Design and Fabrication of PVC Pipe Cutting Machine with Hot Wire Mechanism

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Abstract. The utilization of cutting tools presents inherent limitations, encompassing sluggish production rates, inconsistent cutting precision, and elevated manufacturing expenses in the cutting of PVC (Poly-Vinyl Chloride) pipes. Addressing these challenges requires a systematic design approach to engineers to build sustainable new mechanism for PVC pipe cutting apparatus capable of streamlined operation. This study endeavours to conceptualize and develop a unique mechanism comprised of Ni-Chrome heated wire as a replacement of traditional cutter. The design focus is aimed at enhancing the cutting operation within low cost and enhanced sustainability. The methodology for machine design encompasses a complete machine design approach for each single component if a machine utilizing Solidworks 2023, complemented by rigorous mathematical design calculations. The outcomes of this study manifest in the creation of a prototype of Ni-Chrome heated wire machine capable of cutting the pipes within thickness range from 20-35mm and more based on the heated capability of wire. Noteworthy advantages of this machine design include expedited manufacturing processes, reduced energy consumption, and enhanced labour efficiency, thereby augmenting overall productivity. Future research avenues are suggested to encompass an analysis of operator safety considerations, establishment of periodic maintenance protocols, automation, and optimization of spare parts accessibility to further refine the efficacy and longevity of the proposed system.

1 Introduction

Modern industry requires machinery that can produce many identical parts whilst being cost effective and giving maximized production values. PVC pipe industry is one of the best examples of modern-day industry which are manufacturing their products in mass production [1]. PVC pipes are incredibly versatile and durable, making them indispensable in various technical applications [2, 3]. PVC pipes are generally made through conventional manufacturing too along with additive manufacturing [4]. PVC pipes are basically resistant to corrosion [5], long lasting, insulation purpose and cost effective [6]. It is widely used in construction industries such as plumbing, irrigation, electrical equipment's, sewerage, and chemical resistance [7]. Their popularity in technical applications is further enhanced by their lightweight nature, making them easy to handle and install [8].

PVC pipes are produced in large amounts daily. The basic machine which is employed to perform these operations on a large scale is a pipe cutting machine. Generally, these machines comprise of cutter as a cutting tool and performs on cutting operations [9]. Over time, various cutting machines have been developed to carry out the cutting process effectively. The inception of pipe cutting machines dates to the 1900s when the first ones were created to cut pipes made of metal [10]. These early cutting machines included tools of different shapes, sizes, and materials, as detailed by Graham T. Smith [11]. Despite advancements, it was apparent that maintaining these heavy machines required significant resources. To enhance efficiency, oxyacetylene cutters replaced traditional cutting tools, and CNC mechanisms, like the one introduced by Mueller Op laden in 1953 [12], became prevalent. In subsequent years, plasma cutting further improved the efficiency and precision of pipe cutting machines significantly [13].

Although metal cutters are the primary tools for cutting processes, there's a growing demand for higher accuracy and enhanced safety measures [9]. In the past, machines relied on large cutters made from various materials, resulting in high maintenance, substantial debris production, and significant safety risks for the crew [14]. Despite these challenges, the use of cutters became a standard practice over time, and now, cutting machines across various types predominantly employ cutters or blades for their operations [15].

However, these machines, while incorporating cutters, caused complexities, high costs, and elevated risks due to the substantial debris generation and the elevated temperatures involved in their operations [16]. These factors not only compromised the safety of the working staff but also posed risks to others in the vicinity, including other machinery, and had environmental implications [17]. Consequently, these machines often necessitate dedicated rooms within factories, consuming significant space to mitigate these safety and environmental concerns [18].

After examining existing literature and industry practices, the complexity of machines led the idea to ponder to design and develop the PVC pipe cutting machine without the use of heavy cutters. To address this challenge, the study unfolds in two distinct phases: (i) designing each individual component of the machine under a limited budget of $30. (ii) fabricating and testing the machine. Careful consideration and careful design characterize the selection of each element that will be incorporated into the machine. To validate the design, a CAD model was created in the form of detailed assembly. In place of traditional cutters, the machine utilizes Ni-Chrome heated wire for enhanced precision. The results demonstrated superior performance in cutting PVC pipes of varying diameters and thicknesses, establishing the machine as a cost-effective alternative to others in the market.

2 DESIGN

2.1 Design Methodology

This study unfolded through several stages of design. The focus was to generate an idea for an optimal cutting tool, aiming to replace the traditional metal cutter. The design process then delved into each individual element of the machine. Utilizing a commercial software, specifically Solid Works by Dassault Systems Inc, CAD models were meticulously crafted to assess the suitability of the designed components when assembled. The machine was then assembled, and a prototype was fabricated by the team. The evaluation phase involved a comprehensive analysis of precision, cutting efficiency, cost-effectiveness, and sustainability of the machine. Results were then derived from this thorough examination, providing

valuable insight into the overall performance and viability of the developed PVC pipe cutting machine. The methodology framework is illustrated in figure 1.

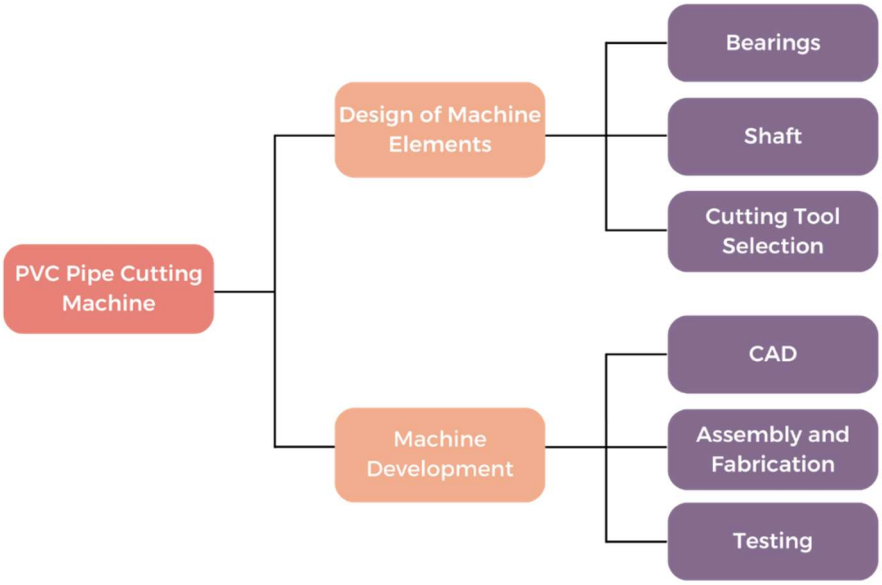

Figure 1. Methodology Framework

2.2 Components Design

In machine design, the bearing plays a pivotal role by minimizing friction and ensuring a smooth rotation of the shaft. Various standardized bearings are readily available in the catalogues of different manufacturers. In the context of this PVC pipe cutting machine, where the predominant load is axial, stemming from the weight of the top bed, ball bearings were preferred over roller bearings. The decision was based on the lower friction facilitated by point contact in ball bearings compared to roller bearings. Further categorizing ball bearings, tests were conducted to determine the most suitable option for the specific requirements of the machine. After careful consideration, the deep groove ball bearing from Timken was chosen. This bearing was deemed ideal for its capacity to withstand substantial axial loads. The calculations of the load are as follows:

$$C_{10} = F_D \left(\frac{L_D}{L_R}\right) \quad (1)$$

The dimensionless multiple of rating life is

$$x_D = \frac{L_D}{L_R} \quad (2)$$

The relation between catalogue load rating and desired load can also be expressed as

$$C_{10} = a_f F_D \left[\frac{x_D}{x_o + (\theta - x_o)(1 - R_D)^{1/b}}\right]^{1/a} \quad (3)$$

The dimensionless multiple of the rating life, denoted as x_d was calculated. By planting predetermined values such as the application factor, Weibull parameters, and reliability into equation (3), we determined the required load, which turned out to be 1.87kN. This implies that a load of 1.87kN can be applied to each of the deep groove ball bearings.

Standardized charts were also consulted to identify the dynamic and static load-carrying capacities, tailoring the selection to meet specific requirements. The Timken bearing's rated life, determined through a series of equations found in the MATLAB code provided in the

appendix, was established to be 90×10^6. This outcome confirms the bearing's durability and its suitability for incorporation into the PVC pipe cutting machine.
Mild steel shaft was then selected for mounting these bearings. As the bore diameter of the ball bearings was 12mm, so shafts of diameter 12mm were selected. Mild steel shafts were selected due to their easy availability and cost-effectiveness. Moreover, the mild steel shaft has a high tensile strength making it suitable for use in other high stress applications.

2.3 CAD Design

CAD design was done on Solid works by Dassault System Inc. Different parts that were used to make the final assembly of the PVC pipe cutting machine were carefully modelled. The initial step involved the design of a wooden baseplate (bottom bed) to accommodate the deep groove ball bearings. Six mild steel shafts measuring 70mm in length and 12mm in diameter, along with four shafts of 30mm length and 12mm diameter, were designed. Ten deep groove ball bearings were incorporated into the bottom bed to support the assembly. Two pipe holders were created to secure the PVC pipe in place. Crafting the top frame was essential for setting up the Ni-Chrome hot wire mechanism. To facilitate vertical movement in the Ni-Chrome hot wire mechanism, a slider mechanism was implemented on both sides of the top frame. To achieve smooth cutting, it was imperative to maintain a temperature within the range of 100-260℃, corresponding to the melting point of PVC. Initially, the wire setup caused overheating of the Ni-Chrome wire, leading to the burning of the PVC pipe. This challenge was addressed by incorporating a potentiometer, a variable resistor capable of regulating heat by adjusting resistance levels. Additionally, extending the length of the Ni-Chrome wire with some folds could also mitigate issues related to burning and overheating.

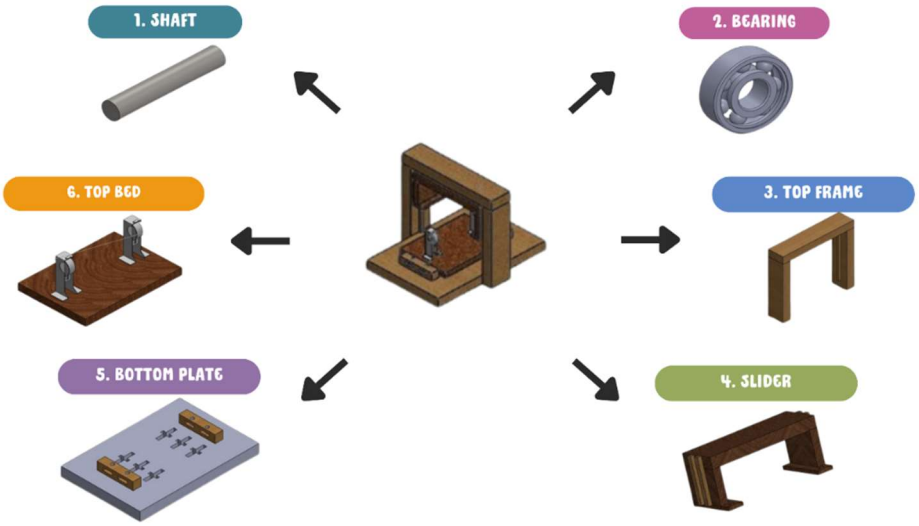

Figure 2. CAD Design

In the final phase, all these components were assembled to create the PVC pipe cutting machine. SolidWorks Assembly feature was utilized for the assembly process. Furthermore, 2D engineering drawings for each part and the final assembly were generated following the first-angle projection standard.

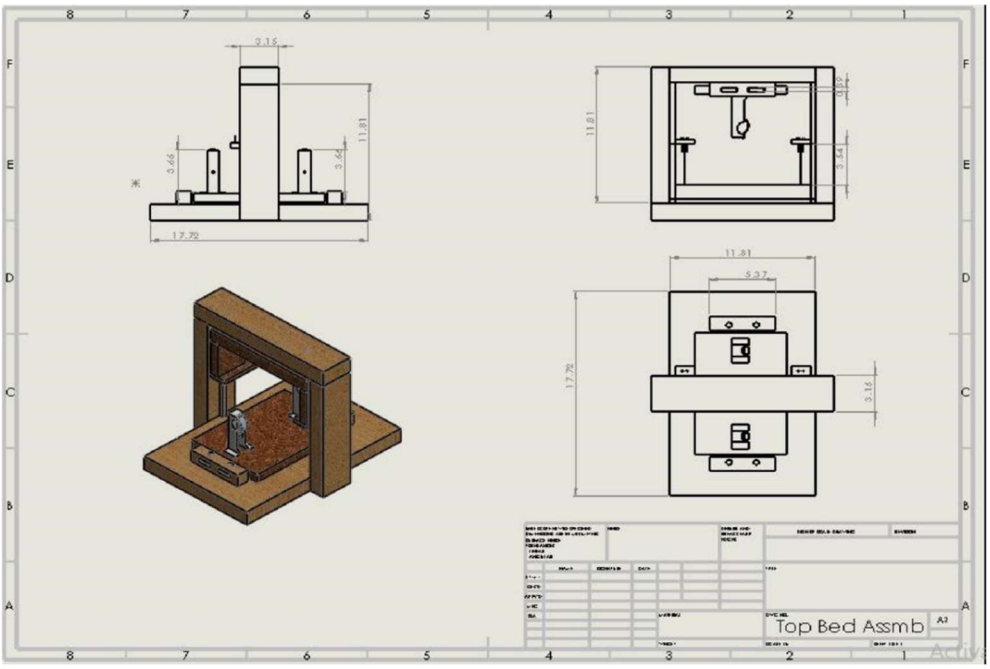

Figure 3. Engineering Drawing of Assembly

3 Fabrication

3.1 Fabrication

The fabrication process for the PVC pipe cutting machine involved a step-by-step approach. It was necessary to choose the proper material for the structure and other components of the machine. Wood was chosen as the primary material for the machine structure. Mild steel shafts were selected for the bearings. A wooden base plate was made according to the dimensions of the design. Six bearings were mounted on the base plate to allow the sliding motion of bottom plate on which the pipe holders were to be attached. Two side plates were constructed, each equipped with four bearings to prevent any lateral movement of the bottom plate. A bottom plate was constructed on which the pipe clamping mechanism was made. For the cutting of pipe, a Ni-Chrome wire mechanism was established. A 19.5 V adapter was used to supply power to the Ni-Chrome wire. The sliding mechanism was made to facilitate the vertical motion of the hot wire mechanism.

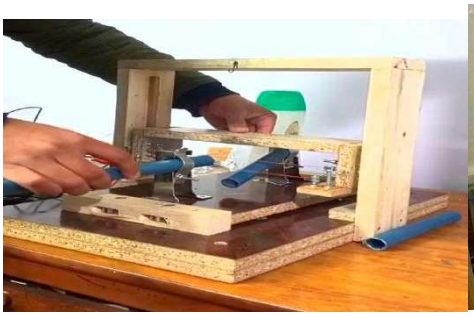

Figure 4.1 Prototype

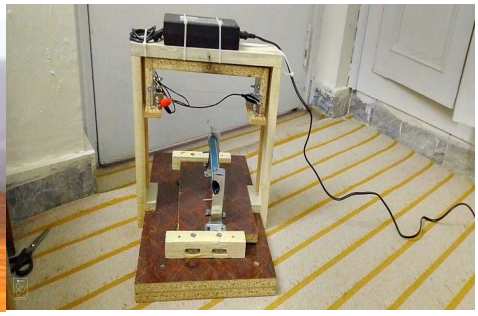

Figure 5.2 Prototype

3.2 Testing

Testing was carried out after the fabrication to record and validate the working of the machine. A PVC pipe was clamped using the clamping mechanism. As the machine was made to allow the cutting process of Pipes of different diameters, the clamping mechanism was adjusted accordingly using the screws on both holders. Ni-Chrome hot-wire mechanism was switched on and the wire started to heat up. As the wire became red-hot after being heated for 3 to 4 seconds, the slider was given a slow downwards movement until the wire touched the pipe. Then, the bottom plate was given a to-and-fro motion whilst also ensuring a slow but steady downwards motion of the hot-wire mechanism. The results of operation were very satisfactory. A fine finish with a precise cut was achieved without any residue. The procedure was then carried out to cut as many pipes as possible with a single wire to determine the limitations of the machine (discussed later in the sustainability section). This prototype can cut PVC pipes of diameters ranging from 20 to 35mm by adjusting the clamping mechanism accordingly.

Figure 6. Tested Samples

3.3 Sustainability

Thorough testing was conducted to evaluate the PVC pipe cutting machine's life and environmental impact. This prototype can efficiently cut up to 60 pipes with a single wire, optimizing resource utilization. However, the wire requires renewal after this threshold. This can be easily done by simply unwinding the old wire and binding of a new one onto the nut and bolts assembly in the hot-wire mechanism. The bearings used, have a lifespan of about 540 million revolutions, which adds to the durability and reliability of the machine. Though there's a very minor possibility of bearing failure, their replacement is not complicated. They can all be easily accessed by simply removing the top plate. This prototype can accommodate

pipes of diameters ranging from 20 to 35mm. This range mostly depends on the clamper's capacity, hence by changing the installed clampers with the clampers of required needs, this range can be increased. This can be done by unscrewing the installed clampers and screwing on the new ones. However, it shall be made sure that the pipe, once clamped, does not touch the plate surface.

Overall, the machine has portrayed a reliable level of sustainability and efficiency with near zero debris production and a high operational safety. Since no sharp cutters are involved in it, the limitations due to the cutters (bluntness, damage, etc.) have also been minimized. Hence it can be safely said that the machine is very reliable.

Table 1. Budgeting of Machine.

PRODUCTS	QUANTITY	PRICE
Wood		1200
Bearings	10	1000
Adaptor	1	1000
MS shafts	2 ft	240
Pipe Holder	2	200
Ni-Chrome Wire	1 coil	100
Nuts and Bolts	10	50
Crocodile clips	2	100
Total= 3890 Pkr = $14		

Table 2. Comparison of different manufacturers' prices.

MANUFACTURER	PRICE
Suzhou Bona Ende Technology Co., Ltd	7000 dollars
Lishui Keensaw Machine Co., Ltd.	5600 dollars
Zhangjiagang Yuanrui Machinery Co., Ltd.	8000 dollars
Zhangjiagang Kooen Machinery Co., Ltd.	5000 dollars

The budgeting of the machine is provided above in Table 1, according to which our machine is manufactured in 3890 Rs or 14 dollars. On the other hand, according to Table 2, the selling cost of different manufacturers conclude that the market price of PVC pipe cutting machine lies between 5000 to 8000 dollars. This proves that our machine is budget-friendly and can provide a cost-effective solution to the industry for PVC pipe cutting.
Furthermore, for the mass-scale production of this machine at a commercial level, it is essential to procure materials in bulk quantities. Table 3 in the manuscript provides an overview of material prices when bought in bulk, including the quantity required for assembling a single machine mirroring the size, components, and specifications of the prototype. Upon analysis, a reasonable estimate for labor costs for this prototype is Rs. 1500/- per day, considering it was completed within a single day by the authors. With an experienced laborer capable of producing two machines in a day, the inclusive cost per machine would amount to Rs. 3630/-. This cost may potentially decrease further, contingent upon factors such as the volume of materials procured, labor intensity, and machinery utilized during production processes (e.g., cutting, drilling).
Table 3. Machine Budget on Mass-Scale Production.

Material	Bulk Market Price	Price per machine
18mm Plywood Hardwood	Rs. 6000/(4x8) ft2	Rs. 953.7/-
Ni-Chrome wire	Rs. 100/6m coil	Rs. 9.83/-
Bearing	Rs. 2000/24 pieces	Rs. 833.3/-
Mild Steel shaft	Rs. 120/ft	Rs. 212.4/-
Adapter	Rs. 9300/12 pieces	Rs. 775/-
Clamp	Rs. 400/12 pieces	Rs. 66.67/-
Nuts and bolts	Rs. 900/300 pieces	Rs. 30/-

4 Conclusion

The conventional pipe cutting machines rely on heavy cutters, leading to complexities, high production and maintenance costs, safety risks, and environmental concerns. This study presents an innovative approach that eliminates the need for such heavy cutters. The introduced model of PVC pipe cutting machine utilizes a heated Ni-Chrome wire as an alternative to heavy cutters or blades, enhancing precision and reducing complexities. The CAD design facilitated better selection and integration of each component, optimizing performance within budget constraints. The innovative design and fabrication techniques address key industry challenges while prioritizing efficiency, safety, and environmental responsibility. Testing of the prototype demonstrates that PVC pipes of various diameters and thicknesses can be cut with precision and minimal residue using this machine. Its sustainability is confirmed by its ability to cut up to 60 pipes ranging from 3 to 30mm in thickness without requiring wire replacement. The durability of the bearings and ease of maintenance further contribute to the sustainability and reliability of the machine. The absence of sharp operating components significantly reduces safety hazards, minimizing risks to personnel and equipment. This research presents a unique contribution in its design and working principles, potentially marking a milestone in the development of simpler, more efficient cutting machines, not only for industrial use but also for everyday consumers.

Appendix

Some calculations were performed using MATLAB to provide a deeper understanding of the characteristics of the machine. The MATLAB code can be accessed using the link below :

https://drive.google.com/file/d/1FoYWJVFFQs4U0x-bNv9Hbr2TtxB0LGNr/view?usp=sharing

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