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Department of Mechanical Engineering

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Senior Design Project Report

**Design and Fabrication a Manual Roller
Bending Machine**

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

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Abstract

This paper aims to develop a roller bending helpful machine to bend pipes and metal strips in the workshop. This project is to vogue and constructs a negotiable roller bending machine. This machine is utilized to bend steel pipes and meta strips into a curve and so the choice curvature shapes. The scale of the machine is very convenient for movable work. It is entirely created by steel. Moreover, it is easy to carry and use at anytime and anywhere. It reduces human effort and, in addition, required low less talent to figure this machine. We incline to face live arising with operated by hand roller bending machine using block, motors, gears, and support (frame). Power is that the machine for pipe bending, and everything works manually. Therefore, our objective is to extend preciseness at low costs while not moving the pipe bending's productivity. This machine works on the simple kinematic system instead of subtle vogue. Because of its mobility, it are usually utilized by workshop or fabrication search. A bending machine is also a standard tool in the workshop that is accustomed bend a metal.

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List of Acronyms (Symbols) used in the report:

p	<i>pitch</i>
z	<i>Number of the teeth of sprocket</i>
d_c	<i>major diameter</i>
d_0	<i>minor diameter</i>
μ	<i>co – efficient of friction</i>
w	<i>weight of the roller</i>
α	<i>Helix angle</i>
\emptyset	<i>Friction angle</i>
T	<i>torque</i>
σ_s	<i>material yield limit</i>
B	<i>maximum width of rolled shield</i>
δ	<i>Thickness of rolled sheet in mm</i>
d_{min}	<i>minimum diameter of the rolling plate in mm</i>
d_2	<i>lower roller diameter in mm</i>
F	<i>Force</i>
a	<i>lower roller center distance in mm</i>
f	<i>co-efficient of rolling friction</i>
R	<i>Bending radius</i>
C	<i>Distance between two fixed rollers</i>
d	<i>Deflection in the middle roller</i>

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Chapter 1: Introduction

1.1 Project Definition

The main focus of this project is to design the manual roller bending machine. This machine helps bend the different sheets according to the requirement. This machine does not involve any external force or electricity; instead, it involved only a man force, i.e., a person can run the machine with the help of a hand. The design of this machine is so that it requires a little force to perform the task. This machine helps us in doing the bending tasks that required little effort. Different components that are used in this machine and its mechanism will also be discussed in this project. This project is to vogue and constructs a negotiable roller bending machine. This machine uses to bend steel pipes and metal strips into a curve, so the choice curvature shapes. This machine is very convenient for movable work and is created of steel and easy to run. Moreover, it is easy to carry and use at anytime and anywhere. It reduces human effort and, in addition, required low less talent to figure this machine. We incline to face live arising with operated by hand roller bending machine using block, motors, gears, and support (frame). Power is that the machine for pipe bending, and everyone works manually. Therefore, our objective is to extend preciseness at low costs while not moving the pipe bending's productivity. This machine works on the simple kinematic system instead of subtle vogue. Because of its mobility, it is usually utilized by a tiny workshop or fabrication search. A bending machine is also a standard tool in the workshop that is accustomed bend a metal.

1.2 Project Objectives

The important objectives of this project are given as follows

1. Design of the manual roller bending machine.
2. Design of the components required for this machine.
3. The design of the machine should be cost efficient and easy to handle.
4. Design the machine so that it performs its work efficiently with minimum effort.

1.3 Project Specifications

The specifications of this project mainly involve the use of different types of mechanisms, in a manual roller bending machine, the gear mechanism, power transmission, speed controller. In

simple words, most specifications are linked with the theory of machines. Since the project's objective is to design a manual roller bending machine, the concepts of mechanisms must be clear. Mostly, the engineering standards involved in this design are taken from ASME codes. First of all, all the parts are separately designed, and then they are assembled. The machine design standards were used for designing the gears and mechanism of power transmission. The specifications of the manual roller bending machine must be like it consumes very little power and delivers much work. Moreover, the machine must have reliability so that it can operate for longer hours.

1.4 Applications

The major uses of this roller bending machine is given as follows

- This machine is helpful in bending the metal sheets easily.
- It can bend the sheet without any electricity.
- Manually operated to do the task at domestic level.
- Also, helpful in moving from one place to another place.
- Through this machine, no heavy labor is required.
- Easy to handle and operate.
- Little maintenance is required for such type of machines.

Chapter 2: Literature Review

2.1 Project background

Roller bending machines are very much utilized worldwide in the industries to perform the different types of functions on metal sheets. The size of these machines is very much significant as compared to the other machines. These machines are involved many components that help bend the metal sheets. Bending of the metal sheets is necessary for different industries to make the different parts according to the given requirements. Metal structures are made up of different types of metal sheets and strips. These strips are made over the roller bending machines. The metal sheet is placed between the roller, and through the rolling force of the rollers, it bends in the forward direction. The thickness of the sheet is also reduced through this machine. These machines required much effort in bending the metal strips. In construction and metallic projects, different bending metal strips are used. Also, These machines consume a lot of energy and effort, for example, fuel or electricity, to bend the sheets. The primary purpose of this project is to reduce the operating cost and maintenance costs of the roller bending machine. Moreover, this manual machine is required less maintenance and easy to handle. Also, the manual roller bending machines required no electricity to operate. So, the design of these projects is helpful for the industries to minimize the cost of a specific project.

The onset of the industrial revolution took place from the 17th century until the mid-18th. This revolution was the reason for the existence of functioning machines today. The main branch of this revolution is manufacturing since it allowed the use of machines that significantly made daily human tasks much more accessible. Cold bending has been around since 1800B.C; it slowly developed until the industrial revolution in the 1760s'. Many types of bending are available nowadays. A pyramidal type was chosen with a three-roller bending setup because of its various capabilities with just two degrees of freedom. The goal is to improve this type of process using analytical geometry and empirical techniques to achieve an ameliorated design. There are many types of bending techniques present now, but every type has its advantages and disadvantages. The two rollers on the bottom are used to fix the workpiece in a horizontal direction, and the upper roller will apply a downward force. The upper roller is adjusted using a hydraulic jack; thus, the roller only moves in the vertical direction. When defining the current bend angle, this clamp is locked. The bottom rollers start to rotate, thus making a bending force

Figure 1 on the workpiece, which will result in deforming the workpiece hence achieving plastic deformation. The main advantages of this process are that this mechanism is straightforward and straightforward. It can remedy the workpiece that has been deformed in a wrong way, such as skew (Bending Error), accurate, consistent, and convenient. However, the disadvantages of such a process are unusable scrap parts. It occurs mainly in vertical three roller bending [2], which means if the pipe is long, due to its weight (workpiece weight) while being rolled, it will bend to a side and cause torsion. Moreover, it is a type of manufacturing inaccuracy of unwanted deformation or deflection.

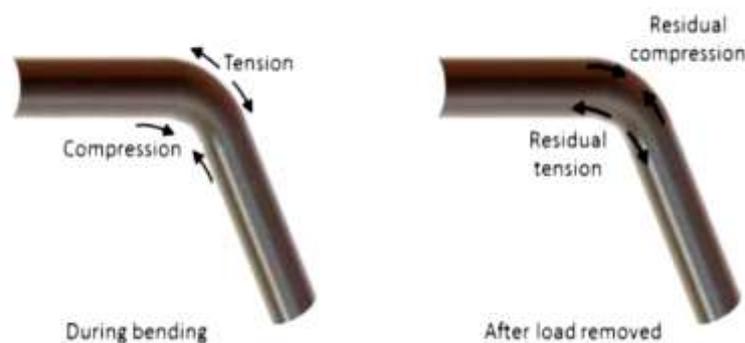


Figure 1: compression and Tension

Our revolutionary life and inventions depend heavily on rolling part bearings. They are used in nearly all rotary devices, assisting rotation and helping complex forces. If a rolling part bearing fails without being noticed and followed up on, it may have disastrous consequences for the system. We try to keep an eye on these critical components by measuring their temperature, noise, vibrations, and oil wears debris, among other things. Vibration signals have proved to be extremely useful for maintenance workers, not just in detecting the location of a fault but also in finding the source. Input from vibration signals has lately been used to provide observers an understanding of the scale of the fault and, as a result, to estimate the bearing's usable remaining life. On the other hand, vibrations picked up by accelerometers must go through a series of rigorous processing steps to extract fault symptoms and identify and quantify fault size.

2.2 Previous Work

H. Yang et al. created a pipe bending system with many parts and a wide variety of shapes and sizes. From a material and structural standpoint, bent tube parts meet the growing need for lightweight and high-strength components. Tube bending has been one of the essential engineering innovations for the development of lightweight products. and Advances in exploring the typical problems in tube bending are summarized by studying bending characteristics and various defects, including wrinkling instability at the intrados, wall thinning (cracking) at the extrados, springback phenomena, cross-section deformation, shaping limit, and process/tooling configuration. The benefits and disadvantages of specific recently established bending techniques are discussed. Finally, the growth developments and related obstacles for realizing precise and high-efficiency tube bending deformation are posed in light of the urgent requirements for high-performance complex bent tube components with difficult-to-deform and lightweight materials aviation and aerospace sectors. (Hea, 2012)



Figure 2: Experimental bent tubes with large diameter (Hea, 2012)

Hiroyuki Goto and colleagues describe a new versatile bending machine and its implementations. The proposed computer employs a novel approach. Tubes are twisted by changing the relative direction of the mobile die as they are inserted into the fixed and mobile dies. Also, the relative distance and direction between the mobile die and the tube determine the bending radius. The length of the fed conduit determines the bent angle. This shaping method has a significant benefit. A variation in the anticipated bending form will not necessitate a tooling device change. However, it will necessitate a new understanding of the active die's motion and the length of the fed tube. A 6-DOF Parallel Kinematic Mechanism (PKM) with hydraulic servo drive controls the active die motions. The PKM is used to achieve a full motion over six axes and a high dynamic motion of the bending machine. Designer

interiors, universally manufactured goods, and car components are examples of where the bending machine can be used. These processes have previously been impossible to accomplish with a traditional bending system. (Goto, 2008)

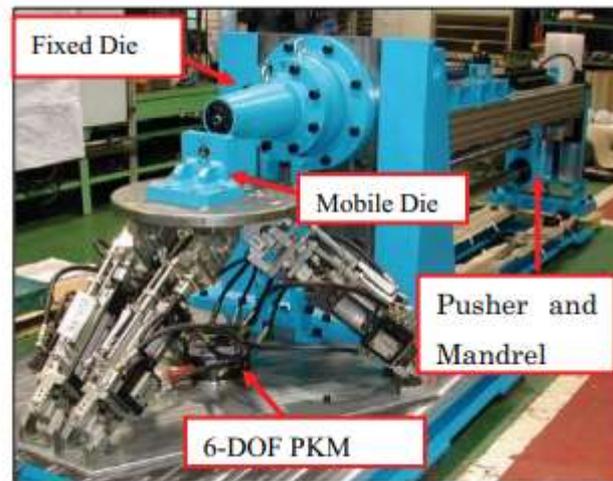


Figure 3: The Proposed Bending Machine (Goto, 2008)

A bicycle integrated pipe bending system was engineered and developed by H. A. Hussain. The unit has a chain drive and a compound gear train for bending steel pipe with an outside diameter of 25 mm and a thickness of 2 mm. The bending mechanism's kinematic synthesis is completed. It was decided to do a dimensional analysis. The deduced relationships forecast the efficiency of the bicycle integrated pipe bending mechanism, and all of the parameters must be adjusted to achieve the best machine performance. (Hussain, 2014)

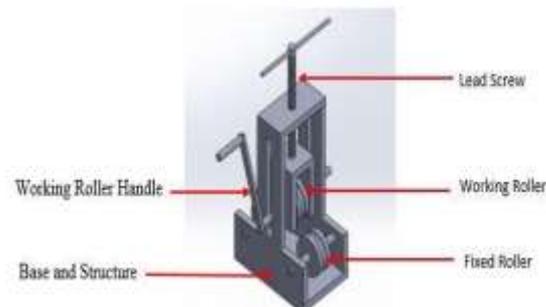


Figure 4: Schematic of manual pipe bending machine (Hussain, 2014)

2.3 Comparative Study

During the roll bending operation, the sheet or pipe is passed through a series of rollers that progressively add pressure to the pipe, as developed by Prof. A.D.ZOPE. The radius of the pipe or layer changes as a result of this friction. This project aims to create a portable metal bending system. This unit bends sheets into curves and other forms of curvature. In comparison to other computers, this machine is tiny. It is ideal for on-the-go jobs. We are working on a manual metal bending system that uses a metal shaft, a hydraulic bottle jack, a pedestal bearing, and a brace. Instead of a complex architecture, this computer uses a primary kinematic device. It can be used by a small factory, fabrication shop, small scale industry, and lightweight and portable. A *bending machine* is a machine that is used to bend metal in a machine shop. For bending a pipe, there is no suitable small-scale bending unit. Steel is bent using a roller in a Metal Bending rig. The bent machine has three rollers. Pipe (square and circular) bending and sheet bending are two of the most popular products of metal bending machines. The board, plate, or pipe is passed through a series of rollers that progressively add pressure to the pipe during the roll bending operation. The radius of the pipe or layer changes as a result of this friction. Because of the different arrangements of the three rollers, the rolling process is usually done by a three-roll bending system, also known as a pyramid type.

The procedure is divided into three steps:

- 1) The sheet or pipe must be properly positioned.
- 2) The central roller is lowered.
- 3) By repeating feed of pipe. (A.D.Zope, 2017)

II. Block Diagram:

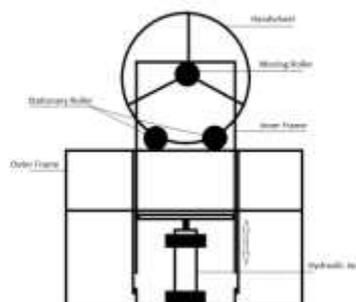


Figure 5: Block diagram of metal bending machine (A.D.Zope, 2017)

Anand Jayakumar, Ph.D. All of this creativity has made it more attractive and cost-effective. It is beneficial to the building industry and specific other sectors. Bending is a method of deforming metal by plastically deforming the material and altering its shape. The substance is strained past its yield strength but not yet to its maximum tensile strength. Sheet metal and metal bars can all be bent with a roll. If a bar is used, the cross-section is considered uniform but not strictly rectangular, as long as there are no overhanging contours. Between the rollers, the bar section would take on the form of a cubic polynomial, which approximates a circular arc. The rollers are then rotated, which causes the bar to rotate as well. As a segment of the bar leaves the region between the rollers, the elastic deformation is reversed. To obtain the desired radius, this "spring-back" must be compensated when changing the middle roller. The sum of spring back is determined by the material's elastic conformity (inverse of stiffness) to its ductility. Steel bars are more difficult to fold into an arc than aluminum bars. Pumping may be done with the aid of a handle on the jack. The oil inside the cylinder assists the piston rod in moving upwards as the handle is pressing once. A roller is fixed to the piston rod's tip. A pipe is held within these arrangements for the bending phase. This breakthrough has made them more appealing and cost-effective. This prototype, titled "ROLL BENDING MACHINE," was created in the hopes of being very cost-effective and beneficial to construction and other industries. (Jayakumar, 2019)

P. P. Khandare et al. built a project to design and construct a compact pipe bending system that could turn steel pipes into curves and other shapes. It was simple to transport and use at any time and in any place, requiring less human labor and requiring a less trained workforce. It can bend pipes with a thickness of up to 4-5 mm, but it is only suitable for use in a small workshop or welding shop. (Khandare, 2016)

This paper aims to create a roller bending machine used in a workshop to bend metal strips. This project aims to develop and construct a mobile roller bending system. Metal strips are bent into curves and other curvature forms using this unit. The machine's scale makes it ideal for mobile work. It is entirely made of titanium. Furthermore, it is simple to transport and use at any time and in any place. This computer requires less human effort and requires less ability to run. We are developing a manually controlled roller bending system through the use of rollers, chain sprockets, and assistance. The bending system for rollers is run by hand. As a result, our goal is to improve precision at a low cost without sacrificing bending efficiency. Instead of a complex architecture, this computer uses a primary kinematic device. It may be

used by a small workshop or fabrication shop due to its portability. A *bending machine* is a machine shop instrument that is used to bend metal. (Pachange, 2019)



Figure 6: Manual Roller Bending Machine (Pachange, 2019)

Chapter 3: System Design

3.1 Design Constraints and Design Methodology

3.1.1: Geometrical Constraints:

Since our project aims to make a curve and bend martial, it also aims to make the design helpful in every aspect of the industry. Also, the idea is to develop and design a small roller bending machine that will help improve the use of roller bending in the industry at a lower cost and make sure that our prototype is portable and can be easily used everywhere.

3.1.2: Sustainability:

Sustainability is concerned for the prototype. It was made sure that selection of components, like Bending rollers and Chain drive and Spindle wheel and Sprocket Brass and Supporting frame, was made according to choose the proper material. Also, our concerns are that there is a limitation for our prototype like the capability for bending material sheet because it should be suitable and can sustain for 4mm thickness and less, and it should be below 145 torque. Also, another concern is corrosion that can affect the prototype because it can be exposed to erosion, so we must consider controlling the corrosion by using barrier coatings like paint.

3.1.3: Environmental Concern:

Our prototype is friendly to the environment because it does not require a gas motor that will not release emissions. So, it will not affect and harm the environment because the bending machine is a manual roller. So, there are workshops that is use an engine roller machine bending instead of manual, and that harm the environment. However, using this prototype in the industry very helpful for the environment.

3.1.4: Social Impact:

Since most of the projects are carried out to develop products and contribute to making the industry better and efficient by using the minimum amount of resources possible, develop this product. This project aims to present such an idea were making the machine portable for industry use and a self-use for everyone. Also, it can provide to save time for the users because it does not require any skills to rub the machine.

3.1.5: Economic:

On the economic side, it helps to save energy because it does not require any energy cost. So that will help the users not thinking about energy consumption. Also, it is effort able for everyone according to the price for the roller bending machine.

3.1.6: Safety:

When you are using the manual bending machine, there are some instructions for safety to operate the machine. For example, you must wear safety glasses to protect your eyes and keep them safe. The other thing you must wear is sturdy footwear while you work in this machine. There are things not require to wear like gloves and rings and jewelry while you are working. Before operating the machine, you must check that the workspaces are lubricated and that the rollers do not contain any rust and dirt. For the operation, you must hold the workpiece that you want to bend far back from the edge, and only one person can operate the machine. Safety after operating, you must make sure that the handle is safe after cleaning the machine and putting it in a safe place. If you do not follow this safety instruction, there is potential to face some hazards, and always check the machine's capacity before bending any workpiece.

3.1.7: Ethics:

Morally, we are obligated to choose a special topic and idea that the Kingdom will benefit from in the industry. And although one idea cannot implement any project or prototype or even some studies, it requires some context and information from some topics and some advice from previous work. Although the project can only be implemented by taking some inspiration, ideas and information from some of the previous works that are relevant in this idea about industry around the world in our topic. This gives us more confidence and an accurate perspective of how the project will work the way we wanted.

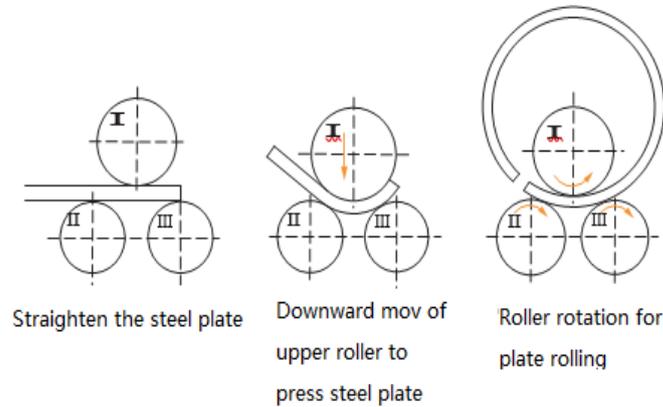
3.2 Engineering Design Standards

Since our project includes readily available market components, the engineering specifications are based on the manufacturers that produce those components. However, the following is a list of parts, along with their grade and standards.

<i>Components</i>	<i>Engineering Standards</i>	<i>Details</i>
Bending Rollers	alloy steel	Length = 155 mm , Diameter = 70 Ø
Spindle Wheel	410 stainless	Length = 173.20 mm , width = 25 mm, Diameter = 10 Ø
Chain Sprockets	Stainless Steel	Diameter = 60 Ø, Thickness = 4 mm
Bearings	52100 chrome steel	Diameter = 30 Ø, Thickness = 9 mm
Stand	stainless steel	Length = 400 mm , Height = 153 mm
Screw	AISI 4037	Length = 135mm , Height = 22mm ,
Moving Roller	alloy steel	Length = 155 mm , Diameter = 70 Ø
Supporting Frame	SAE 52100	
Mount Plate	Stainless Steel	Length = 100 mm , width = 60 mm, height =181.2 mm
Joints	AISI 4037	Diameter = 40 Ø, width = 10 mm

Table # 1: Engineering Standards

3.3 Theory and Theoretical Calculations



Some theoretical aspects have been taken into consideration to come up with the required requirements with how our system should function and outcomes to carry out accurate calculations of our system design properly. We considered variables such as force applied to rollers, the torque applied to rollers, and frictional force. The calculation at the bottom would undoubtedly be used to assist in defining the parameters and working criteria for our prototype. Components may be rolled after a simple shearing procedure on sheet metal to define material properties that influence component bending.

3.3.1 Design chain drive

$z_1 = \text{Number of the teeth of sprocket} = 27$

$z_2 = \text{Number of the teeth of sprocket} = 27$

$a = \text{distance between driving sprocket} = 200 \text{ mm}$

$p = \text{pitch} = 4 \text{ mm}$

$$eq_1 \rightarrow L_n = 2 \left(\frac{a}{p} \right) + \left(\frac{z_1 + z_2}{2} \right) + \left(\frac{z_1 - z_2}{2\pi} \right)^2 \frac{p}{a}$$

$$L_n = 2 \left(\frac{200}{4} \right) + \left(\frac{27 + 27}{2} \right) + \left(\frac{27 - 27}{2\pi} \right)^2 \frac{4}{200}$$

$$L_n = 127 \text{ mm}$$

$$eq_2 \rightarrow L = L_n P$$

$$L = 127 \times 4 = 508 \text{ mm}$$

$$\alpha = \frac{360}{27} = 13.33^\circ$$

$$D = \frac{p}{\sin\left(\frac{\alpha}{2}\right)} = \frac{4}{\sin\left(\frac{13.33}{2}\right)} = 34.46 \text{ mm}$$

$$D = D_1 = D_2$$

3.3.2 Design of power screw

- Specifications

$d_c = \text{major diameter} = 7.4 \text{ mm}$

$d_0 = \text{minor diameter} = 6.04$

$\text{lead} = \text{pitch} = 6.35$

$\phi = \text{Friction angle}$

$\mu = \text{co-efficient of friction} = 0.15$

$w = \text{weight of the roller} = 2.5 \text{ kg} = 24.54 \text{ N}$

$\alpha = \text{Helix angle}$

$$eq_1 \rightarrow d = \frac{d_0 + d_c}{2} = \frac{7.4 + 6.04}{2} = 6.72 \text{ mm}$$

$$eq_2 \rightarrow \text{helix angle} = \tan \alpha = \frac{\text{lead}}{\pi d}$$

$$\tan \alpha = \frac{6.35}{\pi(6.72)}$$

$$\alpha = 5.41$$

$$\tan \phi = \mu$$

$$\phi = \tan^{-1}(\mu) = \tan^{-1}(0.15) = 8.53^\circ$$

- Torque required raising the load (for 1 revolution of one screw)

$$eq_3 \rightarrow T_1 = w \times \tan(\alpha + \phi) \times \frac{d}{2}$$

$$T_1 = 24.52 \times \tan(5.41 + 8.53) \times \frac{6.72}{2} = 20.45 \text{ N-mm}$$

$$\text{Total torque} = 20.45 \times 54 = 1104.3 \text{ N-mm}$$

$$\text{Total force} = \frac{\text{Torque}}{\text{Distance}} = \frac{1104.3}{85} = 13 \text{ N}$$

- Torque required to lowering the load

$$T_2 = w \times \tan(\alpha + \phi) \times \frac{d}{2} = 24.52 \times \tan(8.58 - 5.41) \times \frac{6.72}{2}$$

$$T_2 = 4.4 \text{ N} - \text{mm}$$

It is the force acting on a single screw. Since the lowering load is positive, the screw is self-locking.

3.3.3 Force analysis

Maximum torque required for a cylinder rolling Specifications

σ_s : material yield limit=218 N/mm²

B: maximum width of rolled shield= 40mm

δ : Thickness of rolled sheet in mm

- 1) For thickness $\delta = 2\text{mm}$

There is reinforcement when considering the deformation of the material, and the reinforcement co-efficient K is added to change the equation.

$$M_t = K\sigma_s \frac{B\delta^2}{4} = 1.15 \times 218 \times \frac{40 \times 2^2}{4} = 10028 \text{ N} - \text{mm}$$

- 2) For thickness $\delta = 3\text{mm}$

$$M_t = K\sigma_s \frac{B\delta^2}{4} = 1.15 \times 218 \times \frac{40 \times 3^2}{4} = 22563 \text{ N} - \text{mm}$$

- 3) For thickness $\delta = 4\text{mm}$

$$M_t = K\sigma_s \frac{B\delta^2}{4} = 1.15 \times 218 \times \frac{40 \times 4^2}{4} = 40112 \text{ N} - \text{mm}$$

3.3.4 Force condition

The force condition when rolling steel plate is depicted in the preceding figure. The following formula can be used to determine the supporting F2 on the roll plate based on the force balance.

$$F_2 = \frac{M}{R \sin \phi}$$

a = lower roller center distance in mm.

d_{min} = minimum diameter of the rolling plate in mm = 388mm

d_2 = lower roller diameter in mm = 62mm

$$\phi = \sin^{-1} \frac{a}{d_{min} + d_2} = \sin^{-1} \frac{201}{388 + 62} = 26.5^\circ$$

1) For thickness $\delta = 2mm$

$$F_2 = \frac{M}{R \sin \phi} = \frac{10.2 \times 10^3}{194 \sin(26.53)} = 115.63 N$$

$$F_1 = 2F_2 \cos \phi = 2 \times 115.63 \cos 26.53 = 206.91N$$

2) For thickness $\delta = 3mm$

$$F_2 = \frac{M}{R \sin \phi} = \frac{22.56 \times 10^3}{194 \sin(26.53)} = 260 N$$

$$F_1 = 2F_2 \cos \phi = 2 \times 260 \cos 26.53 = 461 N$$

3) For thickness $\delta = 4mm$

$$F_2 = \frac{M}{R \sin \phi} = \frac{40.1 \times 10^3}{194 \sin(26.53)} = 462 N$$

$$F_1 = 2F_2 \cos \phi = 2 \times 462 \cos 26.53 = 828 N$$

R = neutral layer's radius of the rolling in mm

R = 0.5 d_{min}

R = 0.5 × 388 = 194 mm

3.3.5 Calculation of driving Torque:

The driving roller is the lower roller of the plate of the rolling unit, and the driving torque on the lower roller is used to resolve the deformation torque T_{n1} and friction torque T_{n2} .

$$T_{n1} = \frac{Md_2}{2R} = \frac{10.02 \times 10^3 \times 62}{2 \times 194} = 1601.13 N - mm$$

The rolling friction torque between the upper and lower rollers and the steel plate, as well as the moving friction torque between the roller neck and the shaft sleeve, can be measured as follows.

$$T_{n2} = f(F_1 + 2F_2) + \mu \left(F_1 \frac{D_1 d_1}{2 d_2} + F_2 D_2 \right)$$

$$T_{n2} = 0.008 \times 10^3 (206 + 2(115 - 63)) + 0.04 \times 10^3 \left(206 \frac{31 \cdot 61}{2 \cdot 62} + 115 \times 31 \right)$$

$$= 3508 \text{ N}$$

In the above formula,

f =co-efficient of rolling friction = 0.008×10^3 mm

μ =co-efficient sliding friction

d_1, d_2 = upper roller and lower roller diameter (mm)

D_1, D_2 = upper roller and lower roller neck diameter (mm)

$D_i = 0.5 d_i$ ($i=1,2$)

$D_1 = 0.5 d_1$

$D_1 = 0.5 \cdot 62 = 31$ mm

$D_1 = D_2$

- Total torque $T = T_{n1} + T_{n2}$

$$T = 1601.13 + 3508.07$$

$$T = 5109.206 \text{ N-mm}$$

3.4 Product Subsystems and selection of Components

3.4.1 Bending Rollers

Since we are designing and manufacturing a prototype for a manual roller bending machine, the roller mechanism works to bend, and the roller's design must consider achieving the desired bending. The rollers are fitted with bearings.

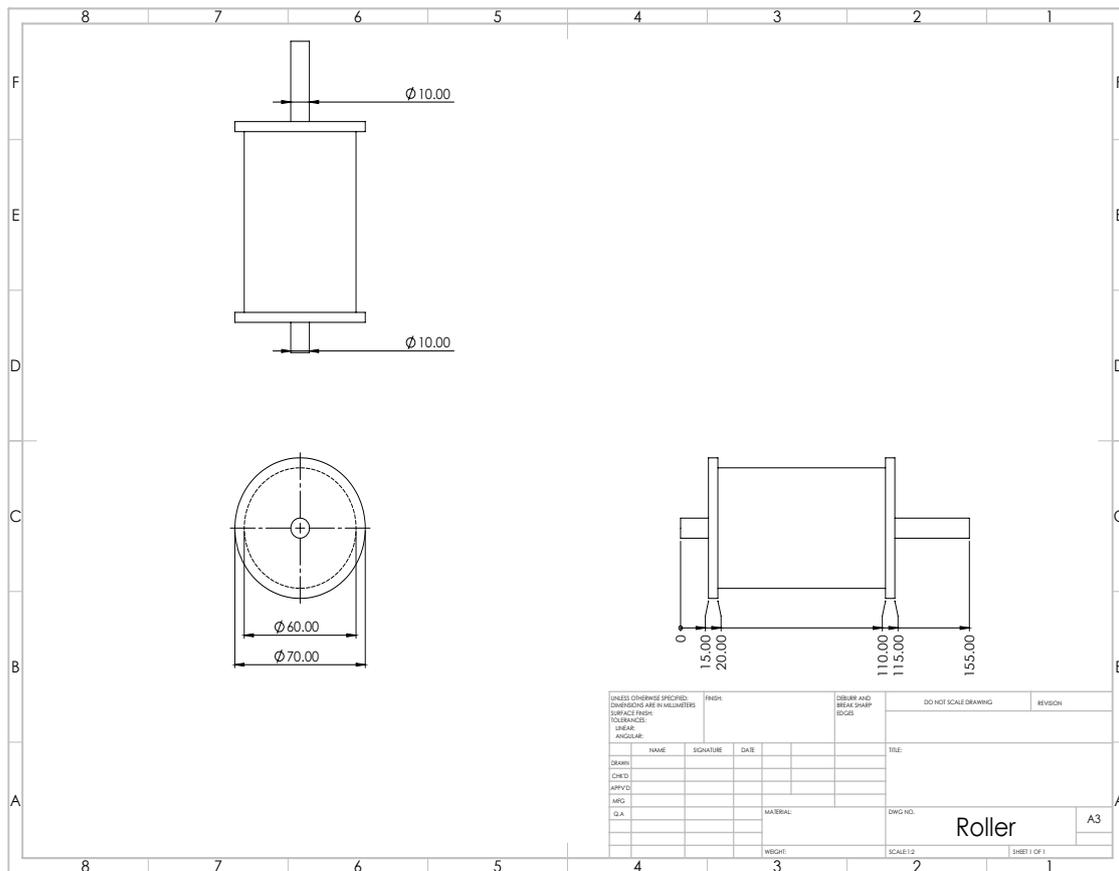


Figure 7: 2D drawing for roller

3.4.2 Spindle Wheel

One of the rollers is equipped with a hand-operated spindle wheel that allows it to be driven manually. This wheel is also linked to the other roller through a chain sprocket mechanism, which drives it at the same pace as the spindle.

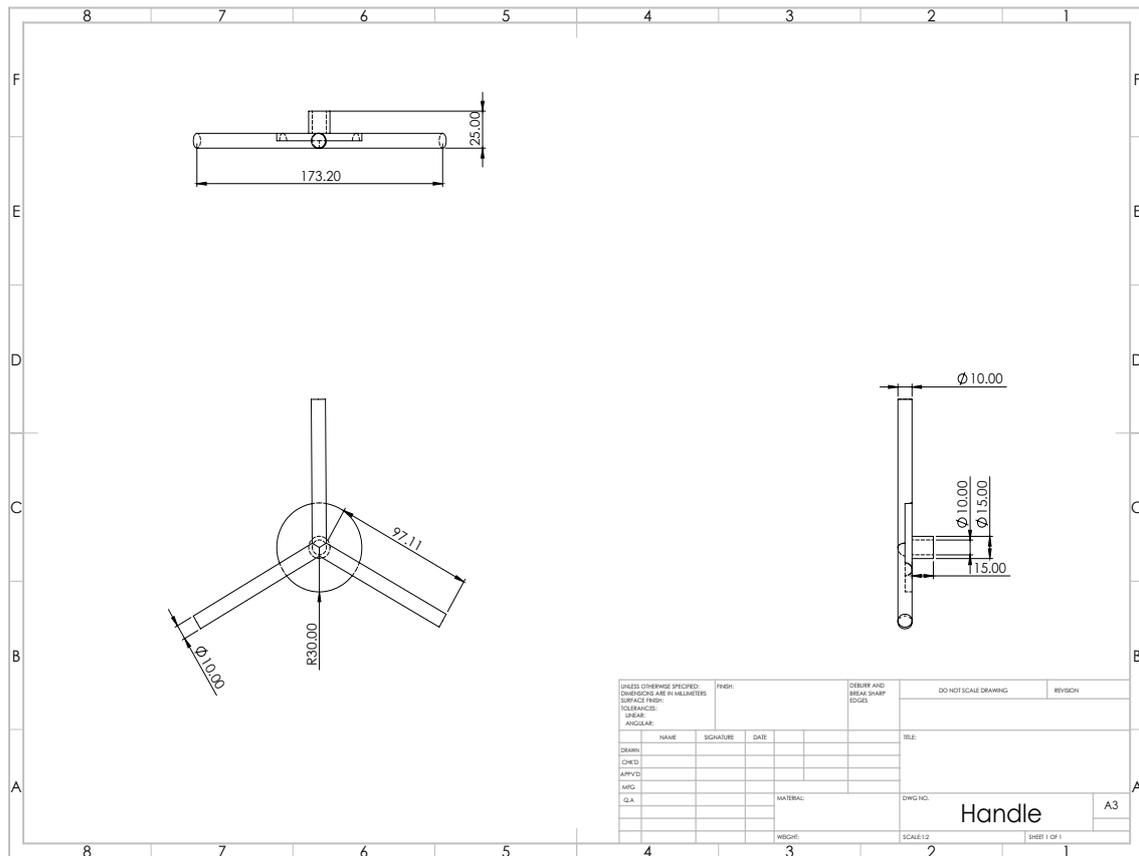


Figure 8: 2D drawing for handle

3.4.3 Chain Sprockets

Sprockets were built with a total of 27 teeth with different face widths. To design the sprocket of the manual roller bending machine, the form of material is Stainless Steel. Table 1 shows the mechanical properties. Also, SolidWorks Simulation, Dassault Systems SolidWorks was used to measure the proposed sprocket measurements. The dimensions of the sprockets were determined by the manual roller's power requirements, and modeled sprocket gears were measured using the Lewis, AGMA, and FEAmethods. The results of the analytical and software-based simulations were compared and checked.

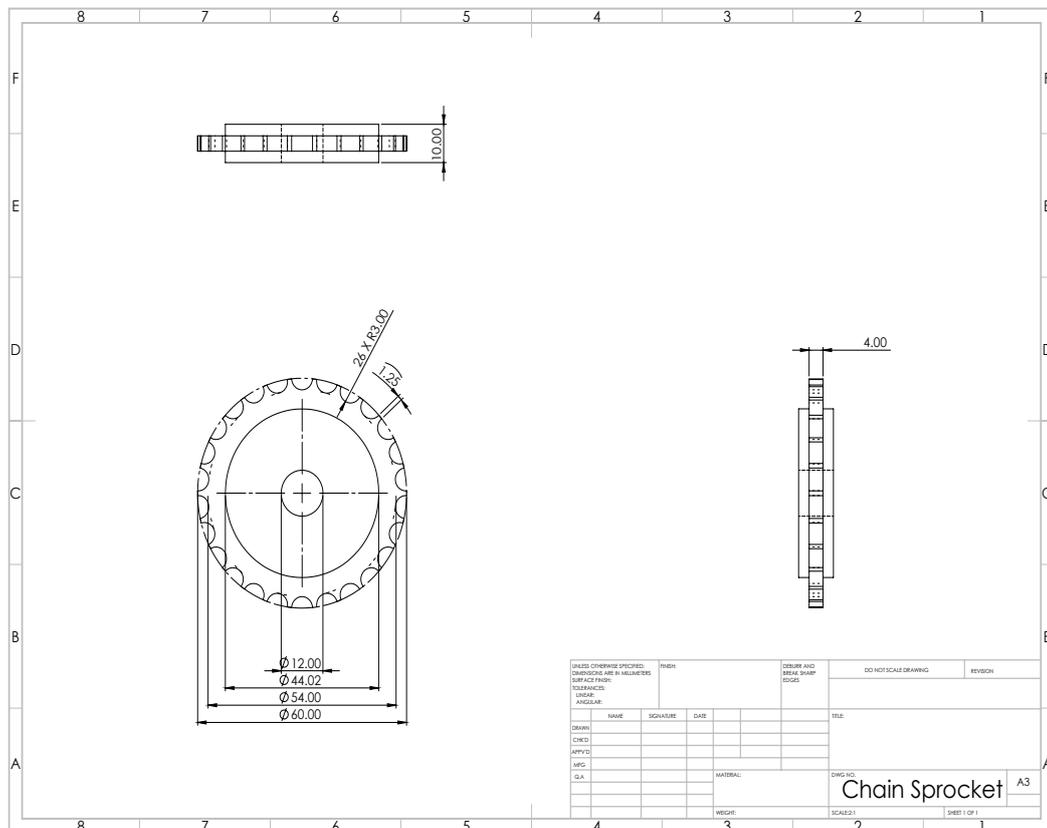


Figure 9: 2D drawing of chain sprocket

3.4.4 Bearings

Since we are designing the rings, the radius of the curvature on the internal ring path is 51-52 percent of the ball diameter, and the radius of the curvature is 53-54 percent of the ball diameter on the external ring path. Suppose the curvature range reaches 50% of the ball diameter (100% of the radius), the tension between the ball and the route decreases. In that case, however, the contact between the ball also increases as the balls rotate around the bearing. With the path curvature just over 50 percent as defined above for the interior and outer rings, the best balance between stress and friction is obtained.

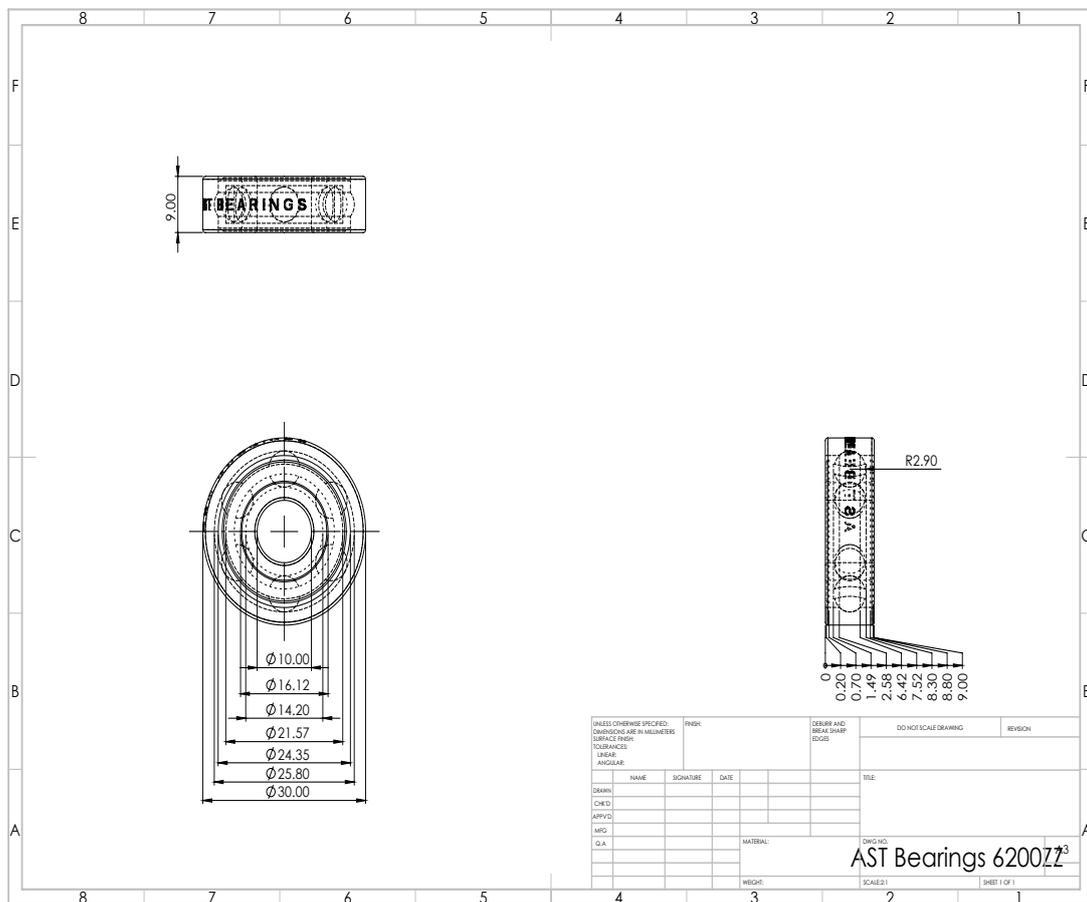


Figure 10: 2D drawing of bearings

3.4.5 Supporting Frame

The frame was designed with a mechanism to fit a moving roller via a screw mechanism into the center. The bending angle is modified. The unit is equipped with a slot made in the middle of the frame. The components can be rolled to give a definite shape following the standard shearing method on sheet metal.

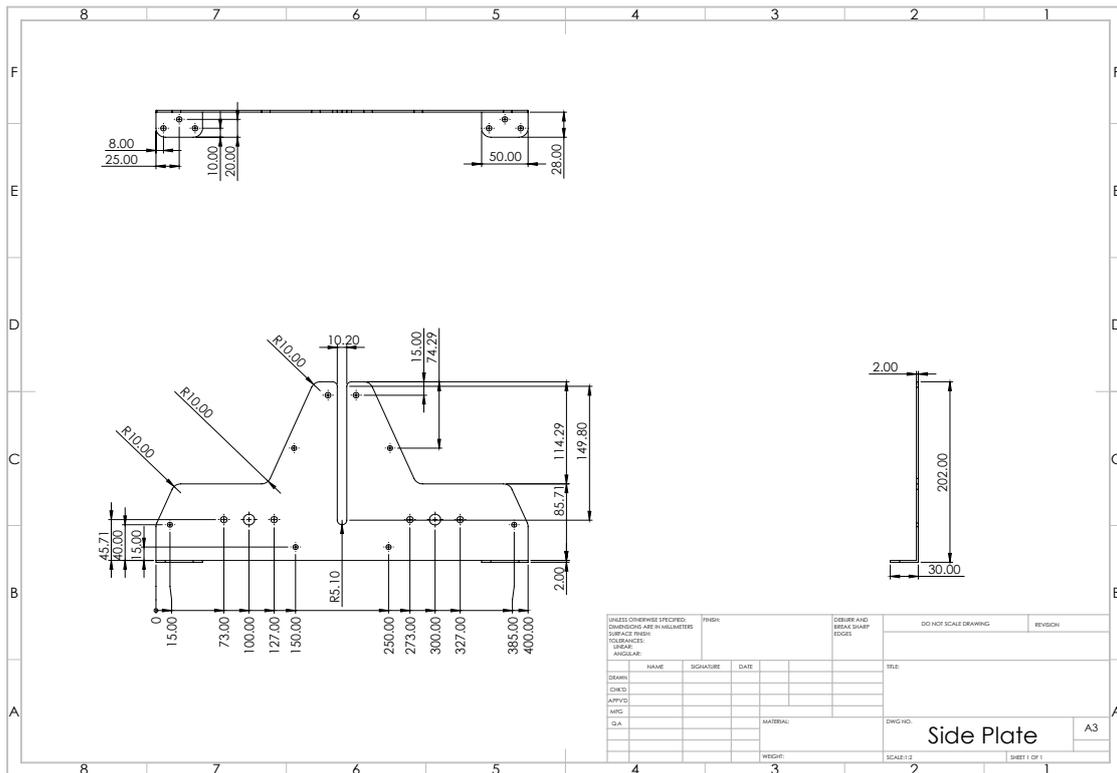


Figure 11: 2D drawing of the plate

3.5 Manufacturing and Assembling (Implementation)

In terms of selecting materials, we have in our project ten parts made in different kinds of material. Three bending roles and the moving roller made (Alloy steel) have some advantages like strength, hardness, wear resistance, and toughness, so there will not be difficulties while sheet metal is bending. Chain sprocket, Housing, and Mount are made from (stainless steel) because for several reasons. For example, low cost, corrosion resistance, and ease of fabrication. All of the parts have been carefully selected so that our project works perfectly. Since our main aim is to design a manual bending machine, we were highly accurate in getting all the dimensions right and manufacture it.

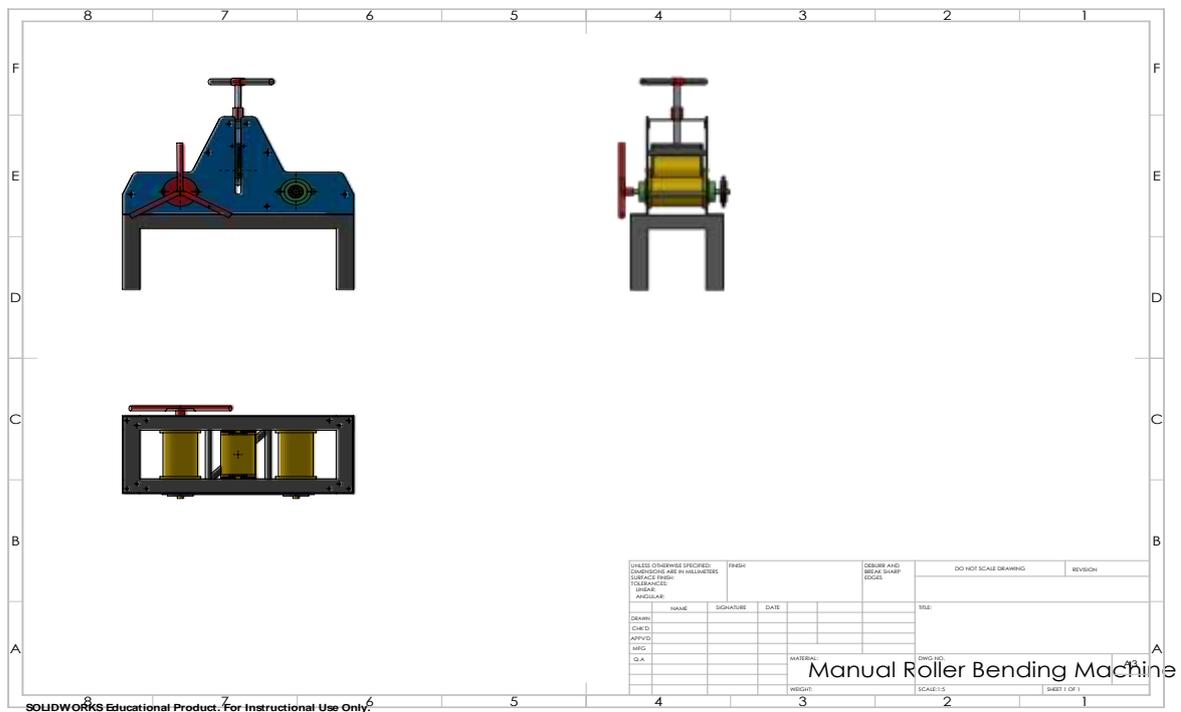


Figure 13: 2D drawing for the assembly

3.6 Economic Evaluation

	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	30,905,00	22,075,00	26,490,00	26,490,00	30,905,00	26,490,00	26,490,00	30,905,00	22,075,00	22,075,00	22,075,00
Construction	7,500,00	-	0	0	0	3,500,00	0	0	-	0	5,000,00
Total	38,405,00	22,075,00	26,490,00	26,490,00	30,905,00	29,990,00	26,490,00	30,905,00	22,075,00	22,075,00	27,075,00
Operating Costs											
Energy	-	-	-	-	-	-	-	-	-	-	-
Electricity	-	-	-	-	-	-	-	-	-	-	-
Labour	4,200,00	7,200,00	7,200,00	8,640,00	8,064,00	8,640,00	5,600,00	5,280,00	5,184,00	4,896,00	5,040,00
Insurance	2,000,00	2,500,00	2,800,00	2,750,00	3,720,00	4,310,00	4,750,00	3,980,00	4,240,00	4,990,00	4,700,00
Taxes	20,000,00	2,500,00	-	-	-	12,500,00	-	2,500,00	-	-	12,500,00
Total	26,200,00	12,200,00	10,000,00	11,390,00	11,784,00	25,450,00	10,350,00	11,760,00	9,424,00	9,886,00	22,240,00
Revenues											
Product 1		15,000,00	15,450,00	15,759,00	15,759,00	16,546,95	16,712,42	17,046,67	17,046,67	17,899,00	18,077,99
Product 2		25,000,00	25,750,00	26,265,00	26,265,00	27,578,25	28,129,82	28,692,41	28,692,41	30,127,03	30,428,30
Product 3		30,000,00	30,900,00	31,518,00	31,518,00	33,093,90	34,086,72	34,768,45	34,768,45	36,506,87	37,237,01
Total	-	70,000,00	72,100,00	73,542,00	73,542,00	77,219,10	78,928,95	80,507,53	80,507,53	84,532,91	85,743,30
Profits	- 64,605,00	35,725,00	35,610,00	35,662,00	30,853,00	21,779,10	42,088,95	37,842,53	49,008,53	52,571,91	36,428,30
			Pay Back Period								

Chapter 4: System Testing and Analysis

4.1 Experimentation and Data Acquisition

The tests were carried out with 15 mm and 20 mm GI pipe in the output test. Since this size pipe was not usable in the lab, the test with a 25 mm pipe was canceled. The diameters of the pipes were determined at different midpoint deflections. The bending force was applied by applying torque to the lead screw through the lead screw's lever. The pipe was then pushed forward and backward using the middle roller's handle, and the necessary bending diameter was obtained by gradually raising the bending pressure. The needed bending was achieved, and a smooth bending was discovered through a repetitive method. The diameter of pipes of varying values and their deflection has been measured and is shown in the table below:

Pipe Diameter (mm)	Deflection (mm)	Bending Diameter (mm)	Remarks
15	31.755	457.20	Initially, 15 mm pipe suffered minor damage.
	38.100	412.75	
	50.800	330.20	
20	31.755	495.30	However, there is no harm to the 20 mm pipe.
	38.100	444.50	
	50.800	361.95	

Table 2: Data for bending test of 15 and 20 mm pipe

In the case of simply supported beam deflection, the radius is given by:

$$R = \frac{c^2 + 4d^2}{8d}$$

Where

R= Bending radius

C= Distance between two fixed rollers

d= Deflection in the middle roller

In the present case, the value of c= 254 mm.

From the above formula, the value of theoretical bending radius has been calculated which has been given in the table below:

Pipe Diameter Mm	Deflection mm	Bending diameter in mm		Deviation	
		Experimental (De)	Theoretical (Dt)	(De – Dt) mm	% (De – Dt)/ Dt
15	31.755	457.20	539.75	82.55	15.30
	38.100	412.75	461.52	48.77	10.56
	50.800	330.20	368.30	38.10	10.34
20	31.755	495.30	539.75	44.45	8.24
	38.100	444.50	461.52	17.02	3.69
	50.800	361.95	368.30	26.35	1.72

Table 3 : Comparison between theoretical and experimental bending radius values

4.2 Results

For 15 and 20 mm tubing, a schematic depiction of the contrast between theoretical and experimental bending radius (diameter) values is displayed. As can be seen in the table, the variance decreases as the bending radius increases.

The pipe is balanced on the bottom roller when bent, and the middle roller applies friction. In any case, it's possible that the two ends aren't bending properly.

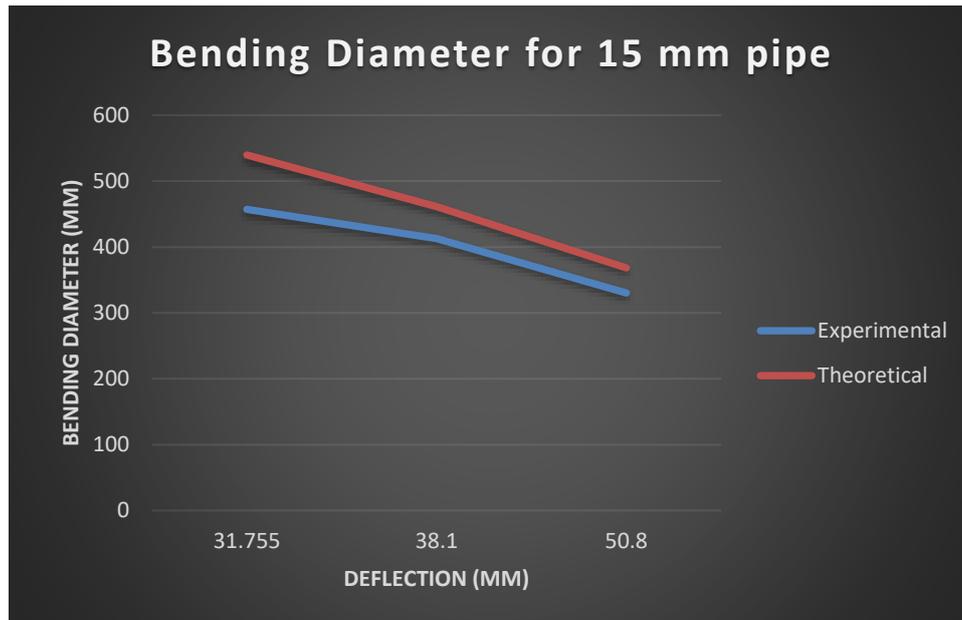


Chart 1: Graphical representation of experimental and theoretical value for bending of 15 mm pipe.

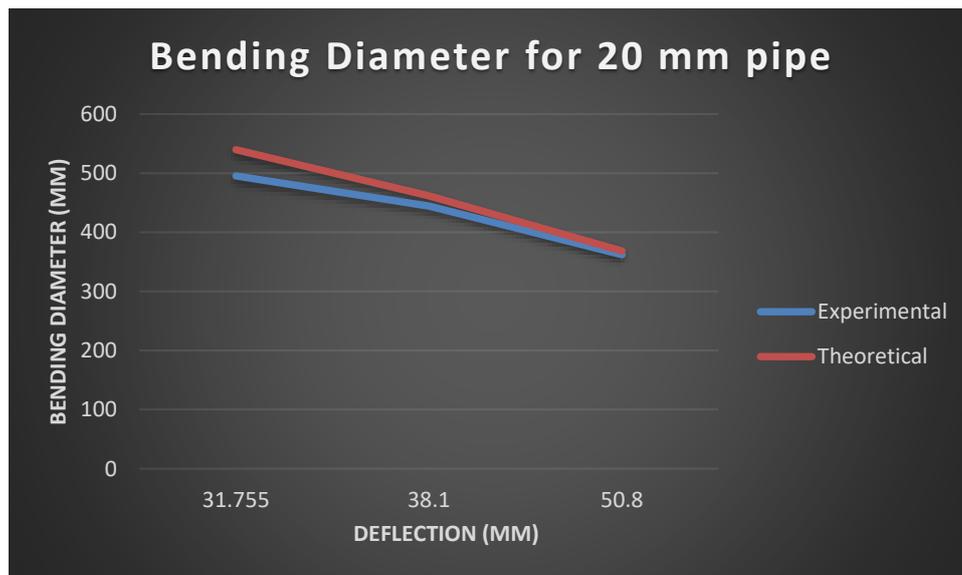


Chart 2: Graphical representation of experimental and theoretical value for bending of 20 mm pipe.

4.3 Discussions

There are two ways to adjust the bending angle and radius in a three-roller bending machine: one is to change the distance between two fixed rollers, and the other is to change the vertical displacement in the middle roller. In this initiative, the above is taken into account in order to reduce design complexity. As a result, the bending radius is solely determined by the middle roller's bending power. The bending radius is calculated using the above-mentioned equation.

Since the distance between the two rollers is set, the distance 'd' is the only one that can be changed.

The findings are showing deviation in results. This deviation could be minimized by using a steady and smooth operation. Also, the variation is decreased as the middle roller displacement increases. The theoretical value is significantly higher than the experimental value, as seen in charts 1 and 2.

- The curves in 15 mm pipe are parallel.
- For 20 mm tubing, though, the two curves appear to converge, resulting in greater deflection.

It can be concluded from the results that there is no difference between theoretical and experimental values. The variance may be minimized by ensuring a proper bending procedure and smooth operation.

Chapter 5: Project Management

5.1 Project Plan

In our project, there are many tasks included. Each task is assigned to one or more members. The details about division of whole work is being presented below:

S. No.	Tasks	Start	End	Duration	
1	Ch. 1: Introduction	4/2/2021	6/2/2021	2	
2	Ch. 2: Literature Review	Project Background	9/2/2021	15/2/2021	5
		Previous Work			
		Comparative Study			
3	Ch. 3: System Design	Design Constraints & Methodology	20/2/2021	27/2/2021	7
		Engineering Design Standards			
		Theory & Theoretical Calculations			
		Product Subsystems & Component Selection			
		Manufacturing & Assembly			
4	Ch. 4: System Testing & Analysis	Experimental Setup, Sensors & Data	27/3/2021	1/4/2021	5
		Results, Analysis & Discussion			

5	Ch. 5: Project Management	Contribution of Team Members	6/4/2021	10/4/2021	4
		Project Execution Monitoring			
		Challenges & Decision Making			
		Project Bill of Materials & Budget			
6	Ch. 6: Project Analysis	Impact of Engineering Solution	10/4/2021	14/4/2021	4
		Contemporary Issues Addressed			
7	Ch. 7: Conclusion & Recommendation	Conclusion	15/4/2021	16/4/2021	1
		Future Recommendation			
8	Design of Prototype		4/3/2021	30/3/2021	26
9	Parts Purchased		20/4/2021	22/4/2021	2
10	Manufacturing		2/4/2021	26/4/2021	24
11	Testing		30/4/2021	2/5/2021	3

Table # 4: Tasks and their Duration

Table 4 identifies the team members responsible for their respected tasks.

S. No.	Task	Assigned Members
1	Introduction	Mohammed Alamri

2	Literature Review	Mohanad & Faisal Alotaibi
3	System Design	Mohanad & Faisal Alotaibi
4	Testing and Analysis	Faisal Alqahtani
5	Project Management	Faisal Alqahtani
6	Project Analysis	Faisal Alotaibi
7	Conclusion and Recommendation	Mohanad
8	Design	Mohanad & Faisal Alotaibi
9	Parts Purchased	Firas
10	Manufacturing	Firas & Mohammed Alamri
11	Testing	Everyone

Table # 5: Assigned Members for Each Task

5.2 Contribution of Team Members

S. No.	Tasks	Assigned Member	Contribution	
1	Ch. 1: Introduction	Mohammed Alamri	100%	
2	Ch. 2: Literature Review	Project Background	Mohanad & Faisal Alotaibi	33%
		Previous Work	Mohanad	33%
		Comparative Study	Faisal Alotaibi	34%
3	Ch. 3: System Design	Design Constraints & Methodology	Mohanad, Firas & Mohammed	20%
		Engineering Design Standards	Mohanad	20%
		Theory & Theoretical Calculations	Faisal Alotaibi & Mohammed	20%

		Product Subsystems & Component Selection	Faisal Alqahtani	20%
		Manufacturing & Assembly	Firas	20%
4	Ch. 4: System Testing & Analysis	Experimental Setup, Sensors & Data	Mohammed	40%
		Results, Analysis & Discussion	Faisal Alqahtani	60%
5	Ch. 5: Project Management	Contribution of Team Members	Mohanad &Firas	100%
		Project Execution Monitoring		
		Challenges & Decision Making		
		Project Bill of Materials & Budget		
6	Ch. 6: Project Analysis	Impact of Engineering Solution	Faisal Alotaibi	100%
		Contemporary Issues Addressed		
7	Ch. 7: Conclusion & Recommendation	Conclusion	Faisal Alqahtni & Faisal Alotaibi	100%
		Future Recommendation		
8	Design of Prototype		Mohanad	50%
			Faisal	50%
9	Parts Purchased		Firas	20%

		Faisal Alotaibi	30%
		Faisal Alqahtani	30%
		Mohammed	20%
10	Manufacturing	Mohanad	60%
		Faisal Alotaibi	40%
11	Testing	Everyone	100%

Table # 6: Contribution of Tasks

5.3 Project Execution Monitoring

During our project, for the successful accomplishment of goals, regular meetings and sittings were arranged to ensure the continuous monitoring and meeting deadlines. Following is the list of events and meetings being conducted during this whole period of project formulation:

Activities and/or Events	Time and Date
Assessment Class	Once a week
Meeting with the group members	Weekly
Meeting with the Advisor	Bi-Weekly
Midterm Presentation	8 th April, 2021
Finishing Final Prototype	30 th April, 2021
Test of the System	2 nd May , 2021
Final Submission of Report	15 th May, 2021
Final Presentation	22 th May, 2021

Table # 7: Dates of Activities and Events

5.4 Challenges and Decision Making

Following are the issues and challenges being encountered during the execution of project:

1. Issues in equipments:

As far as sustainability is concerned for the prototype, it was made sure that selection of components, like Bending rollers and Chain drive and Spindle wheel and Sprocket Brass and Supporting frame were made according to choose the proper materiel. Also,

our concerns are there is a limitation for our prototype like the capability for bending material sheet in fact that it should be suitable and can sustain for 4mm thickness and less and it should be below 145 torque. Also, another concern is corrosion that can affect the prototype because it can be exposed to erosion so we must consider to control the corrosion by use barrier coatings like paint.

2. Testing and Safety Concerns:

When working, there are certain items that are not required to be worn, such as gloves, rings, and jewelry. Before using the gadget, make sure the workspaces are lubricated and the rollers are free of rust and debris. You must keep the workpiece well back from the edge of the machine to perform the task, and only one person can control the machine. After you finish cleaning the unit and putting it in a safe position, you must ensure that the handle is in a safe place. There is a risk of injury if you do not meet this safety order, and you should always verify the machine's capability before bending some workpiece.

3. Design Problems:

During the fabrication and assembling of roller bending machine, we faced challenges in the matting of parts because of wrong tolerances we maintained in the first attempt. Then we redesigned chain sprockets and bearings to meet the close tolerances to ensure a close fit during assembly. Moreover, we faced problem in designing complex parts like bending rollers and supporting frame etc. But later on, things get smooth when we successfully done with the testing of manual roller bending machine.

5.5 Project Bill of Materials and Budget

The table below is showing the cost of parts that we purchased and the one we designed. Moreover, it also illustrates about the cost of material of which we designed this manual roller bending machine.

Components	Costs (SR)
Bearings	500
Chain Sprocket	550
Spindle Wheel	150
Bending Rollers	1000
Supporting Frame	300

Table #8: Overall cost of project analysis

Total Cost of Project: 2500 SAR

Chapter 6: Project Analysis

6.1 Life-long Learning

When we worked on our project, we gained diverse knowledge about different things: software skills, hardware skills, time management skills, and project management skills. By working as a team, we learned how to manage tasks by ensuring time management and good communication skills with the team members. This part will explain the number of skills we gained since we worked on this project.

6.1.1 Software Skills

In this project, we gained hands-on experience working on software like MS Word, MS PowerPoint, and Solidworks. We used Solidworks software to design a roller bending machine, which helped us polish our skills in this design. In addition to this, we learned about using word and PowerPoint while writing report and making brochure.

6.1.2 Hardware Skills

We learned about assembling the designed parts to fabricate our desired project of roller bending machine during our project. We also have hands-on experience of the skill of welding. Moreover, I also learned about doing sound calculations before moving towards the fabrication part of the project. A slight difference in calculations can result in a massive difference during the fabrication of the project.

6.1.3 Management Skills

During project work, we learned about time management that how deadlines can be met efficiently during the execution of the project. Moreover, there are many skills like distribution of work, teamwork, and leading the team in the right direction that I learned during the completion of the project.

6.2 Impact of Engineering Solutions

Following are the social, economic and environmental impacts of our project:

6.2.1 Social Impacts of project

Since most of the projects are carried out to develop products and contribute to making the industry better and efficient by using the minimum amount of resources possible to develop this product, this project aims to present such an idea that made the machine portable for

industry use a self-use for everyone. Also, it can provide to save time for the users because it does not require any skills to run the machine.

6.2.2 Economic Impacts of project

On the economic side, it helps to save energy because it does not require any energy cost. So that will help the users not thinking about energy consumption. Also, it is effort able for everyone according to the price for the roller bending machine.

6.2.3 Environmental Impacts of project

The project does not affect the environment because of zero power consumption and zero emissions. So will not cause any environmental concerns for the public.

6.3 Contemporary Issues Addressed

The most significant issue that this project is addressing is high levels of pollution into the environment because of high dependency on machines, but as this roller bending machine is operating manually so it will not cause environmental deterioration. The other most crucial issue is high power consumption, which leads to economic strains over pipe manufacturing industries. This project is entirely human operation and has zero power consumption.

Chapter 7: Conclusion and Future Recommendations

7.1 Conclusion

Nowadays, pipe bending is a common occurrence. Various automatic and semi-automatic bending systems are used in mass manufacturing. However, automated and semi-automatic pipe bending machines are expensive for limited manufacturing. They still cannot be used in areas where electricity is scarce and expensive. Manual pipe bending, on the other hand, is less costly and simple to build and run. The plans, development, and performance tests are all depicted in this article. Also, below is a summary of the successful test results:

- 1) With two fixed rollers, the bent diameter is solely determined by the mid roller's deflection.
- 2) The deviation in outcomes is decreased as the deflection increases.

7.2 Future Recommendations

By adjusting the roller guides on the bending unit, we can bend tubes and pipes. By incorporating various parts, the hydraulic bending system can be semi-automated and automated.

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