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Senior Design Project Report

Design of Bench Tapping Machine

In partial fulfillment of the requirements for the Degree of Bachelor of Science in Mechanical Engineering

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Abstract

Tapping is a process that is widely used in the field of engineering, it entails cutting of screw threads onto or into a work-piece. A tap is usually used to cut threads on the female part of the nut part, for external threads a die is usually used to obtain the desire thread size and form. This project focuses on the design of a manually operated bench tapping machine, the main problem that is encountered during tapping process is usually misalignment of threads which might occur due to inadequate clamping forces and misalignment of tap and work-piece. This design provides a solution by providing a machine which ensures accurate alignment of tap and work-piece during the threading process. The machine is composed of supporting frame and shaft, machine bed, bench holder, spindle shaft and a tab holder, the combination of these components ensures that a uniform torque is applied to the tap and as a result the threading process is accurate and precise. The machine also as the flexibility advantage because it allows for attachment of various tap sizes and work-piece forms and hence it can be used for numerous applications within a limited space setting. The average torque on the spindle rod was calculated to be 1.2252Nm which is the average value that an average human being can produce, this torque can be handled by the spindle shaft material and hence the machine service life is improved and safety is assured.

Acknowledgments

We would like to acknowledge everyone who contributed to our success during our academic accomplishments. Our professors, who supported and advise us with everything that we need. Without our professors, we could never have reached this current level of success. Many thanks all for your unwavering support.

List of Acronyms (Symbols) used in the report:

Symbol	Definition
$\boldsymbol{t}$	Time
G	Shear Modulus
$\boldsymbol{\alpha}$	Rotational acceleration
$\boldsymbol{\theta}$	Angle of twist
$\boldsymbol{\tau}$	Shear stress
L	Shaft Length
$\boldsymbol{\omega}$	Angular rotation of the shaft
Kg	Kilogram
N	Newton
T	Torque
Nm	Newton-Meter
D	Diameter
J	Polar Moment of Inertia
R	Shaft radius
F	Applied force
A	Cross-sectional area of shaft

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Chapter 1: Introduction

1.1 Project Definition

To proceed with the introduction of Bench Tapping Device, we first begin by defining what is meant by Tapping and why a specific bench-mounted apparatus is needed to properly execute said process on a work-piece. The tools employed for the formation of internal screw threads are taps and dies. A joint has both male and female parts which in conjunction form the mating pair; a tap is usually used to form threads on female portions of a work-piece whereas a die is used to form threads on male portions of a work-piece.
The process of tapping can be done manually but for it to be accomplished properly we require a 'Bench Tapping Device' to grip the work-piece in the desired place to get the proper formation of screws. This tapping station equipped with a tapping head allows the formation of proper angular oriented taps through grasping the tapping shaft in place and ensuring proper guidance for the tapping head to ensure that tapping goes smoothly, perpendicular alignment is crucial. Though by use of traditional means, manual tapping can form threads, they are in most cases improperly aligned. But using a Bench Apparatus, proper alignment is assured. This alignment must be close to perfection to avoid breaking the tap and producing reliable threads. Once the initial threads start in the wrong direction, as the thread proceeds deeper into the work-piece the rest of the threads follow resulting in a much more pronounced angular misalignment as was present before.

1.2 Project Objectives

Bench Tapping Stations can be employed wherever screw threads are in need to allow usage of fasteners, but manual tapping faces an abundance of issues some of which are to be redeemed by inclusion of these possible improvements:

1. Ensure proper alignment (i.e., coaxial and no angular error) between tap and work-piece via use of several kinds of jigs and fixtures such as a hand-tapper or a tapping guide. By employing this threads of recurring usage/longer lifetime can be created.
2. Proper disposal of chips to avoid clogging.
3. Mounting of required taps of varying materials depending upon requirements of the user.
4. Ensure presence of sufficient amount of cutting lubricant to ensure long service life of taps.
5. Bench tapping device be of a strong structural integrity to allow for longer usage while having ease of removal of individual modules forming the structure to allow for easy repairs and replacements.
6. Having minimal frictional losses to ensure that maximum efficiency is retained.
7. Inclusion of a torque limiting feature for sustenance of taps.
8. Zero or Improper float when employed with screw machines (recommended feed 0.1 slower to establish float for 40 tpi or higher and 0.15 slower for 40 tpi or finer)

Other objectives can be included later as the project scope may be subjected to change.

1.3 Project Motivation

The motivation for doing this project was primarily to focus on an easier and simpler way of acquiring precise, accurate and aligned threads using the manual approach. During the first years of our engineering course we did workshop practice where we focused on thread cutting process using dies and taps, the process was however not as accurate and precise as needed, this made us think of simpler and cheaper ways of acquiring perfect internal threads, the solution was to design a manual bench tapping machine.

1.4 Project Specifications

The machine is a shaft-driven machine that consists of a strong frame to hold the tapping shaft in place. The shaft is rotated through a smooth bearing mechanism for easy operation and its tip is fitted with a tap holder. The holder can be mounted with taps as and when desired. The machine bed consists of a work-piece holder to hold it in place for tapping. This machine allows for accurate tapping results for perfectly aligned screw threads.

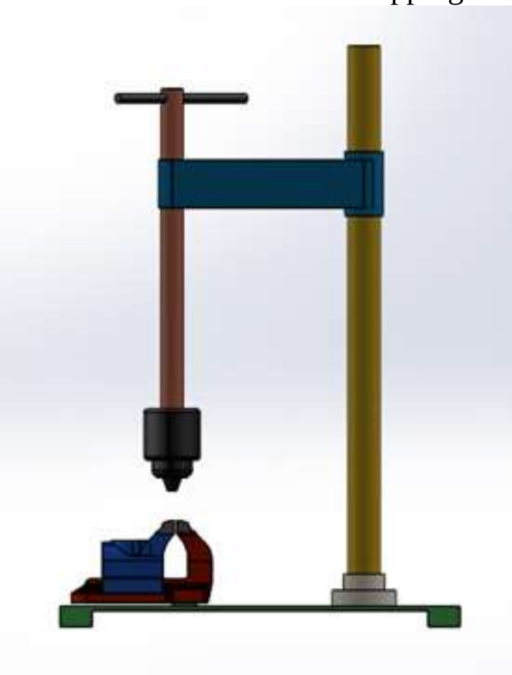

Figure 1: Side View

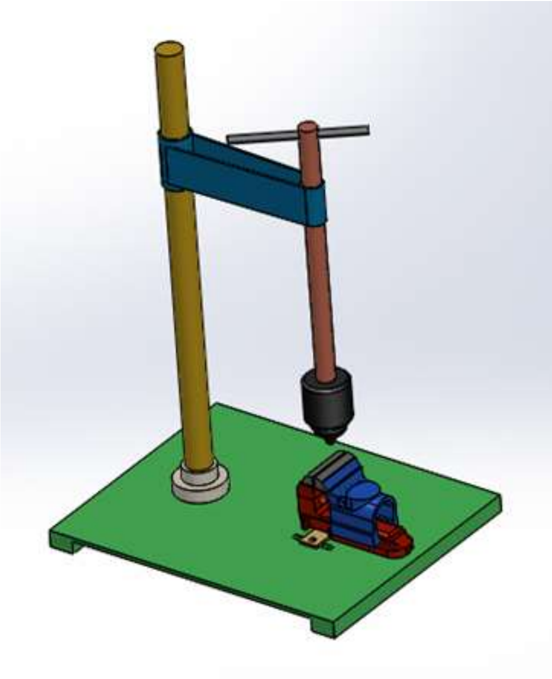

Figure 2: Isometric View

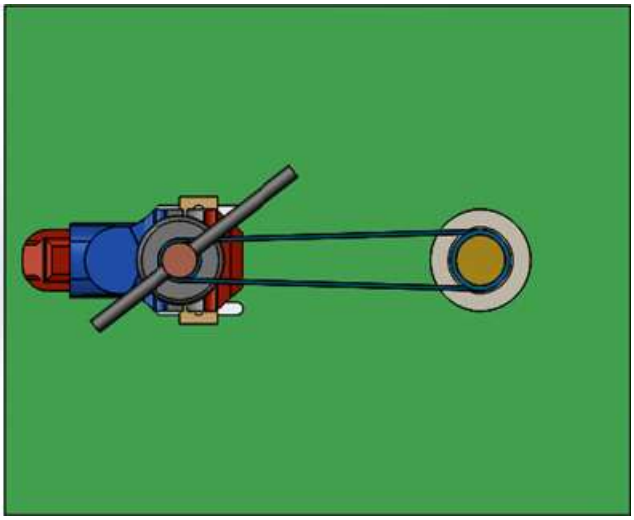

Figure 3: Top view

The key marketing strategies will revolve around it being economic, less power consuming and delivering perfect threads. The idea behind the novelty here is that it would be operable under minimum power requirements while at the same time ensuring proper lubrication throughout. Though being battery and motor operable in the future, it is not employed here; this project will stick to a manually operated bench tapping machine.


Figure 4: Electric tapping and drilling machines [3]

It will also be easier to have it transported from one bench location to another, wherever thread generation may be needed. With respect to the standards the ones employed here are ISO Metric Screw Thread Systems similar to those employed in Europe and the rest of the world excluding North America [3].
For manufacturing, it possible that we may employ shafts of polymers or plastics as a way for a lighter bench apparatus as well as strain sensors to ensure that the taps do not undergo higher levels of strain beyond their set limit. The calculation takes a sample from existing models available and optimizes them where needed.

1.5 Applications

Screw threads have become a part of every extensive machine requiring extensions, fastening and fittings. These extensions of parts and components are present in a wide range of instruments to ensure proper grip that can be disconnected and reconnected time and again depending upon the requirements, such as:

1- Fasteners employing nuts, bolts, and screws in the Locomotive industry for junctions.
2- Components used in the manufacturing of firearms are heavily reliant on thread-based junctions that are frequently removed and subsequently cleaned for proper maintenance of said firearms.
3- Used in textile industry for the formation of junctions of specific diameters.
4- Formation of fasteners and fittings used in the connection of Threaded Hoses and Pipes

Chapter 2: Literature Review

2.1 Project background

Although manual tapping is employed depending upon the usage, the risk of human error is higher compared to most automatic tapping machines. On the other hand, via machine tapping alongside an arsenal of taps (of varying materials, thread dimensions, and finishes) the work is faster, accurate, and more reliable though care is to be exercised when it comes to the lifetime of the equipment as well as that of the taps employed in this process. Wear and tear of taps either by improper spindle speed, under-or over-feeding the tap causing axial failure, tap and work-piece misalignment, chip clogging and the absence of proper torque limitation are some of the problems that still depicts the manual bench tapping process [7]. Also, without the aid of proper taps and dies, termed as chasers, the formation of weaker threads with poor durability is likely to occur. These threads usually have non-uniform tolerances and always have loose fittings to their respective female or male components. In tapping it is important that only the required materials for the formation of threads are removed and not any more than that otherwise the efficiency of the threads is highly affected, making the whole mechanism joint more susceptible to failure.
To ensure recurring usage of thread screws the threads must maintain their strength in the long run with recurring usage without falling prey to breakage, too much material removal and improper angularity as such even the minutiae of alteration can devastate the joint strength resulting in unwanted, sudden failures after overtime usage [2].

2.2 Previous Work

Prior to the availability of hand-powered benches, thread cutting operations were carried out under the supervision of skilled workers that could achieve limited accuracy in their operations and were dominantly dependent on the workers instead of on the tools.
To further delve into the history of the subject in this matter we must first go into the history of screws with their design hypothesis dating all the way back to Archimedes' screw, then after going through the hands of the great Greek mathematicians and after being implemented in carpentry industry and also in the advent of machines after the dawn of Industrial revolution, thereafter lathes came forth and various forms of rolling started to be developed [2]. During the period between 1760 and 1800, means for proper threaded fastening increased through various attempts of Standardization. Later, for the rolling of screw threads, the first patent came about in 1836 by William Keane of Monroe in New York, afterward in the 1940s, the ISO standards came forth for screw threads and by that time numerous methods for machining threads had become the norm [5].
Now from a few years back, specific hand tapping benches have been made commercially available for internal thread creation which is useful where hand operations are to be performed.

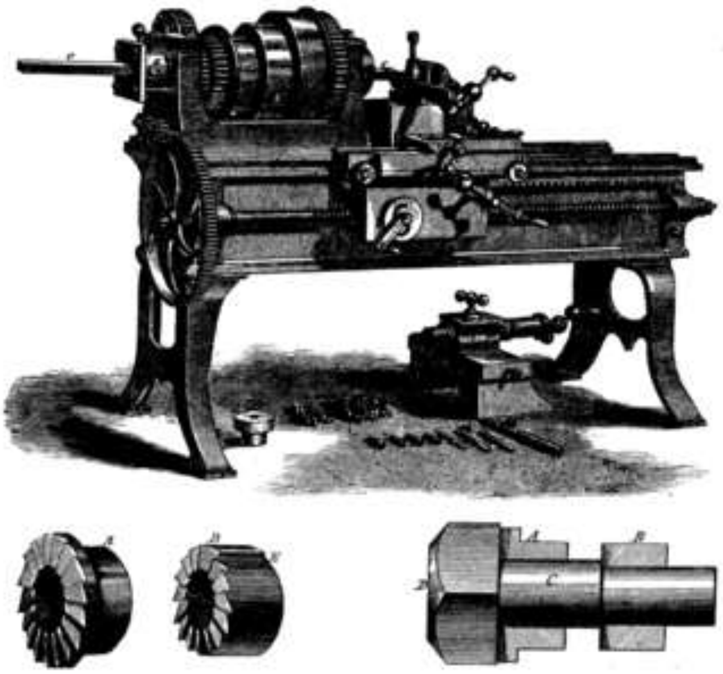

Figure 5: Ancient threading process [2]

2.3 Comparative Study

Some of the recent studies available are reviews on means of optimizing thread tapping process and the ways that their improvement can be achieved. As of now there remains substantial difficulty in having to perform tapping on certain materials such as Titanium where ultrasonic vibration tapping can be utilized thus reducing the tapping torque requirements and thus decreasing the likelihood of tap breakage. Punch Tapping is another hot topic in this regard, this process is mainly employed in threading aluminum and other light weight alloys work-pieces, punch tapping is utilized in the automotive industry where with single twisting and exiting motion threads are generated. Currently, only Audi has the exclusive rights to this technology. There’s also extensive research done with regards to Cast Iron tapping where varying the cutting speed, and application of cutting fluid and its application method while monitoring the axial loads can help in analyzing the tapping process in extensive detail while comparing normal lubrication with minimal quantity (MQF) methods.

Chapter 3: System Design

3.1 Design Constraints an Design Methodology

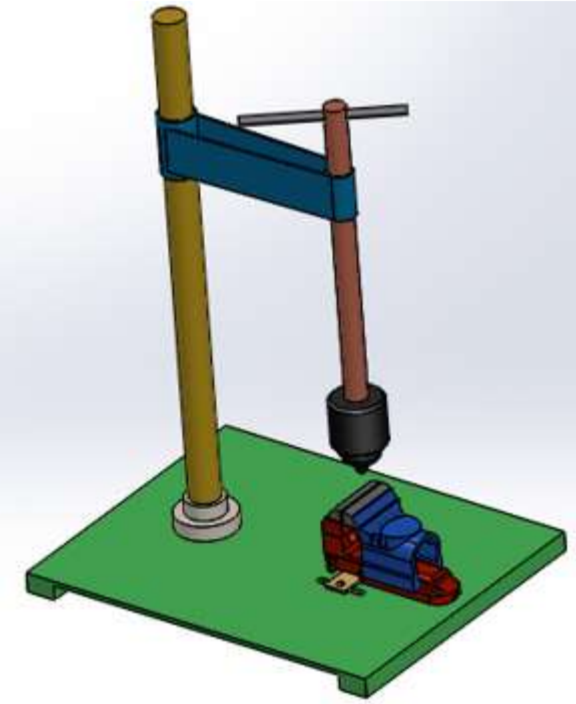

Figure 6: Project architecture diagram

The main aim of this project was to design a simple machine that will allow for easier and precise thread cutting on various sizes and geometries of work pieces, the initial stage in the design process entailed researching on the available types of bench tapping machines and brainstorming on how to best improve them in order to obtain the best out of the process. A simple manually operated bench tapping machine was thereafter selected, what followed was coming up with a Solidworks representation of the machine which helped with the expected final dimensions of the machine after simulation using the same software. Failure analysis by application of the expected loads allowed for selection of the best suited materials for the components and subsystems of the bench tapping machine.

The following are the design constraints for the project;

1) The bench tapping machine and its subsystem and respective components must conform to the relative engineering standards, considering this is a simple design project the bench tapping machine is designed to produce the three most common thread forms (inch-based Unified coarse/fine (UNF/UNC), metric coarse/fine threads and ISO general purpose screw threads).

2) The next design constraint considered in the design process are the maximum torque and rotational spindle speed of the shaft connected to the tap. In order to obtain perfect threads on any work piece, the correct values of applied torque and rotational speed of the shaft must be adhered to, for a manually operated bench tapping machine, the rotational speed is expected to be very low and as a result creating a larger torque within the rotating shaft. However a

large torque may lead to tap breakage and hence including a torque limiting feature is necessary.

3) Provision of an efficient lubrication and cooling system is also crucial for effective functioning of the bench tapping machine, this system includes an appropriate cooling and lubricating fluid which can be recycled in order to cut down on the machine operation costs. Since the system is manually operated, it is also advisable for the cutting lubricant to be applied manually via an appropriately set nozzle which will release the liquid at a desired flow rate.

4) Alignment of the tap holder and the work piece holder is crucial in order to obtained well aligned threads on the work piece, this also reduces the probability of tap breakage as thread cutting is carried on. The holders show provide for clamping and holding of various work piece geometries as well as various sizes of taps. Another feature that should be included on the work piece holder is the mechanism for chip removal and also a mechanism for lubricant drainage and recycling. Chip removal will ensure limited disturbance of the thread cutting process due to chip clogging within the work piece.

3.2 Engineering Design Standards

These are the engineering standards that relate to these thread forms include:

Table 1: Engineering standards [9]

Standard	Name	Type
ASME B1.1-2003 (R2018)	Unified Inch Screw Threads (UN and UNR Thread Form)	V Thread Form
ASME B.1.10M-2004 (R2014)	Unified Miniature Screw Threads	V Thread Form
ASME B.1.13M-2005 (R2015)	Metric Screw Threads: M Profile	V Thread Form
ASME B.1.15-1995 (R2003)	Unified Inch Screw Threads (UNJ Thread Form)	V Thread Form
ASME B1.21M-1997 (R2013)	Metric Screw Threads-MJ Profile	V Thread Form
ASTM A400	Standard Practice for Steel Bars, Selection Guide, Composition, and Mechanical Properties	For steel bars manufacturing process
ASTM A488/A488M A01.18	Standard Practice for Steel Castings, Welding, Qualifications of Procedure and Personnel	For Welding processes
ISO 68-1:1998	ISO general purpose screw threads-Basic Profile-Part 1: Metric screw threads	V Thread Form
ISO 68-2:1998	ISO general purpose screw threads-Basic Profile-Part 2: Inch screw threads	V Thread Form
ISO 261:1998	ISO general purpose metric screw threads-General plan	V Thread Form
ISO 262:1998	ISO general purpose metric	V Thread Form

	screw threads-Selected sizes for screws, bolts and nuts	
ISO 724:1993	ISO general purpose metric screw threads-Basic dimensions	V Thread Form
ISO 725:2009	ISO inch screw threads	V Thread Form 51386

The list above indicates the standards that the produced threads should meet whenever they are produced by the designed tapping machine. Different types of taps can be fitted to the bench tapping machine but the main thread form considered in this design is the V Thread form which can be categorized by the mentioned engineering standards.

3.3 Theory and Theoretical calculations

The bench tapping machine does not include cyclic and bending force analysis, this is mainly because the machine is manually operated and the shaft rarely receives any repeated loads during its normal operation. The property that determines tap breakage is mainly torque which can be calculated by the following expression [3];

Torque required to rotate the shaft is:

$$T = J\alpha = J\frac{\omega}{t}$$

$T =$ Torque required to rotate the shaft
$J =$ Moment of inertia of the shaft
$\alpha =$ Rotational acceleration of the shaft
$\omega =$ Angular rotation (RPM) of the shaft
$t =$ Time

The torsion formula can also be used to calculate the torque transmitted by the spindle shaft to the tap holder [7];

$$\frac{T}{J} = \frac{\tau}{r} = \frac{G\theta}{L}$$

$T =$ Torque required to rotate the shaft
$J =$ Moment of inertia of the shaft
τ = Shear stress
r = Radius of the shaft
G = Shear Modulus
θ = Angle of twist
L = Shaft length

Taking the force applied by an average human on the turning pipe to be 350N, we can calculate the shear stress to be;

$$\tau = \frac{F}{A}$$

F = Applied force
A = Cross-sectional Area of the shaft

$$\tau = \frac{350N}{A}$$

$$A = \frac{\pi}{4}\left(\frac{14}{1000}\right)^2 = 1.5394m^2$$

Therefore,

$$\tau = \frac{350N}{1.5394m^2} = 2.274 \times 10^6 Pa$$

But

$$J = \frac{\pi}{32} d^4 = \frac{\pi}{32} \left(\frac{14}{1000}\right)^4 = 3.7715 \times 10^{-9} m^4$$

Calculating the torque;

$$T = \frac{\tau \times J}{r} = \frac{(2.274 \times 10^6 Pa) \times 3.7715 \times 10^{-9} m^4}{\frac{7}{1000} m} = 1.2252Nm$$

3.4: Product Subsystems and selection of components

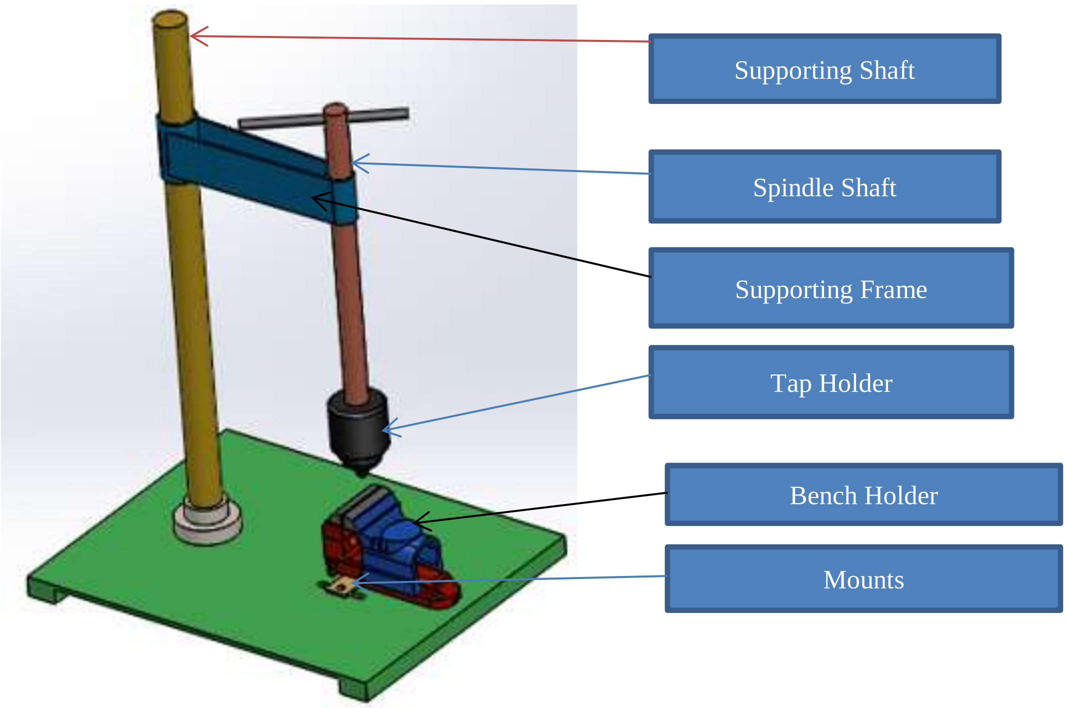

Figure 7: Bench Tapping Machine

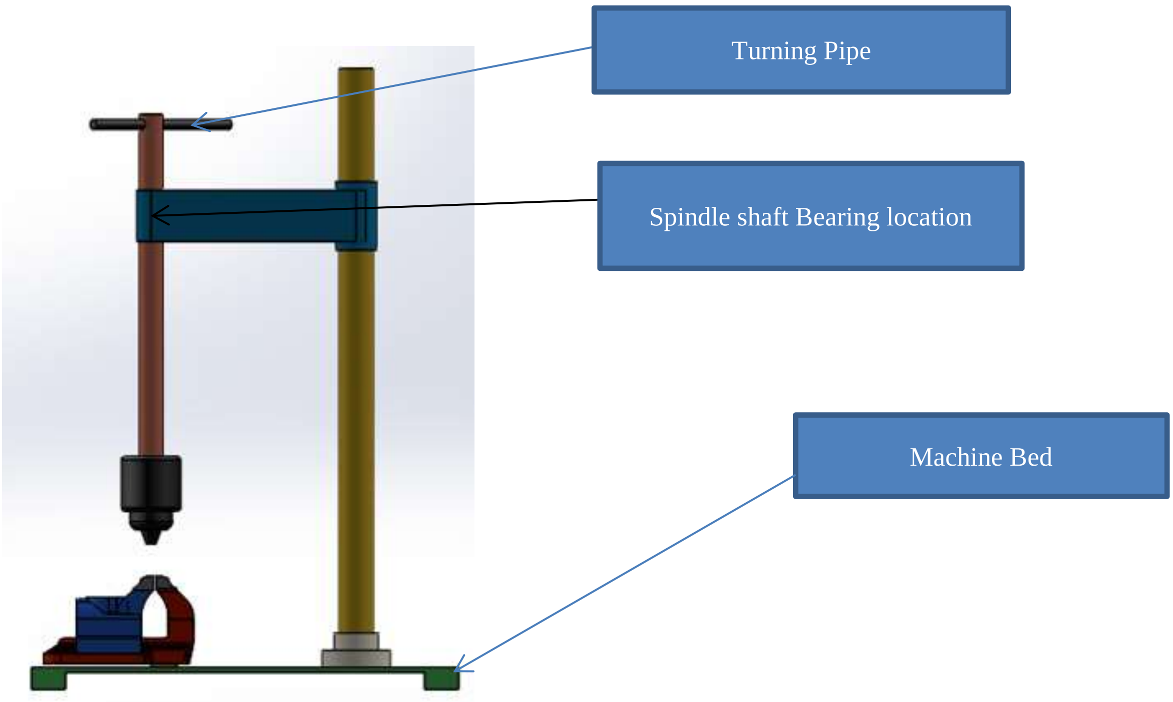

Figure 8: Side view of the Bench Tapping Machine

The bench tapping machine has the following components;

A) Spindle Shaft

The is a shaft that runs down from the turning mechanism of the tapping machine and connects to the tap holder, the main function of this component is to transmit the circular motion to the tap holder and thereafter to the tap itself.

B) Bearing

The bearing is located between the spindle shaft and the supporting frame, it provides for the circular motion of the spindle shaft within a stationary enclosure of the supporting frame.

C) Supporting frame

The supporting frame connects the supporting shaft to the spindle shaft, its geometry has an extended part which increases its ability to sustain higher loads and cyclic stresses.

D) Supporting shaft

The base of the supporting shaft is connected to the machine bed whereas the top end is connected to the supporting frame, its main function is to provide support for the supporting frame, bearing, pipe and the tap holder.

E) Tap Holder

The component is connected at the base of the spindle shaft and rotates at the same speed as the spindle shaft. It provides for the mounting of various sizes of taps on the bench tapping machine.

F) Machine Bed

The machine bed is at the base of the bench tapping machine and provides room for mounting of the supporting shaft and the work piece holder. It also provides support for all the other parts of the machine and hence it must be rigid and strong.

G) Turning Pipe

This allows the spindle shaft to be rotated at a desired speed, provision of the pipes allows for the circular motion to be obtained via a simple turning of the pipe.

H) Mounts

This includes screws and joints which provides for attachment of various components into the main parts of the bench tapping machine, they provide a firm and rigid assembly of subsystems and components into the base of the machine.

I) Bench Holder

The acts as the work piece holder, it has a vice like mechanism which provides for simpler rigid attachment and detachment work pieces onto the machine bed. It also has mechanisms for lubricant drainage and chip removal.

3.5: Manufacturing and assembly (Implementation)

Considering that there are four different component materials to be used (cast iron, mild steel, fiber and gun metal), each component is to be manufactured separately then assembled together to form the bench tapping machine. The machine bed is the base of the machine and hence this acts as the initial assembly point, the bench holder and the supporting shaft are fitted first and ensure they are rigid and strong, the supporting frame, bearing, the spindle shaft and the turning pipe are fitted next. Finally, the tap holder is fitted to the spindle shaft. The mountings are then fitted to ensure everything fits perfectly and rigidly. The bearing selected depends on the internal diameter of the mounting on the supporting frame and also the external diameter of the spindle shaft. There are various internationally recognized bearing sizes which mainly depend on the amount and types of loads the bearing will be subjected to during normal operation. It is important to consider this before making the final decision of the type and size of bearing to use on this design, since this design does not include a large amount of loads and it also has a lower rotational speed selecting a bearing to use is slightly easier.

3.6 Economic Evaluation

The total economic cost of the project includes; cost of buying the equipment needed for the fabrication of the bench tapping machine, buying various tap sizes, acquiring the lubricant and coolant, cost of replacing the depleted parts of the machine and wage costs.

Table 2: Cost Evaluation template

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Capital Costs											
Equipment	500	500	500	500	500	500	500	500	500	500	500
Construction	1000	50	100	100	100	100	200	200	200	200	200
Total	1500	550	600	600	600	600	700	700	700	700	700
Operating Cost											
Energy	0	0	0	0	0	0	0	0	0	0	0
Electricity	0	0	0	0	0	0	0	0	0	0	0
Labour	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500
Insurance	100	100	100	100	100	100	100	100	100	100	100
Taxes	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000
Total	7600	7600	7600	7600	7600	7600	7600	7600	7600	7600	7600

Revenues											
Product 1	30000	30000	30000	30000	30000	30000	30000	30000	30000	30000	30000
Product 2	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000
Product 3	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
Total	55000	55000	55000	55000	55000	55000	55000	55000	55000	55000	55000
Profits	45900	46850	46800	46800	46800	46800	45850	45850	45850	45850	45850

Chapter 4: System Testing and Analysis

4.1 Experimental Setup, Sensors and Data Acquisition System

In order to perform the system analysis, it is crucial to perform a well suited experiment on the practical model, or in our case the fabricated machine. The experimental testing allows for comparison of the fabricated bench tapping machine to other available machines that are utilized for the tapping process, in our case we chose to compare the use of the bench tapping machine for thread cutting and the use of conventional manual thread cutting process. The conventional thread cutting process usually involves the use of dies and taps without the necessary clamping mechanisms which ensure aligned and accurate threads. In this experimental test process we utilize the two methods of thread cutting (specifically tapping) and compare them in relation to; ease of threading, time required to form complete threads, force requirements and the accuracy/alignment of the end threads. The figure below shows the experimental setup for testing of the fabricated bench tapping machine;

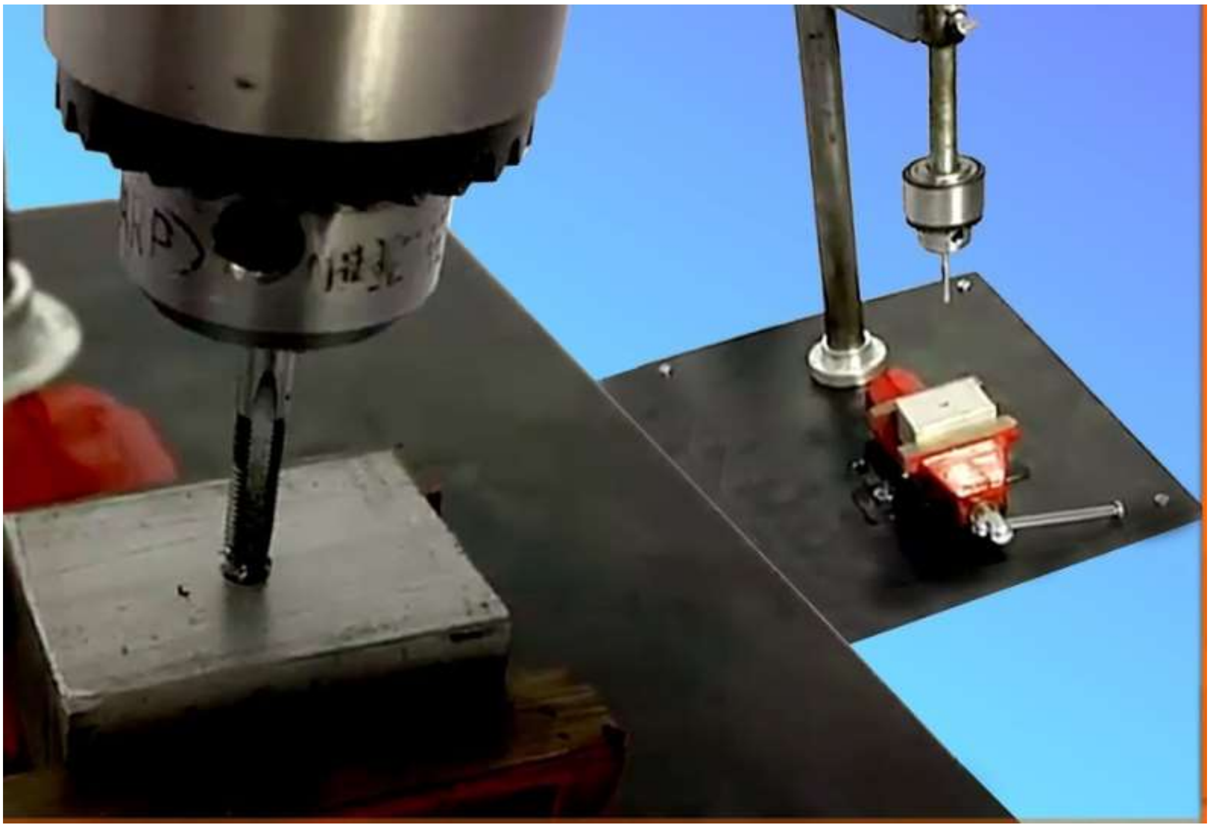

Figure 9: Use of Bench-tapping machine in tapping

The setup above entailed the use of an appropriate tap size (same for both tests) and ensuring the work-piece is tightly held on the bench holder. The amount of force required and the ease of threading is judged by the operator whereas the threads formed can be examined to determine the accuracy and alignment of threads. For the conventional threading process (also manual but does not include camping of tap and work-piece) the setup is slightly different but the experimental procedure is exactly the same as the one mentioned above.

Figure 10: Manual tapping experimental setup

Figure 11: Manual tapping process

The manual tapping process entails clamping the work-piece of a normal vice and attaching the tap to a holder which also acts as the turning mechanism.

4.2 Overall Results, Analysis and Discussion

The results of the two experiments proved that the use of the bench tapping machine highly improves the tapping process, the first thing to be considered was the ease of the tapping process; use of the bench tapping machine made the entire tapping process so easy and simple compare to the manual tapping process which necessitated the need to find a workshop with a preset clamping mechanism and also the tap holding mechanism for the bench tapping machine is simpler than the one for manual tapping. The turning force is lower for the bench tapping machine mainly due to the inclusion of a bearing which makes it easier to obtain the require tapping force, the risk of tap breakage is also reduced when using the bench tapping machine [6]. Using the basis of force used by the operator to obtain the need threads (the operator was required to estimate which experiment required a higher force), it was established that the manual tapping process required a force higher than when the bench tapping machine was used to obtain the same threads while using the same size and type of tap.

As for the accuracy and alignment of threads, it was expected that the most advanced tapping system will produce a superior quality of internal threads and true to this expectation, threads obtained by use of the bench tapping machine were accurately aligned and with uniform thread properties such as pitch and thread spacing. Those obtained via the manual tapping process were slightly misaligned and irregular in shape.

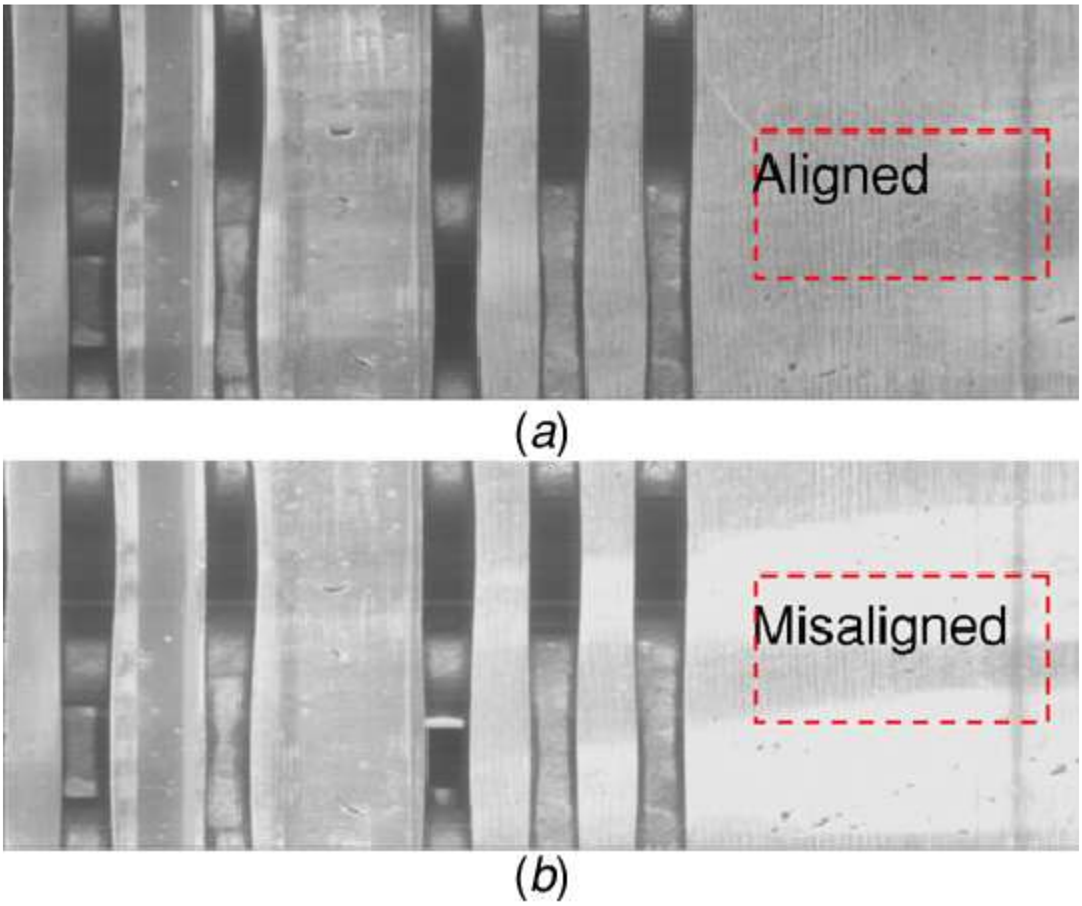

Figure 12: Aligned and Misaligned threads comparison [6]

Chapter 5: Project Management

5.1 Project Plan

For any project to be successful there must be a perfect pre-laid plan which will govern how the entire design, development and execution process is to be done. The initial stage of this project involved selection of group members (five in total), thereafter the group members met and came up with a project plan which was to run for a period of around four months. The group settled on the following breakdown of project tasks;

a) Identification of a problem based on tapping and writing done a working problem statement and project aims and objectives
b) Coming up with an appropriate project title
c) Formulation of a detailed project introduction and literature review
d) Obtaining design standards and constraints
e) Developing a detailed 3D project model
f) Determining machine dimensions
g) Material selection based on design constraints and cost analysis
h) Component and material sourcing
i) Project fabrication and testing
j) Analysis of test results and discussion
k) Writing a detailed report summarizing the entire project

Time duration of specific tasks

The project duration had limited time running from 4th February to 10th May, this necessitated the need to squeeze the project tasks within the short period of time and due to this some of the tasks had to be overlapped. The following task indicates how the tasks were performed during the entire project;

Table 3: Task time duration

Task	February	March	April	May
Task 1	Project title, problem statement and project aims			
Task 2	Introduction and Literature review			
Task 3		Material Selection and Cost Analysis		
Task 4		3D Modeling and Machine Fabrication		
Task 5			Machine Testing	
Task 6			Test result analysis and Discussion	
Task 7	Report Writing			

5.2 Team Members Contributions

During the first team session the members decided that each individual should contribute fully in most is not all the tasks that were to be undertaken during the project design, development, fabrication and report writing. However due to the unique experiences and skills possessed by the different individuals of the team, it seemed more efficient if each member lead on parts that he/she felt comfortable and well suited for, the following is list shows which members took charge of the various project tasks;

Team Members	Tasks in charge
Member 1	Introduction and Literature Review Report Writing
Member 2	Material selection Cost analysis Determining component dimensions
Member 3	3D model development Design calculations
Member 4	Problem statement Project title Project aims and objectives
Member 5	Project fabrication and testing Analysis and discussion

5.3 Project Execution and Monitoring

This being a senior project, our team had to be assigned to a specific supervisor who had the task of monitoring our project progress all through the project duration. After the selection of our project title and problem statement, we presented it to our supervisor who gave us a green light to proceed with the project development. Thereafter the project introduction and literature review based on our project title was developed and presented for approval by the project advisor; each chapter had to be presented in slides form with the main points clearly highlighted. Chapter 3 of our project mainly focused on the project design phase, it comprised of formulation of the design constraints and establishment of the appropriate engineering standards (both design and manufacturing) that govern the design project. After obtaining the required spindle shaft torque, it was simpler to obtain the component dimensions and thereafter to develop a detailed 3D model of the bench tapping machine. The model was crucial in obtaining a simulation of how the machine will behave when operating under the expected normal loads during its normal operation. Once established that the loads are safe, the fabrication process began and thereafter the appropriate tests were performed on the bench tapping machine in order to compare it to the conventional manual tapping process. Analysis and discussion of the test results determined that indeed the development and fabrication of the bench tapping machine provided a cheaper and improved manual tapping process.

5.4 Decision Making Process and Challenges Faced

From the onset of the project, the team was usually faced with a scenario whereby the members had several ideas on how to handle issues experienced within the project tasks, and as a result the group had to develop a system on how the best ideas had to be selected in order to improve and simplify the entire design process. The initial decision that the team had to make was what project was best suited for us, we eventually settled to design a manual bench tapping machine which will likely solve the problem of obtaining misaligned threads when using the available conventional manual tapping techniques. Other decisions that the team had to make include;

a) Suitable material selection
b) Tests to carry out and analyze
c) Which software to use in the 3D modeling
d) What tasks to allocate to individual members of the team

Challenges Faced

This being a very tough year, the challenges were highly magnified and as a result the project design, development and fabrications were a bit slow and uncertain at times. But despite these challenges the project was generally successful. The following are some of the challenges encountered;

i) Lateness and absenteeism of team members. The project involved numerous tasks and therefore it was crucial for each member to perform their specific task on time in order to avoid project stalling and lateness.
ii) COVID-19. This is a global pandemic which has affected our normal activities, as a team this was the main challenge which piled up on the other small challenges. Meeting of team members and advisor was restricted due to the protocols imposed by the government (mainly lockdown), availability of parts was affected to due closure of some major companies and also the delay of delivery of machine parts and components.
iii) This being a unique project, settling on the best experimental tests was a problem, it was hard to determine what specific measurable properties of the bench tapping machine will provide the needed data in order to plot and compare them to the available manual tapping techniques.

5.5 Project Bill of Materials and Budget

The table below indicates the quantity and cost of parts ordered from the available suppliers;

Table 4: Project bill of material and budget

Component/ Part	Unit	Unit Price	Total Price
Bench holder	1	$30	$30
Mild steel shaft	600mm	$10/300mm	$20
Tap holder		$50	$50
Fiber (For machine bed)	250mm*200mm	$30	$30
Cast Iron frame	120mm*30mm	$20	$20
Bearing	1	$10	$10
Tap	3	$20/unit	$60
Mounts	6	$5/unit	$30
Turning cost			$20
Welding cost			$20
Total			$290

From the table above it can be seen that the total cost of fabrication amounted to $290 which was within the pre-set budget of the project. The manufacturing cost included turning the acquired shafts into the desired diameters and also ensuring their surfaces are smooth and soft enough, welding is necessary in order to make the supporting frame strong enough.

Chapter 6: Project Analysis

6.1 Life-Long Learning

Our project was mainly based on the tapping process and how it can be made simpler and easier to perform, this project enabled as to acquire the following life-long learning that will be helpful to us in the future;

a) The use of modeling software in obtaining the 3D model of the bench tapping machine has enabled as to acquire the much needed knowledge on such software. Our world is constantly shifting the use of improved technologies to solve life-long issues and therefore have enough knowledge can be highly advantageous. Our group members were able to acquire some knowledge on software's such as CAD, Autodesk Inventor and Solidworks.
b) Due to the short project duration it was essential for the team to learn on how to make the most out of a limited time period. This enabled us to manage our time better and be able to do all the required tasks within this duration of time.
c) Material selection is a crucial design process which ensures the materials selected are best suited for a particular application while at the same time maintaining the least possible cost. Our team was able to learn from experience how to best select the materials within the design constraints while ensuring we are within our project budget.
d) Since the project was to be done by a group of five individuals, it was crucial for the team members to learn on how to best relate to each other and also what motivations can be used to bring the best out of each team member.
e) The project also acted as a refresher on some engineering skills and knowledge which included welding, turning, tapping process, and a few mathematical calculations.
f) The project was a huge step in applying what we had learnt in class into a real life problem, and in the end we were able to provide an improved version on a bench tapping machine which increases the efficiency and effectiveness of the tapping process.

6.2 Impact of Engineering Solutions

In the beginning of this project our main aim was to design, develop and fabricate a machine which would improve the manual tapping process, at the end of this project we managed to improve various parts of the conventional manual tapping process. The engineering improvements of the tapping process include;

i) The process has been made fast and effective by the use of a bench tapping machine which is easier and simpler to setup and use for the tapping process.
ii) The threads obtained are accurate and aligned which increases the service life of the component and also reduces the risk of tap breakage during thread cutting.
iii) Flexibility of the process is also assured by the fitting of a variable tap and bench holder which can hold different sizes and forms of taps as well as work-pieces.
iv) The operation of the machine has been made safer by ensuring the torque transmitted within the spindle shaft is within the set range, this also allows the spindle shaft to have a longer service life [6].

v) The use of fiber in the machine bed highly reduces the cost of the machine but at the same time it makes the machine lighter and can support the maximum amount of load in the bench tapping machine.

6.3 Contemporary Issues Addressed

The design of the bench tapping machine has addressed the following key issues;

i) Prevents misalignment of threads which is mainly caused by misalignments of the center of the tap and the center of the work-piece.
ii) Reduction in the risk of tap breakage by ensuring the spindle shaft operates within the safe torque range
iii) Reduced turning force due to the fitting of a ball bearing between the spindle shaft and the supporting frame
iv) Providing an inbuilt bench holder which provided for tight holding of the work-piece during the tapping process

Chapter 7: Conclusion and Future Recommendations

7.1 Conclusion

The project aims and objectives were sufficiently achieved and hence the project was successful; a manually operated bench tapping machine was design, developed, fabricated and tested. The team also manage to perform other project minor objectives which includes; development of a 3D model of the bench tapping machine on Solidworks and simulating the model to determine the safe limits of the machine, material selection for the components and parts that make up the bench tapping machine, cost analysis and analysis of the experimental test results obtained. Despite all the challenges faced and the human, technical and experimental errors that might have been experienced during the project, our team was able to pull through and develop a machine that's one of its own unique kind. The machine is able to produce threads on the internal parts of work-pieces while the operator is using a lower amount of force compared to when using the conventional method of tapping.

7.2 Future Recommendations

Although the bench tapping machine designed in this project solves most if not all of the problems which were listed in the problem statement, there is still huge room for improving this machine is order to obtain the best out of it. The following are the recommendations our time provided that might help is making it more efficient and productive;

i) Design of an enhanced chip removal system, this will help further prevent chip clogging and thereby improving the tapping process. Chip clogging also increases the risk of tap breakage and hence this recommendation will also reduce the risk of tap breakage

ii) Attachment of a cooling and lubrication system, cooling and lubrication of the tap during operation reduces friction and rise in temperature and hence it makes the entire process smooth and efficient. This also highly increases the tool service life and also helps with chip removal from the work-piece [6].

iii) Automation of the bench tapping machine is also another possibility that will increase the efficiency and speed of the tapping process. Although the aim of this project was to save on power, the machine can be designed to consume the least amount of power while producing more favorable quality of threads in a much lower amount of time compared to a manual bench tapping machine.

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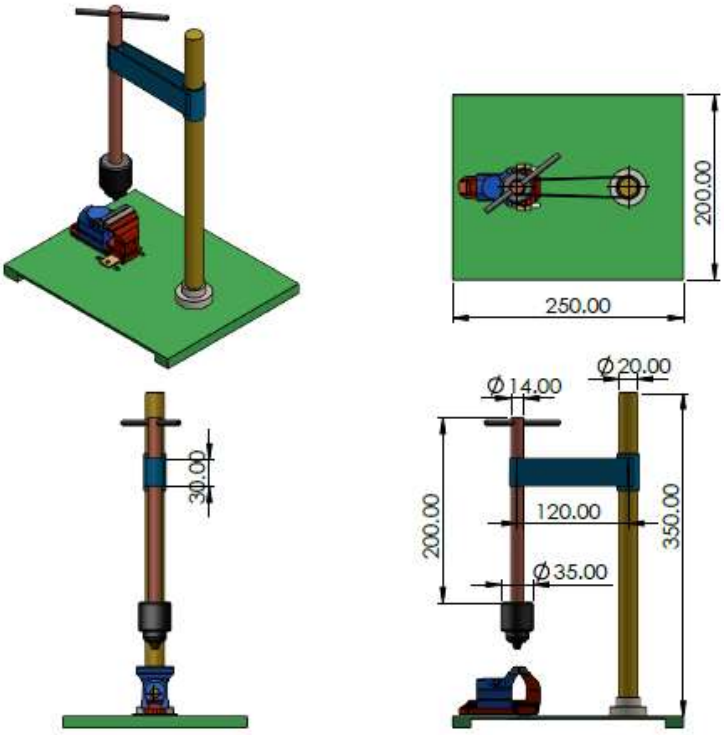
Appendix A: CAD drawing and Bill of Materials



Component/ Part	Unit	Unit Price	Total Price
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Bearing	1	$10	$10
Tap	3	$20/unit	$60
Mounts	6	$5/unit	$30
Turning cost			$20
Welding cost			$20
Total			$290

Appendix B: Engineering Standards

Standard	Name	Type
ASME B1.1-2003 (R2018)	Unified Inch Screw Threads (UN and UNR Thread Form)	V Thread Form
ASME B.1.10M-2004 (R2014)	Unified Miniature Screw Threads	V Thread Form
ASME B.1.13M-2005 (R2015)	Metric Screw Threads: M Profile	V Thread Form
ASME B.1.15-1995 (R2003)	Unified Inch Screw Threads (UNJ Thread Form)	V Thread Form
ASME B1.21M-1997 (R2013)	Metric Screw Threads-MJ Profile	V Thread Form
ASTM A400	Standard Practice for Steel Bars, Selection Guide, Composition, and Mechanical Properties	For steel bars manufacturing process
ASTM A488/A488M A01.18	Standard Practice for Steel Castings, Welding, Qualifications of Procedure and Personnel	For Welding processes
ISO 68-1:1998	ISO general purpose screw threads-Basic Profile-Part 1: Metric screw threads	V Thread Form
ISO 68-2:1998	ISO general purpose screw threads-Basic Profile-Part 2: Inch screw threads	V Thread Form
ISO 261:1998	ISO general purpose metric screw threads-General plan	V Thread Form
ISO 262:1998	ISO general purpose metric screw threads-Selected sizes for screws, bolts and nuts	V Thread Form
ISO 724:1993	ISO general purpose metric screw threads-Basic dimensions	V Thread Form
ISO 725:2009	ISO inch screw threads	V Thread Form 51386