DESIGN AND FABRICATION OF THREE POINT BENDING MACHINE

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Dedication

With the blessings of ALLAH (Glory to him, The Exalted), we were able to complete this final year project thesis. First of all, we dedicate this humble effort.

“To our Holy Prophet Muhammad (Peace be upon him) the greatest mentor for the mankind.”

Then, dedication is our supervisor, Dr. Muhammad Shoaib Naseem, who supported us like a mentor in hard times and our beloved parents for all their love, kindness, and support.

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Abstract

The growth of the aerospace and aviation sectors has highlighted the critical importance of precise metal bending. Perfect accuracy in bends is essential, as there's no margin for mistakes. Metal bending is a technique widely used across numerous industries.

In Pakistan, the production of equipment such as industrial mixers for bending and rolling structural steel, offshore and petrochemical tools, playground and fitness gear made of bent metals, HVAC components, transportation machinery, farming tools, air transfer systems, processing plant ducts, support for tanks and steel vessels, streetlights, signage, construction embellishments, various furniture pieces, and many other products like detergents, primarily relies on manual labor. Producers often opt for paddle mixers or resort to manually forging the metal, either through cold or hot processes.

There's a gap in the market for machines that efficiently produce conical ribbons. Existing profile bending machines tend to waste materials at the ends and might crack the flat bar due to excessive pressure. These machines also involve intricate calculations to achieve precision. Our solution is a newly designed machine capable of producing both conical and straight ribbons. With a unique design allowing the bottom roller to arc around the top roller, it minimizes end waste and needs minimal upkeep. The machine is tailored for creating ribbons with varied pitch and diameter.

This innovative device can bend mild steel strips up to 2 inches wide and 3mm thick. By switching rollers, it can also bend rods, emboss designs, and handle round/profile pipes, even allowing for the creation of ribbons with variable pitches suitable for different mixing stages. A standout feature is its efficiency, as it prevents material wastage at the ends. It's also designed to gauge the necessary force to bend a given metal strip, optimizing the bending process. An added steel swing arm mechanism aids in efficient bending, minimizing costs and waste. With a 30-ton hydraulic control system and robust 1070 grade carbon steel rollers, the machine promises durability and high-performance bending.

Keywords: 3 point bending machine, rolling process, modal/static structural analysis.

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ACRONYMS

CAD	Computer Aided Design
ANN	Artificial Neural Network
MIMO	Multiple input Multiple output
SIM	Subspace identification method
HRC	Rockiness Hardness scale
FEM	Finite Element Method
FEA	Finite Element Analysis
FDM	Finite Difference Method

NOMENCLATURE

N	Normal Reaction force
b	Moment Arm
Ri	Radius
T	Torque
σy	Yield Strength
y	Distance

Chapter 1 : INTRODUCTION

This project emphasizes the design, evaluation, and creation of a roll bender tailored to shape steel strips into spirals, specifically for crafting ribbons used in straight and conical mixers. The objective is to develop a compact, lightweight bending machine that delivers precise mixer ribbons swiftly. Our focus is solely on crafting steel ribbons for industrial mixers. The fixed curve defect is believed to stem from improper curving methods; typically, the deformed section of the work piece consists of two portions bent beyond the intended curve and two inside it. Factors like the top roller's diameter and the spacing between the bottom rollers play a pivotal role in the weight-force exerted by the top roller and the resulting deformation. Historically, scholars have extensively studied the mechanical model, deformation pattern, and process optimization during pre-bending and roll bending stages.[1]

1.1 Three-point rolling process:

Cold rolling is the preferred technique for creating mixer ribbons, screw conveyors, augers, bending beams, and forming cylinders from sheets. These items are crafted using a method known as the three-point rolling process. As implied by its name, this method utilizes three rollers set in a triangular layout. The bottom two rollers are powered, allowing for the desired input on the material, while the free-moving top roller applies the necessary force to permanently shape the metal. This approach is frequently employed in the production of storage tanks, boilers, and pressure vessels. Furthermore, it's utilized to bend or straighten materials like C-channels and I-beams, which are essential for machinery construction, as well as to roll metal sheets for boilers and pressure vessels.[2]

1.2 Working of Roll Bender:

A roll bender operates on the principle of the three-point rolling technique to shape steel strips, sheets, and profiles, producing items like mixer ribbons and tanks. This adaptable machine can generate spirals, contours, or mold steel profiles, and even imprint designs onto surfaces by simply adjusting the roller profile. Notably, the roll bender achieves the desired curvature by permanently deforming the metal without removing any of its material. An example of roll bender is shown in Fig.1

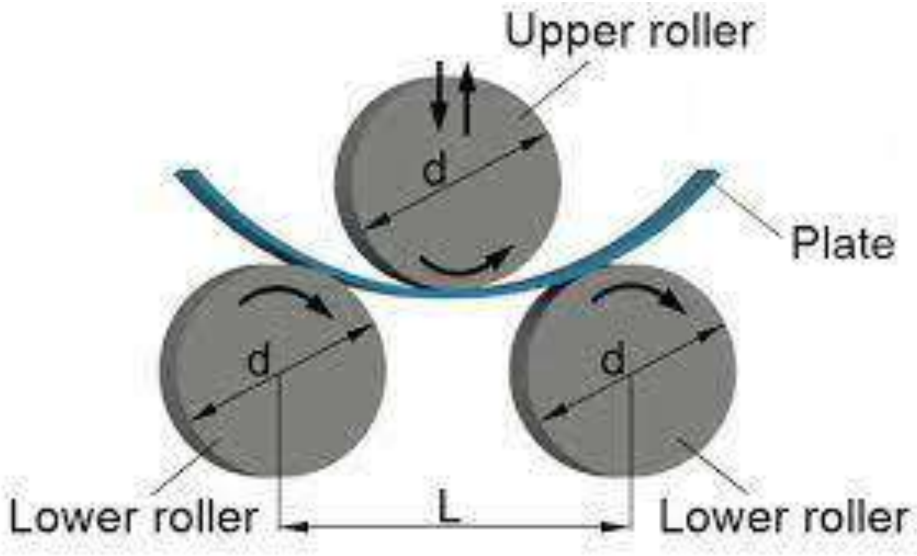


Figure 1 Three-point roll bending of metal plate

1.3 Historical background:

Typical roll benders in both local and international markets are manually operated based on trial and error, necessitating multiple passes of the specimen through the rollers to achieve the desired curve. This approach prolongs production time and isn't suitable for bulk manufacturing. Manually operated bending also compromises the precision and uniformity of the final product. A significant issue with traditional bending techniques is material wastage at the ends. Presently, using pre-bent sheets or strips is the only way to minimize this wastage. Gandi AH Rawal proposed an analytical model for the top roller's position in 2008, suggesting that the most cost-effective and efficient method to produce cylindrical forms is to rotate the material around the roller in one turn. This requires specific equipment features and control systems. Jun Zhao, Gaochao YU, and Rui Ma's 2016 research on a mechanical model for a roll bender designed to shape thin-walled tubes will inform our design criteria and measurements.[4]

Another research examined the fatigue behavior of cold-rolled sections during roll forming. Experts such as S.J. Qadir, V.B. Nguyen, I. Hajirasouliha, B. Ceranic, and E. Tracada utilized finite element analysis, experimental design, and response surface methodology to enhance the strength of specific sections. They employed a versatile data program to perfect the design of sections, ensuring maximum buckling resistance and stability while using the same material quantity. Adjusting the design of specific cold-rolled sections could lead to cost savings, especially if these sections are optimized for strength. This takes into account the impact of profiling and the changes in material properties due to cold working during the manufacturing process .[5]

In 1993, a method was introduced to predict the optimal shape and deformation distance of a metal alloy during cold-roll forming, even before the first roll stand was set. The middle layer of the metal was described using a Coons patch based on a measurable standard. This method was implemented on an advanced PC with high-resolution capabilities, typically used for Computer-Aided Design, enabling quick simulation of the process. N. Kim introduced a digital approach based on a three-dimensional finite element method to study the deformation in roll forming. The approach proved useful in forecasting the process.[6]

Simulation of cold-roll forming

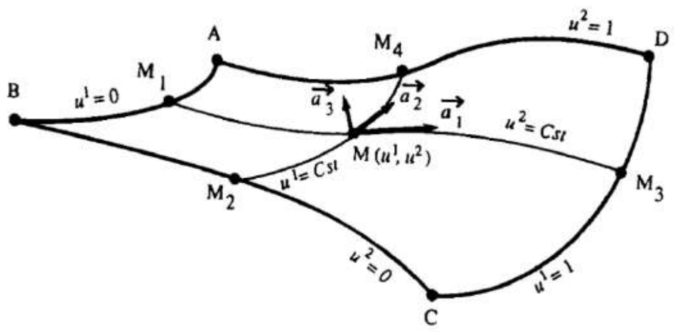


FIG. 1. Coons patch.

Figure 2 Simulation of cold-roll forming

In 2020, researchers Cheng, Jiaojiao, Cao, Jianguo, Zhao, Jianwei, Liu, Jiang, and Liu, Shiquan presented a study focused on floral designs and roller configurations. The results indicated that rollers with a pronounced curve segment had superior functionality, while the subsequent segments prevented changes in the ribbon during the W-type formation process.[7]

1.4 Literature review:

In today's modern era, roll forming has become a primary focus among sheet metal techniques due to its widespread application and simplicity. Despite numerous studies in the field, manufacturers still grapple with challenges in specific processes, such as predicting ribbon behavior and refining the accuracy and properties of the end product. Therefore, the prediction methods in use were not fully addressing these challenges. In 1993, G. NEFUSSI and P. GILORMIN introduced a unique, simulation-based approach to predict the precise geometry and deformation of materials during the roll forming process, resulting in enhanced accuracy. By 1997, a contemporary segmented feature software was utilized to assess geometric designs, capable of detailing attributes of segments of any distinct shape. In 2008, an approach combining geometry and math was introduced to determine the position of the top mobile unit (roller) in relation to the cylindrical deformation of the material[8].

By 2016, a technical simulation focusing on fixed deflection stages was launched. This utilized a progressive weight force approach, relying on varying step sizes, to document changes in the form and size of materials using appropriate software tools. Consequently, the influence of different factors on the weight exerted on the top roller and the deformation trajectory were studied. In 2020, Jiaojiao Cheng and colleagues employed computational evaluations alongside finite element analysis. They uncovered the intricate relationship between the material and the rolling elements, finding that the adjacent vertical effect in the boundary curve area is crucial, indicating its importance in shaping that specific section. In 2022, J.S. Xia and team introduced the artificial neural network (ANN) method, based on the real-time data collection from the shaping process. This method could also explore the effects of forces, such as resistance and variations in rotational speed[9].

A literature review is conducted to understand the research carried out by scholars. This information can be sourced from books, articles in both national and international journals, conference papers, as well as postgraduate and doctoral studies.

In the modern context, roll forming stands out as a primary focus in the realm of sheet metal processes due to its widespread application and convenience. Despite the vast amount of research in this area, manufacturers still grapple with certain challenges in this specific process. These challenges include predicting ribbon behavior and ensuring the accuracy and quality of the final product. As a result, forecasting methodologies have been developed, though they haven't always been successful in addressing all concerns.[10]

N. E. Hansen and O. Jannerup [10] primarily focused their research on improving the understanding of the geometry involved in the three-roller beam bending method. They used a triangular moment distribution assumption between the rollers to attain this. Their main aim was to formulate a more accurate geometric model to enhance the management of the bending procedure. Their study mainly applied the foundational beam bending theory to the bending of beams.

D. E. Hardt and team [11] introduced a real-time approach with a closed-loop system to manage the shape during the three-roller bending operation. Their aspiration was to obtain a distinct curvature for a material at each point of its length. They achieved this by consistently monitoring the shape, the moment exerted, and the effective stiffness of the material as the bending took place in real-time.

Michael Hale and David E. Hardt [12] aimed to bring automation to the roll bending procedure through closed-loop control. They devised dynamic models for both individual elements of the roll bending equipment and the overall process.

V. Ramamurti and team [13] delved into assessing the stability of the stands in a robust three-roller plate bending machine under varied loading situations. A detailed parametric study was conducted, encompassing the evaluation of two separate machines. While the machine was active, the Finite Element Method (FEM) was used to gauge the static reactions of the stands. The analysis primarily centered on discerning the response during the most demanding loading condition.

Jong Gye Shin and colleagues [14] introduced a structured approach to determine the central roller's movement in the three-roll bending operation. The research thoroughly inspected the mechanics of the procedure using both analytical tools and finite element analysis. There was a meticulous comparison of results from both analytical and finite element methods. Moreover, they proposed a relationship between the central roller's displacement and the remaining curvature in the bent material.[14]

H. V. Gajjar and co-authors [15] presented a strategy for evaluating a material's bending potential within a bending machine's limits, considering factors like plate thickness, shell diameter, and material attributes. In this context, they developed analytical models, including ones for equivalent thickness, equivalent width, and maximum width, based on the power law material model. These models were employed to probe and understand the material's bending capacity. Notably, they used the equivalent thickness model to evaluate the bending responses of four distinct C-Mn steel plate grades[15].

A.H. Gandhi and team[15] developed a mathematical framework to determine the top roller load needed for pre-bending a plate in a three-roller bending machine. Using real data from

C-Mn steel plates, they computed analytical top roller offsets. Additionally, they used the Hyperform LS-Dyna software for finite element analysis during pre-bending, opting for a 2D model with symmetrical boundaries. Their research showed that an increased coefficient of friction between the rollers and plate led to a higher pre-bending load.

Zhengkun Feng and Henri Champliaud[16] investigated an uneven three-roll bending procedure using numerical simulations. They used these simulations to forecast the lateral roll's position and performed tensile tests to understand the plate material's stress-strain dynamics. To tackle the nonlinear nature of the task, they used the Belytschko-Tsay shell formulation within ANSYS/LS-DYNA.

Dachao Hu's team [16] introduced a mathematical approach to foresee the spring back radius in sheet metal roll bending. The model, based on orthogonal testing and regression analysis, linked the spring back radius to factors such as the upper roller's vertical movement, sheet thickness, and the material's yield strength and Young's modulus. Their analysis revealed that the upper roller's downward motion greatly influenced the spring-back radius.

Quan Hoang Tran and colleagues [17] utilized ANSYS/LS-DYNA to craft a 3D dynamic finite element model simulating uneven roll bending. They pinpointed crucial parameters affecting the process and assessed their impact on the forces and final shape quality. Their model's predictions were then cross-checked with experiments on a real roll bending machine.

In 2020, Jiao jiao Cheng [18] and team embraced computational evaluation and finite element analysis. They discerned the relationship between the workpiece and rolling components, highlighting the importance of the adjacent perpendicular impact in shaping the boundary curve section.

By 2022, J.S. Xia [19] and colleagues integrated the Artificial Neural Network (ANN) approach, leveraging real-time forming data for training and verification. This method could also evaluate the influence of factors such as resistance force and rotational speed status.

Chapter 2 : THEORY

2.1 Mathematical Modeling of 3 Point Roll Bender:

The 3-point roll bender is a widely used machine in sectors like construction and manufacturing. It bends cylindrical items like metal rods and tubes by exerting force at three specific points, yielding a smooth and exact curve.

Grasping mathematical modeling is essential when creating a precise model for the 3-point roll bending process. Such modeling entails crafting mathematical representations for real-world activities, which can then predict the responses under various scenarios. To precisely depict the 3-point roll bending mechanism, the model should account for elements influencing the material's bending tendencies [20]

A thorough mathematical depiction is crucial for effectively predicting and managing the 3-point roll bender's bending actions. This representation should factor in aspects like resistance to bending at the top roll, variations in plate thickness, and the material's elastic to elastoplastic deformation. Several scholars have formulated mathematical frameworks to assess material behavior during bending tasks[12]. For instance, Bai and colleagues devised a model calculating roll deformation in a standalone cold rolling mill and created two predictive models for bending force. These models can aptly estimate the needed bending force for specific material-shape combinations in a 3-point roll bender. Furthermore, a novel roll bending approach has been suggested that rectifies some shortcomings of the conventional methods and provides added versatility in bending larger workpieces. Both finite element techniques and real-life tests were used to ascertain the efficacy of this innovation.

In the realm of 3-point roll bending, mathematical frameworks are instrumental. They offer a structured means to anticipate material behavior during bending, enabling precise calculations of necessary forces for specific material-shape pairs. Additionally, these frameworks facilitate process optimization by revealing how varying parameters, like the thickness of the plate or the material's characteristics, impact bending outcomes**.**Detailed Analysis of 3 Point Roll Bender:

In this study, specific design parameters were established. All three rollers, made of hardened 1070 steel, had an identical effective diameter of 80mm. They were used to estimate the force needed to bend a stainless-steel strip, which had a maximum thickness of 3mm and was

50mm wide. It's important to mention that a prior study [21] indicated problems arise when the upper roller's downward movement meets or surpasses its radius. Therefore, we limited the displacement to 30mm.

We started by analytically determining the curvature radius, factoring in a 2D layout of the rollers and accounting for the plate's spring-back and deformation. It's essential to consider these elements as ignoring them often results in overestimating the inner radius [21]. Following that, we computed the force necessary for bending, making a few assumptions along the way. With the data on force and curvature radius, we were then able to calculate the torque needed for the bending process.

2.1.1 Radius of curvature:

Figure 3 illustrates the initial 2D configuration of the rollers and the metal strip situated between them. In this depiction, the figure represents only the effective radius of the rollers.

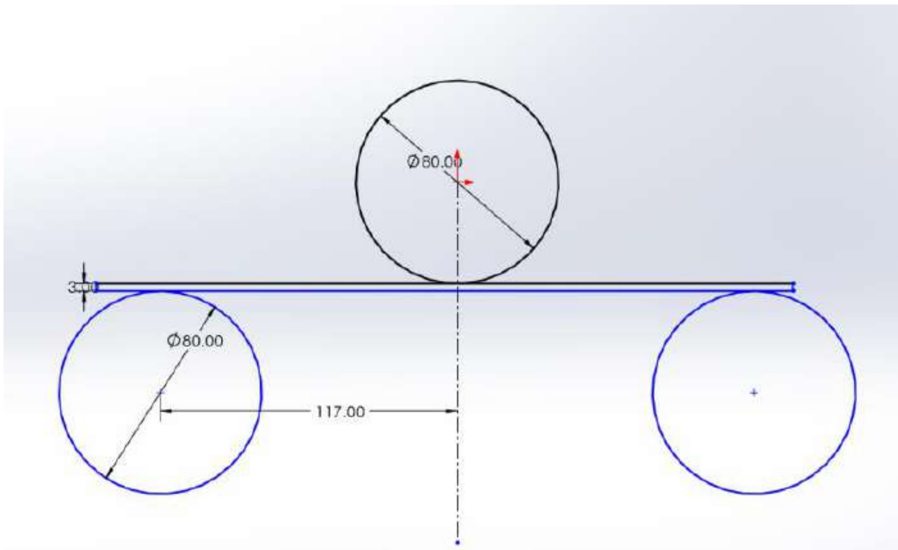


Figure 3 2D geometrical arrangement before bending.

Figure 4 depicts the identical configuration following the roller's displacement to its maximum possible position, resulting in the bending of the metal strip.

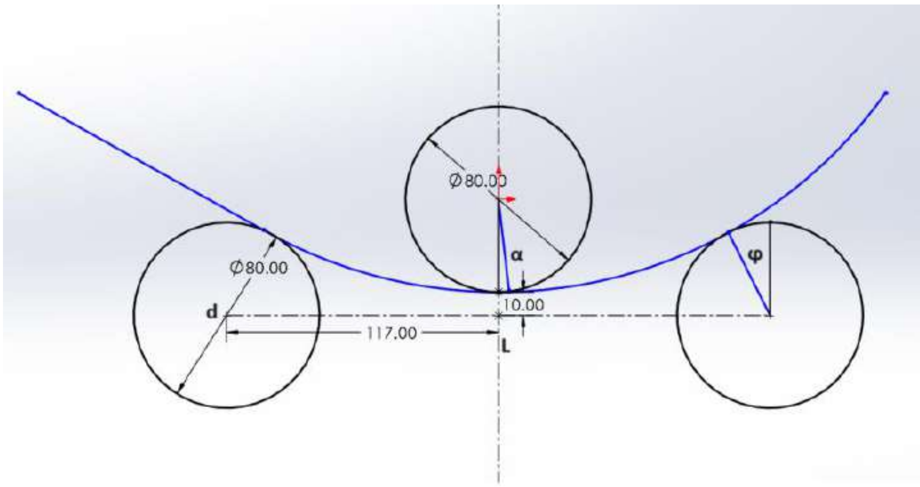


Figure 4 Geometric model after bending

Using the basic trigonometric principle "sin^2ϕ + cos^2ϕ = 1" and considering the strip's deformation properties, we can determine the curvature radius based on an equation from a previous study [14].

$$\left(\frac{L/2-\left(Ri-d/2\right)\sqrt{1-\left(\frac{d/2}{d/2+t}\right)^2}}{Ri+t+d/2}\right)^2+\left(\frac{y-d/2+\left(Ri-d/2\right)\left(\frac{d/2}{d/2+t}\right)}{Ri+t+d/t}\right)^2=1$$

Where:

y is the distance between the horizontal axis of the lower rollers and the deformed outer layer of the strip

L is the distance between the lower rollers

d is the diameter of the rollers

t is the thickness of the plate

R_i is the radius of curvature.

As highlighted earlier, the downward shift should not surpass the roller's radius, so we set the "y" value at 2 millimeters. Other details involve a 234-millimeter gap between the lower rollers, an 80-millimeter roller diameter, and a strip thickness of 50 millimeters.

When we simplify the aforementioned equation and substitute these values, it can be expressed as follows:

$$\left(\frac{117-\frac{\sqrt{65}}{9}(Ri-40)}{Ri+90}\right)^2+\left(\frac{2-40+\frac{4}{9}(Ri-40)}{Ri+90}\right)^2=1$$

18358.8 - 143.4Ri = 0

Ri = 128mm

the radius of curvature in our case is equal to 128mm

2.1.2 Torque:

In the study referenced [21], a few primary assumptions were taken. Firstly, the thickness of the strip was deemed insignificant for determining its altered position. Secondly, friction's impact was not factored into the computations. Lastly, the bending moment was viewed under intense plastic bending scenarios. Lastly, it was assumed that the moment in section 3 (as depicted in Figure 5) was zero.[22]

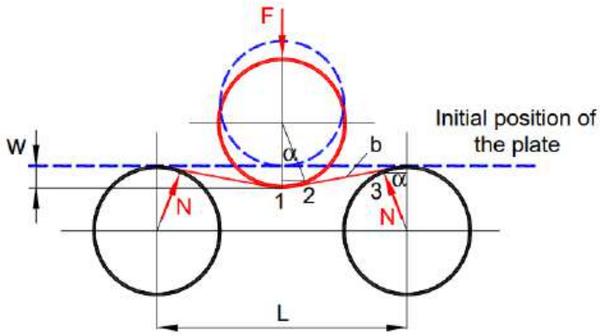


Figure 5 [14]

In figure 5, the dotted line shows the un-deformed strip whereas the solid line shows the deformed one. The bending moment M_b is represented by the formula:

$$\mathbf{M_b}=\sigma y\frac{l*t^2}{4}$$

Where,

σy is the yield strength of the metal strip, l is the width of the strip

We have bent stainless steel strips of $\boldsymbol{\sigma y}$ **= 235MPa.** The width of the strip is 3mm.

M_b = 440.6 Nm

M_b can also be calculated by:

M_b = N * b

Where;

N is the normal reaction force

b is the moment arm

b can be calculated by the following equation

$$\mathbf{b} = \frac{1}{cos\alpha}\left(\frac{L}{2} - dsin\alpha\right), \qquad \alpha = \frac{L/2 - w}{d}$$

After putting in values

α = 0.987, b = 91.2mm

Therefore,

$$N = \frac{440.6 N.m}{91.2*10^{-3} m}$$

N = 4831N

F = 2Ncosα

F = 5325.8N

The upper roller must exert a force of 5325.8 Newton’s to achieve the desired radius of curvature, which is 128 millimeters. This necessitates a torque, which can be calculated using the following formula:

T = F * Ri

T = 681Nm

2.2 Conclusion:

Considering the most challenging bending conditions and using the strongest material suitable for this roll bender, it's determined that a force of roughly 5325 Newtons is required. As a result, a torque of about 681 Newton-meters is essential to effectively bend a stainless-steel strip. This strip has a yield strength of 235 Mega Pascals and dimensions of 3 millimeters thick and 50 millimeters wide.

Chapter 3 : DESIGN AND 3D MODELING

The main focus of the discussed content is to enhance and modernize cold rolling processes in the metal industry, emphasizing optimization, automation, and cost savings. Effective automation, consistent monitoring, and precise control are pivotal during production. It's essential for workers to have profound knowledge in both theoretical and metallurgical-technological aspects, playing a pivotal role in crafting, studying, and manufacturing rolled steel sheets. Quality assurance during rolling reiterates the necessity of total mill automation.

A key innovation is the introduction of a novel method for determining the central technological parameters of a rolling mill. This method contrasts with traditional static calculations, which often don't account for the genuine stress-deformation attributes of materials. By considering the material's deformation characteristics and the ideal deformation transmission rate, there's a marked improvement in both operational efficiency and product standards. Embracing advanced control mechanisms can further elevate product quality, acknowledging the intricate aspects of tandem cold rolling, marked by its many process variables, inherent non-linearity, and inherent delays. Design goals also involve creating proper process control models. The emphasis is on crafting a model that mirrors real process variables in nearby operating points, ensuring computational ease. Such modeling is typically achieved using state-space methods, optimal for systems with multiple inputs and multiple outputs (MIMO)[24].

The essence of the detailed context is the imperative role of process identification in the evolution of controller systems. The subspace identification method (SIM) is pinpointed as the go-to method for deriving MIMO black-box linear state-space models. Resorting to simulations is indicative of the focus on rigorously assessing and fine-tuning control mechanisms. This dedication is a pathway towards refining the quality of products in the cold rolling procedure. Central to these design ideologies and goals is the synergy of automation, avant-garde control techniques, precise process modeling, and rigorous quality assurance. This ensemble seeks to uplift the efficacy, product quality, and financial viability of cold rolling within the metal sector.

3.1 Design Goals:

Moreover, versatility was at the heart of the design. The vision was to create a Three-Point Roll Forming Machine adaptable to a variety of materials and profiles. This adaptability ensures the machine's relevance across diverse applications and industries, fostering a wider market reach and meeting the varied requirements of clients. Such a feature is essential in an industry where customer demands are constantly evolving, and the ability to cater to a myriad of specifications sets a machine apart.

Lastly, a pivotal design tenet revolved around customization. Recognizing that every client's needs are unique, the machine was engineered with flexibility in mind. This meant that beyond its standard functionalities, it could be easily reconfigured or adjusted to suit specific project requirements, be it in terms of material type, thickness, or specific bend profiles. This client-centric approach not only enhances the machine's value proposition but also fosters long-term client relationships, as it positions the machine as an invaluable asset capable of evolving alongside client needs.

In conclusion, the design and creation of the Three-Point Roll Forming Machine were grounded in a holistic approach that considered every facet of the roll forming process. By emphasizing efficiency, sustainability, versatility, and customization, the machine stands as a testament to innovation in the metal forming industry. This comprehensive approach ensures that the machine not only meets the immediate needs of the industry but is also primed for future challenges and opportunities. The design principles underscore the importance of marrying technology with practicality to create solutions that are both advanced and relevant to the end user.

One of the primary objectives was to enhance production efficiency by ensuring that the machine could operate continuously without interruptions. The ability to run production consistently without breaks significantly boosts output, reducing the overall time taken for production cycles. The Three-Point Roll Forming Machine was crafted with this in mind, offering uninterrupted operations.

Furthermore, a significant design element of the machine was its adaptability. This machine is built to produce a broad spectrum of profiles, catering to specific client requirements. From detailed architectural patterns to complex structural elements and tailored designs, the machine offers unparalleled versatility, enabling producers to meet varied market demands.

This section delves deeply into the unique design features, foundational engineering concepts, and intricate fabrication techniques that bring these essential goals to fruition. A thorough analysis of the Three-Point Roll Forming Machine's design and capabilities showcases its ability to not just fulfill, but also surpass, contemporary roll forming requirements, ushering in new benchmarks in terms of productivity, eco-friendliness, and tailored production**.**

3.2 CAD Modeling and Component Assembly:

The process of CAD modeling and component assembly serves as the backbone of the design and fabrication of our Three-Point Roll Forming Machine. For this critical phase of the project, we turned to CREO Parametric 7.0, advanced Computer-Aided Design (CAD) software known for its powerful features and versatility.[26]

CREO Parametric 7.0 is industry-leading CAD software renowned for its comprehensive suite of design tools and robust capabilities. It proved to be an ideal choice for our project due to several key reasons.

3.2.1 Versatility:

CREO Parametric 7.0 provides an extensive array of both parametric and direct modeling capabilities, allowing for the detailed 3D representation of machine parts with accuracy and adaptability. From crafting intricate curves specific to roll forming to devising the mechanical elements for flawless functionality, CREO Parametric 7.0 catered adeptly to our varied design requirements.

3.2.2 Assembly Management:

A prominent strength of CREO is its powerful assembly management functions. It allowed us to effortlessly bring together and assemble the numerous parts of the Three-Point Roll Forming Machine. The assembly features of the software guaranteed a perfect fit for each component, paving the way for an efficient production process.

3.3 Component Modeling:

For the detailed design of the Three-Point Roll Forming Machine, we utilized CREO Parametric 7.0 to shape its critical components. Using CREO, we expertly modeled elements such as shafts, rollers, the machine frame, bearings, sliders, and wedges.

The precision and adaptability of CREO ensured that we could design these parts meticulously, ensuring a perfect interlock among them. From sturdy shafts to detailed sliders, every component was tailored to function in unity, ensuring maximum efficiency and dependability.

In the following segments, we will delve deeper into how CREO Parametric 7.0 facilitated the design of these fundamental parts, aiding us in our journey to construct our cutting-edge Three-Point Roll Forming Machine**.**

3.3.1 Shafts:

CREO Parametric 7.0 was utilized to model the critical shafts of the Three-Point Roll Forming Machine. Leveraging commands such as "Extrude" and "Round," the shafts were meticulously shaped and refined, ensuring precision and functionality within the machine's design.

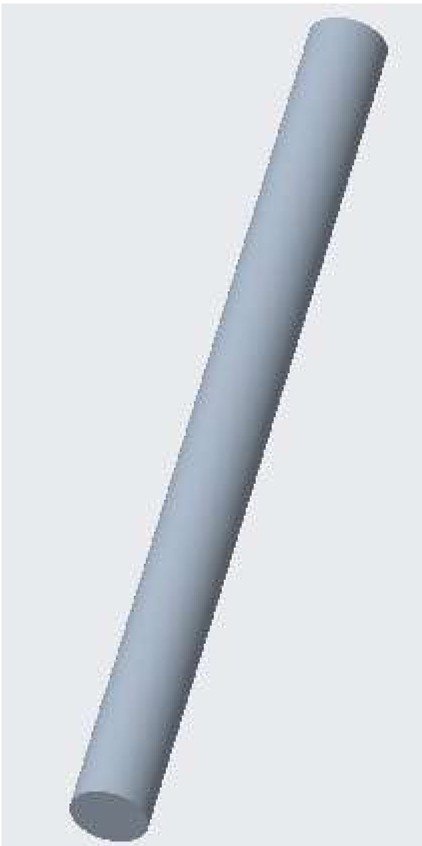


Figure 6 3D model of shaft

3.3.2 Rollers:

Employing CREO Parametric 7.0, the rollers for the Three-Point Roll Forming Machine were meticulously modeled. Utilizing commands like "Revolve" and "Pattern," these essential components were crafted, guaranteeing their seamless rotation and precise performance within the machine's framework.

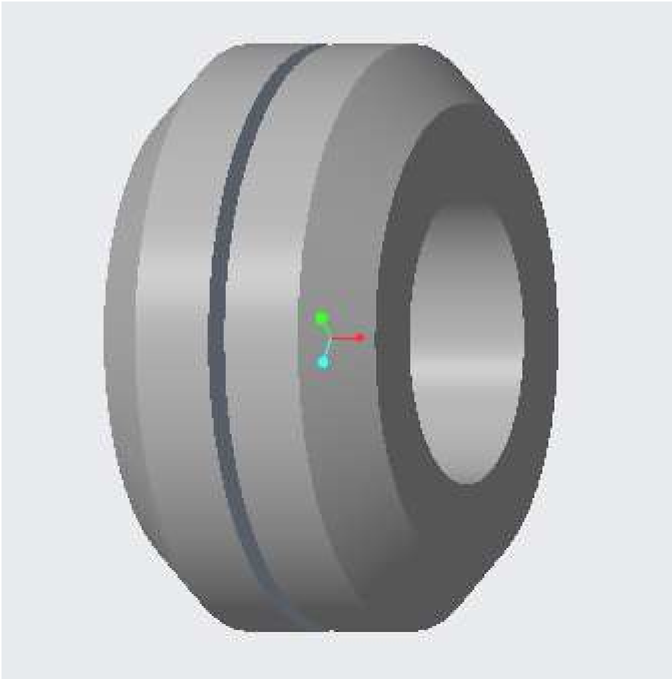


Figure 7 3D model of roller

3.3.3 Main Body:

The accuracy in the core structure of the Three-Point Roll Forming Machine went beyond just the initial extrusion process. Utilizing CREO Parametric 7.0, specific openings were carefully designed for the rollers, ensuring their flawless incorporation. Commands such as "Extrude," "Remove," and "Create Section" were strategically combined to shape unique attributes.

For the top roller, an opening was expertly carved out from the main structure. The bottom left rollers were positioned through meticulous cutout techniques. The slider, an essential component, was designed with a square cut to enhance its performance. On the other hand, the bottom right roller was accommodated by designing a curved section within the main body for a snug fit. This rigorous focus on detail while shaping the central structure, combined with the integration of diverse design features, highlights the excellence achieved with CREO Parametric 7.0. The outcome is a harmoniously constructed and highly effective machine design.

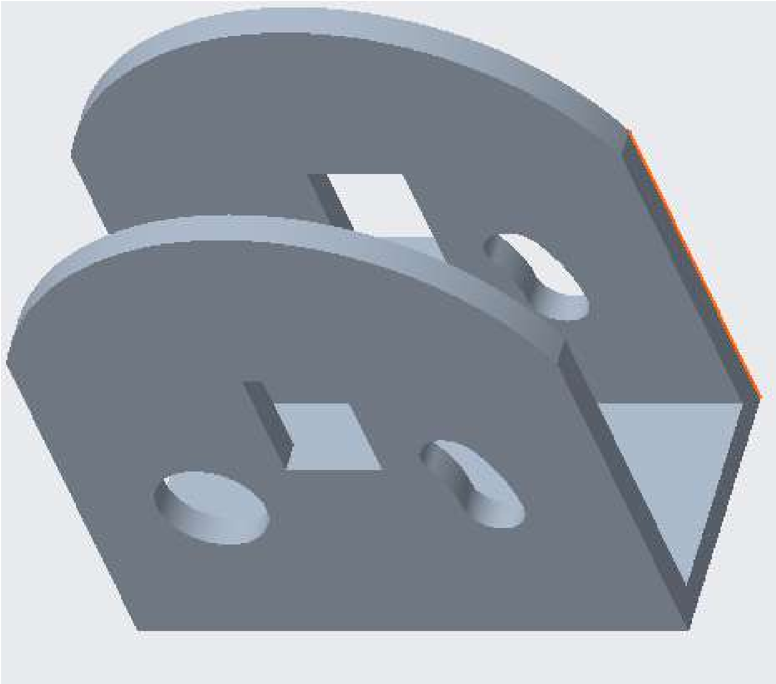


Figure 8 3D Model of Main Body

3.3.4 Slider:

The process of crafting the slider component began with a detailed design sketch in CREO Parametric 7.0. Setting out the slider's design was the primary step, followed by using the "Extrude" command to select the right development plane.

Further refinement was achieved with another round of careful sketching. Once the design met our requirements, the "Extrude" command was reapplied, sculpting the slider's form to the highest precision. To finalize the design and ensure both its functionality and visual appeal, the "Round" feature was applied to smooth out the edges. This detailed modeling approach in CREO Parametric 7.0 ensured that the slider was both precise and efficient, crucial for the machine's peak performance[27].

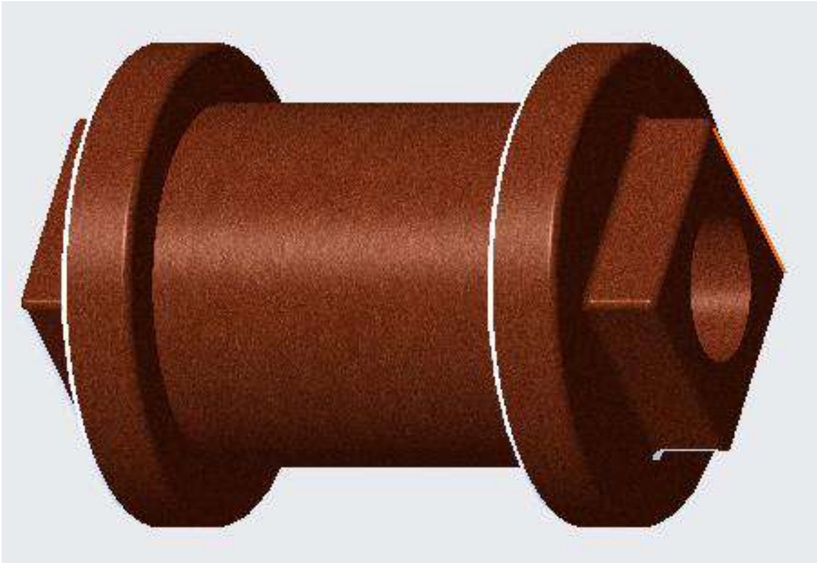


Figure 9 3D Model of slider

3.3.5 Swing Arm:

The design phase for the swing arm in CREO Parametric 7.0 kicked off with an intricate sketch outlining its shape and structure. The "Extrude" command was then used to transform this sketch into a 3D model. To make space for the bearings, a carefully designed hollow section was incorporated within the arm's design. Through this systematic procedure in CREO Parametric 7.0, a swing arm that embodies both detailed design and essential functions was realized.

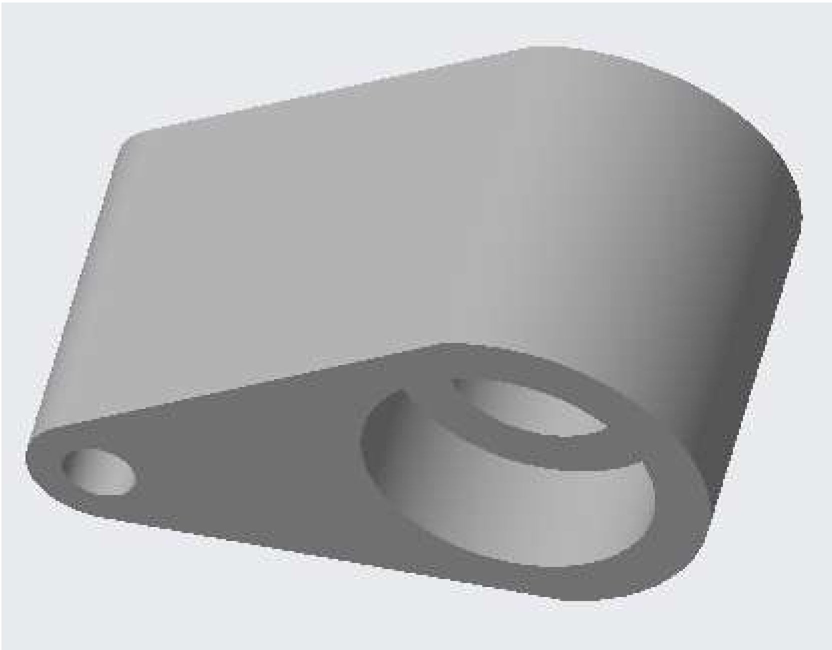


Figure 10 3D Model of Swing Arm

3.3.6 Bearings

The design of the bearing in CREO Parametric 7.0 began with the "Sketch" and "Extrude" commands to produce a detailed and dimensionally accurate blueprint. The "Revolve" command was then used to give the bearing its three-dimensional shape. To enhance its design and smooth out sharp edges, the "Round" command was employed. This careful approach in CREO Parametric 7.0 led to the development of a bearing component that stands out for its accuracy and its ability to fit perfectly within the machine assembly.

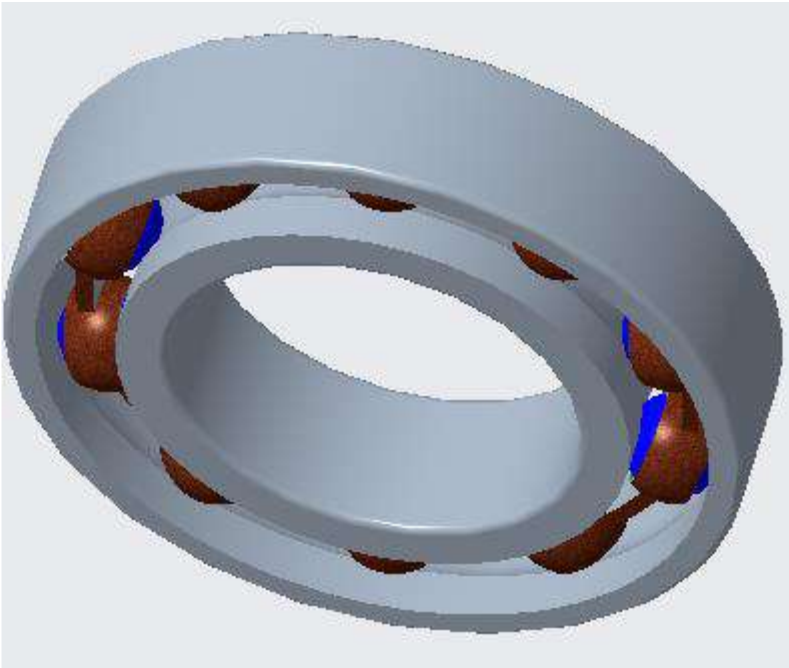


Figure 11 model of bearings 6210

Figure 12 3D Modeling of Bearing 6010

3.4 Assembly process:

The assembly process involved systematically addressing each component's degrees of freedom within the CREO assembly module. For the rollers on the shaft and the upper slider, we allowed rotational and vertical movement to ensure optimal functionality. In contrast, the shaft connected to the swing arm was configured to permit unrestricted arc motion while remaining securely in place. To maintain stability and enable effortless shaft rotation, the bearings were meticulously anchored using appropriate assembly techniques. This comprehensive approach ensured that all components were seamlessly integrated, enabling the machine to operate as a unified and highly functional system [28]

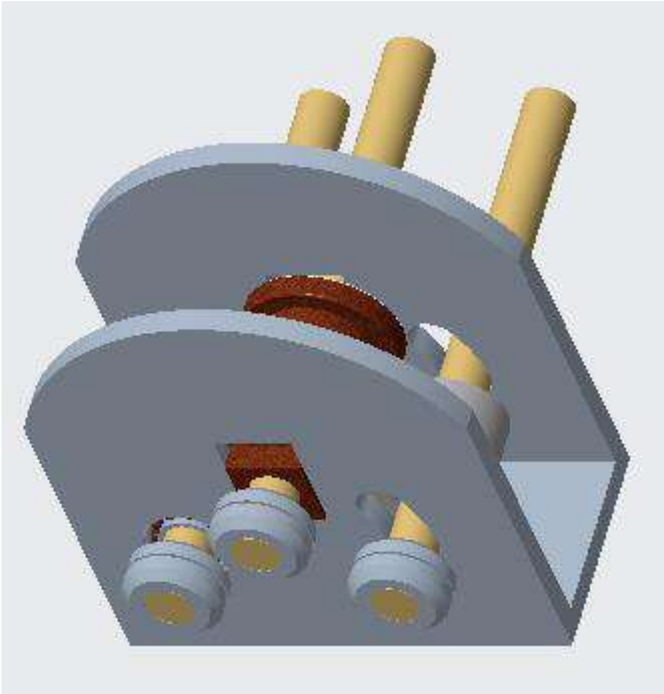


Figure 13 Assembled 3D Model of Machine

3.5 Material Selection and Considerations

When building our Three-Point Roll Forming Machine, the selection of materials was crucial. For essential parts like the shaft, body, slider, and swing arm, we chose mild steel due to its specific qualities that met the machine's needs. Recognized for its low carbon concentration and superior welding capabilities, mild steel emerged as an ideal choice. With a tensile strength between 400-550 MPa and a yield strength around 250 MPa, it provided the necessary sturdiness for these integral components. Its malleability was beneficial for detailed machining, resulting in exact component measurements. Additionally, its cost-effectiveness made it even more attractive, fitting within our budget.

On the other hand, for the rollers, we utilized high carbon steel, known for its impressive hardness and resistance to wear. With a carbon concentration usually surpassing 0.60%, high carbon steel attained a hardness of 55-60 HRC on the Rockwell Hardness Scale. This was crucial considering the rollers' challenging task, facing substantial wear and friction during the roll forming operation. The inherent strength and resilience of high carbon steel ensured the rollers maintained their form and functionality even in such demanding scenarios.

This judicious selection of materials based on their specific numerical properties and advantages not only enhanced the machine's overall efficiency but also extended its operational lifespan. In summary, the utilization of mild steel and high carbon steel for the respective components of the Three-Point Roll Forming Machine underscored the meticulous consideration of material properties, contributing to the machine's reliability and longevity.

3.6 Material database

3.6.1 Mild Steel:

Table 1 Material Selection Mild Steel

Young's Modulus (E)	200 GPa
Density (ρ)	7.85 g/cm³
Yield Strength (σy)	250 MPa
Ultimate Tensile Strength (σu)	400-550 MPa
Poisson's Ratio (ν)	0.29
Hardness (Brinell)	120-180 HB
Thermal Conductivity (k)	50 W/(m·K)
Specific Heat Capacity (Cp):	0.465 J/(g·K)

3.6.2 High Carbon Steel:

Table 2 Material Selection High Carbon Steel

Young's Modulus (E)	190-210 GPa
Density (ρ)	7.7-8.1 g/cm³
Yield Strength (σy)	450-900 MPa
Ultimate Tensile Strength (σu)	650-2,100 MPa
Poisson's Ratio (ν)	0.27-0.30
Hardness (RockWelll)	55-60 HRC
Thermal Conductivity (k)	50-60 W/(m·K)
Specific Heat Capacity (Cp):	0.465 J/(g·K)

Chapter 4 : NUMERICAL ANALYSIS

This chapter delves into the examination of the 3-point roll forming machine design using market-leading simulation tools. We utilized ANSYS 2023 R1 for the simulation, focusing on static structural and prestressed modal analyses. The groundwork for this analysis, encompassing boundary conditions and input parameters, is elaborated on in this segment of the presented thesis. For clarity, the chapter is bifurcated into two primary sections: first, a static structural study to pinpoint the reaction forces emerging from the roller-imposed loads, and second, utilizing these reaction forces in a prestressed modal evaluation to ensure the structure's integrity under peak load scenarios[29].

The 3-point roll forming machine's blueprint greatly benefited from modern computational analysis techniques. ANSYS 2023 R1, a commercial-grade software, facilitated a meticulous representation of both fluidic and structural attributes by leveraging clearly defined boundary conditions and material specifics. In our analysis, we combined structural and prestressed modal methodologies via finite element analysis (FEA). FEA is invaluable when seeking an in-depth grasp of physical events grounded in their mathematical derivations. For situations that require insights into structural, thermal, or fluid dynamics through FEA applications, solving using partial differential equations has proven crucial. In this study, our simulation goals were threefold: to comprehend the static structural demeanor of the shaft roller assembly, to analyze the system's natural frequency under peak load conditions from the static analysis, and to observe the system's mode shapes during operational phases**.**

4.1 Methodology:

Numerical analysis is paramount in evaluating the design and function of intricate machinery, such as rolling mills, a fact supported by numerous scholarly articles. As modern manufacturing processes evolve, numerical analysis has emerged as a crucial instrument for research and innovation. Through mathematical modeling, which forms the foundation of numerical analysis, we gain deep insights into the reactions of materials during diverse operations, like forming and rolling. Using these mathematical constructs to depict real-world operations allows experts to run accurate computations and simulations. For rolling mills, numerical analysis is vital for refining operations, ensuring ease of use, and forecasting essential outcomes. The literature referenced underscores the importance of these numerical simulations in gauging and refining machine accuracy. Through these simulations, experts can study how materials respond during rolling, shedding light on vital aspects such as shape, temperature, resistance, thickness alteration, tension, deformation, and deformation rate fields. Such holistic evaluations are crucial in determining product quality and mechanical attributes, which in turn affect the manufacturing process's efficacy [30].

Numerical analysis, as evidenced by the referenced studies, is critical for foreseeing and enhancing the nuanced responses of materials during rolling. This analytical method minimizes the need for extensive physical testing, leading to cost efficiency. Furthermore, it refines the design and initiation processes, bolstering both effectiveness and uniformity in manufacturing. These insights underscore the importance of numerical analysis in advancing the design, accuracy, and functionality of rolling mills, positioning it as a central theme in your thesis's methodology section. Utilizing this analytical technique justifies the logic of conducting numerical assessments, offering a comprehensive view of the complexities in manufacturing and furnishing key details about material responses under diverse circumstances.

4.2 Design Analysis:

The basic design of the analysis will be discussed in this section. The cad model of the 3point roll forming machine was developed using drawings already discussed in the manufacturing stage. The CAD designs were created using CREO Parametric 7.0 at a 1:1 scale, and the assemblies were put together to validate the blueprints. The shaft and the Turbine roller were constructed in accordance with the sketches, with each part fitted together in the CREO modeling software using the appropriate connections and fits.

The modeled geometries of shaft and roller were converted in IGES format so that they can be imported into ANSYS Design modeler without loss of any parametric detail relevant to the design. The shaft and roller models were imported in separated design modeler modules where separate parameters and named selections were defined based on the different surface to surface interactions expected in the simulation. The imported models were linked to mesh, modeler, where optimum meshes were produced. After the model definition and meshing the model was imported in static structural where input parameters and boundary conditions were defined, and simulations were solved for the given conditions. After a successful solution, the outputs of the static structural were applied as inputs to the pre-stressed modal to determine the mode shapes.

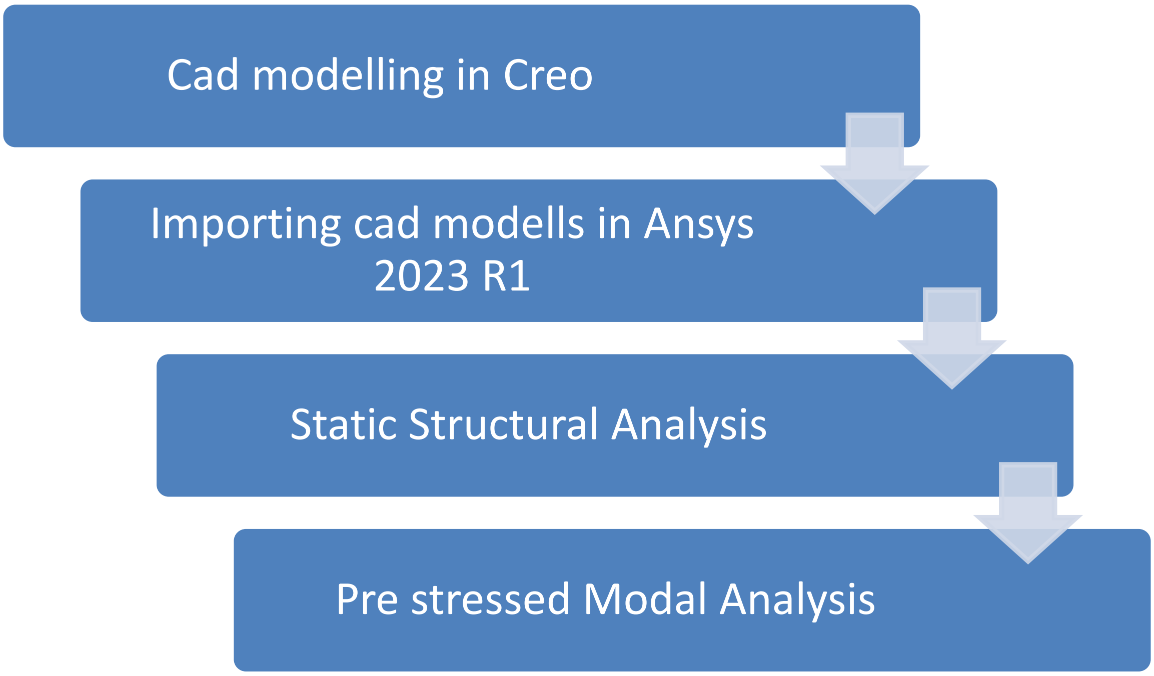


Figure 14 Computational Analysis Topology

4.3 Preparation of CAD Model:

Parametric modeling for the 3-point roll forming machine design analysis was done using CREO software. To perform the analysis, the model consisted of three components namely the shaft with the roller and the body. The models after preparation were converted into IGES file format so that could be imported in ANSYS. The figure below shows the cad model of the 3-point roll forming machine created to perform static structural and pre-stressed modal analysis using ANSYS. The design was made for easier assembly using dimension clearance as per produced cad drawings.

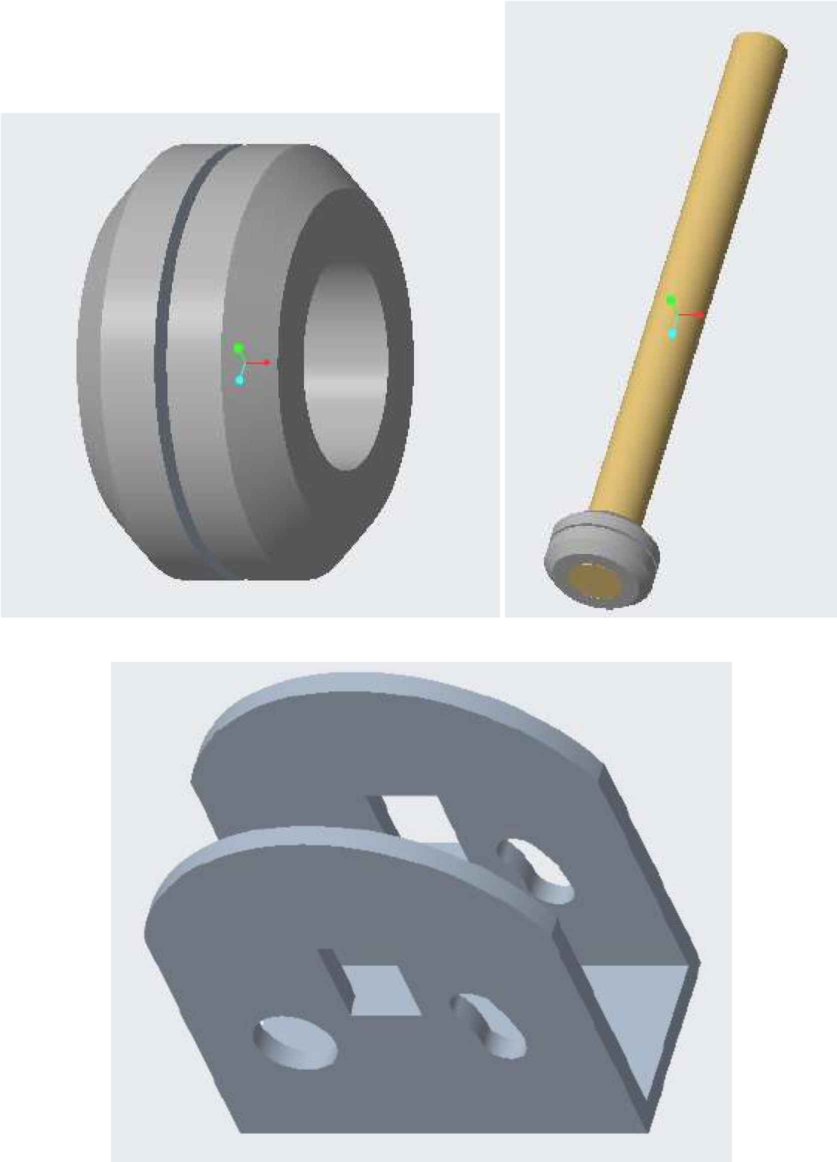


Figure 15 Cad Models Prepared for Static Structural Analysis

The model for roller and shaft were imported as an assembly into design modeler modules of ANSYS to assign their geometric and meshed parameters. The roller and shaft are considered stationary domain for this analysis.[32]

4.4 Meshing of Geometries:

Once the geometric attributes of the CAD models were set in the design modeler, the assembly modules for the roller and shaft were connected to their respective meshing modules to determine the meshing characteristics for the entire assembly. A mesh element size of 5 mm was chosen to ensure detailed precision. Additionally, the body was introduced into the meshing module with a mesh element size set at 3 mm.

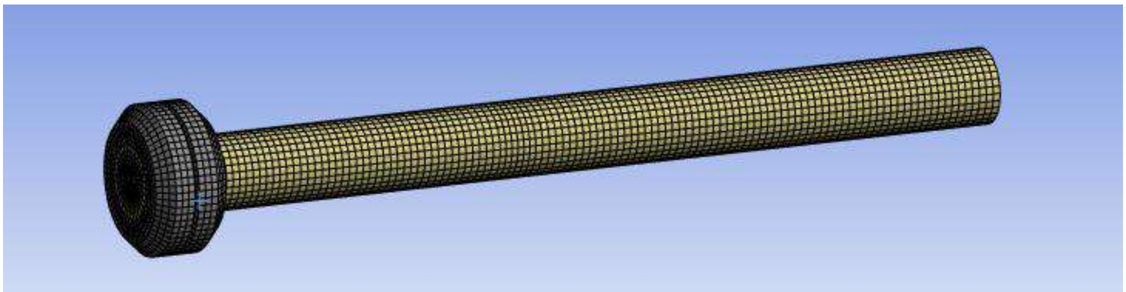


Figure 16 Shaft Roller Assembly Meshed

Figure 17 Body Meshed

4.5 Static Structural Analysis:

After completion of the model the parts were imported in the static structural analysis module to directly couple the reaction forces produced as input load parameters for the static structural analysis. The same mesh was also imported was imported in the structural analysis domain and material properties were described for the chosen material.

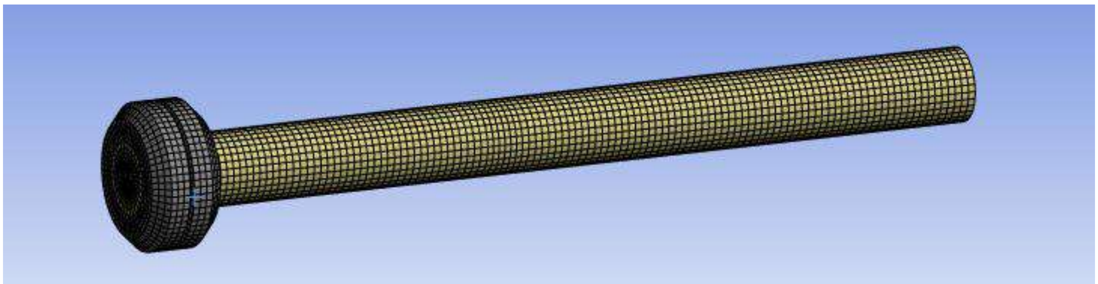


Figure 18 Meshed Model For Static Structural Analysis

Name selection was created for the fixed support and applied load surfaces to apply the load on the surface of the roller by selecting only the desired surface of the roller. Applied load in the case of the upper roller was defined as 30 tones.

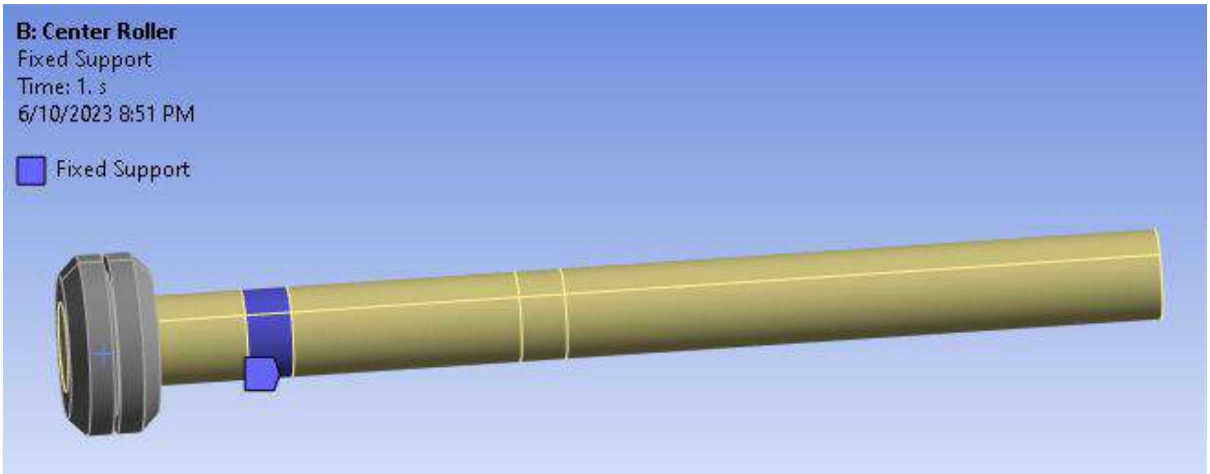


Figure 19 First Fixed Support

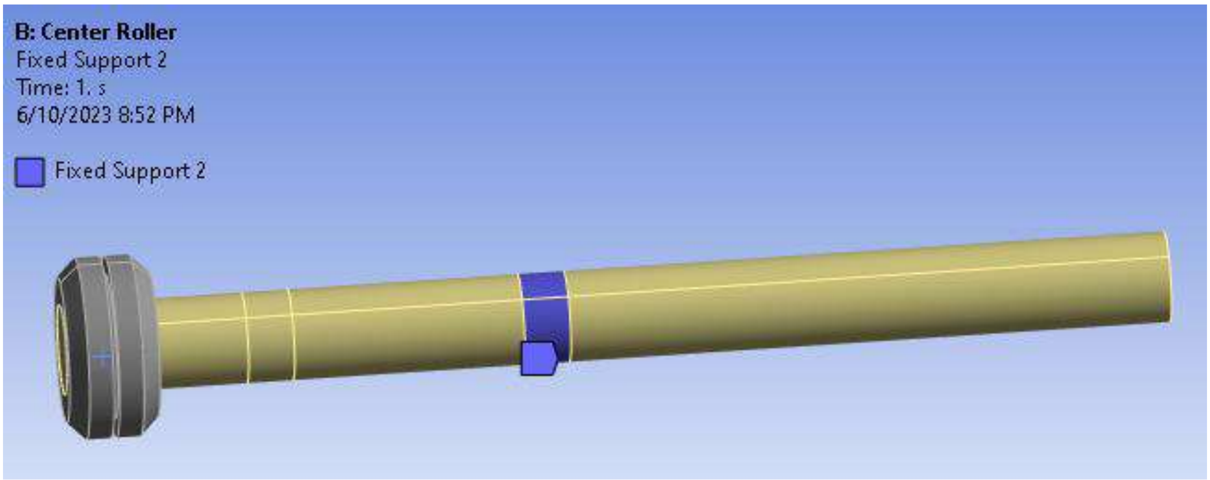


Figure 20 Second Fixed Support

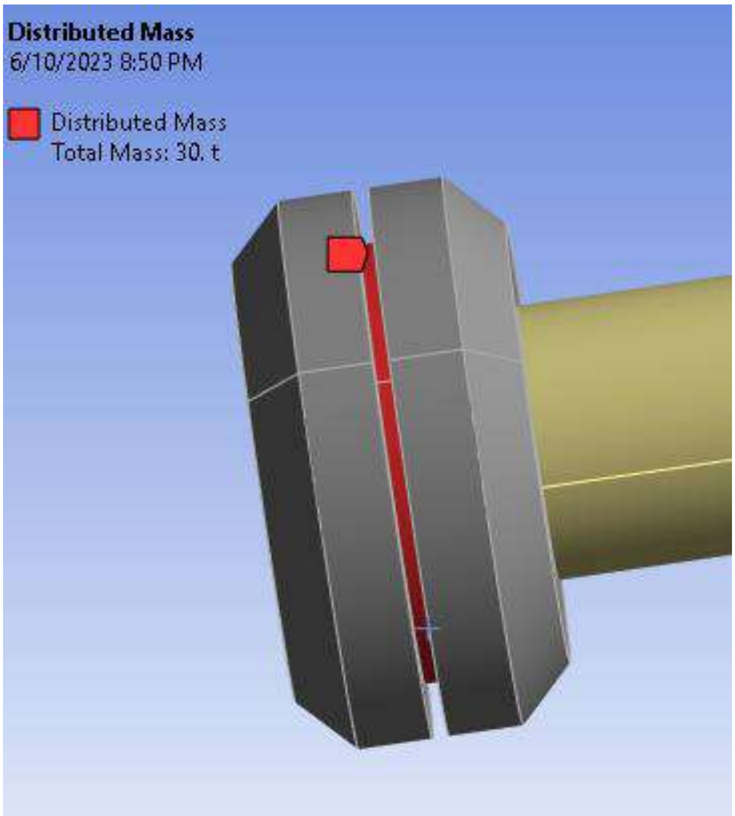
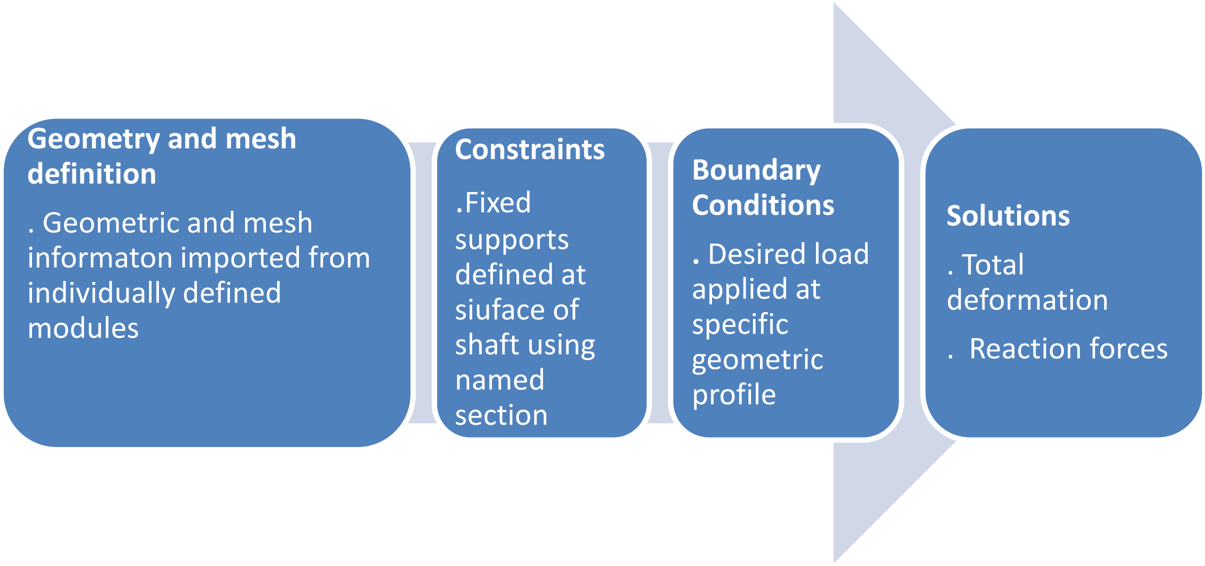


Figure 21 Applied Load Surface of the Roller

In ANSYS, when applying loads to the static structural module, we first established the module's boundary conditions for fixed support using the surface selection feature. A distributed load was then applied to the inner surface of the roller by opting for the load feature description. After successfully setting the boundary conditions for structure support and load, these were utilized to compute the system's total deformation and the resultant forces. These reaction forces were subsequently employed as the forces exerted on the body to derive the results for total deformation and mode shapes in ANSYS.

The reaction forces for the imported load are show below in the figure 22 and 23.



The reaction forces for the imported load is show below in the figure 22 and 23.

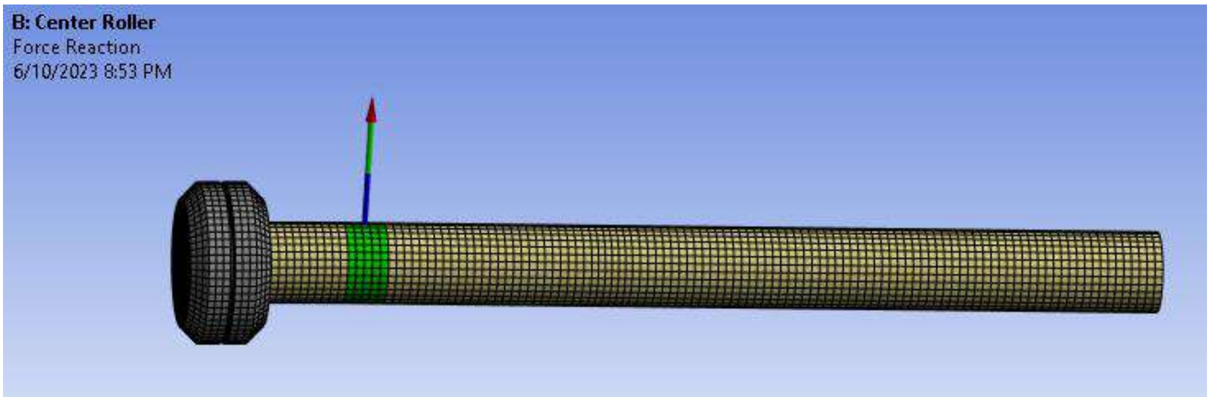


Figure 22 Front Reaction Force for Upper and Lower Shaft

Front fixed support reaction force for the upper shaft roller was 2.9651e+005 N and for the lower shaft roller was 98868 N.

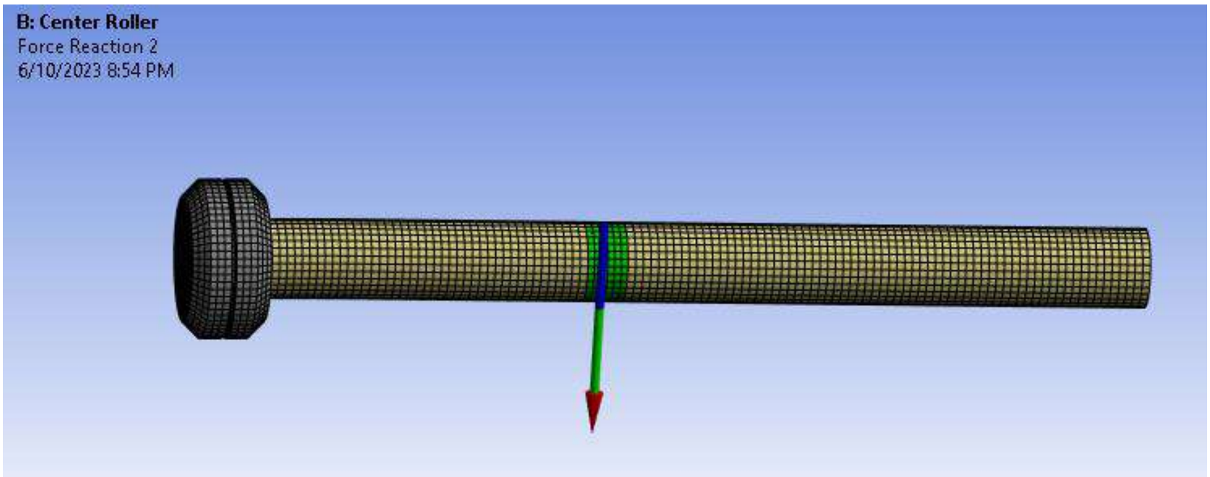


Figure 23 Back Reaction for Lower and Upper Shaft

Back fixed support reaction force for the upper shaft roller was -2107.4 N and for lower shaft roller was -659.75 N.

4.6 Static Structural Results:

The following results were obtained after solving for structural analysis under the defined load conditions. The parameters allocated for output were reaction forces and total deformation of the shaft roller assembly and the results are discussed and reaction forces and total deformation of the roller under a pre-stress condition of maximum load applied at the upper and lower roller shaft assembly is given here.[33]

- Maximum deformation observed for the upper roller is 1.39 mm for high carbon steel.
- Maximum deformation observed for the lower roller is 0.46 mm for high carbon steel.
- Reaction forces observed for the upper shaft were 5.92e005 and -2107.4 N.
- Reaction forces observed for the lower shaft were 98868 and -659.75 N.
- The produced deflection and stress are quite low as compared to the shaft roller geometry and material chosen, hence indicating that the design is safe from a structural point of view.

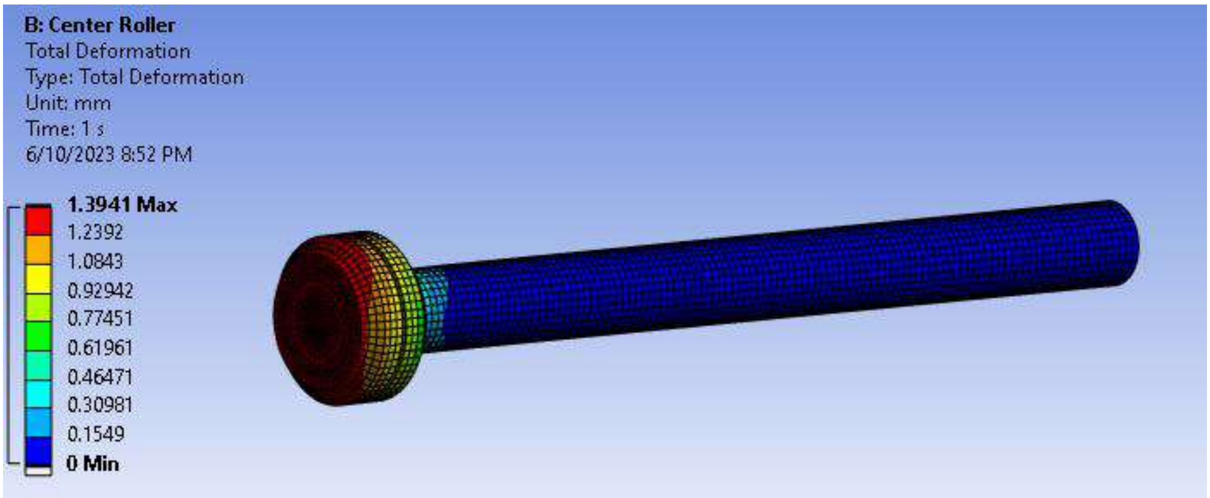


Figure 24 Total Deformation Results for Upper Roller

The color scale on the left side of the image provides a visual representation of the magnitude of the deformation. The scale starts at "0 mm" (no deformation) and goes up to "1.3941 mm Max" (maximum deformation). The color gradient from blue to red corresponds to increasing levels of deformation. Blue areas indicate little to no deformation, while red areas indicate the maximum deformation.

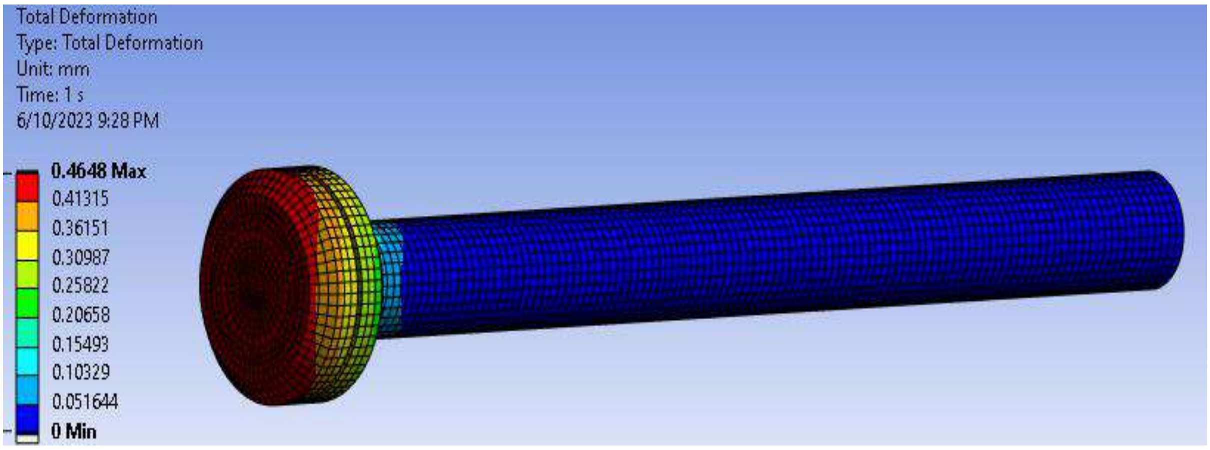


Figure 25 Total Deformation Results for Lower Roller

The deformation values are provided in millimeters. The color scale provides a visual representation of the deformation magnitude **0 mm (Min):** Represents no deformation. This is denoted by the blue color. **0.5468 mm (Max)**. Represents the maximum deformation in this simulation. This is indicated by the red color. The color gradient transitions from blue (minimal deformation) to green, yellow, and finally red (maximum deformation).

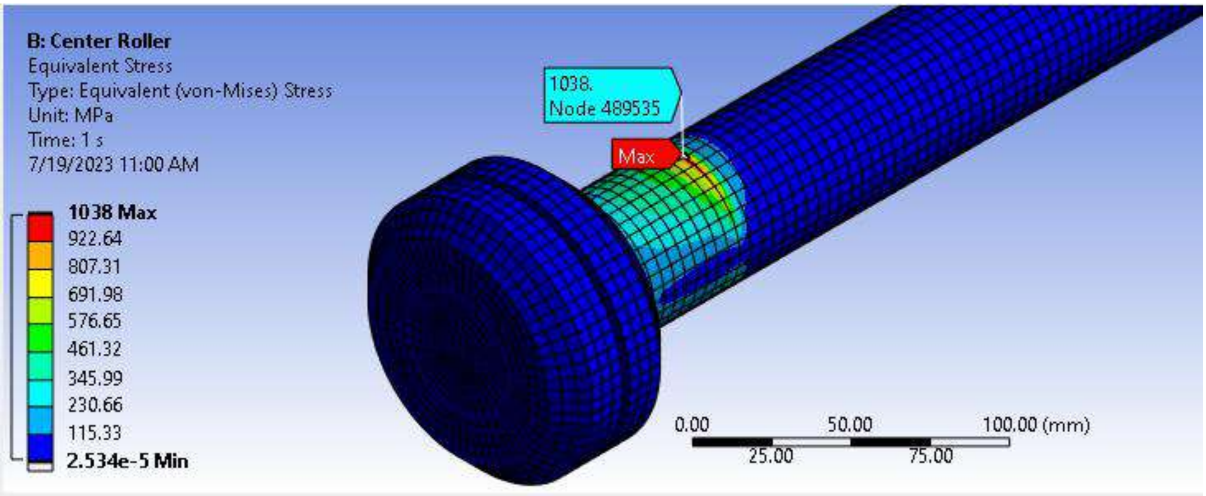


Figure 26 Von-Misses for Upper Shaft Roller

The stress values are given in megapascals (MPa), a unit of pressure or stress. The scale provides a visual representation of the stress magnitude. **2.534e-5 Min**: Represents the minimum stress value, denoted by the blue color. The "e-5" signifies that the value is in scientific notation, and it represents 2.534 x 10^-5 MPa. **102.86 Max**: Represents the maximum stress value in this simulation, denoted by the red color.

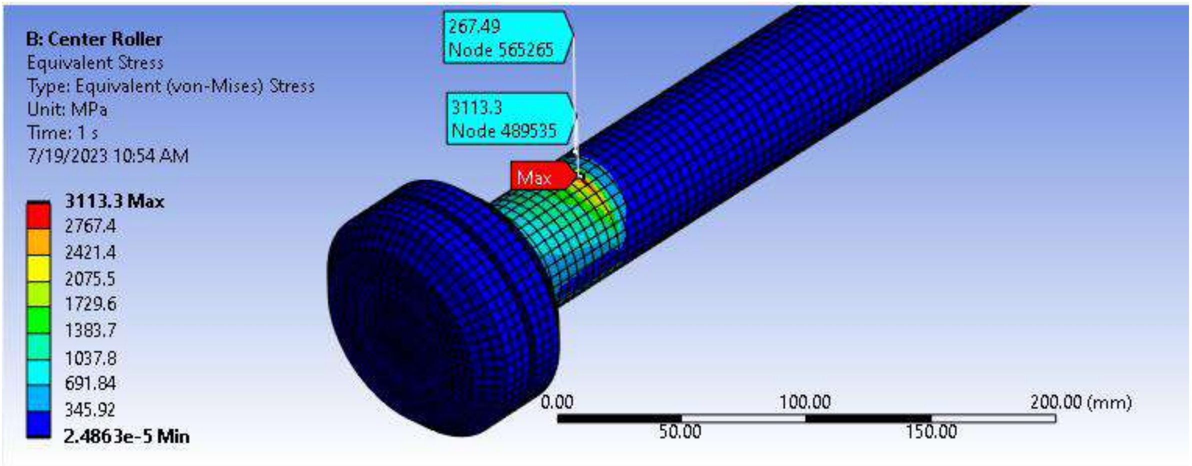


Figure 27 Von-Misses for Lower Shaft Roller

4.7 Modal Analysis:

Modal analysis examines the boundaries of a system, specifically focusing on its natural frequencies under certain conditions, like vibration amplitude. Every system has inherent natural frequencies, and at these specific frequencies, energy can be most efficiently transferred between forms. When the system's frequency approaches its natural or resonant frequency, its amplitude can drastically increase. Thus, modal analysis aids in pinpointing the exact frequency at which a system will display its highest amplitude [34].

The outputs of the static structural analysis were imported to the modal analysis module of ANSYS software, and the Pre-Stress static structural option was selected as the input conditions were already linked from the static structural module.

The number of max modes under modal analysis settings was set to 2 and under the solutions tab total deformation was selected as the outcome criteria. After defining the criteria, the system was solved and the following results were obtained to find the natural mode shapes and corresponding frequencies of our system during free vibration when the reaction forces were applied at the body. As per the input parameter, the natural frequency of our system comes out to be 110 Hz, and correspondingly the following 2 modal shapes were obtained [35].

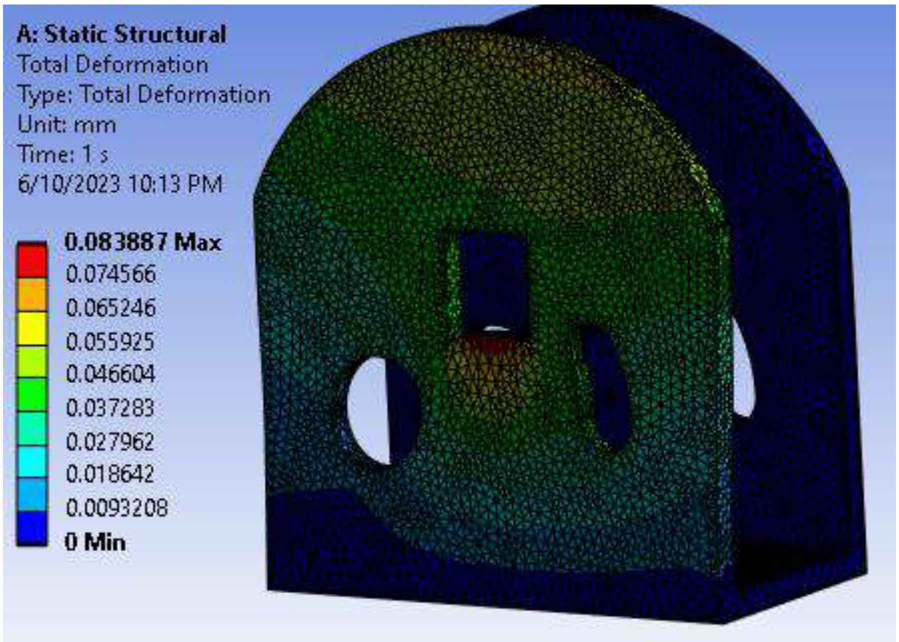


Figure 28 Total Deformation

The color gradient on the right side represents the deformation magnitude, with different colors representing different levels of deformation. In this scale: **0.083887 Max**: This is the maximum deformation value observed in the structure, and it corresponds to the color at the top of the scale. **0 Min**: Represents no deformation and corresponds to the color at the bottom of the scale.

From the modal analysis, the following natural frequencies were obtained. It can be seen here that there is no cross-over resonance at low order of excitation levels and it is clear that there is no overlapping of the reaction force resonant frequency with the operating frequency of the reaction force thus making our design the same for operation [36]

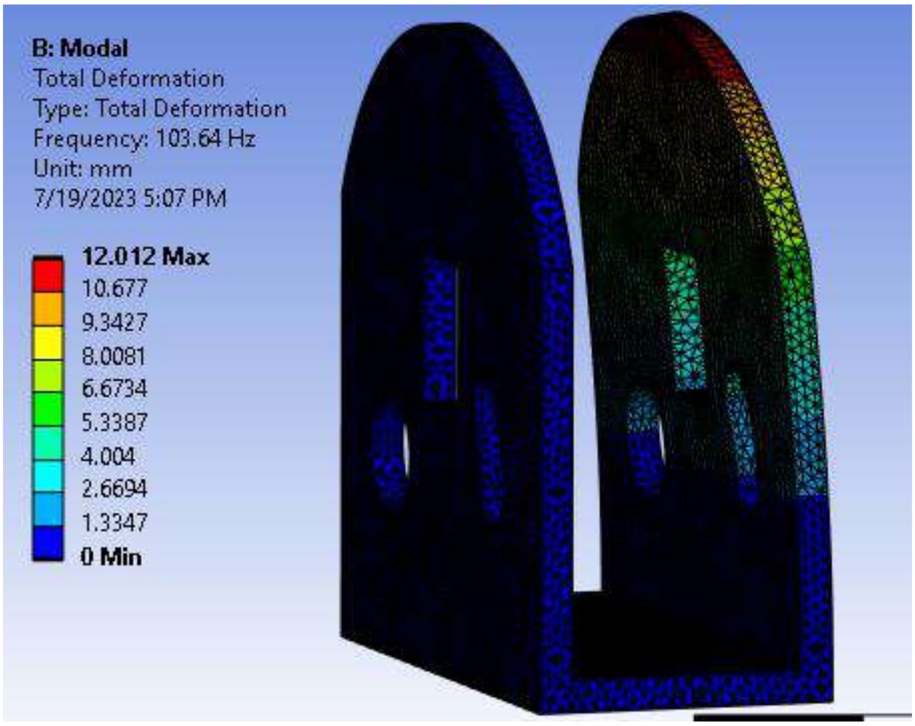


Figure 29 Mode 1 shape at Frequency 50 Hz

Similar to the previous image, deformation refers to the displacement or change in shape of a structure. Here, the analysis is showing "total deformation," which typically indicates the maximum displacement magnitude of the structure at the specified frequency. **12.012 Max**: Represents the maximum deformation value observed in the structure at this frequency. It corresponds to the color at the top of the scale. **0 Min**: Indicates no deformation and corresponds to the color at the bottom of the scale.

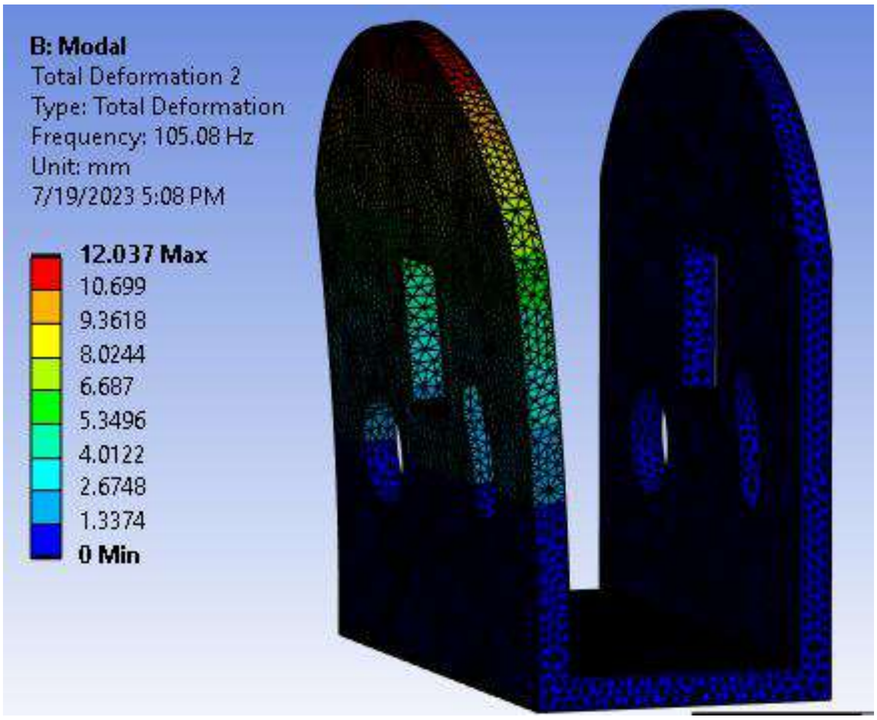


Figure 30 Mode 2 Shape at frequency 105.08 Hz

12.0037 Max is the maximum deformation magnitude observed in the structure at the specified frequency, and it corresponds to the color at the top of the scale. Any part of the structure colored with this hue has undergone deformation of approximately 12.0037 mm. **0 Min** is the minimum value on the scale, which indicates no deformation. It corresponds to the dark blue color at the bottom of the gradient. Parts of the structure with this color have experienced little to no deformation. The numbers in between the maximum and minimum values (like 10.699, 9.618, 8.024, etc.) are intermediate deformation magnitudes. The corresponding colors on the structure denote the regions with those specific deformation magnitudes. For instance, regions of the structure with the color corresponding to 9.618 have experienced a deformation of approximately 9.618 mm.

The results from our analysis shows that our body is safe under maximum loading conditions and under full load rotation on 10 rpm the vibrations of the machine does not match with the natural frequency of the machine as the modal frequencies of the two mode shapes of the body are achieved at frequencies 103.64 and 105.08 Hz respectively and our applied motor does not excite the machine to such frequency even at full loading conditions.

Chapter 5 : MANUFACTURING

5.1 Manufacturing of the three-point roll bending mill

Manufacturing and fabrication employ methods of machining and joining to convert raw materials into desired products. These processes enhance the value of the raw materials, enabling their use in machinery parts. Creating a system, technique, or machine requires a series of meticulous manufacturing steps and advanced methods. For this project, various components were crafted from materials like mild steel, high carbon steel, stainless steel, and Teflon using precision machinery, with a keen focus on accuracy, tolerances, and safety. The production of the three-point roll bender encompassed creating the body, shafts, rollers, swing arm, wedge, hydraulic containers, spring adjusters, end covers, base plates, spacer bushings, and hole threading [37].

5.2 Requirements:

The rolling mill was required to be bench-top, small enough to be transported easily and versatile to cater the different bending needs of the local industry. The second challenge was to make it energy efficient as the electricity prices in the country have sky rocketed in the recent times. Furthermore, we also focused on the material wastage that occurs during bending,

5.3 Designing:

Starting off by analyzing problems and short comings in the machines and techniques existing in the market we decided to take advantage of gears and hydraulics in our design.

5.3.1 Calculations:

Once some parameters of the machine were decided we started making the mathematical models and calculating the distances between the parts so the machine does not run into a mechanical lock

5.3.2 CAD modeling:

After determining the part dimensions and force assessments, the subsequent step was to translate our concepts into CAD designs for further refinement before fabrication. We created various models of the components to enhance the machine's functionality and aesthetics.

5.3.3 Material selection:

Choosing the right materials for the rolling mill proved challenging, especially given our budgetary limitations. It necessitated extensive brainstorming and searching across several cities to find the necessary materials.

5.3.4 Fabrication:

Once we secured the necessary materials, we commenced the fabrication phase. This phase encompassed various manufacturing techniques like cutting, turning, facing, drilling, boring, threading, grinding, welding, milling, and surface finishing. The components constructed for the machine are detailed below.

5.3.5 Body:

We started the fabrication process of the machine by making its body. The body was cut out of 28mm thick mild steel plates by a oxy-acetylene torch later faced to a thickness of 25mm to remove any distortion or imperfection on the surface. After facing the bores for shaft bearings were made using a big lathe. This was followed a by arc shaped cut and a slot to guide the moving shafts, this process was done on a vertical milling machine.

Figure 31 Mild Steel Body Plate

5.3.6 Mild steel body plate:

The shafts, measuring 15 inches, were crafted from 1050 carbon steel and meticulously tuned to a diameter of 50.01mm to accommodate the “6010” ball bearings with a 50mm bore, ensuring a snug fit. Keyways were carved on both sides of the shaft to fit the rollers and couplings. To enhance their durability and performance, the shafts underwent a hardening and tempering process.

Figure 32 Shafts Behind the Rollers

5.3.7 Rollers:

The shaping rollers are integral to a rolling mill. The machine's efficiency and the precision of the bends largely rely on the quality of these rollers and their machining. Made from 1070 high carbon steel, the rollers were crafted to a 100mm diameter with a 10mm deep groove to accommodate a metal strip that's 3mm thick. Once turned and keywayed, the rollers underwent a hardening process using Potassium Chloride.

Figure 33 Hardened Steel Roller

5.3.8 Key/keyways:

To allow relative motion between shafts, rollers and couplings we installed 10mm square keys in the precut keyways. The keys made from a square mild steel rod cut into 50mm lengths. The keyways in the shafts were cut using a vertical mill and the keyways in the rollers were cut on a shaper machine.

Figure 34 keyways Cut into the Shafts

5.3.9 Swing arm:

Our mechanism also allowed one of the bottom rollers to move upwards in an arc so the end of the strip could be bent, and smallest possible bending radii could be achieved. To do so we introduced a swing arm mechanism in our design. The swing arm was made of mild steel with a 80mm bore cut on both sides to receive “6010” ball bearings for the shafts. On the smaller end a 16.5 mm hole was drilled to allow the swing arm to pivot on a 16mm stainless steel rod.

Figure 35 Swing Arm

5.3.10 Sliders:

The top shaft could move vertically within the grooves crafted in the main body plates. These sliders were constructed from square blocks of mild steel, which were attached to a circular plate. This plate featured a cut-out to fit the housing of the shaft's bearings. To ensure a robust connection, each edge of the block was chamfered before welding. Subsequently, a hole for the shaft was drilled. Additionally, attachments for the hydraulic return springs were welded onto these sliders.

Figure 36 Sliders Along with Shaft Housing, Roller, and Swing Arm can be Seen

5.3.11 Shaft housing:

The shaft housing houses the upper shaft using 6010 bearings. The force applied to the upper roller comes through this housing since the hydraulic jack is positioned within the housing structure. Given the demands on this component, a robust steel grade was essential. We used a piece of tempered steel drill pipe to create the housing for the shaft bearings. During assembly, this housing was fitted into the groove carved in the slider plate.

Figure 37 Shaft Housing with Bearing Installed

5.3.12 Wedge:

A triangular wedge was made out of 4-inch-thick mild steel bar. The wedge being pushed by the hydraulic jack operates the swing arm to move the bottom roller in an arc. The wedge slides on a smooth platform made of a four inch “C” channel and guides welded to the sides of the wedge keeps the wedge on track. Washers were also welded to pull the wedge back when the jack retrieves.

5.3.13 Hydraulic housings:

The hydraulic housings enclose and provides a base for the operation of the hydraulic jacks the housing was made of “C” channel cut, bent, and welded in a “U” shape this housing was later welded to the body plates during the assembly phase. Hazard tape was also placed on the housing to ensure safety.

Figure 38 Hydraulic Housing during Its Fabrication

5.3.14 Spring tensioners:

Springs were fitted to reset the hydraulic jacks to their starting position. Tensioners were incorporated to preload the return springs. These tensioners were created by welding M-10 stainless steel studs to an eyelet, allowing for adjustment of spring tension. One end of the stud was fashioned into a wedge shape, and a corresponding cut was made on a washer. Both components were then fused together using stainless steel welding rods.

Figure 39 Spring Tensioners

5.3.15 Spacer bushings:

To counter the gap between the side plates and the swing arm, mild steel spacer bushings were turned on the lathe machine so that the swing arm stays in the center when the machine is assembled.as it was just a spacer it did not require any special material or heat treatment.

Figure 40 Space Bushing

5.3.16 End caps:

End caps were installed at the end of the shafts so the rollers do not come off during the operation. The end caps were made of Teflon and a dome head M-6 bolt is tightened to the shaft. A chamfer is made on the end cap's circumference and painted matt black to improve its appearance. Although the key fixes the rollers into place the end caps are installed as an added safety feature.

Figure 41 End Cap Painted Plate

5.3.17 Base plate:

The base plate serves as the base for all the other parts and sub-assemblies and also fixed the machine to the bench top of a platform using M-12 bolts. The base is made of three quarter inch (19mm) thick mild steel plate and the body plates are welded to it. The machine can also be lifted by attaching eye-bolts to the base and running a sling trough them.

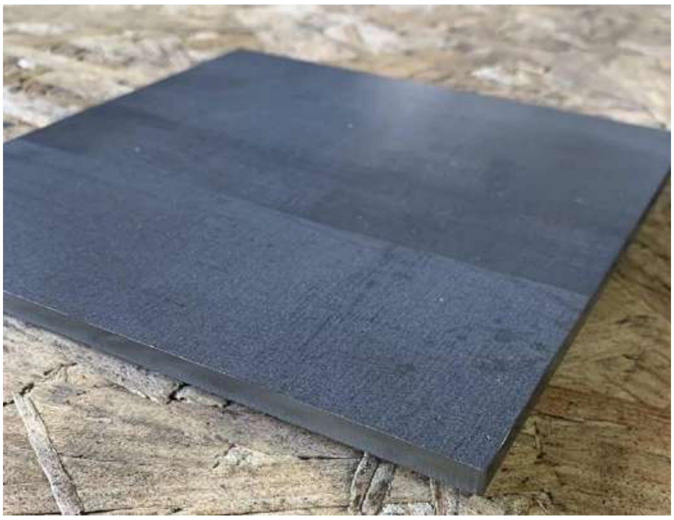


Figure 42 Steel Plate for Base

5.4 Assembly:

Once all the required parts were manufactured and the supporting elements purchased it was time to assemble the parts into sub-assemblies and the machine. First all the bearings were properly cleaned and greased using NLGI3 lithium grease. The housings where the bearings were to be installed were properly de-burred and cleaned of all the dust particles. The bearings were then pressed by a hydraulic press. One 6210 ball bearing was installed in each body plate in the 90mm bore made on the left side. Four 6010 ball bearings two on each side were pressed into the 80mm recess made in the swing arm. Similarly, four 6010 ball bearings two from each side were pressed into the 80mm recess in the top shaft housing. The hole in the front of the shafts was tapped for M-6 bolts. The shafts were then assembled in the specific locations. A 16mm stainless steel rod to pivot the swing arm was pressed into the rear plate. Now the spacer bushings and the swing arm could be assembled. After this the front plate was assembled and this sub assembly was now ready to be attached to the base plate. The base plate was cleaned, and markings were made for all the parts that were attached onto it. The platform for the wedge was welded on the base plate ensuring that the surface is leveled. The body plates with the other parts attached to them were placed at the pre marked location and tack welded temporarily. The machine was then checked to ensure the smooth operation of all the parts, once ensured the body plates were properly welded permanently to the base. In the next step hydraulic housings were welded at the pre marked locations and the hydraulic jacks along with the tensioners and return springs were installed. Once all the parts were assembled and tested the machine was prepared for paint job. After the paint job all the moving parts were lubricated.

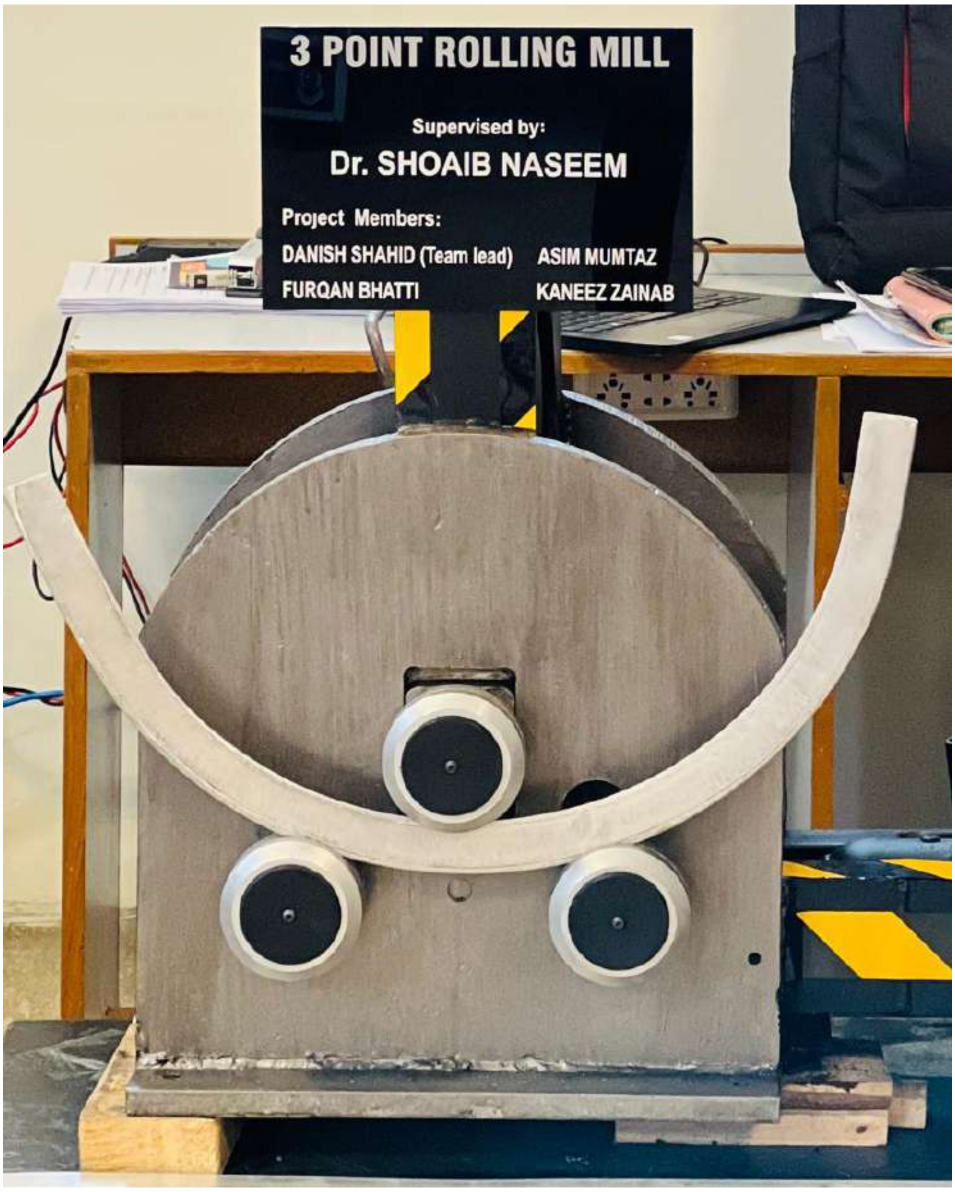


Figure 43 Rolling Mill After Assembly

Chapter 6 : CONCLUSION

The Final chapter provide a summary and recommendations for follow-up study on the accomplishments made in this dissertation.

6.1 Conclusion

- Aerospace and aviation industries demand precise bending due to zero margin for error.
- Bending is crucial across all metalworking industry segments.
- In Pakistan, various metal components are handmade, using manual methods or paddle mixers for bending.
- Current market lacks a machine for effectively producing conical ribbons.
- Existing profile bending machines waste material and may cause flat bar cracking, requiring complex calculations.
- Proposed machine design:
- Bottom roller moves in an arc to wind strips around the upper roller for precision and minimal material wastage.
- Designed for variable pitch and diameter blender ribbons.
- Can bend up to 2-inch wide and 3mm thick mild steel strips.
- Interchangeable rollers for bending rods, round/profile pipes, and embossing during bending.
- Capable of manufacturing variable pitch ribbons for multistage mixing.
- Minimizes material wastage at ends.
- Calculates force required for bending metal strips of set dimensions.
- Features a steel swing arm mechanism for precise bending at strip ends, reducing costs and material wastage.

- Equipped with a 30-ton hydraulic control system.
- Utilizes 1070 grade carbon steel rollers known for high strength and load-bearing capacity.

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