mm	0.2	318	2mm	30min	1:15hr	1:45hr	End mill	V.C

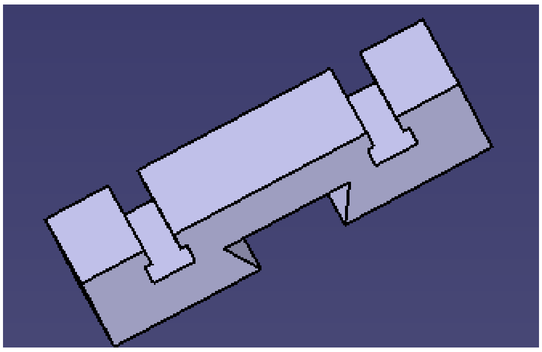
C. Operation sheet for left column support

It is a 30-mm thick steel used to hold upper and lower jaws by a T bolt together with right column support and it is connected with lead screw sliding mechanism.

Material------------ **AISI No.1080 hot rolled.**

Blank size---------350 x 30 x 180 mm

Quantity------------01



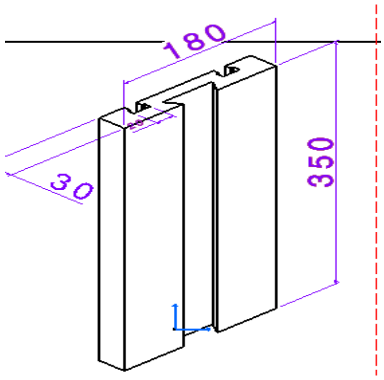


Figure 3-17 Left column support

Table 3-7 Operation sheet for left vertical support

Op No	Operation description	Feed in mm/min	Spindle speed in RPM	Depth of cut	Planned time in minutes			Tools	Measuring tools
					Set up time	Machine time	Total time		
0.05	Mill the rectangular profile 350x180x30mm	0.3	318	2mm	30min	1:30	2hr	Carbide end mill Ø14	V.C
0.010	Mill 2 T-slots profile 16x350x6.5mm depth	0.2	318	2mm			45min	Carbide end mill	V.C
0.015	Mill 25x350x7.5mm depth from edge distance 30mm	0.2	318	2mm			45min	Carbide end mill	V.C

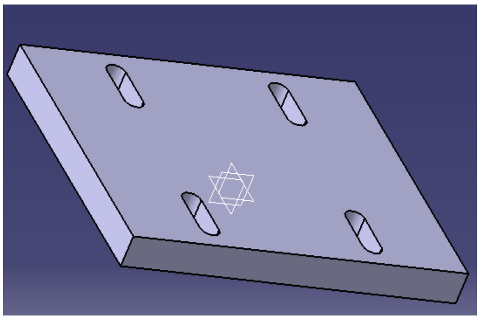
D. Operation sheet base plate

It is a 20 mm thick steel used to hold all parts together such as jaws, column supports and reinforcements. It is connected with lathe cross slide using four 12 diameter bolts.

Material------------ **AISI No.1080 hot rolled.**

Blank size---------210 x 20 x 180 mm

Quantity------------01



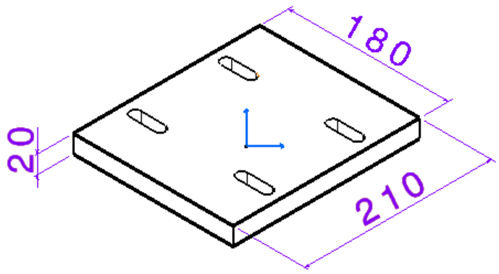


Figure 3-18 Fixture base

Table 3-8 Operation sheet for base plate

Op No	Operation description	Feed in mm/min	Spindle speed in RPM	Depth of cut	Planned time in minutes			Tools	Measuring tools
					Set up time	Machine time	Total time		
0.05	Mill the rectangular profile 210x180x20mm	0.2	318	3	30min	2hr	2:30hr	End mill	V.C
0.010	Contour the four profiles 12x28x20mm depth	0.15	318	1	30min	1:30hr	2hrs	End mill Ø12	V.C

E. Operation sheet lead screw

It is a 20mm diameter circular steel that used to convert the rotary motion produced by the applied load on the screw to linear motion that slide left verticals support over the right vertical support.it is connected with bearing and welding.

Material------------ **AISI No.1080 hot rolled.**

Blank size---------360mm x 20mm diameter

Quantity------------01

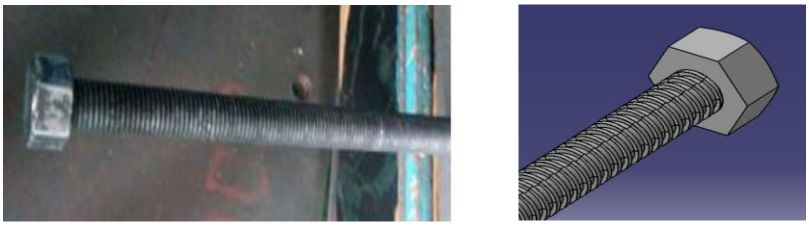


Figure 3-19 Lead screw

Table 3-9 Operation sheet for lead screw

Op No	Operation description	Feed in mm/min	Spindle speed rpm	Planned time in minutes			Tools	Measuring tools
				Set up time	Machine time	Total time		
0.05	Turn a circular profile 360mmxØ20	0.01	600	30min	2hr	2:30hr		V.C
0.010	Make a thread	0.01	600	30min	1:30hr	2hrs		V.C

F. Operation sheet for Reinforcement

These reinforcements are two right angled triangles with length 120mm, height 200mm and thickness 10mm help to join the column supports with the base of the fixture for the final assembly.

Material------------ **AISI No.1080 hot rolled.**

Blank size---------200mm x 120mm x10mm

Quantity------------01

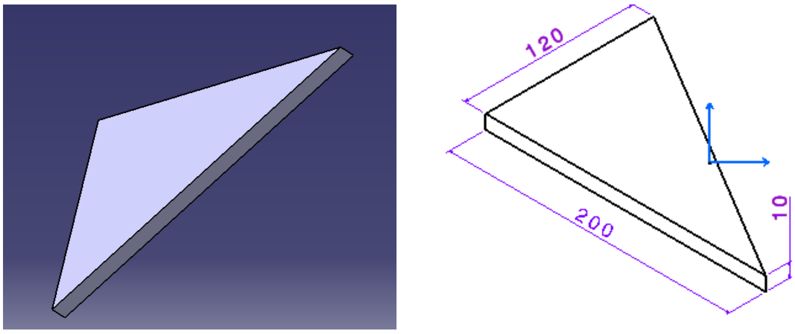


Figure 3-20 Reinforcements to be weld

Table 3-10 Operation sheet for Reinforcements

Op No	Operation description	Feed in mm/min	Spindle speed in	Depth of cut	Planned time in minutes			Tools	Measuring tools
					Set up time	Machine time	Total time		
0.05	Mill the triangular profile	0.3	318	2mm	30min	2hr	2:30hr	End mill	V.C

3.3.4 Assembly process

An assembly operation joins two or more components to create a new entity, called an assembly or subassembly. This process uses joining processes like welding, bolt and nut connection or riveting. In this project the assembly process uses welding and bolt and nut. Five major assembly processes were done in this fabrication process listed below.

1. Assembly of upper and lower clamping jaws with left column support: - This assembly is done with 12mm diameter and 90mm length T bolt.
2. Assembly of left column support with right column support: - These two main components slide over the each other to facilitate additional process. Hear a lead screw that change the rotational movement in to linear motion to slide the left column support on the right column support is used with bearing.
3. Assembly of column supports with fixture base:- The column supports are welded with the base plate by two triangular reinforcements
4. Assembly of fixture with lathe cross slide: -Using a bolt of 12mm diameter in order to attach the fixture near to the tool post.
5. After all the assembling is finished the fixture is mounted on the lathe machine in order to do milling operation.

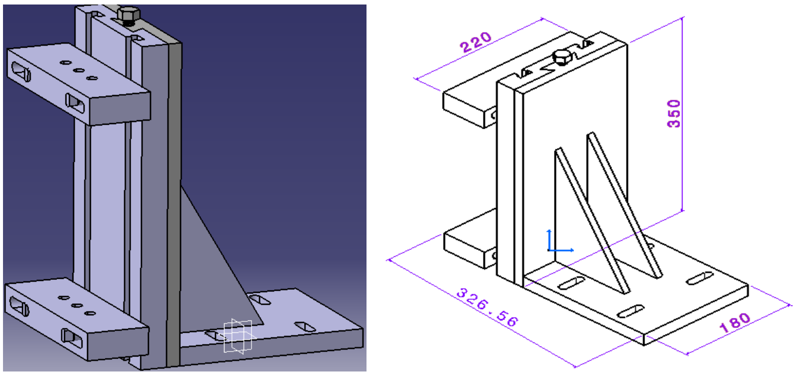


Figure 3-21 Assembly of fixture

Note: *The reader should refer to the detailed drawings and Master CAM code in Appendix J for every information regarding shapes and sizes in the operations sheets.*

3.4 Cost analysis

3.4.1 Cost of raw materials and the cost of standard items

The material costs refer to raw materials and the standard item costs which are purchased from a local market.

Table 3-11 Cost of raw materials

No	Material description	Size required	Unit	Qty	Unit price		Total price	
					Birr per Kg	Cent	Birr	Cent
1	Mild steel plate	350x180x30	Kg	02	70	00	2077	11
2	Mild steel plate	210x180x20	Kg	01	70	00	623	13
3	Mild steel plate	220x70x30	Kg	02	70	00	1305	61
4	Mild steel plate	200x240x10	Kg	01	70	00	527	52
5	Round bar	Ø30x 360	Kg	01	72	00	139	76
6	Aluminum bar	150x100x50	Kg	02	80	00	312	00
7	Aluminum round bar	Ø60x 200	Kg	02	80	00	117	56
		Total cost					5102.69birr	

Table 3-12 Standard material cost

No	Name of Material	Size	Unit	Qty	Unit price		Total price	
					Birr	Cent	Birr	Cent
1	T bolts	M12	Pcs	08	25	00	200	00
2	Hexagonal bolt with nut	M12x30	Pcs	02	10	00	20	00
5	Drill bit	Ø12	Pcs	2	200	00	400	00
6	Ball bearing	6004	Pcs	01	250	00	150	00
7	Anti-rust	Litter	Pcs	01	70	00	70	00
8	Electrode	Ø 2.5	Pkt	01	150	00	150	00
9	Brush	2.5 ˮ	Pcs	02	20	00	40	00
			Total cost				1080birr	

Total Materials Cost = Cost of raw materials+ Cost of Standard items

=5102.69birr+1080birr

=6182.69birr

3.4.2 Labor cost for manufacturing and assembling components

3.4.2.1 Labor cost for manufacturing

It is the cost of the worker spend in making a product. This cost includes the labor cost of component manufacturing and assembly process.

Note: - Operator cost per hours in the factory (HMMBI) rate is 16 Birr per hour. For all components, the labor cost is indicated as follows.

Table 3-13 Manufacturing Labor cost

No	Parts name to be made	Qty	Operation	Working time per hour	Payment per hour	labor cost price per birr	Total cost of part in Birr
1	Jaw (upper and lower)	02	Measuring & cutting to size	0.45	16	10.67	52.01br
			Lay out for drilling holes	0.15	16	4	
			Drilling of three holes Ø12	0.45	16	10.67	
			Drilling of two elongated holes Ø12	1	16	16	
			Making Thread	0.45	16	10.67	
2	Left Vertical supports	01	Measuring & cutting to size	0.45	16	10.67	189.34br
			Face milling	2:30	16	24	
			Grooving of T slots	5	16	80	
			Milling by a dovetail	4	16	64	
			Grinding to make smooth	0.45	16	10.67	
3	Right vertical support	01	Measuring & cutting to size	0.45	16	10.67	
			Face milling	3:30	16	56	
			Layout for end milling	0.30	16	8	

			Milling by a dovetail end mill cutter	4	16	64	180.01br
			Grinding to make smooth	0.45	16	10.67	
			Layout for drilling and drilling	2.00	16	4	
			Drilling	1.45	16	26.67	
3	Fixture base	01	Measuring & cutting to size	0.30	16	8	92birr
			Face milling	3	16	48	
			Layout for end drilling	0.15	16	32	
4	Lead screw	01	Measuring & cutting to size	0.15	16	4	129.33br
			Turning	2.45	16	42.67	
			Make hexagonal nut	2	16	32	
			Facing	0.10	16	2.666	
			Make thread	3	16	48	
5	Reinforcements	02	Measuring & cutting to size	0.30	16	8	34.67br
			Face milling	1.45	16	26.67	
						Total cost	548.03br

3.4.2 Labor cost for assembling components

The time needed for assembling the components is indicated as follows: -

Table 3-14 Assembly labor cost

No	Types of assembly	Method of assembling	Working time per hour	Payment per hour	labor cost price per birr
1	Assembly of upper and lower jaws with left column support	Bolt and nut	0.45	16	10.67
2	Assembly of left vertical support with right column support	Lead screw and bearing	2hr	16	32
3	Assembly of column supports with fixture base	Welding	2hr	16	32
4	Assembly of fixture with lathe cross slide	Bolt and nut	1hr	16	16
			Total cost		90.67

Total Labor Cost = Labor cost for manufacturing components + Labor cost for assembling components

548.03 + 90.67

= 638.70birr

3.4.3 Electrical power consumption cost

It is the cost of electric power needed to machine and weld parts in the fabrication process. Electric power is expressed (measured) by a unit watt (W) or kilo watt (kW). The cost of electric power here is expressed in birr per kWh.

The component, electrical machines used and time consumed in each production are indicated in table 3.16:-

Table 3-15 Machines & time consumed

No	Manufactured part	Types of machines &their machining time in hour						
		Qty	Lathe machine machine	Milling machine	Arc welding machine	Oxy-fuel cutting	Drilling machine	Portable hand grinder
1	Jaw (upper and lower)	02				0.40	4	
2	Left Vertical supports	01		6:30		0.45		0.30
3	Right vertical support	01		7:30	0.30	0.45	1.45	0.30
4	Fixture base	01		3		0.30	2hr	
5	Lead screw	01	2hr	5				
6	Reinforcements	02		1.45	0.30	0.30		
	Total time		2hr	23:45	1hr	3.10	7.45	1hr

Now let's calculate the energy used for each machine and multiply their power rating with their machining time.

Note: - Power rating of each machine is taken from their life history card

Example Lathe machine

Power rating (p) = 2.2 kW

Working time (t) = 2hr

Energy consumed (E) =?

E= P x t

E= 2.2 x 2hr

= 4.4 kWh

Note: - *The energy consumed for each machine was done with the same procedure of the above example. And the electrical power cost for 1kWh is 0.70 Birr, (source from EELPA)*

Table 3.17 Calculates the power rating of each machine used in the fabrication process the fixture with the respective energy consumption. According to the source from EELPA it is 0.70cents per one kilo watt hour for each energy consumption.

Table 3-16 Electrical power consumption cost

No	Machine type	Power rating of the machine in kW	Total machining in hour	Energy consumed in kWh	Payment for I kwh in birr	Total payment in birr
1	Lathe machine	2.2kW	2hr	4.4	0.70	3.08
2	Milling machine	1.5 kW	23.45	35.175	0.70	24.62
3	Arc welding machine	4.9 kW	1hr	4.9	0.70	3.43
4	Oxy fuel cutting machine	0.14 kW	3.10	0.434	0.70	0.3038
5	Drilling machine	1.3 kW	7.45	9.685	0.70	6.7795
6	Portable hand grinder	2 kW	1hr	2	0.70.	1.4
				Total cost		39.6133

3.4.4 Machine Depreciation Cost

Depreciation is defined as the reduction in value of the machine over time as it is working a specific task. Depreciation occurs due to wear that gradually declines the capacity of the piece of equipment to perform its function. The objective of the depreciation schedule is to recover initial investment cost of equipment each year over its economic life.

The mathematical formula for the yearly depreciation charge using the straight-line method is:

$$D = \frac{P-S}{N} \qquad \text{Equ 3. 34}$$

Where, D = Depreciation charge

P = Initial purchase price (actual price)

S = Salvage value (take average 30% initial price P)

N = Economic life (in year or scheduled machine hours)

Example: For this project the depreciation cost of Arc welding machine is calculated as follows and the same is done for other machines.

$D = \frac{P-S}{N} =$ Where D = Depreciation charge

P = 30,000 Birr

S = 30% of 30,000 = 9,000 Birr

N = 5 yrs

$$\frac{30{,}000-9{,}000}{5} = 4200 \text{ Birr per year}$$

In one year we have 12 months, and the depreciation cost for a month, 4200/12 = 350Birr/month since there are 4 weeks in a month, the depreciation cost for a week=350/4=

87.5 Birr /week. In a week we have 5 working days the depreciation cost per day =87.5/5= 17.5 Birr/day. Further we have 8 working hours in a day so the depreciation cost per hour= 17.5/8= 2.18 Birr/hr. Therefore the time period over which hourly depreciation of the machine that is used to manufacture the fixture is already calculated. Therefore, take the depreciation of those machines from the university scheduled data. Therefore by summing up all the time for machining from the operation sheet I can calculate the total depreciation of these machines by multiplying the time of operation and the hourly depreciation.

Table 3-17 Depreciation cost of different machines

No	Type of machines	Life span (years)	Machine price		Depreciation values /hr.		Usage time (hr.)	Total depreciation Value	
			Birr	Cents	Birr	Cents		Birr	Cents
1	Arc welding	5	30000	00	2	18	1hr	2	18
2	Portable grinder	3	4000	00	0	48	1hr	0	48
3	Lathe machine	10	250000	00	3	90	2hr	7	80
4	Drilling machine	10	150000	00	2	34	7.45	17	94
5	Milling machine	12	450000	00	5	85	23.45	139	25
							Total cost	167	65

3.4.5 Total cost of fixture fabrication cost

Manufacturing cost: -

- Material cost ---------------------- 6182.69 Birr
- Labor cost ------------------------- 638.70= Birr
- Electrical power consumption cost = 39.638birr
- Machine depreciation cost ------------167.65 Birr

Manufacturing cost = 7058.67Birr

Contingencies: - it is compensation due to some errors and unexpected failure of time in the project, it is usually taken as 10% of the manufacturing cost.

Contingency = 10% x 7058.67 Birr

= 0.1x7058.67

= 705.86

Total manufacturing cost = Manufacturing cost + Contingency

= 7058.67Birr +705.86

= 7760.53Birr

CHAPTER FOUR

4. TESTING OF THE FIXTURE

4.1 Experimental set up

The aim of the experiment was to compare the workpiece's surface-finish and geometrical configuration that was machined by the fixture and vertical milling machine with an accuracy of 0.001 mm. according to the machines specification and design analysis, the machining was carried out under comparable cutting condition.

For the experiments

- Cylindrical and rectangular Aluminum alloy workpiece (Al 7075) was used
- Rotation between 560 rpm and 1250 rpm was implemented
- Size of 12mm and 20mm diameter end milling cutter made of high speed steel material with three number of teeth used as a cutting tool.

4.1.1 Vertical milling machine:

The universal milling machine shown in Fig. 4.1 is a vertical milling machine. It consists basically of a motor driven spindle, or self-contained electric drive motors, mounts and revolves the milling cutter, and a reciprocating coolant system, variable spindle speeds, and power-operated adjustable worktable, which mounts and feeds the workpiece.

Figure 4-1 Universal milling machine

4.1.2 Modified Lathe machine

The fixture was assembled on top of the lathe machine guide way or bed and hold the workpiece to perform the desired machining operation. It attached to the machine table by clamping mechanism through the radial T slots of the machine table or clamped to cross slide near a tool post as shown in the Figure 4.2. Ideally, there should be a minimum amount of gap between the fixture and machine table to have the maximum amount of rigidity and support from the machine onto the fixture. Though lathe machine was modified to perform the required milling operations. The components of e shown with the arrow clearly in the Figure 4.2.

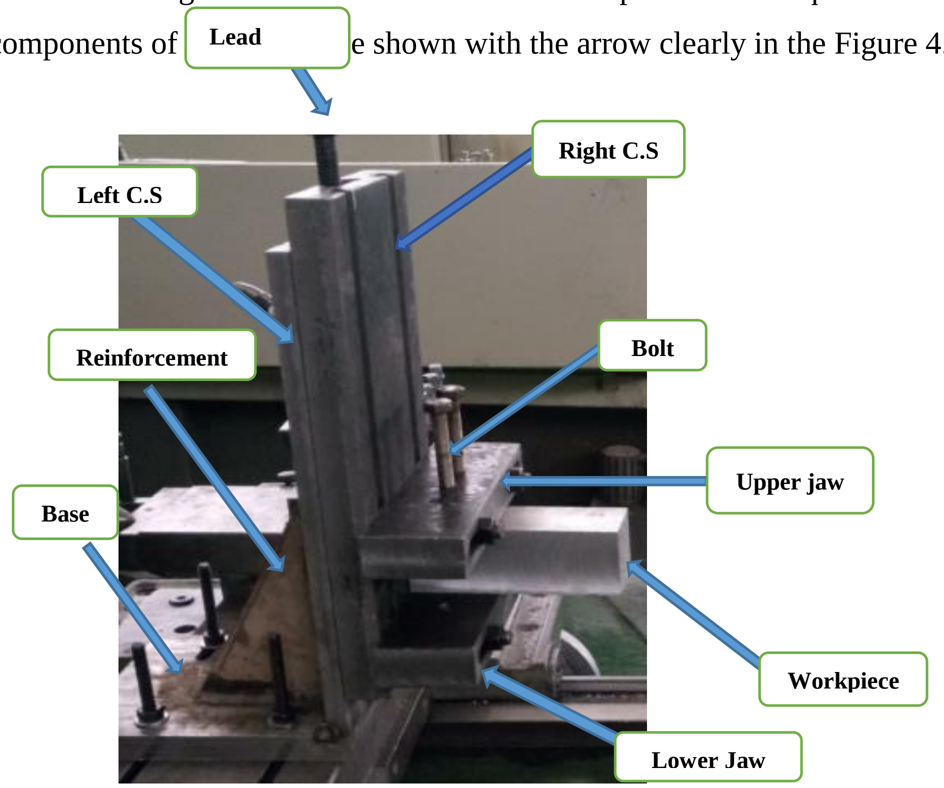


Figure 4-2 Modified lathe machine

4.2 Experimental procedure and cutting conditions

The machining parameters are critical input parameters for this study. They were chosen to best represent an actual milling process. It was impossible to utilize the actual machining parameters from industry due to most companies guarding their specific machining parameters as intellectual Properties. However, the chosen machining parameters which were gathered from literatures were considered to be a generic representation of an actual machining process. A specific set of machining parameter was chosen for this chapter were selected from the standard table found in the appendix C and D.

Experimental procedures

Experiments were conducted on Aluminum workpiece (Al 7075) with three different parameters to understand the effect of various machining parameters on the surface roughness and geometrical configuration. The milling operation conducted were end milling processes, face milling and keyway milling operation. The experiment was conducted in three stages shown in the table 4.1 to establish the effect of cutting speed, depth of cut and feed parameters on the surface. In any machining process, apart from obtaining the accurate dimensions, achieving a good surface quality is also of utmost importance. A machining process involves many process parameters which directly or indirectly influence the surface quality of the product. Surface roughness is caused due to various parameters of which feed, speed and depth of cut are important ones.

Table 4.1 listed each stages with their cutting parameters. The first stage of the experiment was conducted to determine the effect of feed at constant spindle speed and depth of cut. In the second stage the experiment was conducted to determine the effect of depth of cut at constant spindle speed and feed rate. In the third stage the experiment was conducted to determine the effect of spindle speed at constant depth of cut and feed.

Table 4-1 Cutting parameters

Cutting parameters	Stage I	Stage II	Stage III
Revolution speed of the tool(rpm)	800	800	560,630,800 and 1120 and 1250
Depth of the cut(mm)	3	2,3 and 4	3
Axial feed rate (mm/rev)	0.01, 0.15and 0.02	0.01	0.01

4.2.1 Workpiece material preparation

Before any milling job is attempted, some decisions must be made. In addition to selecting the best means of holding the work and the most appropriate cutters to be used, the cutting speed and feed rate must be established to provide good balance between rapid metal removal and long tool life. Aluminum workpiece was selected for the experiments. The property of the workpiece are Shear strength τ =331 MPa, tensile strength σ = 570MPa, density 2.81kg/m^3, and Brinell hardness 150 HV from the standard in appendix A).

The Aluminum workpiece have a geometry shown in the table 4.2. The blank dimension was 150mm long, 30mm wide and 30mm thick. The keyway milling was done on solid circular aluminum of 60mm diameter and 600mm length.

Table 4-2 Specification of Workpiece material

Aluminum bar		Cylindrical Aluminum	
Length	150mm	Diameter	60mm
Width	30mm	Length	600mm
Thickness	30mm		

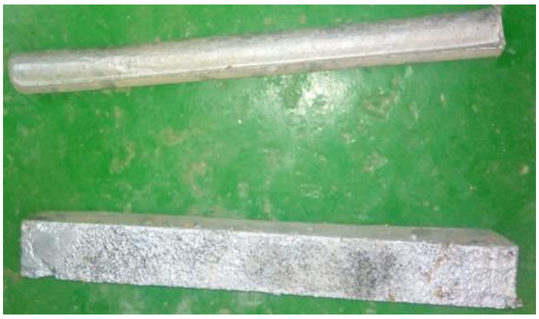


Figure 4-3 Aluminum workpiece material

4.2.2 Machining of Aluminum by milling machine and modified lathe machine

After developing the setup finally, it is ready to take some test on Aluminum with different machining parameters. Within three stages and two milling operations with two machines face milling and keyway milling were conducted by the modified lathe machine and vertical milling machine. The three different machining parameters are cutting speed, depth of cut and feed that are selected from the standard tables for Aluminum materials, (Appendix F).

In face milling, the cutter mounted on a lathe spindle having an axis of rotation perpendicular to the workpiece surface. The milled surface results from the action of cutting edges located on the periphery and face of the cutter as shown in the Figure 4.4. a. Flat surface as well as various profiles can be produced by end milling. The cutter in end milling has either straight or tapered shanks for smaller and larger cutter sizes respectively. The cutter usually rotates on an axis perpendicular to the workpiece, although it can be tilted to machine-tapered surfaces.

Schematic diagram of experimental set-up for face and end milling are shown in Figure 4.4

Figure 4-4 a, keyway end milling   b, face milling

Aluminum bar shown in the Figure 4-5 were milled by a 20mm diameter face milling cutter. The facing was done by implementing different cutting conditions found in table 4.1 to measure the surface roughness of each side and evaluate the effects. Figure 4.5 shows one side of Al bar faced with 20mm end mill cutter on the modified lathe machine and milling machine. This face milling operation applied different cutting parameters.

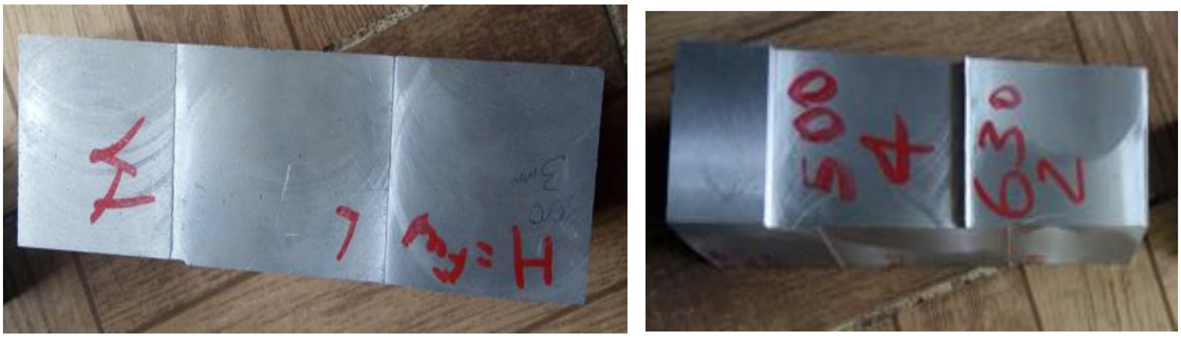


Figure 4-5 Face milling of Aluminum bar by fixture

The keyways on the Cylindrical Aluminum or aluminum shaft shown in the Figure 4.6 are made by a 12mm diameter end mill cutter with depth of 6mm. The grooves were made on 30mm diameter solid cylinder by a modified lathe machine (fixture) and vertical milling machine. Four keyways were done for the comparison between the two set ups.

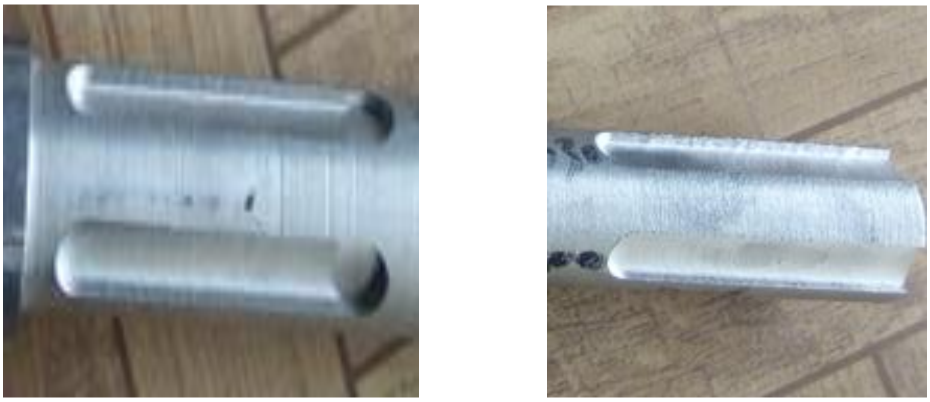


Figure 4-6 Keyway end milling of Aluminum shaft by fixture and vertical milling fixture

The keyways on the rectangular bar shown in the Figure 4.7 are made by a 12mm diameter end mill cutter with depth of 6mm. The grooves were made by a modified lathe machine (fixture) and vertical milling machine.

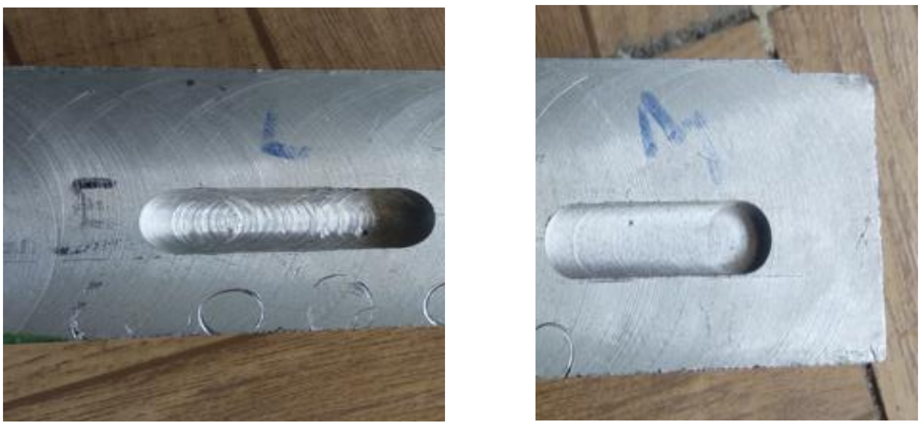


Figure 4-7 Keyway end milling of Aluminum bar by fixture and milling machine

4.3 Experimental work

The experiments were carried out to check the quality of the product in terms of surface roughness test and geometrical configuration.

4.3.1 Surface roughness test

Surface roughness is a measurable surface characteristic quantifying high frequency deviations from an ideal surface. Usually measured in micrometers (μm), it is a subjective property incorporating appearance, smoothness, etc. It is usually described by the arithmetic mean value (R_a), based on the mean of the normal deviations from a nominal surface over a specified "cutoff" length. In general, a surface cannot be adequately described by its Ra or Rq values alone, since these are averages. Mattew *et al.* (2010). Two surfaces could have the same roughness value, but quite different topographies. The process finish capability of a rough machining operation is about 0.05 mm and for finishing is about 0.005 mm. Note however that these values are affected by machining parameters and other factors.

The focus of numerous and extensive studies that evaluate surface finish is usually centered on the effect that machining parameters (speed, feed, depth of cut, etc.) have on the surface quality. However, vibrations within the system can have an even more significant adverse effect on the surface finish of a machined component. Mattew *et al.* (2010)

Many researchers published on finding the relationship between cutting parameters and surface roughness. For example (Wang *et al.* (2005)) explained as surface roughness increased linearly as the tool diameter and spindle speed increases; feed-rate was the most influential parameter when other parameters kept constant. The research found that increasing tool stiffness and decreasing the spindle chatter or vibration will improve workpiece surface quality. The performance of machining processes was assessed by dimensional and geometrical accuracy as well as the surface texture of the part. Factors such as workpiece vibration, machine-tool vibration, process instability, tool wear, and thermal deformation are the major deteriorate of this performance. Sinawi and Kashani (2004).

Abouelatta and Madl (2001) examined the relationship between tool life, surface roughness and vibration by using parameters cutting speed, feed rate, depth of cut, tool nose radius, tool overhang, approach angle, workpiece length and workpiece diameter and the accelerations in both radial and feed directions. Sahoo (2011) stated that in today's manufacturing industry, special attention is given to dimensional accuracy and surface finish. The surface quality was an important parameter to evaluate the productivity of machine tools as well as machined components. Surface roughness was used as the critical quality indicator for the machined surface. Formation of a rough surface is a complicated mechanism involving many parameters. The quality of the workpiece (either roughness or dimension) are greatly influenced by the cutting conditions, tool geometry, tool material, machining process, chip formation, workpiece material, tool wear and vibration during cutting. The machinability of the materials was determined by surface finish. Kiswanto *et al.* (2014) discovered the behavior of cutting parameters and machining time with respect to surface roughness and burr formation in micro-milling operation. The micro-milling process was performed by three variations of feed-rate and spindle speed in three intervals of machining time. Both surface roughness and burr formation were analyzed.

Most common terminologies of surface roughness test are discussed below

1. Roughness Average R_a, is the arithmetic average of the absolute values of the profile heights over the evaluation length.
2. RMS Roughness R_q, is the root mean square average of the profile heights over the evaluation length.
3. Maximum Height of the Profile R_t, the vertical distance between the highest and lowest points of the profile within the evaluation length.
4. Average maximum height of the profile R_z is the average of the successive values of R_t calculated over the evaluation length. This parameter is the same as R_z when there are five sampling lengths within the evaluation length.

Surface roughness test equipment

Measurement of surface roughness is usually accomplished through commercially available surface profile meters, the most common featuring a diamond stylus traveling over a surface. Additionally, it can also be observed directly through interferometry, either optical, Scanning-electron or Atomic-force microscopy. Mattew *et al.* (2010). In this project the testing equipment was TESA RUGOSURF. was specimen used for testing any surface finish quality and that have long proven value in practice which offers a range of 3 portable RUGOSURF roughness gauges adapted for different levels of precision from the production floor to the test laboratory. These devices are particularly appreciated by operators for their ease of use, robustness and reliability. The range includes data management software to process measured values for an optimal overview of roughness profiles, statistical data and customizable measurement reports. TESA RUGOSOFT and measurement studio software was software tools to allow the storage of surface roughness measurements along with roughness parameters and roughness profile. A measuring program created in the software can be transferred to the instrument together with measuring parameters. The results are available at all times, complete with statistical analysis and can be exported for reports like

- ✓ Measuring results with measuring parameters R_a, R_z, R_t, R_q
- ✓ Profiles as coordinates
- ✓ Charts of each parameter
- ✓ Measuring report in format .xls .pdf .doc .rpt (Crystal Report) or also .rtf (Rich Text Format)

The surface roughness test was performed in Addis Ababa university material testing lab. The testing equipment and the computer that generate the test are shown in the Figure 4.8. The results were given in four basic values Ra, Rz, Rt, Rq and the time taken for each test was 20-25 sec per each R values.

Figure 4-8 Surface roughness test equipment

CHAPTER FIVE

5. RESULTS AND DISCUSSION

In this chapter, the test of surface roughness and geometrical configuration are discussed. Surface roughness is a measured parameter that can be used to analyze the quality of the machining process. The test was done by the TESA RUGOSURF equipment in Addis Ababa University, material testing lab. The test results were four different surface roughness parameters R_a, R_z, R_t, R_q from the measurement. The results were for both the surface made by vertical milling machine and modified lathe machine (fixture). The results obtained are clearly discussed. Geometrical configuration test was done by visual inspection using Vernier caliper.

5.1 Experimental result in surface roughness test

The experiments are face milling and keyway milling on the milling machine and modified lathe machine, take place in three stages as discussed in the Table 5.1.

1. Variable depth of cut, at constant feed and spindle speed
   Here the depth is varied between 2mm and 4mm while spindle speed and feed rate are 800rpm and 0.01m/min.
2. Variable spindle speed, at constant depth of cut and feed
   Here the spindles speed is varied between 560rpm and 1250rpm while depth of cut and feed rate are 3mm and 0.01m/min.
3. Variable feed, at constant depth of cut and cutting speed
   Here the feed is varied between 0.01m/min and 0.03m/min while spindle speed and depth of cut are 800rpm and 3mm.

Following tables illustrates the obtained values of the surface roughness test made by HSS end mill cutter with the two set ups, Vertical milling machine (VMM) and fixture or modified lathe machine (MLM).

Experiment I

Table 5.1 gives the results of revolution speed of the tool (rpm): 800, axial feed rate *f* (m/min): 0.01 and depth of the cut, *d* (mm): 2, 3 and 4 with three different trials.

Table 5-1 Face milling at variable depth of cut, constant feed and constant cutting speed

Trial No	Depth (mm)	VMM				Fixture (MLM)			
		R_a (µm)	R_z (µm)	R_q (µm)	R_t (µm)	R_a (µm)	R_z (µm)	R_q (µm)	R_t (µm)
1	2	2.084	5.895	2.084	5.953	2.164	6.125	2.384	6.453
	2	1.894	5.356	1.894	5.409	2.194	5.556	2.204	5.509
	2	2.096	5.929	2.108	5.988	2.223	6.429	2.258	6.188
	2	2.084	5.895	2.084	5.953	2.392	5.978	2.132	6.123
2	3	2.358	6.67	2.373	6.736	2.406	6.805	2.406	6.872
	3	2.561	7.243	2.572	7.314	2.418	6.838	2.418	6.906
	3	2.322	6.569	2.322	6.67	2.322	6.589	2.322	6.634
	3	2.358	6.67	2.358	6.736	2.561	7.243	2.596	7.314
3	4	2.43	6.872	2.43	6.94	2.346	6.636	2.346	6.702
	4	2.132	6.032	2.132	6.09	3.121	8.827	3.145	9.433
	4	2.394	6.771	2.394	6.838	3.335	9.433	3.335	9.526
	4	2.287	6.467	2.298	6.532	3.931	11.11	4.026	11.22

Experiment II

Table 5.2 gives the results of depth of the cut, *d* (mm): 3, axial feed rate *f* (m/min): 0.01 and revolution speed of the tool, (rpm): 560, 630, 800, 1120 and 1250 with three different trials.

Table 5-2 Face milling at variable cutting speed, constant feed and constant depth of cut

Trial No	Speed (rpm)	VMM				Speed (rpm)	Fixture (MLM)			
		R_a (µm)	R_z (µm)	R_q (µm)	R_t (µm)		R_a (µm)	R_z (µm)	R_q (µm)	R_t (µm)
1	630	1.358	3.84	1.364	3.878	560	1.429	4.042	1.435	4.082
	630	1.238	3.503	1.244	3.538	560	1.423	4.025	1.447	4.065
	630	1.787	5.053	1.846	5.103	560	1.941	5.491	2.06	5.545
	630	1.304	3.688	1.334	3.725	560	1.841	5.985	2.17	5.634
2	800	2.751	7.781	2.763	7.859	800	2.739	7.748	2.739	7.875
	800	2.179	6.165	2.179	6.226	800	2.439	6.759	2.797	6.846
	800	2.120	5.996	2.108	6.056	800	2.375	6.149	2.575	7.026
	800	1.894	5.356	1.882	5.409	800	1.894	5.688	1.894	5.725
3	1250	1.965	5.558	2.084	5.613	1120	2.298	6.502	2.298	6.566
	1250	2.225	7.781	2.846	7.859	1120	2.025	5.727	2.025	5.783
	1250	2.084	5.895	2.096	5.953	1120	1.989	5.626	1.977	5.681
	1250	1.863	4.985	1.846	5.035	1120	2.251	6.367	2.263	6.43

Experiment III

Table 5.3 gives the results of revolution speed of the tool, (rpm): 800, depth of the cut, *d* (mm): 3 and axial feed rate *f* (m/min): 0.01, 0.015 and 0.02 with three different trials.

Table 5-3 Face milling at variable feed, constant depth of cut and constant cutting speed

Trial No	Feed (mm/rev)	VMM				Fixture (MLM)			
		R_a (μm)	R_z (μm)	R_q (μm)	R_t (μm)	R_a (μm)	R_z (μm)	R_q (μm)	R_t (μm)
1	0.01	2.608	7.377	2.732	7.45	2.966	8.388	2.977	8.471
	0.01	2.894	8.186	2.894	8.266	3.049	8.624	3.073	8.71
	0.01	2.311	6.535	2.311	6.6	2.596	7.344	2.608	7.416
	0.01	3.001	8.488	3.049	8.572	2.561	7.243	2.561	7.316
2	0.02	3.037	8.59	3.049	8.675	3.431	9.702	3.478	9.798
	0.02	2.608	7.377	2.632	7.45	3.764	10.64	3.788	10.75
	0.02	2.882	7.152	3.192	8.233	3.502	9.904	3.326	10
	0.02	2.489	7.04	2.513	7.11	2.191	6.198	2.161	6.26
3	0.03	3.001	8.488	3.013	8.572	3.901	11.05	3.907	11.15
	0.03	3.097	8.759	3.097	8.846	3.788	10.71	3.788	10.81
	0.03	3.121	8.827	2.739	8.914	2.727	7.827	2.739	8.014
	0.03	3.216	9.096	2.739	9.186	2.68	8.096	2.916	8.186

Experiment IV

Table 5.4 gives the results of Revolution speed of the tool, (rpm): 560, 630, 800, 1120 and 1250 Depth of the cut, *d* (mm): 3 and manual axial feed with four different trials. This experiment measures the surface roughness value of keyways made by the parameters.

Table 5-4 Keyway milling at variable cutting speed and variable feed, constant depth of cut

Trial No	Speed (rpm)	VMM				Speed (rpm)	Fixture (MLM)			
		R_a (μm)	R_z (μm)	R_q (μm)	R_t (μm)		R_a (μm)	R_z (μm)	R_q (μm)	R_t (μm)
1	630	3.716	10.51	3.716	10.61	560	2.739	7.748	2.739	7.825
	630	3.836	10.84	3.859	10.95	560	3.097	8.959	3.097	8.846
	630	3.049	8.624	3.049	8.71	560	2.775	7.849	2.775	7.926
2	800	3.597	10.17	3.621	10.27	800	3.716	10.21	3.714	10.61
	800	4.407	12.46	4.431	12.46	800	4.716	11.84	3.859	10.95
	800	4.193	11.85	4.193	11.97	800	4.549	12.05	4.549	12.05
3	1250	4.097	11.58	4.121	11.7	1120	4.359	12.33	4.383	12.45
	1250	3.811	10.78	3.907	10.88	1120	5.646	15.96	5.622	16.12
	1250	3.716	10.51	3.74	10.61	1120	5.884	16.64	5.884	16.8

From all the results found from the surface roughness tester the average value of each parameter was taken for the measurement of the average value.

The average value can be obtained by the following mathematical formulas.

$$\left\{\begin{aligned} \text{Average } R_a &= \frac{Ra1+Ra2+Ra3+Ra4}{4} \\ \text{Average } R_z &= \frac{Rz1+Rz2+Rz3+Rz4}{4} \\ \text{Average } R_q &= \frac{Rq1+Rq2+Rq3+Rq4}{4} \\ \text{Average } R_t &= \frac{Rt1+Rt2+Rt3+Rt4}{4} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq 5.1)}$$

Average surface roughness result

By calculating the average of each surface roughness values using equation 5.1 the final result is obtained for both the vertical milling machine and modified lathe machine. Table 5.5 shows the average values of each trials in each stages with their respective cutting conditions.

Table 5-5 Average values of surface roughness on face milling operation

Process parameter	VMM					Fixture (MLM)			
	R_a (μm)	R_z (μm)	R_q (μm)	R_t (μm)		R_a (μm)	R_z (μm)	R_q (μm)	R_t (μm)
d_1 2	2.03954	5.7687	2.0425	5.82575	2	2.2432	6.022	2.2445	6.0682
d_2 3	2.39975	6.788	2.40625	6.864	3	2.4267	6.864	2.4355	6.9315
d_3 4	2.3107	6.535	2.3135	6.6	4	3.18325	9.0015	3.213	9.22025
n_1 630	1.4217	4.021	1.447	4.061	560	1.6585	4.8857	1.778	4.8315
n_2 800	2.236	6.3245	2.233	6.3875	800	2.2892	6.386	2.3012	6.568
n_3 1250	2.03425	6.0547	2.218	6.115	1120	2.14075	6.0555	2.14075	6.115
f_1 0.01	2.7035	7.6465	2.7465	7.722	0.01	2.793	7.89975	2.80475	7.97825
f_2 0.02	2.754	7.5397	2.8465	7.867	0.02	3.222	9.111	3.18825	9.202
f_3 0.03	3.1087	8.135	2.739	8.8795	0.03	3.275	9.42075	3.3375	9.54

Table 5.6 shows the average surface roughness result of keyway milling at Feed 0.01, Depth 3mm and variable speed.

Table 5-6 Average values of surface roughness on keyway milling operation

Speed (rpm)	VMM				Fixture (MLM)			
	R_a (μm)	R_z (μm)	R_q (μm)	R_t (μm)	R_a (μm)	R_z (μm)	R_q (μm)	R_t (μm)
630/560	3.53366	9.991333	3.541333	10.09	3.103667	8.518667	3.037	8.579333
800	4.06566	11.49333	4.0816	11.97	4.327	11.366	4.0406	11.2033
1250/1120	3.87466	10.95667	3.922667	11.0633	5.296333	14.97667	5.296333	15.12333

5.1.1 Effect of Depth of cut on surface roughness

The influence of cutting depth can be explained with the help of a graphs shown in Fig. 5.1. A change in depth of cut contributes directly to the change in the height of surface irregularities, where the milling operation made by vertical milling machine and designed fixture. During this experiments feed and speed are constant, while depth varies between 2mm and 4mm. The values obtained as R_a =2.03954, R_z =5.7687, R_t =5.7687 R_q =2.0425 marked that good surface finish is obtained at low depth of cut for the workpiece made by milling machine and R_a =2.2432, R_z =6.022, R_t =6.0682 R_q =2.2445.

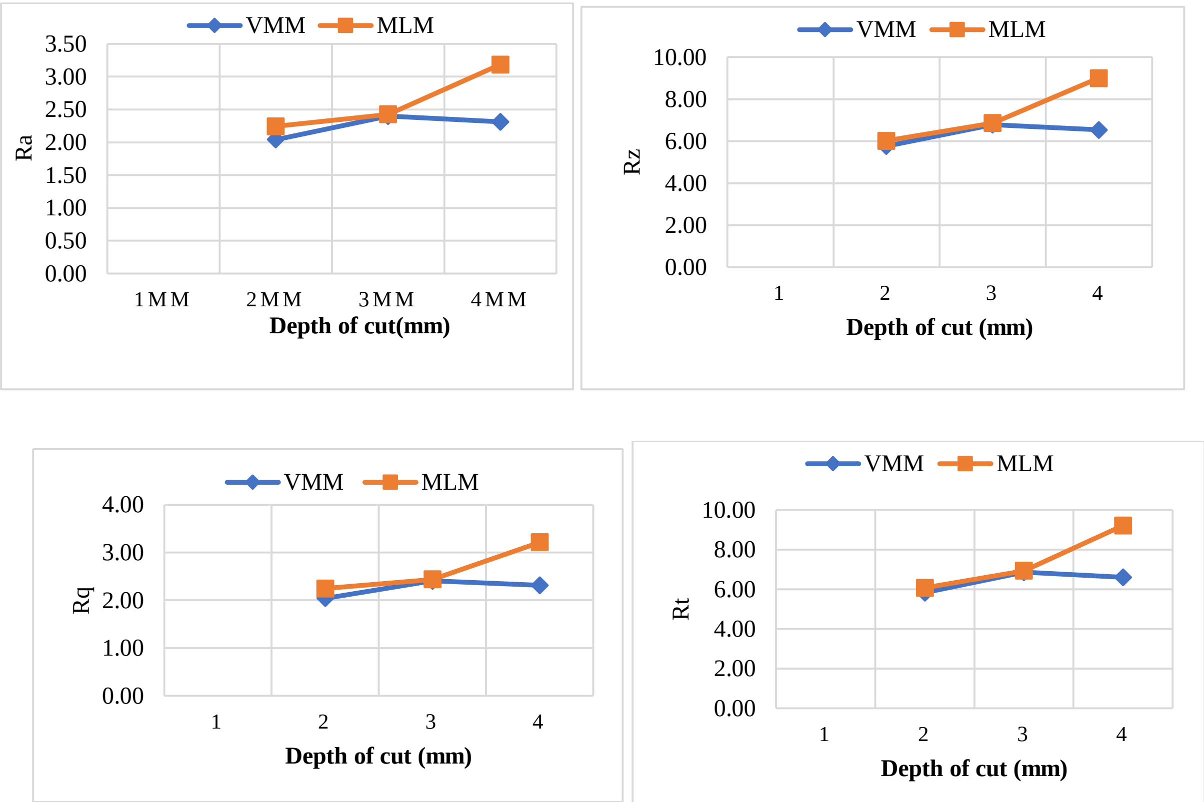


Figure 5-1 Effect of depth of cut on surface roughness

5.1.2 Effect of Spindle speed on surface roughness

The influence of spindle speed on the surface roughness the most influential factor among all cutting parameters (the others being feed and depth of cut). The surface roughness value for milling operation done by a vertical milling machine and designed fixture are nearest values as shown in the Figure 5.2. Here depth of cut and feed rate are constant but spindle speed is different. The values R_a =1.4217, R_z =4.021, R_t =1.447 R_q =4.061 marked that good surface finish is obtained at low spindle speed for the workpiece made by milling machine and values R_a =1.6585, R_z =4.8857, R_q =1.778 R_t =4.8315 marked that good surface finish is obtained at low spindle speed for the workpiece made by fixture.

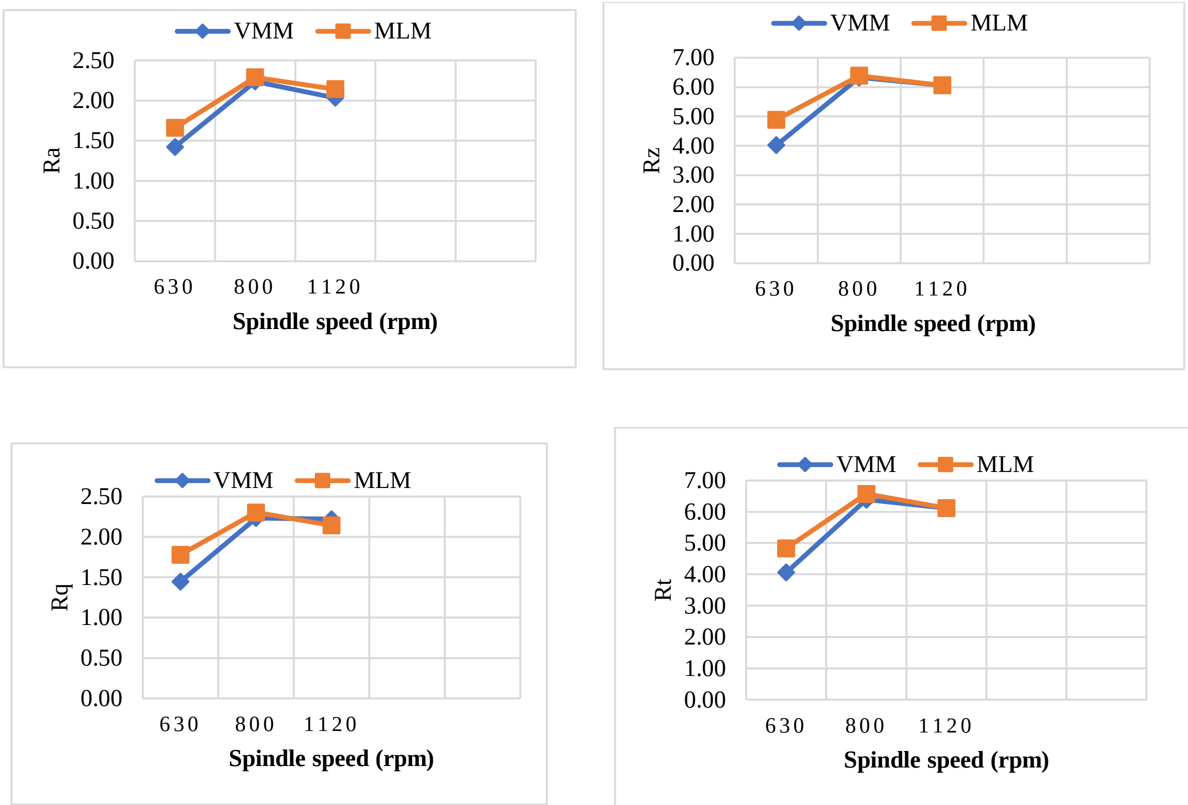
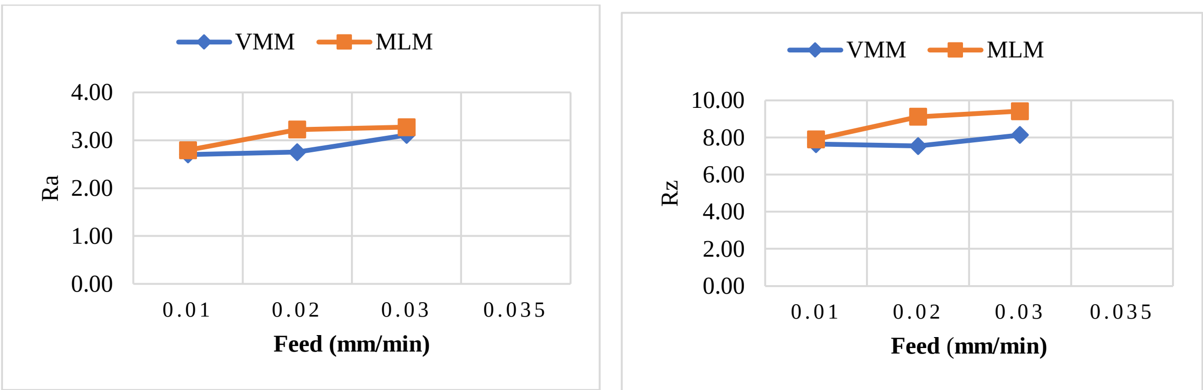
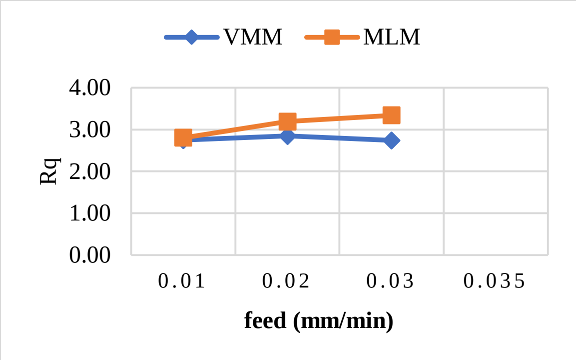


Figure 5-2 Effect of spindle speed on surface roughness

5.1.3 Effect of Feed on surface roughness

Figure 5.3 shows the effect of variable feed rate on surface roughness between milling operation done by vertical milling machine and designed fixture. Here the spindle speed and the depth of cut are at constant levels. The experiment shows that the surface becomes rougher when the feed is increased. The values R_a =2.7035, R_z =7.6465, R_t =2.7465, R_q =7.722 shows that good surface finish is obtained at low feed for the workpiece made by milling machine and R_a =2.793, R_z =7.626, R_q =3.1882, R_t =9.202 shows that good surface finish is obtained at low feed for the workpiece made by fixture.





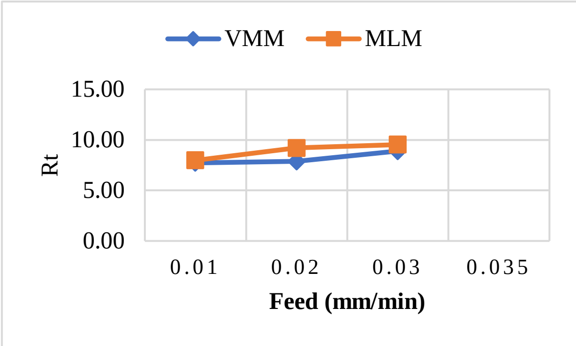


Figure 5-3 Effect of feed on surface roughness

5.1.4 Comparison of surface roughness with the two setups

From the main effects plot, it is clear that, minimal surface roughness results with combination of low feed rate and depth of cut. Surface roughness is highly sensitive to feed and depth of cut however this sensitivity becomes smaller and smaller with the higher values of spindle speed. It is observed that at higher values of spindle speed, roughness varies negligibly with the variation of depth of cut.

Table 5-7 Comparison between the two set ups in face milling operation

Process parameter	VMM		MLM		Deviation
		Ra (μm)		Ra (μm)	
d_1	2	2.03954	2	2.2432	0.02036
d_2	3	2.39975	3	2.4267	0.02695
d_3	4	2.3107	4	3.18325	0.87255
n_1	630	1.4217	560	1.6585	0.2368
n_2	800	2.236	800	2.2892	0.0532
n_3	1250	2.03425	1120	2.14075	0.1065
f_1	0.01	2.7035	0.01	2.793	0.0895
f_2	0.02	2.754	0.02	3.222	0.0468
f_3	0.03	3.1087	0.03	3.275	0.1663

The comparison between the two set ups shows that the deviation in surface roughness parameters are small. According to the surface roughness test, the deviation values shown in the table 5.7 justifies the effectiveness of the designed fixture.

Figure 5.4 shows the comparison in R_a value between modified lathe and milling machine. As the result shows the product made by modified lathe machine has good surface finish with a value R_a=2.2432 at low depth of cut 2mm. On the other hand the product made by vertical milling machine has good surface finish with a value R_a=2.03954 at low depth of cut 2mm. The deviation between the two values becomes 0.02036.

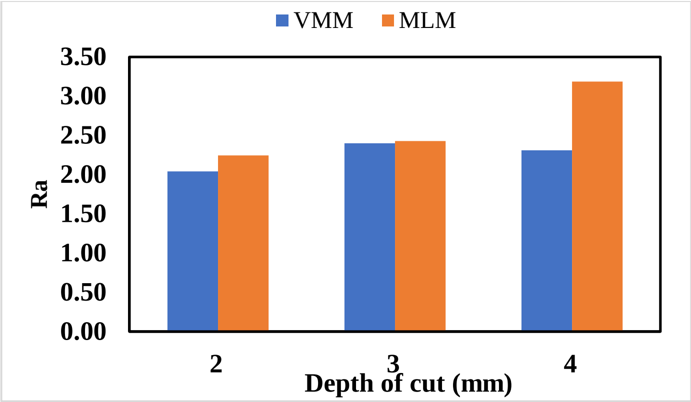


Figure 5-4 Comparison in depth of cut and R_a values for VMM and MLM

Figure 5.5 shows the comparison in R_a value between modified lathe and milling machine. As the graph shows the product made by modified lathe machine has good surface finish with a value R_a=1.6585 at low speed of 560rpm. On the other hand, the product made by vertical milling machine has good surface finish with a value R_a=1.4217 at low speed of 630 rpm. The deviation between the two values is 0.2368. Thus, increasing the spindle speed results in increasing deterioration of the surface condition.

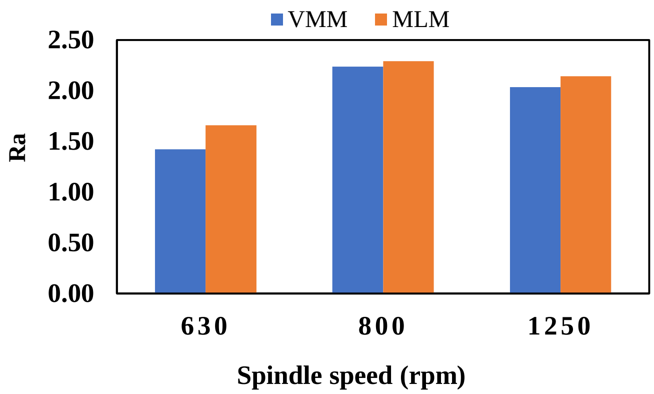


Figure 5-5 Comparison in spindle speed and R_a values for VMM and MLM

Figure 5.6 shows the comparison in R_a value between modified lathe and milling machine. As the Figure 5.5 shows the product made by modified lathe machine has good surface finish with a value R_a= 2.793at low feed 0.01m/min. On the other hand the product made by vertical milling machine has good surface finish with a value R_a=2.7035at low feed 0.01m/min. The deviation between the two values is 0.0895. The surface quality of the machined surface improved with a reduction in the feed rate. Increasing deterioration of surface quality can be observed at higher feed rates.

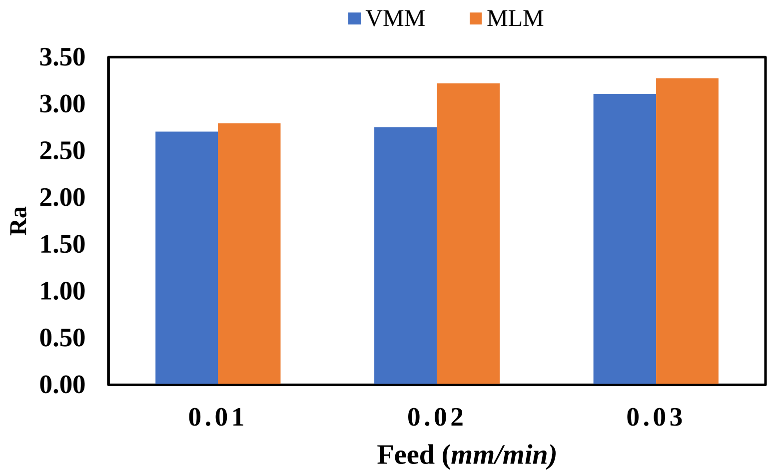


Figure 5-6 Comparison in feed and R_a values for VMM and MLM

In general, it is found that surface roughness is highly affected by cutting feed as it increases with an increase feed rate. Also high depth of cut and increased spindle speed gives rough surface. Reduced surface roughness is obtained at low feed and speed. A larger depth of cut, or in other words a larger chip cross-sectional area adversely affects surface finish. Though it is usually not significant until it is large enough to cause chatter. Note that effect of increased feed is more pronounced on surface finish than effect of an increased depth of cut.

5.2 Experimental result in Geometrical Configuration test

The surface roughness obtained on the keyways is rough because as cutting tool diameter reduces surface finish decreased. Due to the machines problem the experiment here used a manual feed that greatly affect the surface quality of keyways. But the geometrical configuration obtained was better and similar. In this experiment the keyways made were grooved by 12 mm diameter, 50mm length and 3 number of flutes end mill cutter. As the keyways depth, length and width are compared between the product made by the vertical milling machine and designed fixture.

Figure 5.7 shows four keyways on the Aluminum shaft made by the milling machine and fixture. These keyways are made of different depth of cut and spindle speed in order to make the comparison between the two setups. The visual geometrical measurement using proper measuring devises proved that similar keyways can be found from both milling and lathe machine.

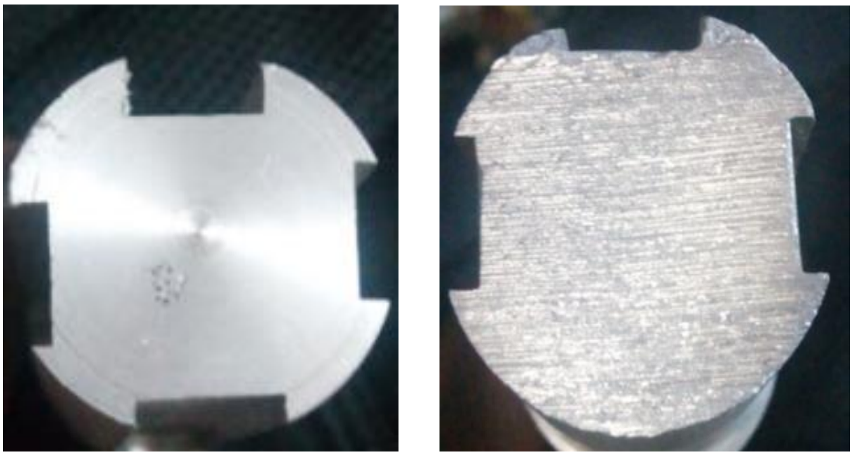


Figure 5-7 Keyway milling on shaft a) by milling machines b) by fixture

Figure 5.8 shows keyway on the Aluminum bar made by the milling machine and fixture. The grooves were made of 3mm depth of cut and 800rpm spindle speed this helps to make the comparison between the two setups. The visual geometrical measurement using proper measuring devises proved that similar keyways on rectangular workpiece can be manufactured from both milling and lathe machine.

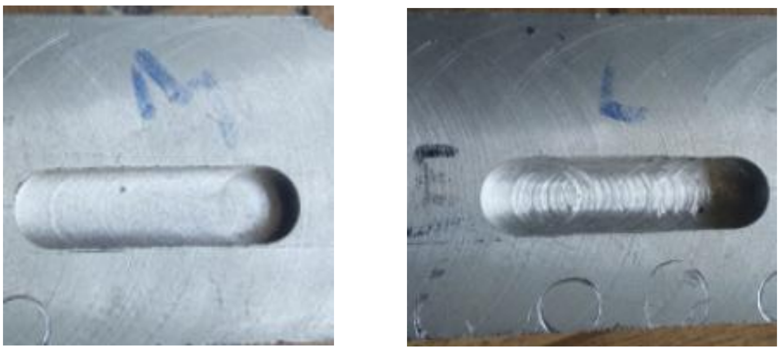


Figure 5-8 Keyway milling on a bar a) by milling machines b) by fixture

Figure 5.9 is geometrical configuration of the keyway made by feed 0.01, depth 3mm, spindle speed 630 rpm for vertical milling machine and modified lathe machine. The keyway shown in left side of Figure 5.9 was made by milling machine and the right side was made by lathe machine.

Figure 5-9 keyways at feed 0.01, depth 6mm, speed 630

Figure 5.10 is geometrical configuration of the keyway made by feed 0.01, depth 3mm, spindle speed 800 rpm for vertical milling machine (left) and modified lathe machine (right).

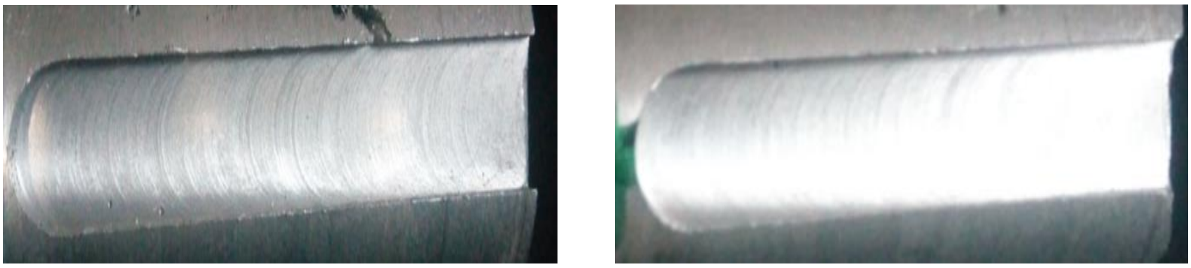


Figure 5-10 keyways at feed 0.01, depth 3mm, speed 800 rpm

Figure 5.11 is geometrical configuration of the keyway made by feed 0.01, depth 3mm, spindle speed 1250 rpm for vertical milling machine (left) and modified lathe machine (right).

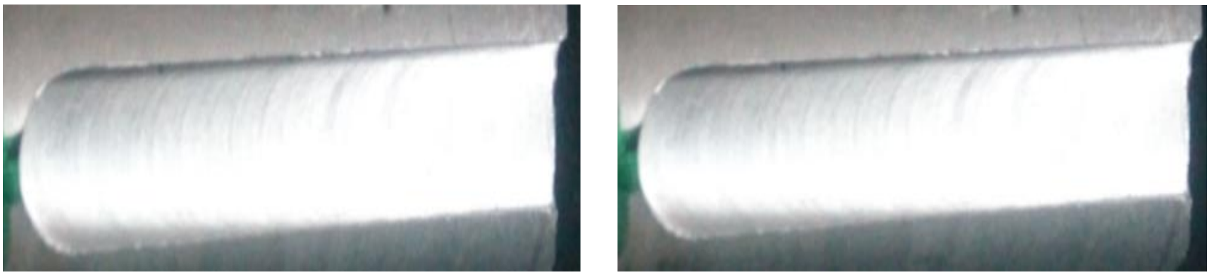


Figure 5-11 Keyways at feed 0.01, depth 3mm, speed 1120 rpm

Generally the keyway made in the experiments proved that the lathe machine modified by using the designed fixture can produce similar keyway produced by a milling machine.

CHAPTER SIX

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

- As explained in the introduction, the design & development of milling fixture for a conventional lathe machine is an effective tool for modern industrialization which will help to improve the productivity of the small and medium scale industries and Universities. The design analysis and fabrication process was successfully completed and tested. The 0methods used were data books and some basic software's like Catia V5, solid works and Master CAM.
- The analysis for fixture parts are based on the cutting force applied on the workpiece determined as 3.547kN. The size of the fixture based on this cutting force was 350mm high, 340mm long and 220mm wide. The clamping jaws on the fixture can be opened up to 250mm height and column supports can slide over each other up to 30mm height by the help of the lead screw.
- After the fixture was fabricated and assembled on the conventional lathe machine, milling operation such as face milling, side milling and keyway milling on Aluminum workpiece with high speed steel end mill cutter were done. The test for surface roughness and geometrical configuration were analyzed by comparing the products made by vertical milling machine and modified lathe machine. By statistical method, the optimum cutting condition were found for smooth surface finish as a combination of 0.01m/min feed rate, 3mm depth and 630rpm spindle speed.

6.2 Conclusions

From the general contents of this thesis results the following point was drawn.

- The maximum cutting force value is 3.547kN that determined from cutting force model and analytical analysis. This value is an input for all fixture static structural analysis.
- The fixture can mount on various kinds of lathe machines with or without removing the tool post. The fixture has ability to move in x, y and z direction with the lathe cross slide. This increases the flexibility of the work to perform the operations. Also it can hold both rectangular and circular workpieces at different angle up to limit of 250mm width.
- The total manufacturing cost of the fixture has become 7760.53 Birr which is economical, to be manufactured locally.

- Optimum cutting condition of feed rate, depth of cut and spindle speed were achieved. Based on these values, the result of surface roughness test determined as 1.4217 and 1.6585 for the product made by milling machine and fixture. This result is in acceptable range with smaller difference.
- Similar geometrical configuration of keyways are obtained from the two setups. Since the modified lathe machine gives the required geometry similar to vertical milling machine, it can be granted that this fixture is an effective tool in working keyways.

6.3 Recommendation

Based on the analysis made, result obtained and conclusions drawn, the following recommendations are suggested as

- Research should be continued in order to incorporate other operations such as drilling, gear cutting and other milling operation on the conventional lathe machine
- For a better surface finish in both setups, the feed rate should be automatic and vibration analysis should be conducted.
- Different techniques like Taguchi and ANOVA methods can be conducted to identify optimal cutting conditions.
- This study recommends that the government should initiate small and medium scale industries to work on combining different operation on the single machine available in the area to reduce machine idle time.

REFERENCES

1. Abouelatta, O. B., & Madl, J. (2001). Surface roughness prediction based on cutting parameters and tool vibrations in turning operations. *Journal of materials processing technology*, *118*(1-3), 269-277.
2. Aguilar, A., Roman-Flores, A., & Huegel, J. C. (2013). Design, refinement, implementation and prototype testing of a reconfigurable lathe-mill. *Journal of manufacturing systems*, *32*(2), 364-371.
3. Ahn, J. H., Kang, D. B., Lee, M. H., Kim, H. Y., Kim, S. H., & Cho, K. K. (2006). Investigation of cutting characteristics in side-milling a multi-thread worm shaft on automatic lathe. *CIRP Annals-Manufacturing Technology*, *55*(1), 63-66.
4. Albu, S. C. (2014). Roughing helical flanks of the worms with frontal-cylindrical milling tools on NC lathes. *Procedia Technology*, *12*, 448-454.
5. Beer, F. (2006). *Statics and mechanics of materials*. McGraw-Hill Higher Education.
6. Bolsunovsky, S., Vermel, V., & Gubanov, G. (2013). Cutting Forces Calculation and Experimental Measurement for 5-axis Ball End Milling. *Procedia CIRP*, *8*, 235-239.
7. Chang, C. S. (2005). Prediction of cutting forces in milling stainless steels using chamfered main cutting-edge tool. *Journal of Mechanics*, *21*(3), 145-155.
8. El-Sinawi, A. H., & Kashani, R. (2005). Improving surface roughness in turning using optimal control of tool's radial position. *Journal of Materials Processing Technology*, *167*(1), 54-61.
9. Fang, M. (2009). *A Study of Fixture Layout and Clamping force for a Ti-6Al-4V Disk in a Vertical Turning Lathe Numerically Controlled Machine* (Doctoral dissertation, Rensselaer Polytechnic Institute).
10. Golenko, A. (2010). Fundamentals of Machine Design. *A Course book for Polish and Foreign Students. Dolnośląska Biblioteka Cyfrowa, Wrocław*.
11. Groover, M. P. (2007). *Fundamentals of modern manufacturing: materials processes, and systems*. John Wiley & Sons.
12. Hricova, J., Kovac, M., & Sugar, P. (2014). Experimental investigation of high speed milling of aluminium alloy. *Tehnički vjesnik*, *21*(4), 773-777.
13. Huang, W., Li, X., Wang, B., Chen, J., & Zhou, J. (2016). An analytical index relating cutting force to axial depth of cut for cylindrical end mills. *International Journal of Machine Tools and Manufacture*, *111*, 63-67.

14. Hunter, R., Rios, J., Perez, J. M., & Vizan, A. (2006). A functional approach for the formalization of the fixture design process. *International Journal of machine tools and manufacture*, *46*(6), 683-697.
15. Jomaa, W., Songmene, V., & Bocher, P. (2014). Surface finish and residual stresses induced by orthogonal dry machining of AA7075-T651. *Materials*, *7*(3), 1603-1624.
16. Kalpakjian, S., & Schmid, S. R. (2014). *Manufacturing engineering and technology* (p. 913). Upper Saddle River, NJ, USA: Pearson.
17. Kaya, N. (2006). Machining fixture locating and clamping position optimization using genetic algorithms. *Computers in Industry*, *57*(2), 112-120.
18. Kessentini, A. (2010). Influence of cutting and geometrical parameters on the cutting force in milling. *Engineering*, *2*(10), 751-761.
19. R.S. Khurmi J.K. Gupta, 2006, A Textbook for the Students of B.E. / B.Tech. U.P.S.C. (Eng. Sevies); Section 'B' of A.M.I.E. (I)
20. Khurmi, R. S., & Gupta, J. K. (2005). *Machine design*. S. Chand.
21. Kiswanto, G., Zariatin, D. L., & Ko, T. J. (2014). The effect of spindle speed, feed-rate and machining time to the surface roughness and burr formation of Aluminum Alloy 1100 in micro-milling operation. *Journal of Manufacturing Processes*, *16*(4), 435-450.
22. Kumar, M. S., 2016 Design and Fabrication of Gear Cutting Attachment to Lathe for Machining A Spur Gear.
23. Kuttolamadom, M., Hamzehlouia, S., & Mears, L. (2010). Effect of machining feed on surface roughness in cutting 6061 aluminum. *SAE International journal of materials and manufacturing*, *3*(2010-01-0218), 108-119.
24. Li, X. P., Nee, A. Y. C., Wong, Y. S., & Zheng, H. Q. (1999). Theoretical modelling and simulation of milling forces. *Journal of Materials Processing Technology*, *89*, 266-272.
25. Linke, B., Harris, P., & Zhang, M. (2015). Development of Desktop Multipurpose Grinding Machine for Educational Purposes. *Procedia Manufacturing*, *1*, 740-746.
26. Nayar, A. (2003). *The steel handbook*. Tata McGraw-Hill.
27. Newby, G., Venkatachalam, S., & Liang, S. Y. (2007). Empirical analysis of cutting force constants in micro-end-milling operations. *Journal of Materials Processing Technology*, *192*, 41-47.
28. Pachbhai, S. S., & Raut, L. P. (2014). A review on design of fixtures. *International Journal of Engineering Research and General Science*, *2*(2), 126-146.

29. Rao, P. N. (2013). *Manufacturing technology: metal cutting and machine tools* (Vol. 2). Tata McGraw-Hill Education.
30. Sahoo, S. (2011). *Prediction of machining parameters for optimum Surface Roughness in turning SS 304* (Doctoral dissertation).
31. Savas, V., & Ozay, C. (2007). Analysis of the surface roughness of tangential turn-milling for machining with end milling cutter. *Journal of Materials Processing Technology*, *186*(1-3), 279-283.
32. Senthil Kumar, A., Subramaniam, V., & Boon Teck, T. (2000). Conceptual design of fixtures using machine learning techniques. *The International Journal of Advanced Manufacturing Technology, 16*(3), 176-181.
33. Songmene, V., Khettabi, R., Zaghbani, I., Kouam, J., & Djebara, A. (2011). Machining and machinability of aluminum alloys. In *aluminium alloys, theory and applications*. InTech.
34. Ullman, D. (2009). *The mechanical design process*. McGraw-Hill Science/Engineering/Math.
35. Wang, H., Rong, Y. K., Li, H., & Shaun, P. (2010). Computer aided fixture design: Recent research and trends. *Computer-Aided Design*, *42*(12), 1085-1094.
36. Wang, J. (2001). Development of a chip flow model for turning operations. *International Journal of Machine Tools and Manufacture*, *41*(9), 1265-1274.
37. Wang, W., Kweon, S. H., & Yang, S. H. (2005). A study on roughness of the micro-end-milled surface produced by a miniature machine tool. *Journal of Materials Processing Technology*, *162*, 702-708.
38. Wernick, S., Pinner, R., & Sheasby, P. G. (1992). The surface treatment and finishing of aluminum and its alloys. *S. Wernick, R. Pinner, and P. G. Sheasby, 1320 pages, 5 th edition, 2 volumes, 492 illustrations, 230 tables and 2534 references. Price. 170(US$ 340. 00). Book.*
39. Zhang, Y. (2007). *The effect of surface roughness parameters on contact and wettability of solid surfaces*. Iowa State University.

APPENDIX

APPENDIX- A Physical Constants of Materials (Beer *et al. (*2006))

Material	Modulus of elasticity E GPa	Modulus of rigidity G GPa	Passion ration *v*	Unit weight *W*
Aluminum (all alloys)	71.7	26.9	0.333	26.6
Beryllium	124	48.3	0.285	80.6
Brass	106	40.1	0.324	83.8
Carbon steel	207	79.3	0.292	76.5
Cast iron	100	414	0.211	70.6
Copper	117	44.7	0.326	87.3
Magnesium	44.8	16.5	0.350	17.6
Molybdenum	331.0	117.0	0.307	100.0
Nickel silver	127.0	48.3	0.322	85.8
Nickel steel	207.0	79.3	0.291	76.0
Phosphor bronze	111.0	41.4	0349	80.1
Stainless steel	190	73.1	0.305	76

APPENDIX - B Values of factor of safety (Beer *et al.(*2006))

Material	Steady load	Live load	Shock load
Cast iron	5 to 6	8 to 12	16 to 20
Wrought iron	4	7	10 to 15
Steel	4	8	12 to 16
Soft maerials & alloys	6	9	15
Leather	9	12	15
Timber	7	10 to 15	20

APPENDIX C Cutting tool materials allowable speed (Newby 2005)

Tool material	Allowable cutting speed	
	Non steel cutting m/min	Steel cutting m/min
Plain carbon steel	Below 10	Below 5
HSS	25-65	17-33
Cobalt alloys	50-200	33-100
Cemented carbides(WC)	330-650	100-300
Cermets (TiC)		165-400
Synthetic diamond		
Cubic boron nitride	390-1300	500-800
Coated Carbides		165-400

APPENDIX D Registered designations and chemical composition limits Jomaa et al.(2014)

Si	Fe	Cu	Mn	Cr	Ni	Zn	Ti
0.4	0.5	1.2-2	0.3	2.1-2.9	0.18-0.28	5.1-6.1	0.2

APPENDIX – E Comparison of cutting speeds used in conventional versus high speed machining for selected work materials (Newby 2005)

Work material	Solid tools (end mills)	
	Conventional speed(mm/min)	High cutting speed(mm/min)
Aluminum	300+	3000+
Cast iron soft	150	360
Cast iron ductile	105	250
Steel	105	360
Steel alloys	75	250
Titanium	40	60

APPENDIX -F Specific energy (U IN N-m/mm^2) requirement for different work material Beer *et al. (*2006)

Material	Brinell hardness	Specific energy (U) in N-m/mm^3
Carbon steel	150-200	1.6
	201-250	2.2
	251-300	2.8
Alloy steel	200-250	2.2
	251-300	2.8
	301-350	3.6
	351-400	4.4
Cast irons	125-175	1.1
	175-250	1.6
Stainless steel	150-250	2.8
Aluminum	50-100	0.7
Aluminum alloys	100-150	0.8
Brass	100-150	2.2
Bronze	50-100	2.2
Magnesium alloy		0.4

APPENDIX - G Approximate material cutting speed and lathe feed per revolution Songmene et al. (2011)

Material	Cutting speed			
	High speed tool	Carbide tool	HSS tool lathe	carbide tool lathe
Low carbon steel	80-120	300-400	0.002-0.02	0.006-0.35
High carbon steel	60-100	200	0.002-0.015	0.006-0.30
Stainless steel	100-120	240-300	0.002-0.005	0006-0.30
Aluminum	400-700	800-1000	0.003-0.03	0.008-0.040

APPENDIX - H Spindle speed in rpm for different materials Songmene et al. (2011)

	Depth of cut(mm)			
Material	6.35mm	10-20mm	20-30mm	40-60-
Low carbon steel	1600	800	267	200
High carbon steel	960	480	160	120
Aluminum	400	2000	667	500
Brass and bronze	3200	1600	533	400

APPENDIX I Recommended tool geometry for turning degree Serope (2000)

	High speed steel					Carbide tools (inserts)				
Material	Back rake	Side rake	End relief	Side relief	Side and end cutting edge	Back rake	Side rake	End relief	Side relief	Side and end cutting edge
Aluminum alloys	20	15	12	10	5	0	5	5	5	15
Magnesium alloys	20	15	12	10	5	0	5	5	5	15
Copper alloys	5	10	8	8	5	0	5	5	5	15
Steels	10	12	5	5	15	-5	-5	5	5	15
Stainless steel (ferritic)	5	8	5	5	15	0	5	5	5	15
Stainless steel (austenic)	0	10	5	5	15	-5	5	5	5	15
Stainless steel (martensitic)	0	10	5	5	15	5	-5	5	5	15
High Temperature alloys	0	10	5	5	15	0	0	5	5	15
Cast irons	5	0	5	5	15	0	-5	5	5	5

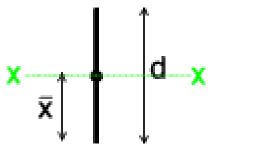
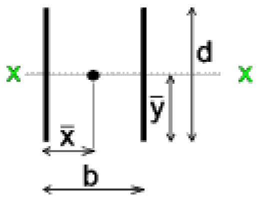
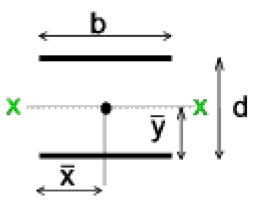
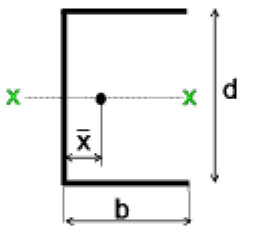
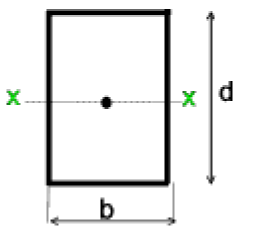
APPENDIX – J Chemical composition of High Speed Steel (HSS) cutting tool material in the industry (Newby 2005)

HSS (1)		HSS (2)	
Composition	Percent (%)	Composition	Percent (%)
Carbon	0.7-0.8	Carbon	0.65-0.75
Silicon	≤ 0.45	Silicon	≤ 0.45
Manganese	≤ 0.45	Manganese	≤ 0.45
Phosphorus	≤ 0.035	Phosphorus	≤ 0.035
S	≤ 0.035	S	≤ 0.035
Cr	3.8-4.6	Cr	3.8-4.6
Mo	≤ 0.5	Mo	≤ 0.5
V	1-1.6	V	1-1.6
W	17-19	W	17-19
Co	4.2 – 5.2	Co	4.2-5.2

APPENDIX – K (ASM Handbook-vol 1)-properties and selection of steel; page 438-439

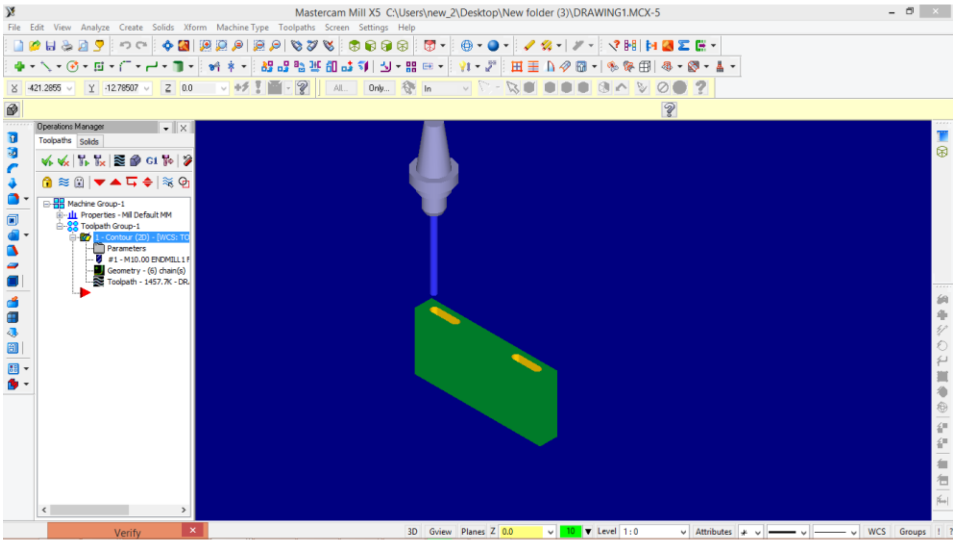
Steel designations		Type of processing	Tensile strength	Yield strength	Hardness	Average machinability
SAE/AISI No			MPa	MPa		
1006	G10060	Hot rolled	300	170	55	50
		Cold drawn	330	280	45	
1017	G10170	Hot rolled	370	200	50	75
		Cold drawn	490	410	40	
1030	G10300	Hot rolled	470	260	42	70
		Cold drawn	520	440	35	
1050	G10500	Hot rolled	620	340	179	45
		Cold drawn	690	580	197	
1080	G10800	Hot rolled	770	420	229	45
		Cold drawn	680	520	192	

APPENDIX L Standard table for polar moment of inertia and section modulus (ASME first edition)

Weld	Throat Area Unit Area	Location of COG **x** **y**	I xx-(unit)	J-(Unit)
	0,707hd d	$\bar{x} = 0$ $\bar{y} = d / 2$	$I_{xx} = \frac{d^3}{12}$	$J = \frac{d^3}{12}$
	1,414hd 2d	$\bar{x} = b/2$ $\bar{y} = d/2$	$I_{xx} = \frac{d^3}{6}$	$J = \frac{d\,(3b^2 + d^2)}{6}$
	1,414hb 2.b	$\bar{x} = b/2$ $\bar{y} = d/2$	$I_{xx} = \frac{bd^2}{2}$	$J = \frac{b\,(3d^2 + b^2)}{6}$
	0,707h(2b+d) 2b +d	$\bar{x} = b^2/(2b+d)$ $\bar{y} = d/2$	$I_{xx} = \frac{d^2(6b + d)}{12}$	$z = 8b^3 + 6bd^2 + d^3$ $J = \frac{z}{12} - \frac{b^4}{2b+d}$
	1,414 h(b+d) 2(b +d)	$\bar{x} = b/2$ $\bar{y} = d/2$	$I_{xx} = \frac{d^2(3b + d)}{6}$	$J = \frac{(b+d)^3}{6}$

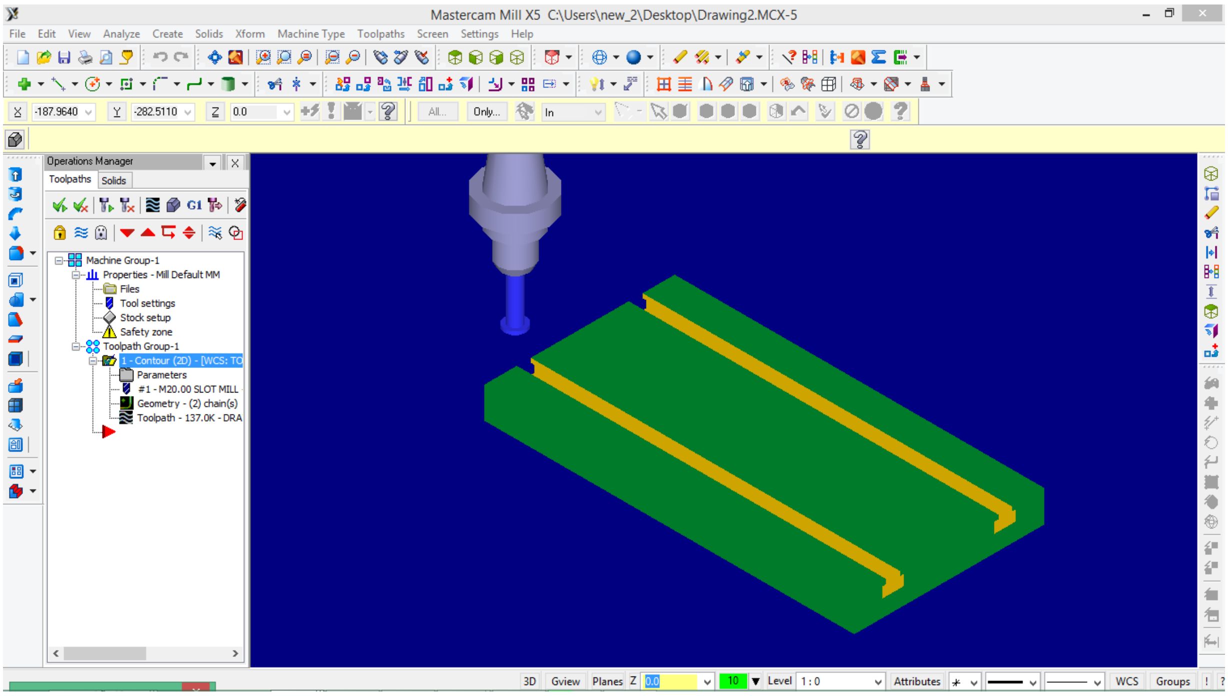
APPENDIX M Master CAM codes for the components

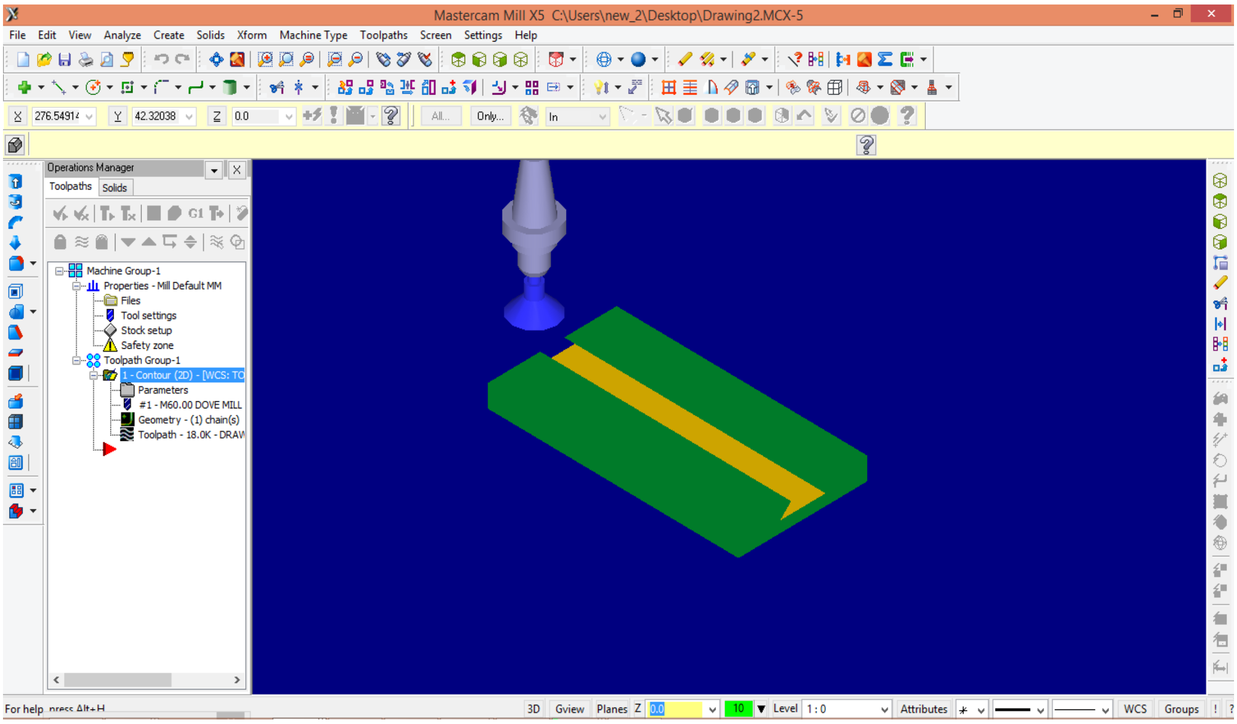
UPPER AND LOWER JAW




```
%
O0000 (VICE)
(DATE=DD-MM-YY -10-01-2018)
(MATERIAL - C45)
(T1 | | H1 )
N100 G21
N102 G0 G17 G40 G49 G80 G90
(POCKET)
N104 T1 M6
N106 G0 G90 G54 X90. Y0. A0. S1000 M3
N108 G43 H1 Z25.
N110 Z10.
N112 G1 Z-2. F300.
N114 Y1. F2864.7
N116 X53.
N118 G3 X52. Y0. I0. J-1.
N120 X53. Y-1. I1. J0.
N122 G1 X90. Y0.
N124 Z-4. F300.
N126 Y1. F2864.7
N128 X53.
N130 G3 X52. Y0. I0. J-1.
N132 X53. Y-1. I1. J0.
N134 G1 X90. Y0.
N136 Z-6. F300.
N138 Y1. F2864.7
N140 X53.
N142 G3 X52. Y0. I0. J-1.
N144 X53. Y-1. I1. J0.
N146 G1 X90. Y0.
N148 Z-8. F300.
N150 Y1. F2864.7
N152 X53.
N154 G3 X52. Y0. I0. J-1.
N156 X53. Y-1. I1. J0.
N158 G1 X90. Y0.
N160 Z-10. F300.
N588 G1 Z-14. F300.
N590 X-90. F2864.7
N592 G3 X-91. Y0. I0. J-1.
N594 X-90. Y-1. I1. J0.
N596 G0 Z25.
N598 X-53. Y1.
N600 Z10.
N602 G1 Z-16. F300.
N604 X-90. F2864.7
N606 G3 X-91. Y0. I0. J-1.
N608 X-90. Y-1. I1. J0.
N610 G0 Z25.
N612 X-53. Y1.
N614 Z10.
N616 G1 Z-18. F300.
N618 X-90. F2864.7
N620 G3 X-91. Y0. I0. J-1.
N622 X-90. Y-1. I1. J0.
N624 G0 Z25.
N626 X-53. Y1.
N628 Z10.
N630 G1 Z-20. F300.
N632 X-90. F2864.7
N634 G3 X-91. Y0. I0. J-1.
N636 X-90. Y-1. I1. J0.
N638 G0 Z25.
N640 M5
N642 G91 G28 Z0.
N644 G28 X0. Y0. A0.
N646M30
```

LEFT COLUMN SUPPORT

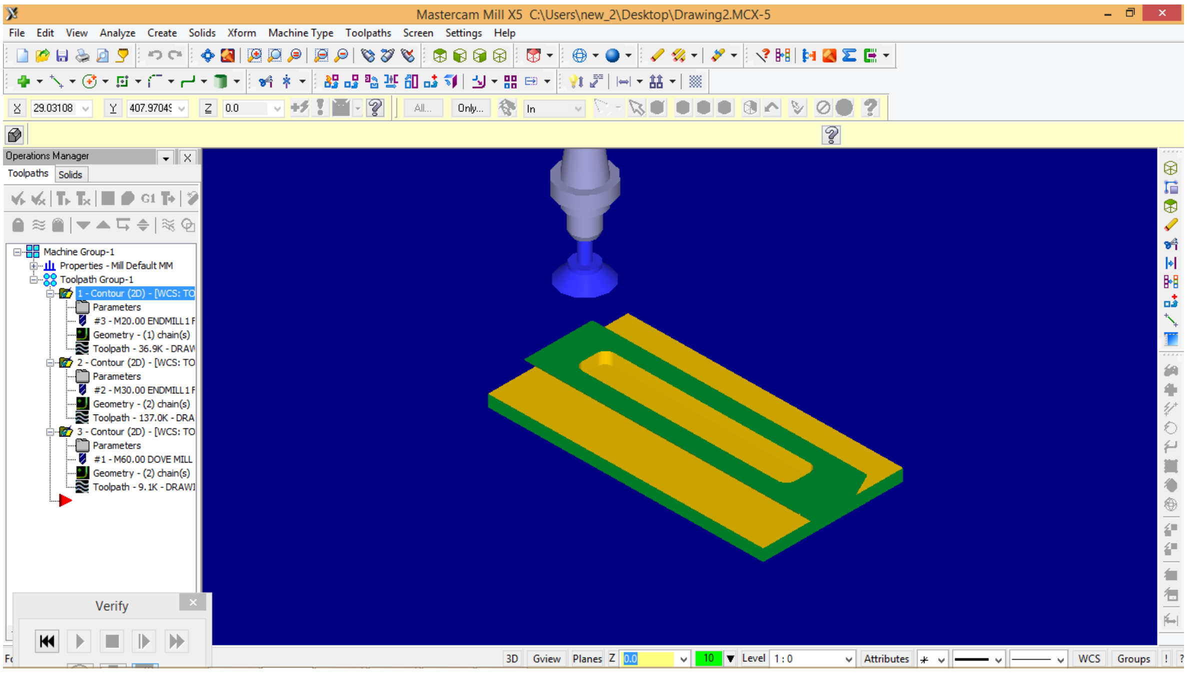





```
%
O0000 (T- SLOT 20)
(DATE=DD-MM-YY - 14-01-2018 -- 11:07)
(MATERIAL - C45)
( T1 | | H1 )
N100 G21
N102 G0 G17 G40 G49 G80 G90
(CONTUR T-SLOT CUTTER 20 )
N104 T1 M6
N106 G0 G90 G54 X183. Y53.  S600 M3
N108 G43 H1 Z25. M8
N110 Z10.
N112 G1 Z-7.438 F150.
N114 X-183. F300.
N116 Z10. F150.
N118 G0 Z25.
N120 X183.
```

```
N122 Z10.
N124 G1 Z-8.375
N126 X-183. F300.
N128 Z10. F150.
N130 G0 Z25.
N132 X183.
N134 Z10.
N136 G1 Z-9.313
N138 X-183. F300.
N140 Z10. F150.
N142 G0 Z25.
N144 X183.
N146 Z10.
N148 G1 Z-10.25
N150 X-183. F300.
N152 Z10. F150.
N154 G0 Z25.
N156 X183.
N158 Z10.
N160 G1 Z-11.188
N162 X-183. F300.
N164 Z10. F150.
N166 G0 Z25.
N168 X183.
N170 Z10.
N172 G1 Z-12.125
N174 X-183. F300.
N176 Z10. F150.
N178 G0 Z25.
N180 X183.
N182 Z10.
N184 G1 Z-13.063
N186 X-183. F300.
N188 Z10. F150.
N190 G0 Z25.
N192 X183.
N194 Z10.
N196 G1 Z-14.
N198 X-183. F300.
N200 Z10. F150.
N202 G0 Z25.
N204 X183. Y-53.
N206 Z10.
N208 G1 Z-7.438
N210 X-183. F300.
N212 Z10. F150.
N214 G0 Z25.
N216 X183.
N218 Z10.
N220 G1 Z-8.375
N222 X-183. F300.
N224 Z10. F150.
N226 G0 Z25.
N228 X183.
N230 Z10.
N232 G1 Z-9.313
N234 X-183. F300.
N236 Z10. F150.
N238 G0 Z25.
N240 X183.
N242 Z10.
N244 G1 Z-10.25
N246 X-183. F300.
N248 Z10. F150.
N250 G0 Z25.
N252 X183.
N254 Z10.
N256 G1 Z-11.188
N258 X-183. F300.
N260 Z10. F150.
N262 G0 Z25.
N264 X183.
N266 Z10.
N268 G1 Z-12.125
N270 X-183. F300.
N272 Z10. F150.
N274 G0 Z25.
N276 X183.
N278 Z10.
N280 G1 Z-13.063
N282 X-183. F300.
N284 Z10. F150.
N286 G0 Z25.
N288 X183.
N290 Z10.
N292 G1 Z-14.
N294 X-183. F300.
N296 Z10. F150.
N298 G0 Z25.
N300 M5
N302 G91 G28 Z0. M9
N304 G28 X0. Y0. A0.
N306 M30
%
```

RIGHT COLUMN SUPPORT

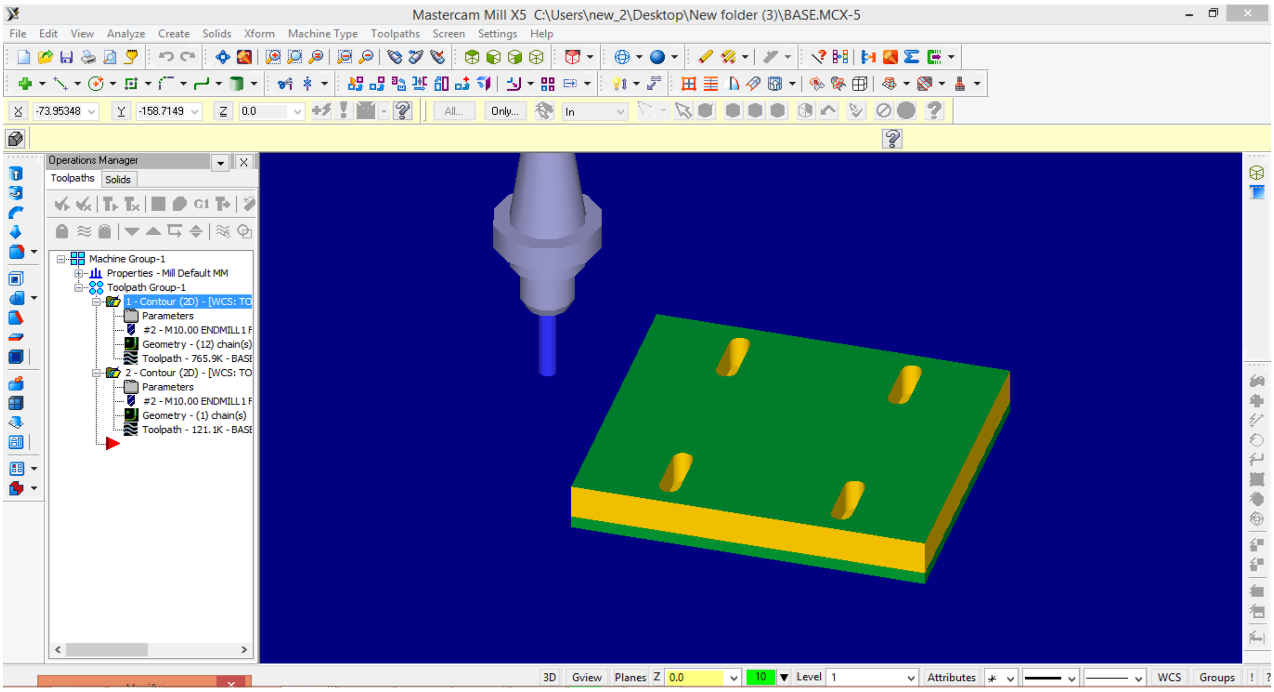



```
%
O0000
(DATE=DD-MM-YY - 21-12-17   = HH:MM -
15:07)
(MCX FILE - RVS.MCX-5)
(MATERIAL - C45)
( T3 | | H3 )
( T2 | | H2 )
( T1 | | H1 )
N100 G21
N102 G0 G17 G40 G49 G80 G90
( POCKET END  MILL 20 )
N104 T3 M6
N106 G0 G90 G54 X0. Y4.406 A0. S800 M3
N108 G43 H3 Z25. M8
N110 Z10.
N112 G1 Z-1.875 F150.
N114 X-125. F300.
N116 Y-15.594
N118 X125.
N120 Y4.406
N122 X0.
N124 Z-3.75 F150.
N126 X-125. F300.
N128 Y-15.594
N130 X125.
N132 Y4.406
N134 X0.
N136 Z-5.625 F150.
N138 X-125. F300.
N140 Y-15.594
N142 X125.
N144 Y4.406
N146 X0.
N148 Z-7.5 F150.
N150 X-125. F300.
N152 Y-15.594
N154 X125.
N156 Y4.406
N158 X0.
N160 Z-9.375 F150.
N162 X-125. F300.
N164 Y-15.594
N166 X125.
N168 Y4.406
N170 X0.
N172 Z-11.25 F150.
N174 X-125. F300.
N176 Y-15.594
N178 X125.
N180 Y4.406
```

```
N182 X0.
N184 Z-13.125 F150.
N186 X-125. F300.
N188 Y-15.594
N190 X125.
N192 Y4.406
N194 X0.
N196 Z-15. F150.
N198 X-125. F300.
N200 Y-15.594
N202 X125.
N204 Y4.406
N206 X0.
N208 Z10. F150.
N210 G0 Z25.
N212 M5
N214 G91 G28 Z0. M9
N216 A0.
N218 M01
(SURFACE MILL END MILL 30)
N220 T2 M6
N222 G0 G90 G54 X175. Y83.834 A0. S1909 M3
N224 G43 H2 Z25. M8
N226 Z10.
N228 G1 Z-1.875 F381.8
N230 X-175. F763.6
N232 Z10. F381.8
N234 G0 Z25.
N236 X175.
N238 Z10.
N240 G1 Z-3.75
N242 X-175. F763.6
N244 Z10. F381.8
N246 G0 Z25.
N248 X175.
N250 Z10.
N252 G1 Z-5.625
N254 X-175. F763.6
N256 Z10. F381.8
N258 G0 Z25.
N260 X175.
N262 Z10.
N264 G1 Z-7.5
N266 X-175. F763.6
N268 Z10. F381.8
N270 G0 Z25.
N272 X175.
N274 Z10.
N276 G1 Z-9.375
N278 X-175. F763.6
N280 Z10. F381.8
N282 G0 Z25.
N284 X175.
N286 Z10.
N288 G1 Z-11.25
N290 X-175. F763.6
N292 Z10. F381.8
N294 G0 Z25.
N296 X175.
N298 Z10.
N300 G1 Z-13.125
N302 X-175. F763.6
N304 Z10. F381.8
N306 G0 Z25.
N308 X175.
N310 Z10.
N312 G1 Z-15.
N314 X-175. F763.6
N316 Z10. F381.8
N318 G0 Z25.
N320 Y-96.166
N322 Z10.
N324 G1 Z-1.875
N326 X175. F763.6
N328 Z10. F381.8
N330 G0 Z25.
N332 X-175.
N334 Z10.
N336 G1 Z-3.75
N338 X175. F763.6
N340 Z10. F381.8
N342 G0 Z25.
N344 X-175.
N346 Z10.
N348 G1 Z-5.625
N350 X175. F763.6
N352 Z10. F381.8
N354 G0 Z25.
N356 X-175.
N358 Z10.
N360 G1 Z-7.5
N362 X175. F763.6
N364 Z10. F381.8
N366 G0 Z25.
N368 X-175.
N370 Z10.
N372 G1 Z-9.375
N374 X175. F763.6
N376 Z10. F381.8
```

```
N378 G0 Z25.
N380 X-175.
N382 Z10.
N384 G1 Z-11.25
N386 X175. F763.6
N388 Z10. F381.8
N390 G0 Z25.
N392 X-175.
N394 Z10.
N396 G1 Z-13.125
N398 X175. F763.6
N400 Z10. F381.8
N402 G0 Z25.
N404 X-175.
N406 Z10.
N408 G1 Z-15.
N410 X175. F763.6
N412 Z10. F381.8
N414 G0 Z25.
N416 M5
N418 G91 G28 Z0. M9
N420 A0.
N422 M01
( DOVE AIL CUTTER  60 )
N424 T1 M6
N426 G0 G90 G54 X200. Y-66.166 A0. S500 M3
N428 G43 H1 Z25.
N430 Z10.
N432 G1 Z-15. F125.
N434 X-200. F250.
N436 Z10. F125.
N438 G0 Z25.
N440 X200. Y53.834
N442 Z10.
N444 G1 Z-15.
N446 X-200. F250.
N448 Z10. F125.
N450 G0 Z25.
N452 M5
N454 G91 G28 Z0.
N456 G28 X0. Y0. A0.
N458 M30
%
```

FIXTURE BASE




```
%
O0000
(BASE)
(DATE=DD-MM-YY - 9-01-18 -16:32)
```

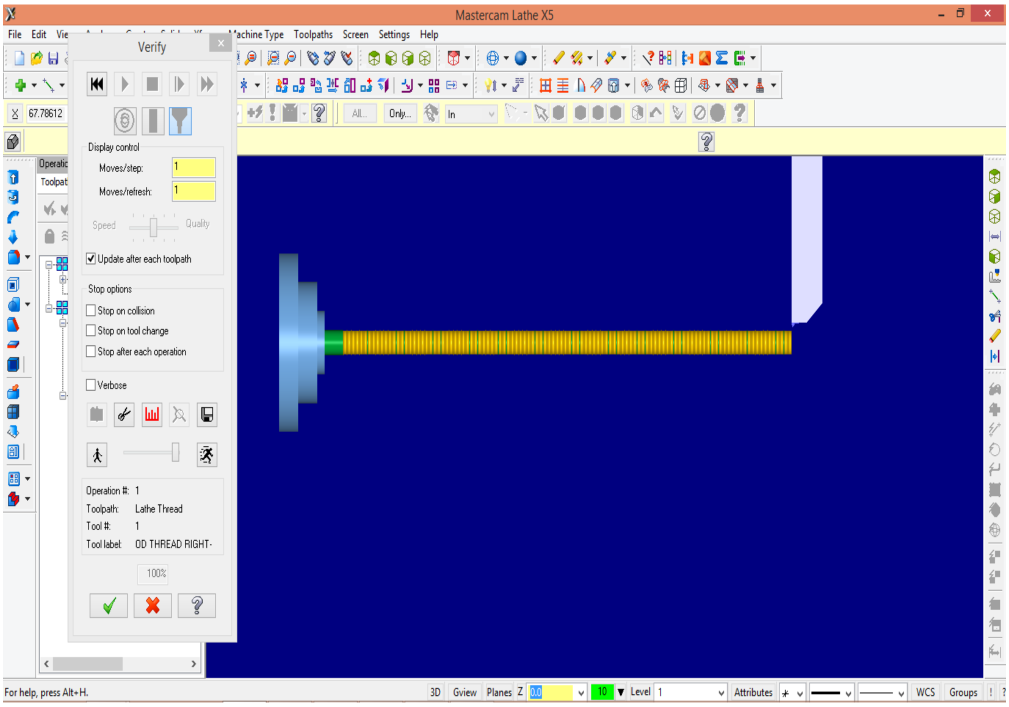
```
(MATERIAL - steel C45
( T2 |    10. FLAT ENDMILL | H2 )
N100 G21
N102 G0 G17 G40 G49 G80 G90
(POCKET END MILL 10 )
N104 T2 M6
N106 G0 G90 G54 X-51. Y74. A0. S1000 m3
N108 G43 H2 Z25.
N110 Z10.
N112 G1 Z-1. F300.
N114 X-50. F3582.8
N116 G3 X-51. Y75. I-1. J0.
N118 X-52. Y74. I0. J-1.
N120 G1 Y46.
N122 X-51. Y74.
N124 Z-2. F300.
N126 X-50. F3582.8
N128 G3 X-51. Y75. I-1. J0.
N130 X-52. Y74. I0. J-1.
N132 G1 Y46.
N134 X-51. Y74.
N136 Z-3. F300.
N138 X-50. F3582.8
N140 G3 X-51. Y75. I-1. J0.
N142 X-52. Y74. I0. J-1.
N144 G1 Y46.
N146 X-51. Y74.
N148 Z-4. F300.
N150 X-50. F3582.8
N152 G3 X-51. Y75. I-1. J0.
N154 X-52. Y74. I0. J-1.
N156 G1 Y46.
N158 X-51. Y74.
N160 Z-5. F300.
N162 X-50. F3582.8
N164 G3 X-51. Y75. I-1. J0.
N166 X-52. Y74. I0. J-1.
N168 G1 Y46.
N170 X-51. Y74.
N172 Z-6. F300.
N174 X-50. F3582.8
N176 G3 X-51. Y75. I-1. J0.
N178 X-52. Y74. I0. J-1.
N180 G1 Y46.
N182 X-51. Y74.
N184 Z-7. F300.
N186 X-50. F3582.8
N188 G3 X-51. Y75. I-1. J0.
N190 X-52. Y74. I0. J-1.
N192 G1 Y46.
N194 X-51. Y74.
N196 Z-8. F300.
N198 X-50. F3582.8
N200 G3 X-51. Y75. I-1. J0.
N202 X-52. Y74. I0. J-1.
N204 G1 Y46.
N206 X-51. Y74.
N208 Z-9. F300.
N210 X-50. F3582.8
N212 G3 X-51. Y75. I-1. J0.
N214 X-52. Y74. I0. J-1.
N216 G1 Y46.
N218 X-51. Y74.
N220 Z-10. F300.
N222 X-50. F3582.8
N224 G3 X-51. Y75. I-1. J0.
N226 X-52. Y74. I0. J-1.
N228 G1 Y46.
N230 X-51. Y74.
N232 Z-11. F300.
N234 X-50. F3582.8
N236 G3 X-51. Y75. I-1. J0.
N238 X-52. Y74. I0. J-1.
N240 G1 Y46.
N242 X-51. Y74.
N244 Z-12. F300.
N246 X-50. F3582.8
N248 G3 X-51. Y75. I-1. J0.
N250 X-52. Y74. I0. J-1.
N252 G1 Y46.
N254 X-51. Y74.
N256 Z-13. F300.
N258 X-50. F3582.8
N260 G3 X-51. Y75. I-1. J0.
N262 X-52. Y74. I0. J-1.
N264 G1 Y46.
N266 X-51. Y74.
N268 Z-14. F300.
N270 X-50. F3582.8
N272 G3 X-51. Y75. I-1. J0.
N274 X-52. Y74. I0. J-1.
N276 G1 Y46.
N278 X-51. Y74.
N280 Z-15. F300.
N282 X-50. F150
N284 G3 X-51. Y75. I-1. J0.
N286 X-52. Y74. I0. J-1.
N288 G1 Y46.
N290 X-51. Y74.
N292 Z-16. F300.
```

```
N294 X-50. F3582.8
N296 G3 X-51. Y75. I-1. J0.
N298 X-52. Y74. I0. J-1.
N300 G1 Y46.
N302 X-51. Y74.
N304 Z-17. F300.
N306 X-50. F3582.8
N308 G3 X-51. Y75. I-1. J0.
N310 X-52. Y74. I0. J-1.
N312 G1 Y46.
N314 X-51. Y74.
N316 Z-18. F300.
N318 X-50. F3582.8
N320 G3 X-51. Y75. I-1. J0.
N322 X-52. Y74. I0. J-1.
N324 G1 Y46.
N326 X-51. Y74.
N328 Z-19. F300.

N330 X-50. F3582.8
N332 G3 X-51. Y75. I-1. J0.
N334 X-52. Y74. I0. J-1.
N336 G1 Y46.
N338 X-51. Y74.
N340 Z-20. F300.
N342 X-50. F3582.8
N344 G3 X-51. Y75. I-1. J0.
N346 X-52. Y74. I0. J-1.
N348 G1 Y46.
N350 X-51. Y74.
N352 Z-21. F300.
N354 X-50. F3582.8
N356 G3 X-51. Y75. I-1. J0.
N358 X-52. Y74. I0. J-1.
N360 G1 Y46.
N362 X-51. Y74.
N364 G0 Z25.
N366 X-52. Y46.
862 Y-15.
N2864 Z10.
N2866 G1 Z-17. F150.
N2868 X125. F1432.2
N2870 G2 X110. Y0. I0. J15.
N2872 G1 Y90.
N2874 G3 X105. Y95. I-5. J0.
N2876 G1 X-105.
N2878 G3 X-110. Y90. I0. J-5.
N2880 G1 Y-90.
N2882 G3 X-105. Y-95. I5. J0.
N2884 G1 X105.
N2886 G3 X110. Y-90. I0. J5.
N2888 G1 Y0.
N2890 G2 X125. Y15. I15. J0.
N2892 G1 X140.
N2894 G0 Z25.
N2896 Y-15.
N2898 Z10.
N2900 G1 Z-18. F150.
N2902 X125. F1432.2
N2904 G2 X110. Y0. I0. J15.
N2906 G1 Y90.
N2908 G3 X105. Y95. I-5. J0.
N2910 G1 X-105.
N2912 G3 X-110. Y90. I0. J-5.
N2914 G1 Y-90.
N2916 G3 X-105. Y-95. I5. J0.
N2918 G1 X105.
N2920 G3 X110. Y-90. I0. J5.
N2922 G1 Y0.
N2924 G2 X125. Y15. I15. J0.
N2926 G1 X140.
N2928 G0 Z25.
N2930 Y-15.
N2932 Z10.
N2934 G1 Z-19. F150.
N2936 X125. F1432.2
N2938 G2 X110. Y0. I0. J15.
N2940 G1 Y90.
N2942 G3 X105. Y95. I-5. J0.
N2944 G1 X-105.
N2946 G3 X-110. Y90. I0. J-5.
N2948 G1 Y-90.
N2950 G3 X-105. Y-95. I5. J0.
N2952 G1 X105.
N2954 G3 X110. Y-90. I0. J5.
N2956 G1 Y0.
N2958 G2 X125. Y15. I15. J0.
N2960 G1 X140.
N2962 G0 Z25.
N2964 Y-15.
N2966 Z10.
N2968 G1 Z-20. F150.
N2970 X125. F1432.2
N2972 G2 X110. Y0. I0. J15.
N2974 G1 Y90.
N2976 G3 X105. Y95. I-5. J0.
N2978 G1 X-105.
N2980 G3 X-110. Y90. I0. J-5.
N2982 G1 Y-90.
```

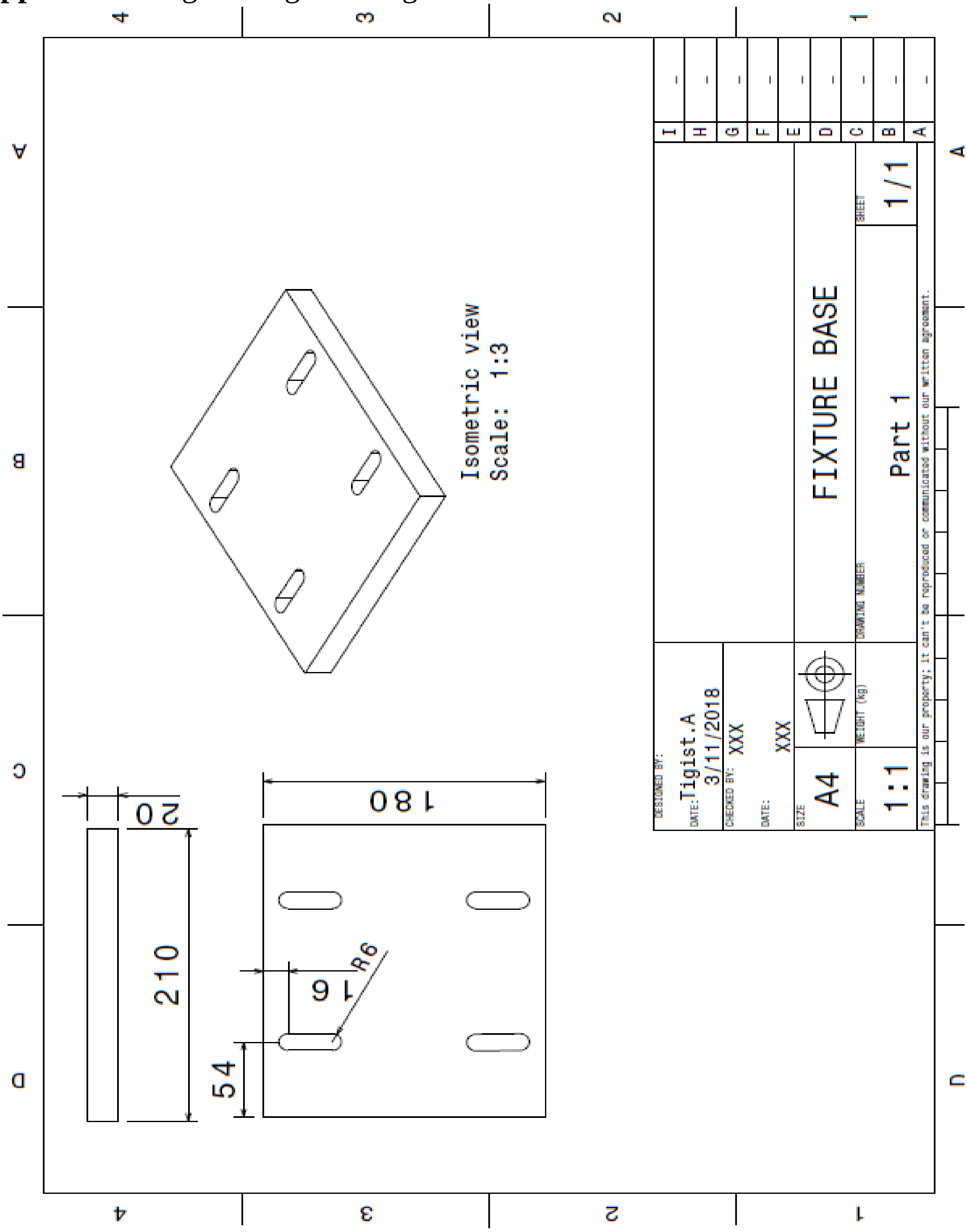
```
N2984 G3 X-105. Y-95. I5. J0.
N2986 G1 X105.
N2988 G3 X110. Y-90. I0. J5.
N2990 G1 Y0.
N2992 G2 X125. Y15. I15. J0.
N2994 G1 X140.
N2996 G0 Z25.
N2998 Y-15.
N3000 Z10.
N3002 G1 Z-21. F150.
N3004 X125. F1432.2
N3006 G2 X110. Y0. I0. J15.
N3008 G1 Y90.
N3010 G3 X105. Y95. I-5. J0.
N3012 G1 X-105.
N3014 G3 X-110. Y90. I0. J-5.
N3016 G1 Y-90.
N3018 G3 X-105. Y-95. I5. J0.
N3020 G1 X105.
N3022 G3 X110. Y-90. I0. J5.
N3024 G1 Y0.
N3026 G2 X125. Y15. I15. J0.
N3028 G1 X140.
N3030 G0 Z25.
N3032 Y-15.
N3034 Z10.
N3036 G1 Z-22. F150.
N3038 X125. F1432.2
N3040 G2 X110. Y0. I0. J15.
N3042 G1 Y90.
N3044 G3 X105. Y95. I-5. J0.
N3046 G1 X-105.
N3048 G3 X-110. Y90. I0. J-5.
N3050 G1 Y-90.
N3052 G3 X-105. Y-95. I5. J0.
N3054 G1 X105.
N3056 G3 X110. Y-90. I0. J5.
N3058 G1 Y0.
N3060 G2 X125. Y15. I15. J0.
N3062 G1 X140.
N3064 G0 Z25.
N3066 M5
N3068 G91 G28 Z0.
N3070 G28 X0. Y0. A0.
```

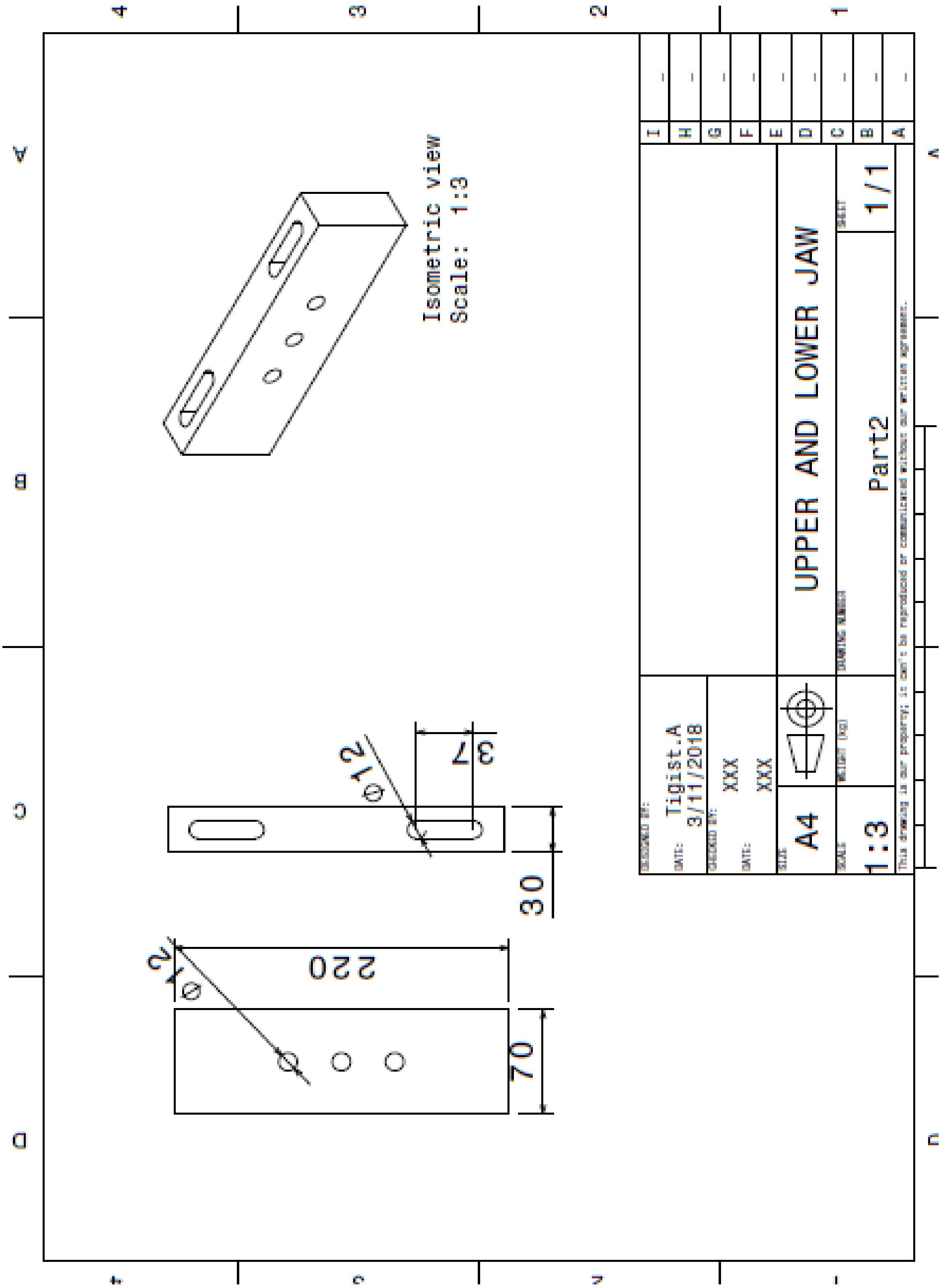
LEAD SCREW

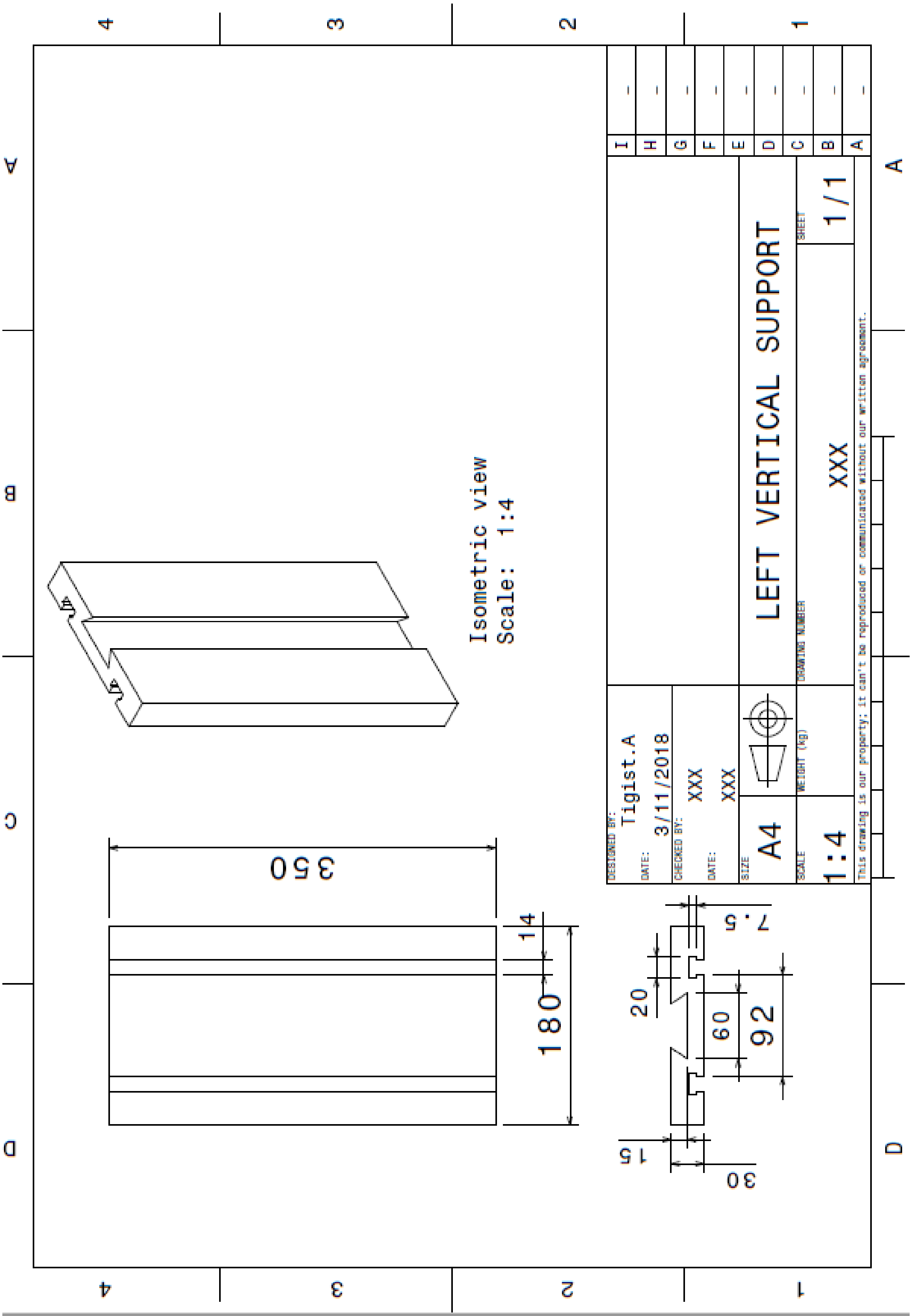


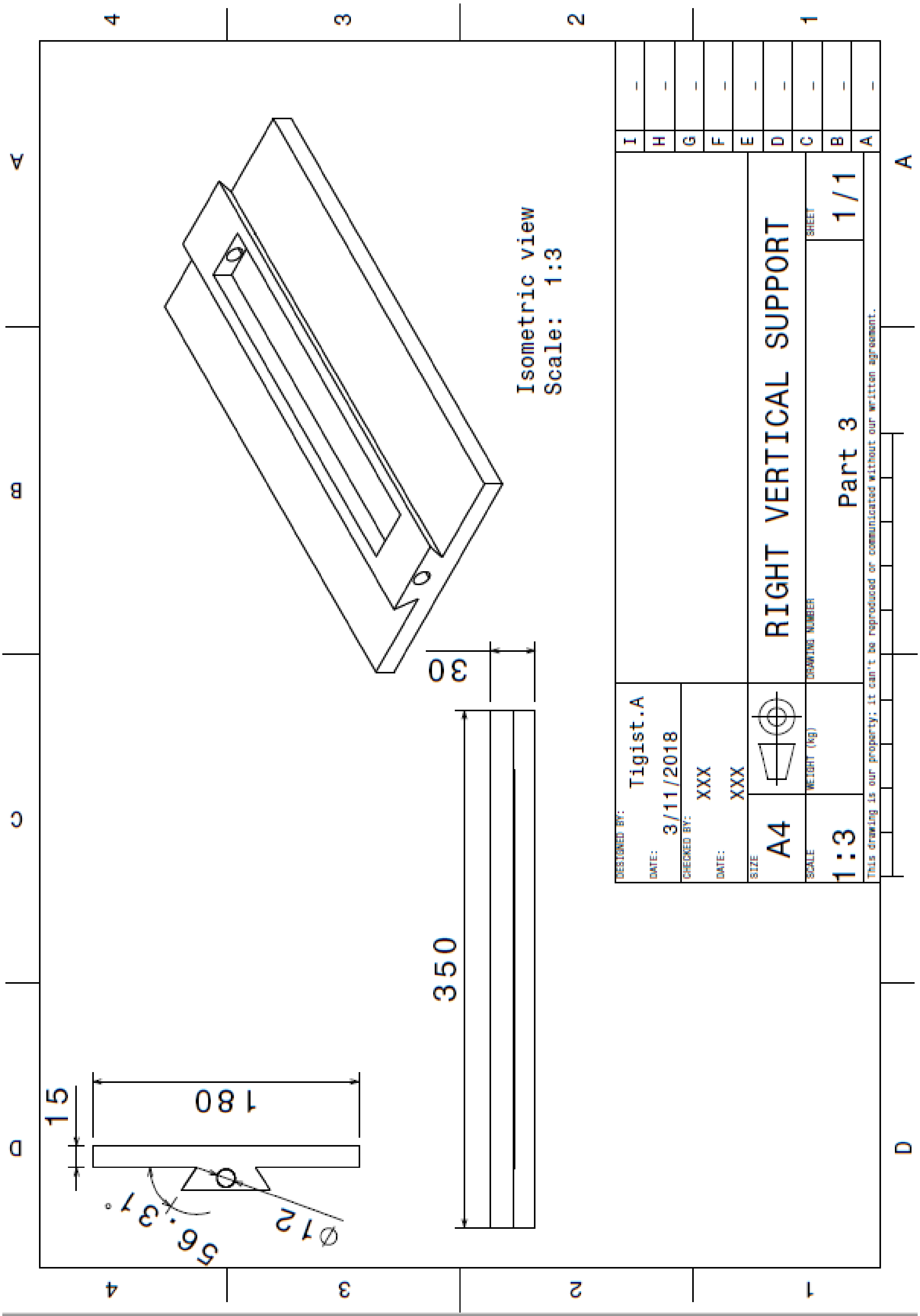

```
%
O0000
(PROGRAM NAME - LEAD SREW)
(DATE=DD-MM-YY - 23-02-18
TIME=HH:MM - 11:18)
(MCX FILE - LEAD SREW.MCX-5)
(EAD SREW)
(MATERIAL - steel
G21
(TOOL - 1 OFFSET - 1)
(OD THREAD RIGHT- LARGE INSERT
16MM01-200)
G0 T0101
G18
M05
G0 G54 X20. Z1.
G99 G92 X15.812 Z-360. F.5
X15.697
X15.605
X15.528
X15.459
X15.459
G0 X20.
G28 U0. V0. W0.
T0100
M30
%
```

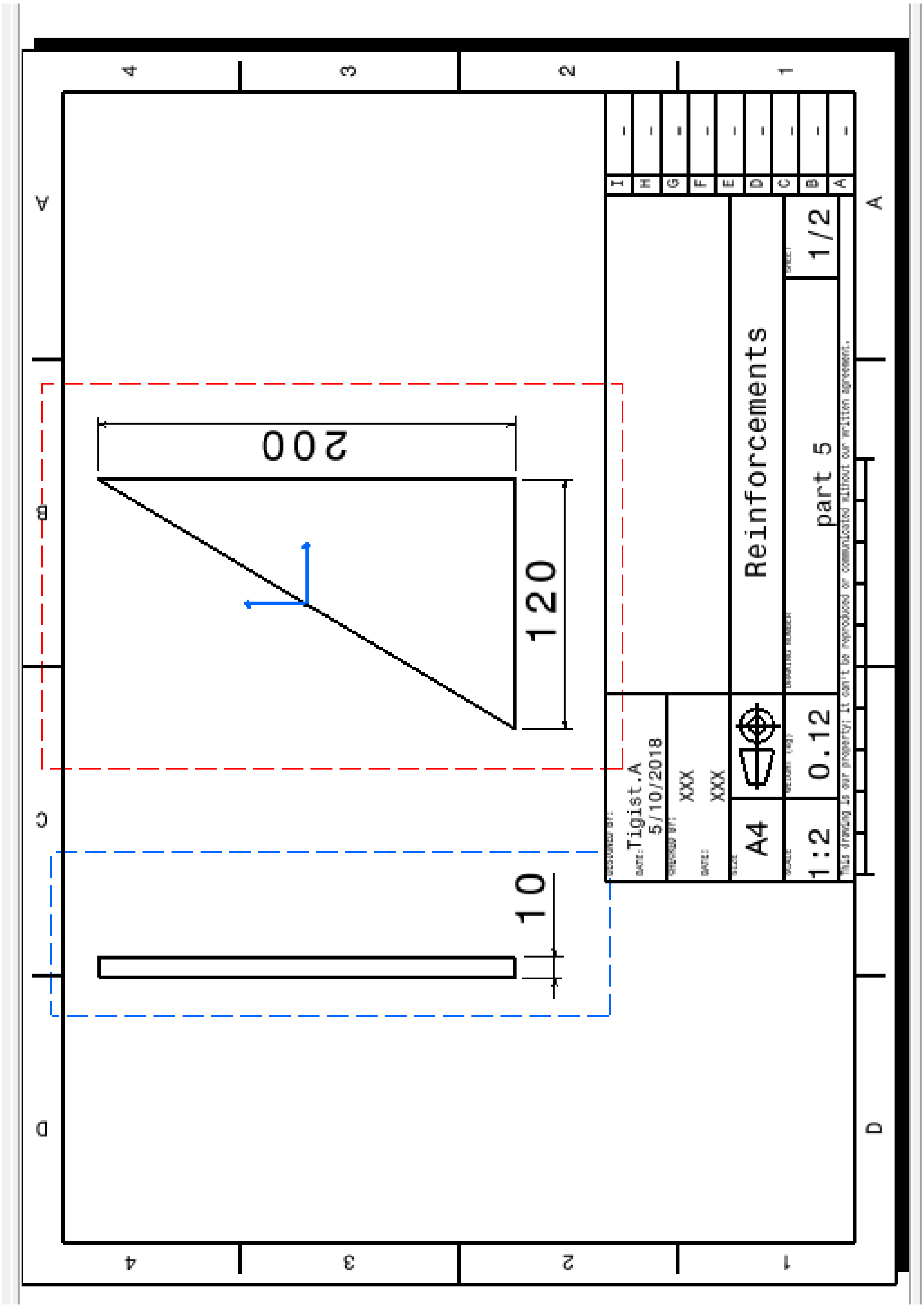
Appendix N Engineering Drawings

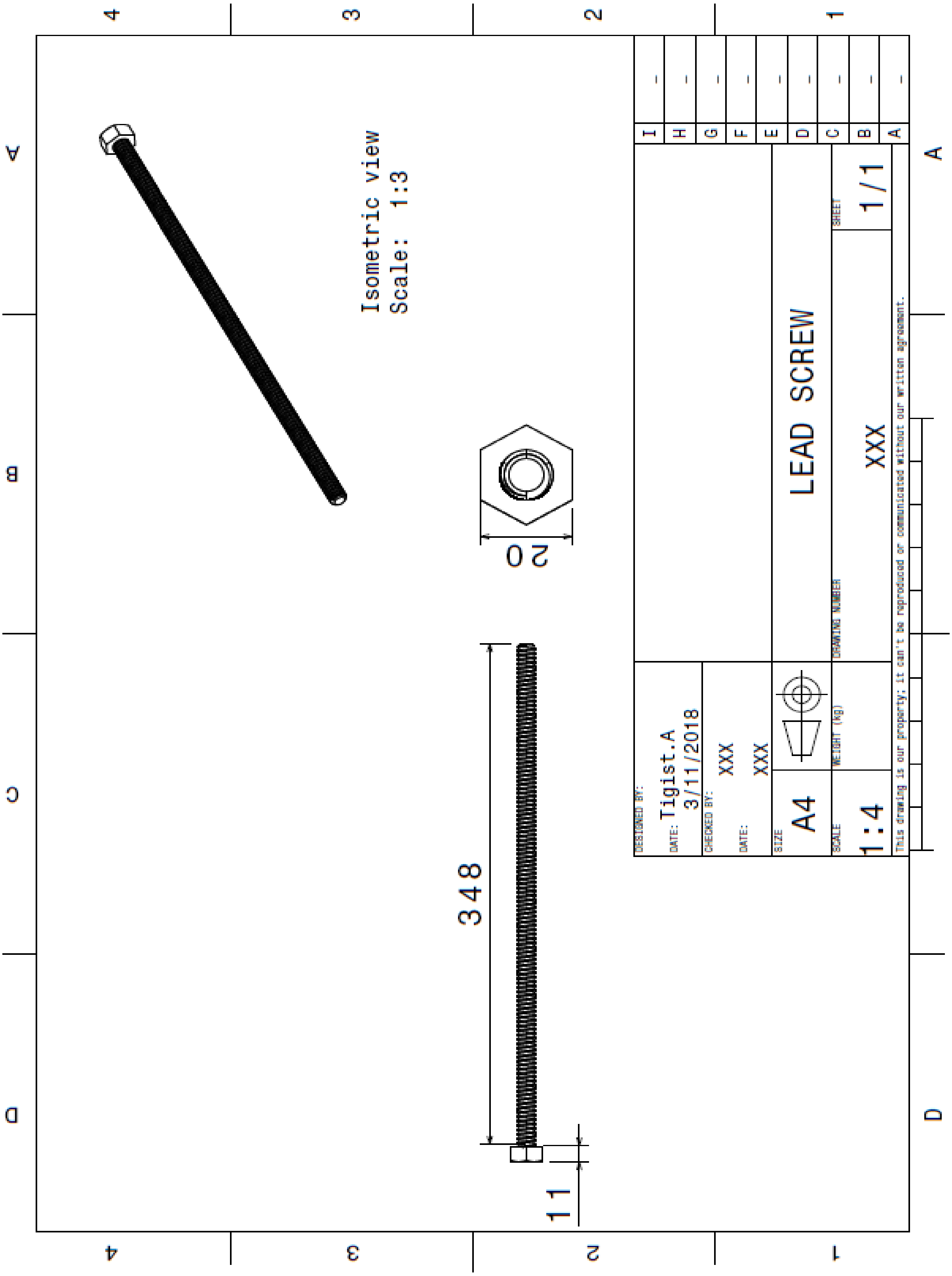


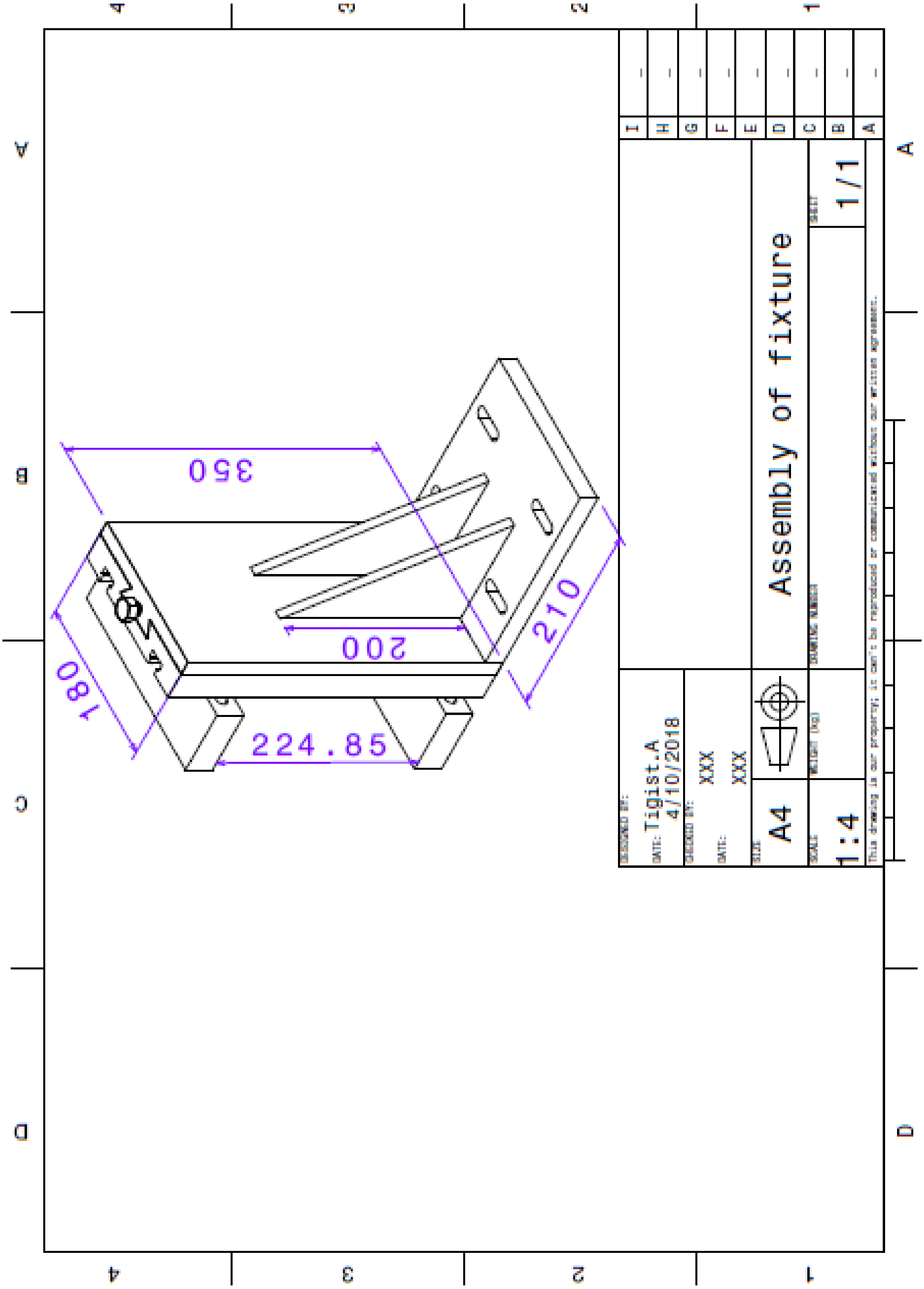

Isometric view
Scale: 1:3
Ø12
37
30
220
70
Tigist.A
3/11/2018
XXX
XXX
A4
1:3
UPPER AND LOWER JAW
Part2
1/1


Isometric view
Scale: 1:4
DESIGNED BY:
Tigist.A
DATE:
3/11/2018
CHECKED BY:
XXX
DATE:
XXX
SIZE
A4
SCALE
1:4
WEIGHT (kg)
DRAWING NUMBER
XXX
SHEET
1/1
LEFT VERTICAL SUPPORT
This drawing is our property; it can't be reproduced or communicated without our written agreement.
350
180
14
20
60
92
7.5
15
30


Isometric view
Scale: 1:3
RIGHT VERTICAL SUPPORT
Part 3
DESIGNED BY:
Tigist.A
DATE:
3/11/2018
CHECKED BY:
XXX
DATE:
XXX
SIZE
A4
SCALE
1:3
SHEET
1/1
DRAWING NUMBER
WEIGHT (kg)
This drawing is our property; it can't be reproduced or communicated without our written agreement.
350
30
180
15
56.31°
⌀12


200
120
10
Reinforcements
part 5
Tigist.A
5/10/2018
XXX
XXX
A4
0.12
1:2
1/2


Isometric view
Scale: 1:3
20
348
11
DESIGNED BY:
Tigist.A
DATE: 3/11/2018
CHECKED BY: XXX
DATE: XXX
SIZE
A4
SCALE
1:4
WEIGHT (kg)
DRAWING NUMBER
XXX
LEAD SCREW
SHEET
1/1
This drawing is our property; it can't be reproduced or communicated without our written agreement.


Assembly of fixture
350
200
210
180
224.85
Tigist.A
4/10/2018
XXX
XXX
A4
1:4
1/1