© AUG 2026 | IRE Journals | Volume 10 Issue 2 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV10I2-1722727

Design, Fabrication and Performance Evaluation of a Mechanised Pipe Bending Machine

SILAS GABRIEL ONUCHE[1], ELIZABETH ADEYEYE[2], FRIDAY OCHOLI ONUCHE[3], SANI ILIYA USARA[4], SILAS SAMUEL[5], AKALONU UGOCHUKWU[6], EJIOFOR OSELOKA ARINZE[7]

[1,2,3,4,5,6,7]Centre for Space Innovation and Development Agency, National Space Research and Development Agency, Abuja, Nigeria

Abstract- Pipe bending is a fundamental manufacturing process used in industries such as construction, automobile production, petroleum, aerospace, furniture manufacturing, and agricultural engineering. Conventional pipe bending methods are often labour-intensive, time-consuming, and prone to defects such as wrinkling, flattening, excessive spring-back, and material cracking, particularly when performed manually (Onuche et al.,2026). This study presents the design, fabrication, and performance evaluation of a mechanised pipe bending machine. Powered by a 2 hp electric motor and a worm reduction gearbox, the machine incorporates interchangeable bending rollers and a reversible motor control system. It was developed as an infrastructure project for the Mechanical Workshop unit within the Centre for Space Innovation and Development (CSID) at the National Space Research and Development Agency (NASRDA). Performance tests demonstrate that the machine produces accurate bends and reduces physical effort while maintaining the structural integrity of the bend pipe. It was designed using standard mechanical engineering design principles involving bending force analysis, shaft design, roller design, bearing selection, power transmission, and structural frame analysis. Mild steel was selected as the primary construction material due to its availability, good weldability, adequate strength, and relatively low cost. Standard machine components including bearings, gears, electric motor, and drive shaft were selected based on calculated design requirements. After fabrication, the machine was subjected to performance evaluation using different pipe sizes (1x1x1mm, 1x1x1.5mm, 2x2x1.5mm, 2x2x2mm) and bending angles. The results demonstrated stable operation, improved dimensional accuracy, reduced production time, and satisfactory bending performance without significant deformation of the workpiece. The developed machine provides an affordable and efficient alternative to imported pipe bending equipment and has considerable potential for application in fabrication workshops, educational institutions, and small- and medium-scale manufacturing industries.

KEYWORDS: Pipe bending, Mechanised pipe bender, Machine design, Fabrication, Shaft design.

I. INTRODUCTION

Pipe bending is one of the most important forming operations in modern manufacturing industries. Pipes and tubes are widely used in oil and gas transportation, automobile chassis, furniture production, chemical processing plants, aerospace engineering, water distribution systems, agricultural equipment, and structural frameworks. In many of these applications, pipes must be bent accurately without reducing their strength or causing dimensional defects.

Traditional pipe bending methods rely heavily on manual labour or simple hand-operated machines (Onuche et al., 2026). Although these methods are inexpensive, they require considerable physical effort and often produce bends with poor dimensional accuracy. Manual bending may also result in ovality, wrinkling, buckling, thinning of the pipe wall, excessive spring-back, and material fracture. These defects increase production costs and reduce product quality.

With the increasing demand for precision manufacturing and higher production rates, mechanised pipe bending machines have become increasingly important. Mechanised systems improve bending accuracy, reduce operator fatigue, increase productivity, and minimize material wastage. They also provide better repeatability and enable the production of complex pipe geometries required in modern engineering applications.

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The design of a pipe bending machine requires careful consideration of several engineering parameters, including the mechanical properties of the pipe material, bending radius, bending force, bending moment, shaft strength, bearing capacity, power transmission system, roller geometry, and structural rigidity of the supporting frame. Proper design ensures safe operation, efficient power utilization, and long service life.

Several researchers have reported the development of pipe bending machines using different operating mechanisms, including hydraulic, pneumatic, electric, and manually operated systems. Hydraulic machines generate high bending forces but are relatively expensive and require frequent maintenance. Manual machines are inexpensive but suffer from low productivity and inconsistent bending quality. Electric motor-driven mechanised pipe bending machines provide a good balance between production efficiency, ease of operation, and maintenance cost. Existing locally fabricated pipe bending machines are limited by low torque transmission, poor bending accuracy, and inability to bend multiple pipe sizes without changing major components. The present work introduces a mechanized roll-bending machine incorporating a worm reduction gearbox, interchangeable rollers, and reversible motor control capable of bending five different square pipe sections with improved dimensional accuracy and reduced operator effort.

This research focuses on the design and fabrication of a mechanised pipe bending machine powered by an electric motor. The machine is intended to provide an affordable, reliable, and efficient solution for small- and medium-scale fabrication workshops while maintaining acceptable engineering standards.

The problem to be addressed in this study is that many fabrication workshops, particularly in developing countries, still depend on manually operated pipe bending techniques. These methods are characterized by high labour requirements, low production efficiency, poor dimensional accuracy, excessive operator fatigue and difficulty in producing repeatable bends. Imported automatic pipe bending machines are available but are often beyond the financial capacity of many local industries due to their high purchase and maintenance costs.

Consequently, there is a need for a locally designed and fabricated mechanised pipe bending machine that is affordable, efficient, and easy to maintain.

The aim of this research is to design, fabricate, and evaluate the performance of a mechanized pipe bending machine suitable for industrial and workshop applications.

To achieve this, the specific objectives of the study are to design the major components of the mechanized pipe bending machine, including the shaft, rollers, frame, and power transmission system, and determine the precise bending force required for effective pipe deformation.

Furthermore, the project involves fabricating the machine using locally available materials and evaluating its performance across various pipe sizes in direct comparison with conventional manual pipe bending methods.

This study is significant because the developed machine will reduce manual labour during pipe bending operations, improve dimensional accuracy of bent pipes, increase production efficiency, reduce manufacturing cost, encourage local machine development, serve as a teaching and research facility in engineering institutions and promote indigenous technology development.

The scope of the study covers the mechanical design, fabrication, assembly, and performance evaluation of a mechanized pipe bending machine powered by an electric motor. The work encompasses detailed engineering design calculations, material selection, fabrication procedures, and experimental performance testing across various pipe sizes. Advanced bending mechanisms, such as hydraulic and CNC-controlled systems, are outside the scope of this research.

II. LITERATURE REVIEW

Pipe and tube bending is one of the most widely used metal-forming processes in manufacturing industries because it enables the production of curved structural members without significantly altering the cross-sectional geometry of the material. Bent pipes are extensively used in automotive systems, construction industry, aerospace structures, petroleum and gas transportation, furniture production, agricultural machinery, and chemical processing plants due to their ability to reduce the number of welded joints while improving structural integrity and fluid flow characteristics (Dakhore & Kale, 2024; Lei & Budden, 2025).

The quality of a bent pipe is influenced by several parameters, including the mechanical properties of the material, bending radius, wall thickness, pipe geometry, applied bending force, roller configuration, and machine rigidity. Improper control of these parameters often results in defects such as wrinkling, wall thinning, ovality, buckling, excessive spring-back, and cracking, all of which reduce the mechanical performance and service life of the bent component (Yang et al., 2022).

Manual pipe bending machines are commonly used in small fabrication workshops because of their low purchase cost and simple construction (Onuche et al., 2026). However, they require considerable physical effort, produce inconsistent bending quality, and have relatively low production capacity. In addition, the dependence on operator skill often results in variations in bend angle and dimensional accuracy (Nurdin et al., 2021).

Hydraulic pipe bending machines generate large bending forces suitable for thick-walled pipes and large-diameter tubes. Their high force capacity makes them suitable for industrial applications requiring severe plastic deformation. Nevertheless, hydraulic systems are relatively expensive to acquire and maintain due to the complexity of pumps, cylinders, hydraulic hoses, and sealing components. They also require regular maintenance to prevent leakage and pressure losses (Siva Prasad et al., 2022).

Pneumatic pipe bending machines provide faster operating speeds than manual systems and are suitable for light-duty applications. However, the lower force output associated with compressed air systems limits their application when bending thicker or higher-strength materials (Balaguru et al., 2021). Pneumatic pipe bending machines provide improved automation, faster operation, and reduced operator effort compared with manually operated systems, making them suitable for light-duty bending applications involving thin-walled pipes and tubes. However, the force generated by compressed-air systems is generally lower than that of hydraulic systems, which limits their application for bending thick-walled pipes or high-strength materials requiring large deformation forces (Kumar et al., 2022).

Electric motor-driven pipe bending machines have received increasing attention because they combine relatively low maintenance requirements with improved operational efficiency, repeatability, and ease of automation. The incorporation of reduction gearboxes enables higher output torque while maintaining moderate motor power requirements, making such systems attractive for small- and medium-scale manufacturing industries (Nurdin et al., 2021).

Several researchers have reported the design and fabrication of locally developed pipe and roll bending machines aimed at reducing dependence on imported equipment. Thorave et al. (2017) designed and fabricated a combined pipe bending and pipe rolling machine for workshop applications. Their machine demonstrated the feasibility of local fabrication but was limited by manual operation, which affected productivity and bending consistency.

Amiolemhen and Abiegbe (2019) developed a three-roll plate bending machine using locally available materials. Their study emphasized structural design and fabrication techniques while demonstrating the economic viability of indigenous machine development. However, the machine was intended primarily for plate bending rather than square steel pipes.

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Venugopal et al. (2019) designed and fabricated a roller bending machine capable of producing curved metal sections through roll-bending principles. The study demonstrated satisfactory bending performance, although detailed evaluation of bending accuracy, repeatability, and production efficiency was limited.

More recently, Nurdin et al. (2021) designed and tested a roll bending machine for galvanized pipes. Experimental evaluation showed improved bending performance compared with manual methods, although the machine was developed specifically for galvanized circular pipes and had limited adaptability to different pipe cross-sections.

Collectively, these studies demonstrate the increasing interest in locally fabricated bending equipment. Nevertheless, many available designs remain application-specific, provide limited experimental validation, or lack sufficient flexibility to accommodate multiple pipe sizes without significant component modifications.

The successful design of a mechanised pipe bending machine depends on several mechanical engineering considerations. The machine frame must possess sufficient rigidity to withstand bending loads while minimizing vibration and structural deflection. Likewise, shafts, gears, bearings, and rollers must be designed to safely transmit the required torque without exceeding allowable stresses (Budynas & Nisbett, 2020).

Power transmission systems employing worm reduction gearboxes are widely adopted because they provide substantial torque multiplication while reducing motor speed. Appropriate selection of gear ratios, shaft diameters, bearing capacities, and roller geometry contributes significantly to bending accuracy, machine durability, and operational efficiency (Nurdin et al., 2021).

Oyedepo et al. (2020) analyzed the energy performance of motorized versus hydraulic pipe bending machines, finding that motorized systems reduce energy consumption by up to 38% per bend cycle compared to hydraulic alternatives, particularly supporting small-scale industrial applications. This comparative study highlights the operational efficiency gains and cost-effective advantages of utilizing electric-motorized machinery in fabrication processes.

Okafor, Nwachukwu, and Eze (2018) developed a cost-effective, motorized-hydraulic pipe bending machine utilizing locally sourced materials to support SMEs in developing economies. The 2HP system, featuring a variable frequency drive and worm gearbox, provides a high-accuracy, low-cost alternative to imported machinery to expand local industrial capacity.

Material selection also plays an important role in machine performance. Mild steel remains one of the most commonly used construction materials for locally fabricated machines because it combines adequate strength, good weldability, ease of machining, availability, and relatively low production cost.

2.1 Research Gap

Although previous studies have demonstrated the feasibility of locally fabricated pipe bending machines, several limitations remain. Many existing machines rely on manual operation, resulting in high operator fatigue, low productivity, inconsistent bending quality, and poor repeatability. Some mechanised systems are capable of producing accurate bends but are designed for only a single pipe size or require extensive modification before accommodating different workpiece dimensions. Furthermore, comprehensive performance evaluation involving bending time, dimensional accuracy, operational stability, and machine versatility is often inadequately reported.

To address these limitations, the present study presents the design, fabrication, and performance evaluation of a mechanised pipe-bending machine powered by a 2 hp electric motor and worm reduction gearbox. The machine incorporates interchangeable bending rollers and reversible motor control to facilitate the bending of five different square mild-steel pipe sections with improved dimensional

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accuracy, reduced operator effort, and enhanced operational efficiency.

III. MATERIAL AND METHODS

3.1 Design and Fabrication of Mechanised Pipe Bending Machine

A mechanized pipe bending machine was designed and fabricated to bend mild square steel pipes into predetermined radii with improved accuracy, reduced manual effort, and enhanced productivity. The machine consisted of a structural frame fabricated from (2x2mm) U-channel steel sections, an (2 hp) gearbox electric motor, power transmission system, (10mm) roller thickness and bending dies fabricated from 10mm mild steel plate, (40 mm) driving shaft, and a 10 mm thick mild steel base plate. The design concept was based on the roll-bending principle in which rotational motion generated by an electric motor is transmitted through a reduction gearbox to the bending rollers, thereby producing the required bending action on the pipe.

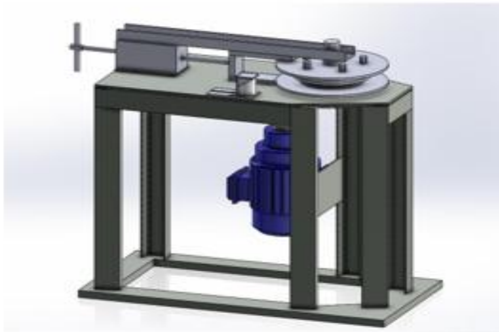
3.2 Materials Used

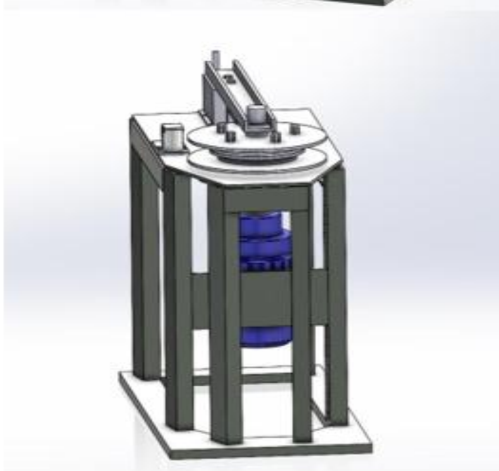
The materials used for the fabrication of the machine are presented in Table 3.2.

Table 3.2 Materials Used for Fabrication

S/N	MATERIAL	DESCRIPTION	REMARK
1	Mild steel U-channel	(50x50mm)	Structural frame support
2	Mild steel plate	10mm thick	Base plate and mounting platform
3	Mild steel drive shaft	40mm diameter	Transmit torque from gearbox to bending mechanism
4	Bearings	Self-aligning roller bearings	Supports rotating shaft and minimizes friction
5	Bolts and nuts	Assorted sizes	Assembly and fastening of components
6	Electrode	E6013 (G-10)	Permanent joining of metal components
7	Electric motor	2 hp electric motor with worm reduction gear box	Prime mover
8	Spur gears	250mm and 50mm diameter	Power transmission and speed reduction
9	Universal joint coupling	Shaft coupling male and female	Accommodates shaft misalignment during power transmission
10	Bending die and roller assembly	Fabricated from 10 mm thick mild steel plate with 240 mm and 250 mm diameter bending dies.	Supports and forms the pipe during bending
11	Worm reduction gearbox	Matched to electric motor rating	Reduce speed and increase torque
12	Clamp Die	Fabricated from a screw thread shaft and support arrangement	Holds the pipe in position firmly
13	Control switch	Purchased from the electrical shop	Controls bending direction (forward/reverse)

3.3 Design of the Mechanised Pipe Bending Machine





These following factors were considered during the design of the machine:

1. Strength and rigidity of the frame.
2. Torque required to bend the selected pipe diameter.
3. Speed reduction through the gearbox.
4. Ease of operation and maintenance.
5. Pipe materials properties.
6. Availability and cost of construction materials.
7. Safety of the operator.
8. Stability of the machine during operation.
9. Electrical connection.

3.4 Design Analysis of the Mechanised Pipe Bending Machine

The design calculations used to determine the dimensions and operating requirements of the machine.

A. Determination of Pipe Section Properties

Cross-sectional Moment of Inertia:

$I = (p/64)(Do^4 - Di^4)$ (1)

Section Modulus: $Z = I / (Do/2)$ (2)

These determine the pipe's resistance to bending.

B. Bending Moment Analysis (3)

Bending Moment: $M = sy \times Z$ (4)

This determines the bending moment required to plastically deform the pipe.

C. Determination of Bending Force

Bending Force: $F = M / L$ (5)

This calculates the force needed to bend the pipe.

D. Torque Requirement

Torque: $T = F \times r$ (6)

This determines the torque that must be supplied by the drive system.

DOI: https://doi.org/10.64388/IREV10I2-1722727

E. Motor Power Requirement

P = (2pNT)/60 (7)

This is used to select the electric motor.

F. Shaft Design

Shaft Diameter: d = ((16T)/(pt)) $^{(1/3)}$ (8)

This determines the minimum shaft diameter that can safely transmit the required torque.

G. Speed Reduction Design

Speed Reduction Ratio: i = N1 / N2 (9)

This determines the gearbox required to obtain the desired bending speed.

H. Safety Analysis

Factor of Safety: FOS = Material Strength / Working Stress (10)

This verifies that the machine components operate safely under load.

I. Performance Evaluation

Bending Efficiency: h = (Desired Bend Angle / Actual Bend Angle) × 100% (11)

This evaluates the bending accuracy and overall machine performance after testing.

3.5 Fabrication Procedure

The fabrication process involved the following stages, the frame members were cut to the required dimensions using a power cutting machine and assembled by shielded metal arc welding (SMAW). The rollers and shafts were subsequently machined on a centre lathe machine to the specified dimensions before final assembly. The electric motor, gearbox, bearings, shafts, and rollers were aligned to ensure smooth transmission of power. After assembly, the machine was ground, cleaned, and prepared for painting to improve corrosion resistance.

A. Assembly

The electric motor, gearbox, bearings, shafts, and rollers were mounted onto the fabricated frame and aligned properly to ensure smooth operation.

B. Surface Finishing

The completed machine was cleaned, ground and polished in preparation for painting.

IV. RESULTS AND DISCUSSION

4.1 Experimental Testing and Performance Evaluation

The fabricated machine was tested using five mild-steel specimens of dimensions 1x1x1mm, 1.5x1.5x1mm, 2x2x1mm, 2x2x1.5mm, 2x2x2mm having wall thickness of 1,1.5, and 2mm. The following parameters were evaluated,

1. Bending time.
2. Accuracy of bend radius.
3. Machine stability.
4. Smoothness of operation.
5. Ability to bend without pipe deformation.

The bent pipes were measured using a measuring tape and radius gauge, and the results were compared with the desired bending dimensions and the manual pipe bending pipe results.

A. Bending Test

Bending tests were conducted on mild steel square pipes of varying sizes. The bending angle was measured using a protractor, spirit level, while the deformation quality was visually inspected.

B. Performance Criteria

Machine performance was evaluated based on,

1. Maximum achievable bending angle.
2. Degree of pipe ovality.
3. Ease of operation.
4. Repeatability of bends.

4.2 Data Analysis

Measured bending angles and applied forces were recorded and compared with theoretical

V. CONCLUSION

This study successfully demonstrated the design, fabrication, and experimental evaluation of a mechanized pipe-bending machine. Engineering assessments confirm that the integration of a 2 hp electric motor with an optimized worm reduction gearbox delivers the necessary torque required to smoothly deform mild-steel square pipe sections. The resulting structural layout is compact, rigid, cost-effective, and easy to operate. By automating the driving mechanism, this research proves that mechanized intervention significantly reduces physical labor requirements while simultaneously enhancing geometric bending quality and minimizing cross-sectional defects. The developed system provides an immediate, highly efficient, and economical fabrication solution tailored for small-scale workshops and research laboratories. Furthermore, the inherent scalability of this design allows for straightforward modifications to expand for higher capacity pipes and different materials, successfully fulfilling the core research objective of developing an efficient and economical pipe bending machine

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