

Design and manufacturing of a specialized lathe for facing operations on 3-inch polyethylene (PE) pipes

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ABSTRACT: This paper presents the design and development of a specialized lathe for end-facing operations on 3-inch polyethylene (PE) pipes. The machine is developed to address the limitations of conventional lathes in terms of productivity, machining consistency, and operator dependence when processing plastic pipes. The proposed system incorporates a dedicated clamping mechanism to ensure stable positioning of the pipe, along with an optimized cutting tool arrangement suitable for PE material characteristics. Key design considerations include spindle configuration, feed mechanism, and cutting parameters to achieve high surface quality and dimensional accuracy. Experimental results demonstrate that the developed machine significantly improves machining efficiency and repeatability while reducing setup time and operator skill requirements. The proposed solution offers a practical and cost-effective approach for mass production applications in plastic pipe manufacturing.

Keywords: Specialized lathe; End-facing; Polyethylene (PE) pipe; Machine design; Machining accuracy; Productivity, ...

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I. INTRODUCTION

Lathes are among the most fundamental and widely used machine tools in manufacturing, playing a critical role in producing cylindrical components with high precision. Conventional lathes, including engine lathes, turret lathes, and CNC lathes, are designed to perform a variety of machining operations such as turning, facing, boring, and threading. While these machines offer high flexibility, they are not always optimized for repetitive and specialized tasks, particularly when machining non-metallic materials such as polymers.

In recent years, polyethylene (PE) pipes have been increasingly used in industries such as water supply, gas distribution, and chemical processing due to their excellent corrosion resistance, lightweight properties, and ease of installation. However, machining PE pipes presents specific challenges, including low stiffness, material deformation, and sensitivity to cutting parameters. In particular, end-facing operations on small-diameter pipes (e.g., 3-inch PE pipes) require stable clamping, controlled cutting forces, and consistent feed to ensure flatness and surface quality [1].

Conventional lathes often rely heavily on operator skill and require significant setup time when processing such components, leading to variations in machining quality and reduced productivity in mass production environments. These limitations highlight the need for a dedicated solution tailored to the characteristics of PE pipes and the requirements of end-facing operations [2], [3].

Therefore, this study focuses on the design and development of a specialized lathe specifically intended for end-facing machining of 3-inch PE pipes. The proposed machine aims to improve machining accuracy, ensure repeatability, reduce operator dependency, and enhance overall production efficiency. By integrating a dedicated clamping system and optimized cutting mechanism, the machine provides a practical and cost-effective solution for industrial applications [4], [5].



Fig.1. Pipe facing machines

II. DESIGN METHODOLOGY

The design of the dedicated facing lathe is developed based on the specific machining requirements of 3-inch polyethylene (PE) pipes. Unlike metallic materials, PE exhibits low stiffness, high elasticity, and a tendency to deform under external forces. Therefore, the machine design must ensure not only machining accuracy but also stability during operation, particularly in the clamping and cutting processes.

2.1. Design Requirements

The primary objective of the machine is to perform facing operations on PE pipes with a nominal diameter of 3 inches. The machining process must ensure that the end surface of the pipe is flat, smooth, and perpendicular to the pipe axis. These requirements are essential to guarantee proper sealing and alignment in pipeline assembly applications [6].

In addition, the machine should meet the following criteria: minimize deformation of the pipe during clamping, provide stable cutting conditions suitable for soft materials, achieve consistent surface quality, and ensure ease of operation and maintenance.

Considering industrial applications, the machine is also expected to improve productivity by reducing setup time and simplifying the machining process compared to conventional lathes.

2.2. Overall Machine Structure

The proposed machine consists of several main subsystems, including a rigid frame, a clamping mechanism, a spindle unit, a cutting tool system, and a feed mechanism. The frame serves as the supporting structure, ensuring rigidity and minimizing vibration during operation.

The spindle system is responsible for generating the rotational motion required for the facing process. Depending on the design approach, either the pipe or the cutting tool may rotate. In this study, a compact configuration is selected to suit small-diameter pipes and reduce machine size [7].

The feed mechanism provides controlled linear motion of the cutting tool along a direction perpendicular to the pipe axis. This motion is critical in achieving the desired flatness and surface finish of the pipe end.

2.3. Clamping Mechanism

The clamping mechanism plays a crucial role in ensuring machining accuracy. Due to the relatively low stiffness of PE material, excessive clamping force may cause deformation of the pipe, leading to dimensional inaccuracies and poor surface quality [8].

To address this issue, the clamping system is designed to distribute the clamping force evenly along the pipe surface. A suitable clamping method, such as external clamping with multiple contact points or an internal expanding mechanism, can be employed. The design must ensure sufficient holding force to prevent slippage during machining while minimizing distortion.

Furthermore, proper alignment of the pipe axis with the spindle axis is essential to maintain perpendicularity of the machined surface. Therefore, the clamping system is designed with alignment features to improve positioning accuracy.

2.4. Cutting Mechanism

The facing operation is carried out using a single-point cutting tool mounted on a tool holder. The tool is designed to move in a direction perpendicular to the pipe axis, removing material from the pipe end.

Since PE is a soft material with low cutting resistance, the cutting process requires careful selection of tool geometry and cutting parameters. A sharp cutting edge with an appropriate rake angle is preferred to reduce cutting force and avoid material deformation [9].

In addition, chip formation in PE machining differs from that of metals, often producing continuous and ductile chips. Therefore, the cutting tool design must also consider chip evacuation to prevent interference with the machining process.

2.5. Cutting Mechanism

The drive system provides the necessary power for spindle rotation and tool feed motion. An electric motor is used as the primary power source, transmitting motion to the spindle through a belt or gear mechanism.

The rotational speed of the spindle is selected based on the machining characteristics of PE material. Compared to metal cutting, PE requires lower cutting forces but may benefit from moderate spindle speeds to achieve a smooth surface finish [10].

The feed motion can be controlled manually or automatically, depending on the level of machine complexity. For a dedicated machine, a simple and reliable feed mechanism is preferred to reduce cost and improve usability.

2.6. Working Principle

The working process of the machine can be described as follows. First, the PE pipe is positioned and fixed securely in the clamping mechanism. Proper alignment is ensured before machining begins.

Next, the spindle is activated to generate rotational motion. The cutting tool is then gradually fed towards the pipe end by the feed mechanism. During this process, material is removed from the pipe end surface until the required flatness and perpendicularity are achieved [11].

After completing the facing operation, the cutting tool is retracted to its initial position, and the spindle is stopped. The finished pipe is then removed from the clamping system, and the machine is ready for the next operation.

III. DESIGN THE KINEMATIC DIAGRAM OF THE LATHE

The kinematic diagram of the proposed facing lathe is developed to describe the motion transmission and interaction between the main functional components of the machine. The system consists of two primary motion chains: the main motion (cutting motion) and the feed motion.

The main motion is generated by an electric motor and transmitted to the spindle through a belt or gear transmission system. This motion provides the rotational movement required for the facing operation, either by rotating the cutting tool or the pipe, depending on the selected configuration. The spindle is supported by bearings to ensure smooth and stable rotation [12].

The feed motion is responsible for advancing the cutting tool toward the pipe end. This motion is typically achieved through a lead screw mechanism driven manually or by a secondary motor. The linear movement of the tool holder is precisely controlled to ensure uniform material removal and high surface quality.

In the kinematic diagram, the relationship between rotational and translational motions is clearly defined. The coordination between these motions ensures that the cutting tool follows a perpendicular path relative to the pipe axis, which is essential for achieving a flat and accurate end surface.

Speed kinematic chain:

$$n_{motor}(\text{round}/\text{min}) \cdot i_{12} \cdot i_v \cdot i_{34} = n_{chuck}(\text{round}/\text{min})$$

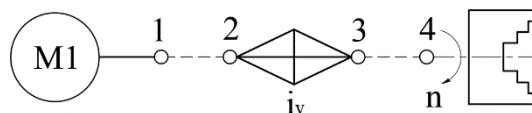


Fig.2. Kinematic diagram of Pipe facing machines

Additionally, the kinematic structure is designed to be simple and reliable, minimizing the number of transmission elements while maintaining sufficient functionality. This approach reduces mechanical losses, simplifies maintenance, and improves the overall efficiency of the machine.

IV. STRUCTURAL DESIGN AND MANUFACTURE OF THE LATHE

To ensure stable and accurate positioning of the polyethylene (PE) pipe during machining, an elastic clamping chuck is employed in the proposed machine. Due to the low stiffness and high deformability of PE material, conventional rigid clamping methods may cause local deformation, leading to dimensional errors and poor surface quality. Therefore, the use of an elastic clamping mechanism is essential.

The elastic clamping chuck is designed to provide uniform clamping force distribution along the contact surface between the chuck and the pipe. This is typically achieved through flexible elements such as slotted sleeves or spring-loaded jaws, which can adapt to slight variations in pipe diameter while maintaining sufficient holding force. As a result, the pipe can be securely fixed without excessive that may distort its circular shape.



Fig.3. Elastic Clamping Chuck without workpiece

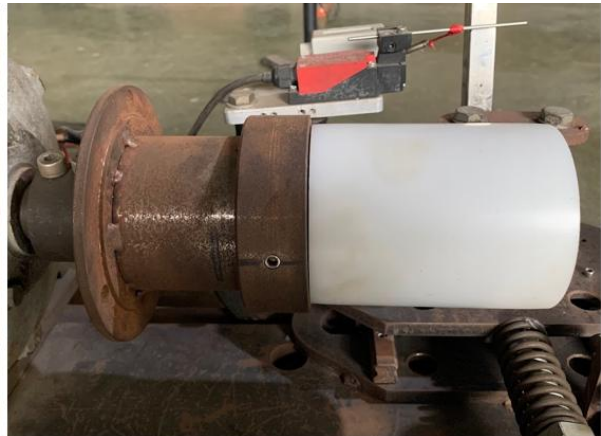


Fig.4. Elastic Clamping Chuck with workpiece

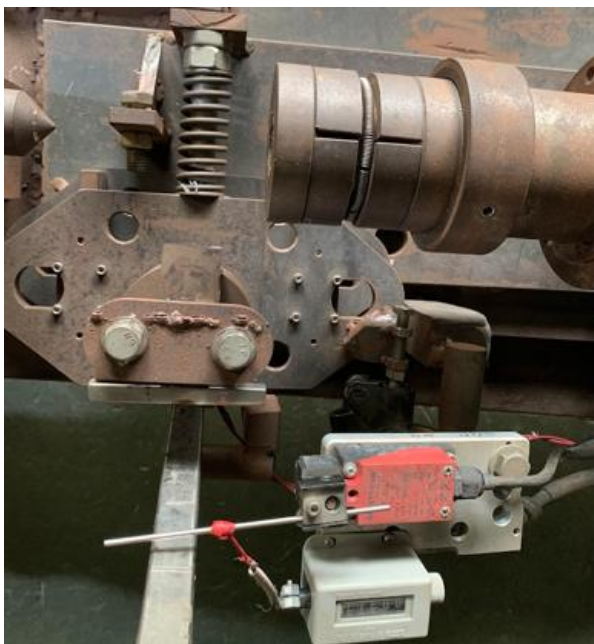


Fig.5. Travel stop and counter



Fig.6. Spindle braking mechanism

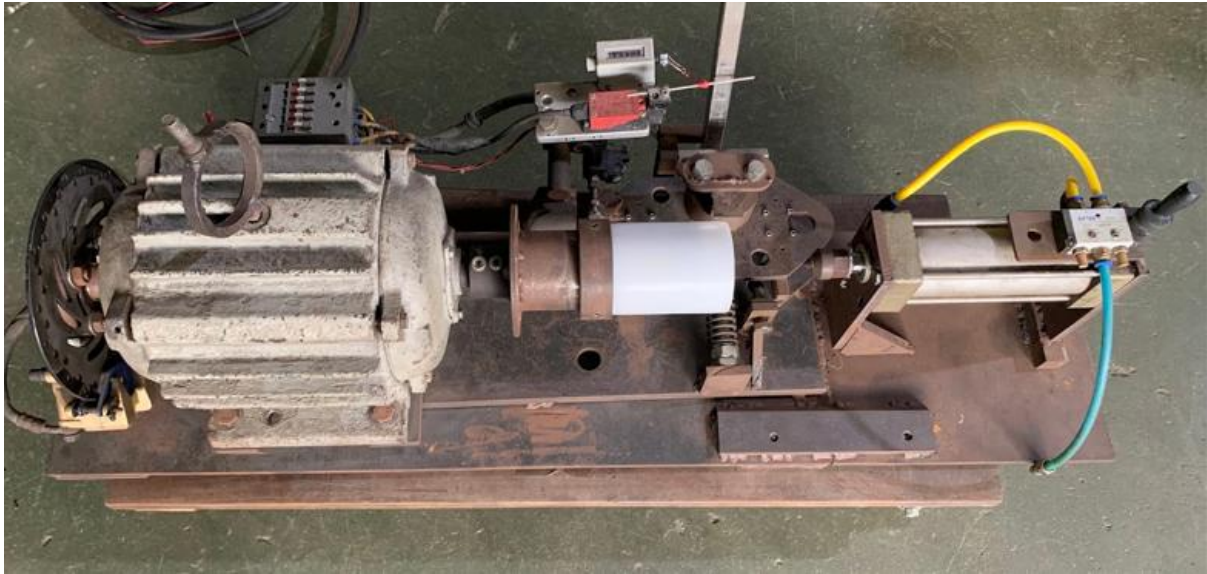


Fig.7. Photo of the whole machine

V. CONCLUSION

This paper presents the design and development of a dedicated facing lathe for machining 3-inch polyethylene (PE) pipes. Based on the specific characteristics of PE material, including low stiffness and high deformability, the machine structure and functional components were carefully designed to ensure machining accuracy and stability. The study proposed a complete machine configuration, including the frame, spindle system, cutting mechanism, feed mechanism, and an elastic clamping chuck to minimize deformation during operation. In addition, auxiliary components such as the travel stop, counter system, and spindle braking mechanism were integrated to improve operational control, safety, and efficiency. The kinematic diagram and working principle of the machine were analyzed to clearly describe the motion transmission and coordination between components. Key design parameters, including cutting speed, feed rate, cutting force, and power requirement, were also determined to ensure proper machine performance when machining PE pipes.

Furthermore, the fabricated machine and its structural components were presented through detailed figures, providing a clear visualization of the design and practical implementation. The results demonstrate that the proposed machine is compact, easy to operate, and suitable for machining small-diameter PE pipes in industrial applications.

In conclusion, the developed facing lathe offers an effective and economical solution compared to conventional machining methods. Future work may focus on improving automation, optimizing cutting parameters, and conducting experimental validation to further enhance machining performance and reliability.

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