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Design And Fabrication of a Manually Operated Pipe Bending Machine

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Abstract- This study presents the design, fabrication, and performance evaluation of a manually operated pipe bending machine developed as a low-cost and energy-independent alternative to electrically powered systems. The machine was designed and constructed at the Centre for Space Innovation and Development of the National Space Research and Development Agency (NASRDA) Abuja, Nigeria. The aim of the project is to produce a manually operated pipe bending machine to meet the fabrication needs of the centre for space innovation and development mechanical workshop. The machine was produced using locally sourced material to promote affordability and ease of maintenance for small-scale workshops and educational laboratories. The machine incorporated a rigid steel frame, a manually driven lever mechanism, adjustable bending dies, and support rollers to ensure uniform force distribution during operation. The machine consists of a 90mm round steel pipe frame welded to a 10mm steel flat bar,10 x 630mm mild steel plate manually driven lever mechanism. 305mm, 315mm, 465mm mild steel adjustable die and 150mm mild steel support rollers to ensure uniform force distribution during bending operations. Engineering design calculations were carried out to determine the required length lever, shaft diameter, bending force, torsional resistance, and structural integrity of the frame. Standard manufacturing processes include cutting, machining, welding, and assembly. Performance testing was carried out by bending the following gauge of metal square pipes,1x1mm,1.5 x 1.5mm, 2 x 2mm to predetermined angles. The results showed smooth bends with minimal wrinkling, cracking and cross-sectional distortion. The bending accuracy repeatedly confirms the machines suitability for fabricating structural frames such as gates, furniture and tricycle components. The developed manual pipe bending machine offers an economical, efficient and easy to operate alternative to conventional bending equipment.

Keywords: Manual Pipe Bending Machine, Pipe Bending Machine Design and Fabrication, Low-Cost Manufacturing Equipment, Lever Operated Bending System, Square Pipe Bending, Locally Fabricated Machine

I. INTRODUCTION

Energy Pipe bending is a fundamental manufacturing process that is widely used in fabrication set-ups for the producing structural frames, automotive components, agricultural equipment and various engineering structures. Bent pipes and hollow sections are commonly utilized to improve structural strength, reduce welding joints, enhance load distribution, and achieve better aesthetic finishing. The quality of bent pipes depends greatly on bending accuracy, surface finish, and absence of bending defects such as wrinkling, flattening, cracking, and excessive springback effects. Several pipe bending machine techniques are employed in industrial practice, including rotary draw bending, compression bending, roll bending, and press bending. While hydraulic and electrically actuated bending machines provide high efficiency and precision, their high acquisition cost, maintenance requirements and electrical power supply limits their accessibility in small-scale workshops and developing economies. Consequently, many local fabrication workshops rely on improvised manual methods such as hammering, heating, or using simple supports, which often results in dimensional defects, structural weakening, and poor surface finishing.

The development of a pipe bending machine provides a cost-effective and practical alternative suitable for small and medium-scale fabrication application. Manual machines are generally easy to maintain, portable, affordable and non-dependent on electricity power, making them the best choice for field operations and rural use. In addition, the local fabrication of such machines encourages indigenous technological development and reduces reliance on imported equipment. Previous studies have investigated the design and fabrication of low-cost

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pipe bending machines, however, some of the existing design flaws such as insufficient structural rigidity, limited bending capacity, inconsistent bending radii, and poor surface finishing quality were present.

Therefore, there is a need for an improved manually operated pipe bending machine capable of producing accurate bends with minimal deformation and better operational efficiency. This study focuses on the design, fabrication, and performance evaluation of a manually operated pipe bending machine for bending mild steel pipes within selected gauges, diameters suitable for small-scale fabrication workshops and laboratories. The developed machine is evaluated based on bending accuracy, deformation characteristics, ease of operation, and mechanical efficiency. The outcome of this research contributes to affordable manufacturing technology and supports the development of locally engineered fabrication through the National Space Research and Development Agency (NASRDA) Innovation and Development Centre. Although advanced hydraulic and electrically powered bending machines provide high precision and efficiency, they require complex maintenance and their cost of procurement is high. Their dependence on electric power supply makes them unsuitable for many small-scale workshops and as a result, local fabricators resort to improvised manual bending methods. Existing low-cost manual pipe bending machines available in some workshops also prevent challenges such as insufficient structural engineering, limited bending capacity, inconsistent bend angles, excessive operator effort, and reduced mechanical efficiency. These limitations highlight the need for an improved manually operated pipe bending machine that is structurally robust, affordable, easy to operate and capable of producing accurate bends with minimal deformation.

The aim of this study is to design, develop and evaluate the performance of a manually operated pipe bending machine capable of producing accurate bends in selected mild steel pipe sizes with good surface finish and minimal structural defects.

The objective of this research is to design the structural component of a manually operated pipe bending machine using appropriate engineering design principles. Performing design calculations to determine required bending force, lever length, shaft diameters, bending stresses, torsional resistance. Compare experimental results with theoretical design predictions and to evaluate the mechanical efficiency and operational reliability of the developed machine.

This study is significant because there was no manually operated pipe bending machine in the mechanical engineering workshop of the Centre for Space Innovation and Development (CSID). It contributes to local manufacturing capability by promoting indigenous design, material selection, and fabrication using locally available resources. The study enhances practical understanding of deformation behaviours in mild steel pipes and the machine has the potential to improve productivity, reduce material wastage, and enhance product quality in workshops.

The scope of the work includes, mechanical design calculation for bending force, lever arm length, shaft diameter, bending stress, torsional resistance. Selection of suitable construction materials based on strength, availability and cost. Fabrication and assembly of the machine using locally sourced materials. Experimental performance evaluation based on bending accuracy, deformation characteristics (flattening and wrinkling), surface finish quality, and flexibility of operations. Assessment of mechanical efficiency and structural stability under manual loading conditions.

II. LITERATURE REVIEW

Several researchers have contributed to the development and improvement of manual pipe bending machines with emphasis on cost, efficiency, and ease of operation.

S. S. Gupta (2015) designed and fabricated a manually operated pipe bending machine using a lever mechanism, focusing on producing a low-cost and simple bending system suitable for small workshops. Their study demonstrated that manual bending machines can effectively replace expensive powered machines for light-duty operations.

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A. H. Khan (2017) worked on the design development and experimental study of pipe bending machines with pipes of varying thickness to reduce the cost of the machine and to reduce human efforts.
M. A. Zainal et al. (2023) discussed the design and fabrication of a hydraulic pipe bending machine, noting that such machines are used for bending iron and steel pipes, that standard pipe benders are usually fixed in a single location, and that portable pipe benders are often extremely expensive.

A. Kot et al. (2020) presented the design and manufacturing of an automatic sheet metal bending machine, explaining that bending machines are commonly used in machine shops for shaping metal in various industrial operations, such as forming coils or V-shaped components, and highlighting the need for a more feasible solution for bending smaller sheet metal in small-scale industries, which the project aims to address.

P. Vikram (2021) presents a finite element–based design and analysis framework for rotary draw tube bending, focusing on the evaluation of stress distribution, deformation characteristics, and key process parameters. The study demonstrates the application of numerical simulation in optimizing bending conditions and reducing reliance on physical prototyping, thereby contributing to improved efficiency, accuracy, and reliability in tube bending machine design and development.

D. Guo et al. (2025) conducted a system design and experimental study of a four-roll bending machine, addressing the urgent need for high-precision manufacturing of curved components through the development of a fully servo-driven, multi-axis controlled bending system.

P. Bałon et al (2024) contributed by detailing the process requirements, material considerations, and strict quality constraints involved in bending pipes for aircraft frame and truss components, providing a high-precision aerospace benchmark that underscores the limitations of manually operated pipe bending machines.

A. Stephen et al (2023) contributed by demonstrating how a centerline radius and bend angle of 1.34° influence the design and construction of a pipe bending machine, emphasizing the importance of geometric control in achieving acceptable accuracy in manually operated, low-cost bending systems.

H. Wen et al (2016) described the design of an automatic pipe bender for greenhouse frames, highlighting how geometric accuracy and consistency in bent pipes directly affect the structural performance and operational efficiency of greenhouse skeletons, and demonstrating the broader engineering significance of pipe bending beyond specialized manufacturing applications.

M. Dakhore et al (2023) presented an overview of pipe bending methods, identifying deformation defects such as ovality and thickness variation as key quality concerns, and emphasized the need for controlled bending mechanisms while providing a theoretical foundation for assessing the performance limitations of simple bending machines.

A. K. Sao et al (Nov 2022) contributed by applying finite element analysis in ANSYS to evaluate the structural integrity of a pipe bending machine, demonstrating how simulation-based approaches can improve design reliability and reduce fabrication uncertainties, even in non-automated bending systems.

M. L. Rathod et al (2025) described the design and development of a cost-effective pipe bending machine, addressing key engineering factors such as actuation method, structural strength, and material selection, and highlighting how affordable bending equipment can enable efficient fabrication while minimizing deformation.

S. A. Ibrahim et al (2024) demonstrated the development of a low-cost manual pipe bending machine using locally available materials, showing that production costs can be reduced without compromising performance.

III. MATERIALS AND METHODS

3.1 Research Design and Methodological Approach

This study adopted an engineering design and experimental methodology involving conceptual design, analytical design calculations, material selection, fabrication, and performance evaluation of a manual pipe-bending machine. The design process followed standard mechanical design principles, ensuring adequate strength, operational safety, maintenance flexibility, and cost-effectiveness for small-scale fabrication workshops. Material purchase was carried out at Diedie building material market in Abuja. Production processes were done at the mechanical workshop of the centre for space innovation and development of Nasrda.

3.2 Materials Selection

3.2.1 Design Considerations

Material selection was guided by the following criteria:

1. Mechanical strength and load-bearing capacity
2. Wear and fatigue resistance
3. Availability and cost in the local market
4. Ease of fabrication and maintenance

3.2.2 Materials Used

The major materials used in the construction of the manual pipe bending machine is,

1. Mild steel

3.3 Design Analysis and Calculations

3.3.1 Pipe Bending Theory

The bending process is based on plastic deformation of the pipe under an applied bending moment. The bending stress in the pipe was estimated using,

I. Bending stress (MPa).
II. Applied bending moment (N·m).
III. Distance from neutral axis (m).
IV. Second moment of area (m^4).

3.3.2 Determination of Bending Force

The manual force required to bend the pipe was calculated using,

I. Applied manual force (N).
II. Bending moment (N·m).
III. Length of the lever arm (m).

A safety factor of 2.0 –3.0 was applied to accommodate operator variability and material imperfections.

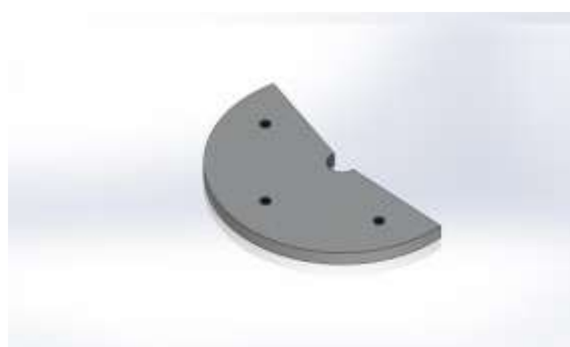
3.3.3 Shaft Design

The shaft diameter was determined using torsional strength theory.

I. Allowable shear stress (MPa).
II. Applied torque (N·m).
III. Shaft diameter (mm).

3.4 Machine Components Description

3.4.1 Frame Assembly



The frame was fabricated from welded mild steel round pipe and flat mild steel flat bar to provide structural rigidity and minimize vibration during bending operations.

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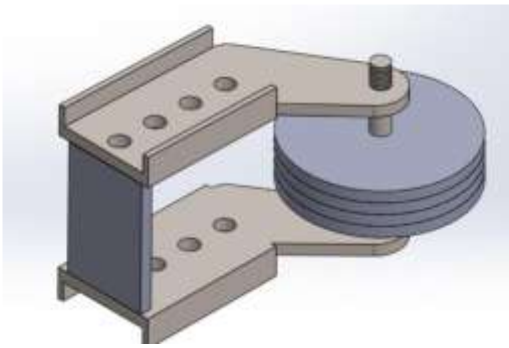
3.4.2 Bending Die and Rollers



Interchangeable dies were used to accommodate different pipe diameters. Rollers were positioned to ensure uniform bending and reduce ovality of the pipe cross-section.

3.4.3 Lever Mechanism
A manually operated lever arm was employed to amplify human effort through mechanical advantage, reducing operator fatigue.

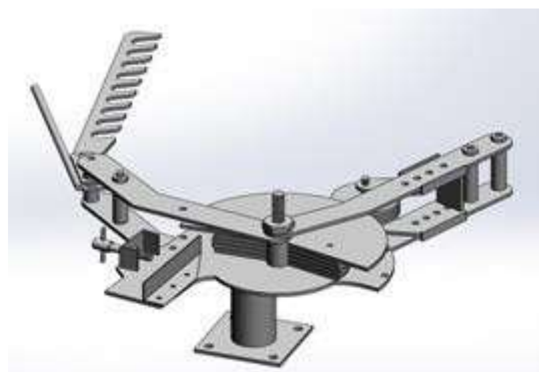
3.5 Fabrication Procedure
The fabrication process involved the following steps:
I. Cutting of mild steel sections to specified dimensions using a cutting disc.
II. Machining of shafts and rollers on a lathe.
III. Welding of frame components using electric arc welding
IV. Assembly of rollers, shafts, and a bending die.
V. Surface finishing and corrosion protection by painting.

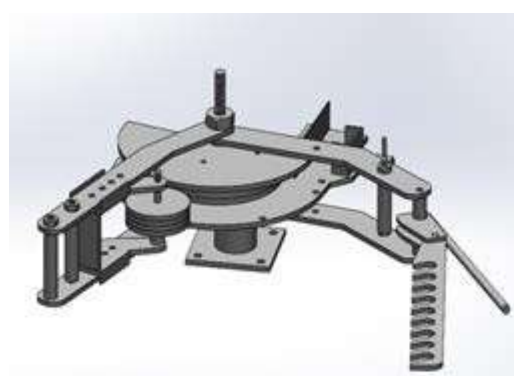
3.6 Data Analysis
Measured bending angles and applied forces were recorded and compared with theoretical predictions. The percentage error was calculated to assess machine accuracy.

3.7 Safety and Ergonomic Considerations
The handle length was optimized to minimize excessive operator strain. Sharp metal edges were dulled to prevent injuries.

IV. RESULTS AND DISCUSSION

4.1 Overview of the Fabricated Machine
The developed manually operated pipe bending machine consists of a rigid mild steel frame, pivoted bending arm (lever), return spring mechanism, and a locking system.





4.2 Calculation
4.2.1 Lever Arm Length
The calculated lever arm extension required was calculated to achieve sufficient mechanical advantage.
$L = T/F$

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Were
T = Required bending Torque (Nm)
F = Applied human force (N)

Using an estimated average human force of 250 – 300Nm. The fabricated lever length of 1.5m.
This length provided sufficient mechanical advantage and reduce operator's fatigue.

Using an estimated average human effort (Force) of 250 – 300N and calculated torque requirement of 420Nm.

L = 420/280 = 1.5m

The fabricated lever length of 1.5m provided adequate mechanical advantage and reduced operator's fatigue.

Discussion:
The lever length achieved efficient force transmission without excessive structural deformation. Increasing lever length beyond 1.5m did not significantly improve bending efficiency but increased machine footprint.

4.2.2 Shaft Diameter Determination
The shaft diameter was determined using torsional shear stress relation.
T = 16T/лd3
For allowable shear stress of 55Mpa (Mild steel) and torque of 420Nm d = 28mm.
A 30mm shaft was selected for safety.

Discussion:
The selected shaft diameter prevented torsional failure during repeated bending cycles. No observation of twisting or yielding occurred. Confirming design adequacy.

4.3 Performance Evaluation
The machine was tested on the following square pipes (1x1mm, 1.5 x 1.5mm, 2 x 2mm) thickness.
All specimens were successfully bent to 45̊, 90̊, 120̊ angles.

Pipe Size	Maximum Angle
1 x 1 mm	120̊
1.5 x 1.5 mm	120̊
2x2mm	90̊ - 120̊

Discussion:
The machine performed optimally within the design thickness range.
Minor wrinkling observed in 2 x 2mm pipes is attributed to material resistance and absence of internal mandrel support. However, deformation is within acceptable fabrication tolerance.

4.3.2 Spring Back Analysis
Spring back angle was measured after load removal.

Pipe Thickness	Intended Angle
1mm	90̊
1.5mm	90̊
2mm	90̊

Discussion:
Spring back increased with pipe thickness due to higher yield strength and elastic recovery. Compensation during operation (Over bending by 3 - 7̊) effectively corrected final angle accuracy.

4.4 Mechanical Efficiency
mechanical efficiency was determined by comparing theoretical torque to practical force input.
ἠ = Output Torque x 100 Input Torque
The machine achieved approximately 85 – 90 % efficiency, accounting for friction losses at pivot joints.

Discussion:
Losses were incurred due to the following.
1. Friction between roller and pipe.
2. Bearing resistance.
3. Slight misalignment during manual operation.

4.5 Structural stability
The bending machine frame exhibited,
1. No buckling.
2. No vibration during operation.

3. No permanent deformation.

4.6 Comparison with Existing Manual Benders (Convectional and imported manual pipe benders)

1. Lower production cost (approximately 40 – 60%) cheaper.
2. Similar bending accuracy (±2° tolerance)
3. Easy maintenance using locally available materials.
4. No dependence on electrical power.

4.7 Limitation Observed

1. Difficulty bending pipes above 2mm thickness.
2. Absence of mandrel support limits in the case, of thin-wall pipe bending precision.
3. Manual operation causes operator fatigue during repetitive tasks.

4.8 Overall Discussion

The results demonstrated that the developed manually operated pipe bending machine,

1. Meets design objective
2. Operates safely within calculated stress limits.
3. Produce bends with acceptable angular accuracy.
4. It is economically viable for local fabrication industries.

The slight spring back and minor wrinkling observed are typical characteristics of cold bending operation and can be minimized with improved die geometry or mandrel incorporation.

The successful performance confirms the reliability of the design calculations and validates the engineering approach adopted in the development process.

CONCLUSION

This study presented the design, fabrication and performance evaluation of a manually operated pipe bending machine developed for bending mild steel square pipes of sizes 1x1mm, 1.5x1.5mm, 2x2mm. The design process incorporated analytical calculations to determine the required bending force, lever length, shaft diameter and torsional resistance ensuring that all structural and load bearing components operated within design limits. The fabricated pipe bending machine demonstrated satisfactory mechanical performance during experimental trials. The bending mechanism produced smooth and uniform bends with minimal surface defects such as wrinkling, excessive flattening, or cracking. Spring-back effects were within acceptable limits, and dimensional accuracy was achieved through proper die alignment and rigid frame construction. The manually operated lever system provided sufficient mechanical advantage, thus reducing operator effort while maintaining accuracy. The absence of electrical or hydraulic systems makes the machine portable, economical, sturdy and suitable for small-scale fabrication workshops, vocational training institutions where power supply may be unreliable.

The use of locally available materials and conventional workshop tools further enhance its manufacturability. The developed pipe bending machine satisfies the functional requirements of light-duty bending applications and contributes to indigenous manufacturing efforts. Future work may incorporate an angle measurement mechanism for improved accuracy, and can also include adapting hydraulic assistance for high strength material.

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