International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 10 Issue: 02 | Feb - 2026 SJIF Rating: 8.659 ISSN: 2582-3930

Design and Development of 3D Wire Bending Machine

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ABSTRACT— This project focuses on designing and developing an automated 3D wire bending machine utilizing an Arduino microcontroller for precise control. Traditional wire bending processes, often manual, suffer from inconsistencies, errors, and low efficiency, which affects product quality and increases production time. To address these challenges, the proposed machine integrates CNC-type control to enable accurate and repeatable bending of wire into complex three-dimensional shapes. The machine design involves CAD modelling of components, 3D printing of gears and parts, and assembly of mechanical and electronic systems. By programming the Arduino controller, the machine controls wire feeding, straightening, and bending operations with high accuracy while minimizing human intervention. Testing demonstrated the prototype's ability to bend wires into desired shapes with improved precision and faster operation, offering a low-cost, flexible solution for industries requiring customized wire bending. This development not only reduces dependency on skilled manual operators but also enhances productivity and product quality in wire bending applications. If a more specific style or detail level is needed, that can be provided as well. This abstract is synthesized based on project report sources describing similar 3D wire bending machines using Arduino and automation principles.

1. INTRODUCTION

Wire bending is a critical process in many manufacturing industries, including automotive, aerospace, electronics, and construction. Traditionally, wire bending has relied on manual operations or basic tools, which limits the complexity of shapes, reduces accuracy, and increases labor costs and production time. As demand for customized and intricate components grows, automation in wire bending has become essential. Automated systems improve precision, ensure repeatability, and significantly enhance production speed.

This project focuses on the design and development of a 3D wire bending machine capable of forming complex threedimensional shapes through computer-controlled operations. The proposed system integrates microcontroller technology for control, stepper motors for actuation, sensors for feedback, and robust mechanical components. These elements enable accurate wire feeding, rotation, and bending while minimizing human intervention. The design offers flexibility for producing intricate shapes that are challenging to achieve manually, reducing errors and accelerating manufacturing processes.

Furthermore, the project explores the integration of CNC principles and programmable control systems to enhance wire forming capabilities. By creating an affordable, reliable, and user-friendly machine, this development aims to support small and medium-sized enterprises, improving their production capabilities and streamlining workflows across various engineering applications.

2.RESEARCH MOTIVE

This paper presents the design and development of an automated 3D wire bending machine for precise and efficient formation of complex wire shapes. The system uses Arduinobased control and CNC-type automation to reduce human error and improve repeatability. This approach offers a costeffective solution for industries requiring customized wire forms. Wire bending plays a vital role in manufacturing sectors such as automotive, aerospace, and electronics, where components often require complex geometries and high precision. Conventional wire bending methods, which rely on manual operations or basic mechanical tools, suffer from significant limitations in accuracy, repeatability, and efficiency. These drawbacks lead to increased labor costs, longer production cycles, and higher chances of human error, making them unsuitable for modern industrial requirements. The growing demand for customized and intricate wire forms has intensified the need for automation in wire bending processes.While CNC-based solutions offer high precision, they are often expensive and inaccessible for small and medium-sized enterprises.

Fig 1 3D Wire Bending Machine

This creates a strong need for a cost-effective, automated system that combines affordability with advanced functionality.The proposed 3D wire bending machine addresses these challenges by integrating Arduino-based control with stepper motors and sensors to achieve precise wire feeding, rotation, and bending operations. This approach minimizes human intervention, enhances flexibility, and enables the production of complex three-dimensional shapes efficiently. The motivation for this research lies in bridging the gap between affordability and advanced automation, thereby improving productivity and quality in wire bending applications.

3. EXPERIMENT DETAIL

3.1. MATERIAL

3.1.1. PETG Filament:

PETG is a thermoplastic polyester widely used in 3D printing and manufacturing applications. It combines the ease of printing of PLA with the strength and durability of ABS, making it suitable for producing mechanical components with good dimensional stability. PETG exhibits excellent chemical resistance and impact strength, making it ideal for functional parts.

Fig:2 PETG Filament

3.1.2. Characteristics of PETG:

- High impact resistance
- Good chemical resistance
- Excellent layer adhesion
- Low shrinkage and warping
- Transparent or semi-transparent finish
- Suitable for mechanical and structural components

3.1.3. Specification:

- Density: 1.27–1.38 g/cm³
- Glass Transition Temperature: ~80°C
- Printing Temperature: 220–250°C
- Bed Temperature: 70–90°C

3.1.4. PETG Properties:

- Tensile Strength: 50–60 MPa
- Flexural Modulus: ~2.1 GPa
- Thermal Conductivity: ~0.2 W/m·K
- Impact Strength: High
- Poisson’s Ratio: ~0.38

3.1.5. CAD Design

The SolidWorks CAD assembly illustrates an automated 3D wire bending machine designed to streamline wire feeding, straightening, and multi-axis bending for complex shapes. The system is mounted on a rigid frame for stability and modularity. Wire straightening is achieved through roller sets, followed by precision feeding using stepper-controlled tensioners to ensure accuracy and prevent slippage. The bending unit incorporates gear trains, rotary supports, and servo-driven heads, enabling intricate 3D profiles such as spirals and cubes. Parametric modeling ensures proper alignment and collision-free motion during simulation. Modular plates and fasteners allow easy maintenance and upgrades, with several components suitable for 3D printing in PETG for cost efficiency. This design integrates mechanical precision, electronic control, and structural robustness, supporting rapid prototyping and consistent production for industrial and educational applications.

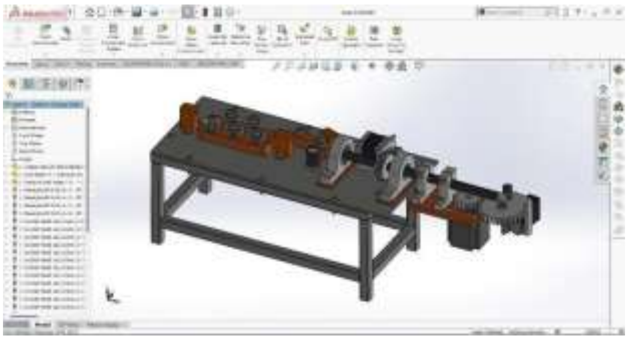


Fig 3 CAD Design

4 ANALYSIS

4.1 GEAR CALCULATION AND GEAR ANALYSIS

Spur Gear Calculations:

w.k.t

Gear Ratio:

$$i = \frac{N}{n} = \frac{30}{18} = 1.67$$

Where

- N: Number of teeth on gear
- n: Number of teeth on pinion

Output Torque

$$T_{out} = i \times T_{in}$$

$$T_{out} = 1.67 \times 0.4 = 0.67 \text{ Nm}$$ Where

- T_{in}: Input torque from NEMA 17 stepper motor (0.4 Nm, typical value)

Take

Pressure Angle $(\boldsymbol{\alpha}) = 20^{\circ}$

Module **(m)** = 1mm

Pitch Diameter:

d = m×n = 1×18 = 18mm

D = m×N = 1×30 =30mm

Centre Distance:

c = (d+D)/2 = (18+30)/2 = 24mm r = d/2 = (0.018/2) = 0.009m

w.k.t

Tangential and Radial Force:

$F_t = T_{out}/r = 0.67/(0.018/2) = 74.07$ N

$F_r = F_t$*tanα = 74.07*tan20 = 26.95 N

$F = F_t$/cosα = 74.07/cos20 = 78.86 N

4.2 MATERIAL ANALYSIS

Material selection plays a critical role in the performance andreliability of the 3D wire bending machine. Components such as gears, housings, and structural frames require materials that offer a balance of strength, stiffness, thermal stability, and impact resistance while remaining easy to manufacture using 3D printing. For this study, three engineering polymers— **PETG**, **ABS**, and **Polycarbonate (PC)**—were compared based on key properties relevant to the machine's operational requirements.

Property Comparison

The comparison focuses on four essential properties:

- **Tensile Strength (MPa):** Determines the material's ability to withstand pulling forces during gear rotation and wire feeding.
- **Flexural Modulus (GPa):** Indicates stiffness, which is crucial for maintaining dimensional accuracy in gears and structural parts.
- **Glass Transition Temperature (°C):** Reflects heat resistance, important for components near motors or under continuous load.
- **Impact Strength (kJ/m²):** Measures toughness against sudden shocks or misfeeds during bending operations.

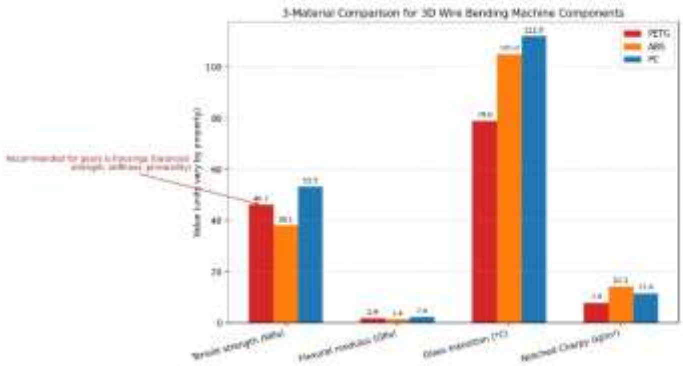
Analysis and Interpretation

- **ABS** offers high impact toughness (14.2 kJ/m²) and good heat resistance (105°C), making it suitable for protective covers and parts exposed to shocks. However, ABS is prone to warping during printing, which can compromise gear accuracy.
- **PC** provides excellent thermal stability (112°C) and strong mechanical properties, but its high printing temperature requirements and tendency for shrinkage make it less practical for small, precise components without specialized equipment.
- **PETG**, highlighted in the comparison, delivers a balanced combination of properties: adequate tensile strength (46.2 MPa), good stiffness (1.88 GPa), moderate heat resistance (79°C), and decent impact toughness (7.9 kJ/m²). PETG's superior layer adhesion and low warping ensure dimensional accuracy, which is critical for gears and housings in the wire bending machine. Additionally, PETG is easier to print than PC and ABS, reducing manufacturing complexity and cost.

Fig 3 Comparison between the Material

5.PRINCIPLE:

5.1 Motion Control:



Working on the principle of motion control, the 3D wire bending machine controls the motion with precision by coordinating the use of stepper motors and gears accurately to feed, rotate, and bend the wire. Controlled motion provides smooth operations and avoids wire deformation during bending.

5.2 Position Accuracy:

Position accuracy is the ability of the machine to maintain the exact bending angle and wire length that were programmed. This is achieved through feedback from sensors and the microcontroller, which further minimizes errors and increases repeatability.

5.3 Distribution of force:

The distribution of the force will be critical in order to avoid extreme stress on the wire and machine components. Gear ratio and torque calculation properly ensure uniform bending without damaging the wire or overloading the motor.

6. TECHNIQUE OF PRECISION CONTROL:

The 3D wire bending machine relies on strict coordination of the stepper motors, gears, and an Arduino-based control system for its accuracy. Programmed motion control operates the feeding, rotation, and bending of the wire without deformation. Feedback from sensors ensures smooth operation, minimizing positional errors.

7. METHOD OF FABRICATION:

Step 1: Design the machine components using CAD software to get the accurate dimensions.

Step 2: Print gears and structural parts in 3D using PETG filament for their strength and durability.

Step 3: On a rigid base, assemble the mechanical frame, bearings, and gear system.
Step 4: Install the stepper motors and connect them to the Arduino controller using proper wiring.
Step 5: Arduino programming for wire feeding, rotation, and bending operations.
Step 6: Conduct bending accuracy tests on the machine, and if necessary, adjust torque and speed settings. Step 7: Validate performance by producing sample wire shapes and comparing them to design specifications.

8.CONCLUSION:

The project entitled Design and Development of 3D Wire Bending Machine successfully merges mechanical design with electronic control for automation in wire bending. The machine incorporates an Arduino microcontroller, stepper and servo motors, a custom PCB, and 3D-printed components to achieve high-precision, repetitive wire shaping. Conventionally, wire bending has been done through manual means, which is timeconsuming and error-prone. This project overcomes those deficiencies with the introduction of a low-cost, automated solution that can form 3D geometrical wires of almost any complexity.
Another appeal of the design of the machine is that it allows flexibility in upgrading components, as well as customization depending on wire size and bending complexity. The use of PETG 3D-printed parts ensures lightweight construction while maintaining mechanical strength. A customized PCB simplifies wiring and improves system reliability, while limit switches enhance safety and positional accuracy. This Arduino-based control system allows programmable automation to reduce human intervention and improve production efficiency. Testing of the prototype also confirmed its ability to produce spirals, stars, and cubes as examples of accurate wire shapes. The machine is intended for small-scale manufacturing, prototyping, and educational uses. Furthermore, it serves as an excellent learning platform for students studying mechanical engineering, robotics, and mechatronics. The open-source nature of the technologies used encourages further development and innovation.
On the whole, this project contributes to the development of the automated wire forming systems through the provision of a scalable, inexpensive, and user-friendly solution. Further work can be done based on this study, including GUI interfacing, advanced sensing, and multi-axis control. The successful completion of this phase validates the feasibility and capability of the proposed system in actual usage.

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