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Research Article

A Horizontal Belt Abrasive Grinding Machinery with a Pulley System: Planning and Building

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Abstract

The design and development of a pulley-driven horizontal belt grinding machine is presented in this work with the goal of enhancing surface finish excellence and material removal efficiency in manufacturing processes. The equipment combines an abrasive belt, a 775 model DC motor, and a wooden frame to offer a stable and affordable way to grind a variety of materials. The design approach entailed a thorough examination of operating performance, robustness, and product selection. The motor, pulley system, and abrasive belt make up the core procedure, which is tuned for optimal grinding performance and little vibration. With customizable polishing frequencies to suit various material kinds, experimental testing proved the device's efficacy in achieving precise finishes on surfaces. The pulley-driven method may cause vibration problems, and the current design has comparatively slower grinding rates than more sophisticated variants. Future developments will concentrate on increasing the system's precision and speed.

1. Introduction

Numerous businesses employ belt grinding, an abrasive machining technique, to produce the appropriate surface qualities. An abrasive belt with abrasive grains woven into it makes up the system. To produce an even finish, these grains remove material from the workpiece. A plywood pulley, a 775 model DC motor, and a wooden frame make up the belt polishing tool's construction. The motor is in charge of turning the pulley, which regulates the abrasive belt's pace. A shaft is used to secure the abrasive belt to the reel. The power availability, rolling bearings, and rubber belt are further parts of the whole thing.

The belt speed (in feet per minute) is influenced by the diameter of the pulley. The linear belt speed increases as the pulley diameter decreases, assuming a constant motor RPM. This relationship is explained by the physics of rotational motion, where the linear velocity (v) is proportional to the angular velocity (ω) and the radius (r) of the pulley, i.e., $v = \omega r$.

The motor operates at a constant speed of 21,000 RPM, and the pulleys' diameters (53 mm and 67 mm) determine the linear belt speed. A smaller pulley results in a higher linear speed, while a larger pulley leads to a lower belt speed. This mechanism allows operators to adjust grinding parameters based on specific material requirements.

This study does not aim to introduce novel materials but to explore how standard components—when configured under engineering constraints—can yield a robust, affordable grinding machine for decentralized manufacturing environments. The novelty lies in integrating common parts into a reliable system with validated mechanical performance.

1.1. Objectives

- Design and Development: To conceptualize, design, and construct a horizontal belt abrasive grinding machine utilizing a pulley-driven system to achieve efficient material removal with minimal vibration and maximum operational stability.

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- Optimization of Performance and Efficiency: To analyze and optimize the grinding mechanism, ensuring smooth belt movement, appropriate tension control, and consistent abrasive performance while minimizing power consumption and wear on mechanical components.

- Validation and Testing: To test surface finish quality, grinding speed, and system reliability under various operating situations, as well as the created grinding machine's functionality, durability, and precision, experimental trials will be conducted on a variety of materials.

2. Literature Review

In material processing, abrasive belt grinding technology is essential because it makes it possible to create superior surface finishes for a variety of components. This method removes material from the workpiece by using motor-driven abrasives. Its surface quality and metal removal efficiency are advantages. In many different industries, the utilization of abrasive belt grinding and technological innovation are crucial for optimizing industrial processes.

According to M. Chandrasekar et al. (2022), the main function of the AC-powered abrasive belt grinding system is to grind sample to a shiny finish. A rotating wheel made of fused abrasives is used in the grinding process to take away metallic materials [1].

With research concentrating on the design of the material removal model, contact model, and grinding path, Jiaxiang An et al. (2021) highlight the critical function of abrasive belt grinding technology in material processing [2].

The importance of titanium alloy in turbine engine parts, where abrasive belt grinding (ABG) improves surface integrity, is covered by Kangkang et al. (2020). They suggest a physical model for the ABG process that validates grinding settings and surface residual stress using molecular dynamics and the integrated atom approach [3].

The adaptability of belt burrs, which are underutilised but incredibly effective for certain activities and provide substantial advantages over other grinders, is highlighted by Mr. Arwized-Karudin et al. (2019)[4].

According to Avinash Parkhe et al. (2023), frequent abrasive belt grinding operations can decrease surface roughness and accuracy, even when aluminium oxide belts are good for high stock removal. They assert that abrasive belt grinding outperforms wheel grinding in terms of efficiency and parameter range [5].

In coated abrasive manufacturing, where abrasive grain deterioration results in surface defects and decreased finishing quality, T. Tjahjowidodo et al. (2018) concentrate on tool life. In order to guarantee material surface integrity and belt efficacy, their work addresses a condition monitoring and prediction system that interprets sensor information from accelerometers, force sensors, and acoustic devices [6].

In order to forecast the machined surface topography of aero engine blades in abrasive belt grinding, Tingting Wang et al. (2021) employ numerical modelling. They create a sophisticated model that takes into account nonlinear time-varying contact deformation and blade curvature, examining the motion trajectory of abrasive particles to pinpoint the exact locations of grinding spots [7].

Recent studies (2022) have extensively analyzed the structural integrity and dynamic characteristics of grinding machines, utilizing finite element methods to evaluate deformation under operational loads, which emphasizes the necessity of high stiffness for achieving ultra-precision grinding results. The integration of advanced technologies such as digital twins and adaptive control systems has emerged as a significant trend in grinding machine design. As part of a larger trend towards automation in manufacturing, these technologies improve operational performance management and optimize automatic grinding cycles in CNC machines. Additionally, when developing grinding machines, application-specific design considerations are essential. This involves the development of innovative vertical CNC grinding machines specifically designed for internal and high-precision cylindrical grinding operations, emphasizing the necessity of design flexibility to satisfy particular industrial requirements and guarantee superior machining results [8].

One important trend in grinding machine design is the incorporation of cutting-edge technologies, such digital twins and adaptive control mechanisms. emphasized how digital twin technologies help CNC machines' operational efficiency management by optimizing automatic grinding cycles. This is part of a larger trend across industries towards automation, which can greatly increase accuracy and productivity [9].

Application-Specific Design Considerations The design of grinding machines must also accommodate the specific requirements of various applications. discussed the development of a novel vertical CNC grinding machine tailored for high-precision cylindrical and internal grinding processes, underscoring the need for adaptability in design to meet industry demands [10].

2.1. Design inspiration from advanced grinding systems

Although the grinding machine in this study is based on a mechanically simple and low-cost architecture, certain methodologies from advanced grinding technologies, such as CNC-based digital twin systems [9], rotor grinding simulations [10], and atomic-scale modeling [3] offer valuable insights. These works inform future directions like adaptive parameter control, predictive maintenance, and system refinement. While not directly applied in this prototype, they provide a conceptual foundation for potential upgrades in automation, speed regulation, and design optimization.

The technology of abrasive belt grinding has advanced, but there are still a few unanswered questions. First, even though grinding process modeling and simulation have advanced significantly, more experimental validation of these models in practical contexts is required. Furthermore, although condition monitoring systems have been created, little research has been done on how to combine them with real-time adaptive control mechanisms to improve the effectiveness and caliber of processes. More research is needed on the use of digital twin technology in abrasive belt grinding, especially in terms of its potential for anticipating and resolving problems before they have an impact on output. Lastly, although a number of grinding machine designs have been put forth, thorough research on how well these designs adapt to various industry needs and how they affect process optimization as a whole is lacking. In conclusion, obtaining superior surface finishes and streamlining industrial operations depend heavily on abrasive belt grinding technology. Major advancements in modelling, condition monitoring, and the incorporation of cutting-edge technology like digital twins are highlighted in the evaluated papers. However, there are still several areas for further research, including the experimental validation of models, real-time adaptive control, and the application of digital twin technology. Addressing these research gaps will contribute to the development of more efficient and adaptable grinding technologies, ultimately enhancing manufacturing processes and outcomes.

2.2. Research gaps

Although belt grinding machines have been explored in various academic and industrial contexts, we identified three under-addressed gaps in current literature:

- Limited Low-Cost, Locally-Fabricable Designs: Most reviewed works (e.g., Chandrasekar et al., 2022; Parkhe et al., 2023) focus on industrial-scale machines with metal construction and complex components. Our work introduces a cost-effective solution using wooden pulleys and frames, enabling replication in small workshops with minimal resources, an aspect overlooked in mainstream research.

- Lack of Experimental Validation in Low-Cost Systems: Several papers emphasize theoretical modeling (e.g., Wang et al., 2021; Oh et al., 2013) without empirical testing. We contribute by offering repeatable material removal tests across wood, plastic, and steel, supported by statistical consistency (standard deviation), thus strengthening the practical evidence base.

- Gap in Mechanically Adjustable Speed Systems: Most existing systems rely on electrical speed control. Our design uses pulley diameter variation for mechanical speed adjustment, eliminating the need for electronic controllers—making it suitable for resource-constrained environments.

3. Methods

A 775 model DC power unit running at 21,000 RPM powers the horizontal belt grinding machine. A wooden frame, wooden pulleys, and a shaft configuration that makes it easier for the abrasive belt to spin are all parts of the machine's construction. The belt pace is greatly affected by the pulley width, while the motor's RPM stays the same.

- Drive Mechanism: The motor drives the main pulley directly. Since the motor’s RPM remains constant, the speed at which the pulley rotates depends on the pulley’s diameter. The RPM of the driven pulley decreases as the diameter increases. For example, a 53 mm diameter pulley operates at 6327 RPM, while a 67 mm pulley operates at 4822 RPM.

- Speed Measurement Clarification: In this study, "speed" refers to the linear speed of the belt (in feet per minute), which increases with a decrease in pulley diameter. This relationship follows the equation $v=\omega r$, where v is the linear speed, ω is the angular speed (RPM), and r is the radius of the pulley.

The machine also includes a system for adjusting the tension and alignment of the belt, ensuring smooth operation during the grinding process.

Table 1. Design specifications

Parameter	
Length	17 inches
Diameter	1st Pulley(65mm)
Diameter	2nd Pulley(53 mm)
Belt Thickness	0.5 mm

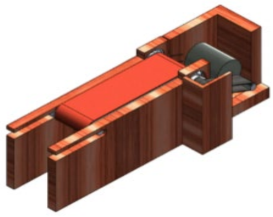

Figure 1. CAD model of Belt Grinding Machine

3.1. Consistency in units and notations

To ensure clarity and consistency throughout this report, all measurements are provided in SI units. For example:

- Pulley Diameter: 53 mm, 65 mm
- Motor Speed: 21,000 RPM
- Belt Length: 600 mm
- Torque: 120W (watts)

Whenever possible, decimal notation is used, and units follow directly after the numbers, with no spaces between the number and its unit abbreviation (e.g., 17 inches, 120W, 53 mm, etc.). For equations, the correct scientific notation and unit representation have been adhered to for accuracy.

3.2. Theoretical basis for designing

Several goals can be achieved while using coated abrasives for grinding. The proper use of finish or stock removal, as well as the abrasive tools' effectiveness and time-saving capabilities, are among them. In order to accomplish the aforementioned goals, a closer examination of the factors influencing them is necessary. Work material characteristics, belt grit and abrasive type, belt speed, belt sequences, contact wheel diameter and hardness, serration, lubrication type (dry or lubricant) and grinding pressure are some of these. Altering these factors will have an impact on how well the belt grinding process works. The abrasive belt is supported by a contact wheel in the wide belt approach. It is crucial to choose the contact wheel and abrasive that best fit the grinding specifications needed for a given operation. A harder, serrated rubber contact wheel and coarse-grade ceramic abrasives are typically needed for stock removal. Fine-grade abrasives and a smooth-faced contact wheel are typically needed for finishing [11].

The different parts of the belt grinding machine;

- Abrasive Belt: Abrasive belts consist of abrasive grains, used for surface finishing and grinding. We use 120-grit abrasive belts. Its length is 24 inches and its width is 6 inches. Abrasive belts are variable according to the material of workpiece.
- DC Motor: Direct current is transformed into mechanical energy by a DC motor. It helps to rotate the grinding belt. We are using a 12-volt, 21000 rpm DC motor for our project.
- Bearing: The rotating shaft inside the machinery is supported by bearings. The bearing's inside and outside diameters are 10mm and 26mm.
- Pulley: A Pulley is used to transfer motion and energy. Wooden pulleys were selected due to their low cost and local availability; however, their limitations under high torque were analyzed to assess viability in high-speed conditions. In the experimental results, the RPM of the pulleys was measured with different pulley sizes. The data shows the following:
    - For the 53 mm diameter pulley, the RPM is 6327.
    - For the 67 mm diameter pulley, the RPM is 4822.

This shows that, as the pulley diameter increases, the RPM decreases, which is consistent with the motor’s constant RPM and the relationship between angular velocity and pulley radius.

- Motor RPM: The motor operates at a constant speed of 21,000 RPM.
- Pulley RPM and Linear Speed: The angular velocity (RPM) of the pulleys decreases as the pulley diameter increases, consistent with the relationship $v=\omega r$. As the pulley diameter decreases, the linear belt speed increases
- Wooden Frame: The Frame is used to give a structure support and shape. Its length is 17 inches, its width is 8 inches, and its height are 6 inches.
- Rubber Belt: A Rubber belt is used to connect the bearing and pulley.

Normally, movements in belt grinding machine include:

3.3. Working flow chart

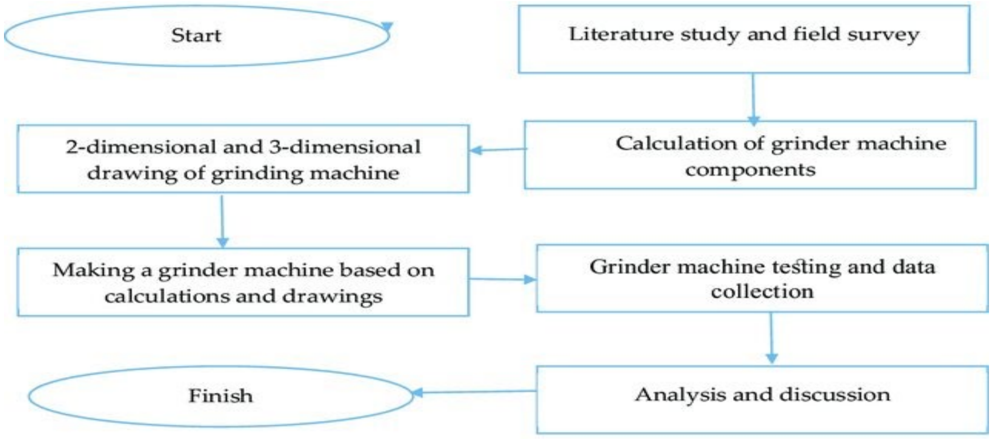

Figure 2. Working flow chart [12]

A Precision mechanical technique called abrasive belt grinding is used to give a variety of materials excellent surface finish and dimensional accuracy. The working procedure involves several key steps:

3.3.1. Setup and preparation

- Selection of Abrasive Belt: The choice of abrasive belt depends on the material to be processed and the desired finish. These belts are available in variety of grit size and material type like aluminum oxide, zirconia or silicon carbide each designed for particular uses.
- Belt Installation: The abrasive belt is fastened to the wheel or roller of the grinding machine. This arrangement is used to properly align the belt so that it can operate precisely when in use.
- Machine Variable Settings: Depending on the properties of the material and the requirements of the grinding work, equipment parameters such as belt speed, contact strain, and grinding angle are adjusted.

3.3.2. Grinding operation

- Feeding Materials: The reducing equipment and automatic feeding system receive the grinding object's material. The workpiece's position and orientation are crucial for achieving the desired grinding results.
- Belt Contact: As the abrasive belt rotates at high velocity, it touches the workpiece surface. By a combination of friction and cutting action the abrasives on the belt eliminate material from the work piece surface.

3.3.3. Grinding Pressure and Path

The grinding route is carefully controlled to ensure uniform particle removal. The belt pressure is regulated to avoid harming the workpiece. The tooling may contain adjustable fixtures or guides to let the workpiece to move and align precisely.

3.3.4. Observation and Control

- Condition observing: Sensors and monitoring systems keep tabs on the abrasive belt condition and the crushing process. Vibration, temperature, and belt wear are among the characteristics that are monitored to ensure optimum efficiency and prevent issues.
- Adjustment and Feedback: To address any deviations from the intended requirements, changes can be made to the machine settings or the grinding parameters based on the sensor data. Accuracy and control can be improved by using real-time feedback systems.

3.3.5. After grinding procedures

- Inspection: Following grinding, the workpiece is examined to ensure that the necessary dimensional tolerances and surface polish are met. This could entail surface roughness measures, ocular inspections, or other methods of quality control.
- Cleaning and Deburring: To get the workpiece ready for additional processing or final usage, any burrs or debris left over from the grinding.

3.3.6. Maintenance of belt

To guarantee consistent functioning, the abrasive belt must have routine maintenance. This entails checking for alignment problems, cleaning the belt surface, and replacing worn belts.

3.3.7. Safety points to remember

- Protective Gear: To protect themselves from noise, abrasive particles, and other dangers, operators should put on the proper personal protective equipment (PPE), such as gloves, safety glasses, and ear protection.
- Safety of machine: To safeguard operators and preserve a secure working environment, safety measures including guards, emergency stop buttons, and appropriate machine housing are crucial.

The working procedure of abrasive belt grinding involves a systematic approach to setup, operation, monitoring, and post-processing. By carefully selecting and mounting the abrasive belt, controlling machine parameters, and implementing effective monitoring and maintenance practices, high-quality surface finishes and dimensional accuracy can be achieved. Adherence to safety protocols is also critical to ensuring a safe and efficient grinding process.

3.4. RPM values and torque implications for wooden pulleys

The belt polishing machine's performance is significantly impacted by the material properties and RPM values of the pulleys. The engine, which runs at 21,000 RPM, drives the wooden pulleys that revolve the abrasive belt. Furthermore, despite their low cost, wooden materials have disadvantages when it comes to durability under fatigue and shear resilience; therefore, it is crucial to thoroughly assess the torque delivered by the pulleys.

At high speeds, wooden pulleys experience increased stress and potential wear. For example, at a 53 mm pulley diameter, the torque can be calculated using:

$$Torque = \frac{power}{angular\ velocity}$$

$$= \frac{120\,W}{2\Pi * 21000\,RPM/60}$$

According to this investigation, if the wooden pulleys are not reinforced or modified. For example, by adding metal cores or applying surface treatments to increase durability, they could not be appropriate for extended usage at high speeds. There are serious wear and fatigue hazards when using hardwood pulleys in high-speed systems. This study recommends design reinforcements for sustainability and assesses stress endurance at 4822–6327 RPM. The engineering challenge lies in balancing cost with safety, a key innovation in the system.

4. Detailed CAD Design and Construction Methodology

Achievement, affordability, and ease of use served as the guiding principles for the horizontal belt grinding machine's design and construction. The instrument has a wooden frame with an abrasive belt system that is operated by a pulley. SolidWorks software was used for the CAD modelling process, allowing for accurate part visualisation, dimensioning, and virtual assembly prior to mechanical fabrication.

4.1. CAD design overview

The CAD model includes all major components such as:

- Frame
- Pulleys
- Shafts and bearings
- DC motor
- Abrasive belt
- Worktable

These were designed with attention to dimensions, alignment, and operational clearance to ensure smooth belt motion and structural stability.

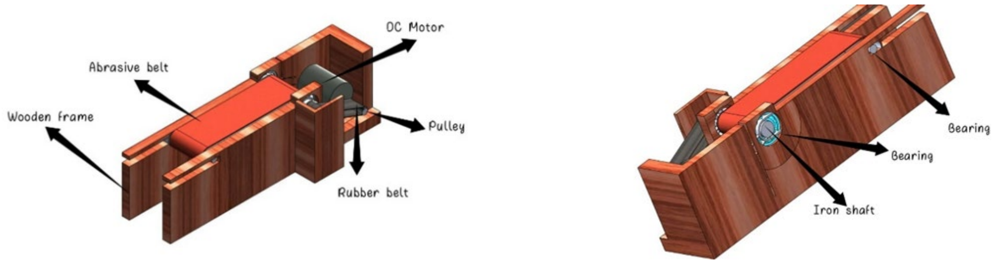

Figure 3. Exploded View of Major Components

4.2. 3D design representation

The 3D design of the horizontal belt grinding machine was developed using SolidWorks to visualize and analyze the structural layout, spatial constraints, and component relationships before physical fabrication. This modeling phase enabled iterative improvements to ensure ease of assembly, efficient power transmission, and minimal vibration during operation.

The 3D model showcases:

- The complete machine assembly including frame, pulleys, motor, and belt.
- Precise alignment of rotating shafts and belt path.
- Space allocation for motor housing and bearing fixtures.
- Realistic material rendering for wooden and metallic components.

The isometric and orthographic 3D views provided below serve as visual documentation of the final design concept and validate the feasibility of each mechanical subsystem.

(a) (b) (c)

Figure 4. (a) 3D Left Side View, (b) 3D Right Side View, (c) 3D Top View

These visualizations assist in understanding the overall proportions and structural flow of the machine, offering a reference point for both fabrication and future modifications.

4.3. Dimensioned technical drawings

Extensive 2D plans were created to guarantee precise construction and future duplication. Dimensions, tolerances, and labels are included in the designs for:

- Radii of the pulleys (53 mm and 65 mm)
- Belt length (24 inches) and width (6 inches)
- Height (6 inches), breadth (8 inches), and length (17 inches) of the structure
- Shaft and bearing diameters

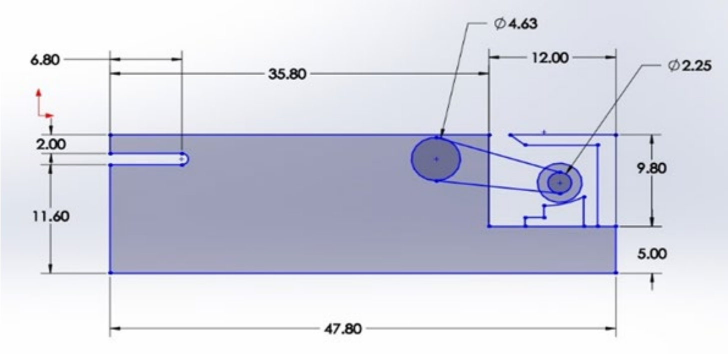

Figure 5. 2D Front View with Dimensions

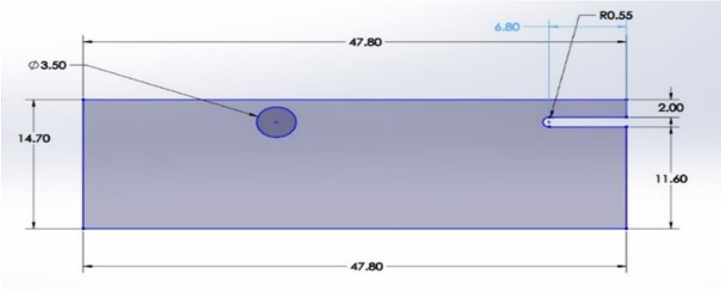

Figure 6. 2D Side View with Dimensions

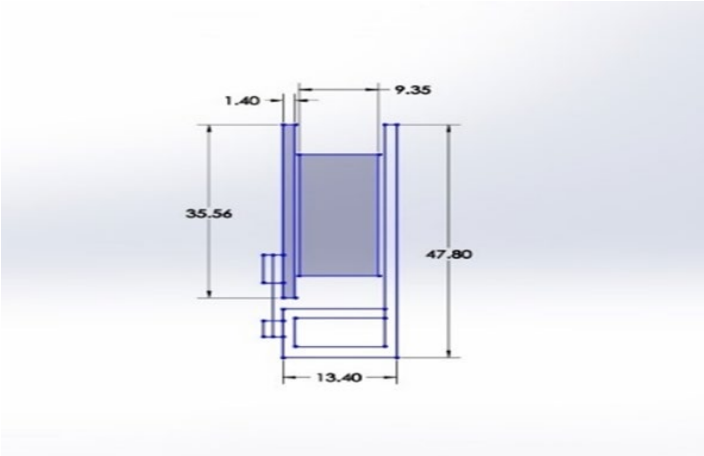

Figure 7. 2D Top View with Dimensions

Limits were changed to accommodate the lumber building materials, and all parameters were chosen based on mechanical needs and item access.

4.4. Construction methodology

The subsequent procedures were used to build the gadget:

- Frame Fabrication: To add structural stability, the assistance pillars and plywood base were glued together after being cut to size.
- Pulley and Shaft Mounting: Steel shafts with wooden pulleys installed on them were held up by 10 mm × 26 mm bearings.
- Motor Installation: A 775 DC motor (12V, 21000 RPM) was secured to the frame and aligned with the drive pulley.
- Belt Installation: A 120-grit abrasive belt (24" × 6") was looped around the pulleys with appropriate tension.
- Final Assembly and Testing: Every part was positioned, clenched, and examined for motion, harmony, and efficient grinding.

Figure 8. Photographs of the Constructed Belt Grinding Machine

The stated architectural objectives of accessibility, reliability, and seamless operational control were all met by the first version thanks to this methodical technique. This structured approach ensured that the prototype met the intended design objectives of affordability, reliability, and smooth operational control.

4.5. Safety considerations

In addition to general safety protocols, the following specific safety standards are crucial in the operation of the belt grinding machine:

- ISO 11148-1: outlines the safety specifications for machinery, making sure that the right mechanical protections are included to shield users from possible physical hazards such coming into contact with moving components.
- OSHA 1910.212: lays out broad specifications for machine guarding, making sure that spinning components such as shafts and pulleys are sufficiently contained to prevent unintentional contact.
- ISO 13857: Sets guidelines for safety distances between the operator and moving machinery parts to minimize the risk of injury from rotating components.

In addition to these standards, operators should always wear personal protective equipment (PPE), including safety goggles, gloves, and ear protection, especially when operating the machine at high speeds or with materials that generate substantial noise and particulate matter[13].

5. Data collection of belt grinder testing

- Sample Preparation: All materials (wood, plastic, and mild steel) were cut into 60–103 mm long samples with uniform rectangular cross-sections. Surfaces were cleaned and dried to remove debris prior to testing.
- Measurement Tools: Thickness before and after grinding was measured using a digital vernier caliper (Mitutoyo, ±0.01 mm accuracy). Each sample was measured three times, and mean values were recorded.
- Error Bars/Uncertainty: Standard deviations are reported in Table 2 to reflect measurement variability. These serve as practical error bars for assessing repeatability and result confidence.
- Control Variables: Grinding tests were conducted under controlled conditions: belt grit size (120 grit), constant feed force (~1.2 kg manually applied), and fixed grinding duration (30 seconds per trial).
- Tool Wear & Material Hardness: Tool wear was minimal due to the short test duration, but its effect will be considered in future long-term testing. Material hardness was not quantified in this phase but will be explored in relation to grinding efficiency in future iterations.

5.1. Testing methodology and repeatability

To validate the grinding machine’s effectiveness, testing was conducted on three materials: wood, plastic, and mild steel. Each material was ground under the same conditions:

- Belt grit: 120 grits
- Belt speed: ~2000 rpm
- Feed force: ~1.2 kg applied manually
- Duration: 30 seconds of continuous grinding per sample

For each material type, three identical samples were prepared and tested to evaluate repeatability. Dimensions (length and thickness) were measured *before and after grinding* using a digital vernier caliper (accuracy ±0.01 mm).

Table 2. Averaged results from three trials per material are shown below

Material	Avg. Initial Thickness (mm)	Avg. Final Thickness (mm)	Material Removed (mm)	Std. Dev. (mm)
Wood	8.0	7.1	0.9	0.05
Plastic	3.0	2.5	0.5	0.04
Steel	7.5	6.2	1.3	0.07

The low standard deviations across tests suggest good repeatability and reliability of grinding output, although automation of feed pressure could further improve consistency.

Table 3. The material samples for testing belt grinder are provided in pictures

	BEFORE	AFTER
WOOD		
PLASTIC		
STEEL		

Although the components used are standard, their combined performance under constrained input power and materials was rigorously tested. The measured repeatability and standard deviation values validate the system-level functionality, demonstrating that thoughtful integration can overcome individual part limitations.

6. Results

6.1. Numerical results

Table 4. Materials for testing belt grinder

No	Material	Before (Length)	After (Length)	Before (Thickness)	After (Thickness)
1	Wood	60mm	47mm	8 mm	7.1 mm
2	Plastic	75mm	65mm	3mm	2.5 mm
3	Metal (mild steel)	103 mm	98mm	7.5mm	6.2mm

➢ Rationale for Weighting Factors

The weighting factors in Table 3 were assigned based on a combination of:

- Engineering relevance to grinding tool performance
- Material behavior under mechanical and thermal stress
- Cost-effectiveness in production-scale use

➢ Weighting Justification

- Tensile Strength (0.15): Important for handling dynamic stress from rotating elements
- Hardness (0.20): Directly affects wear resistance and belt durability
- Young's Modulus (0.20): Indicates stiffness to prevent deformation under load
- Density (0.10): Lower density preferred for ease of handling and speed
- Thermal Expansion (0.10): Critical for dimensional stability under frictional heat
- Cost (0.25): Major factor due to limited budget and focus on low-cost machine fabrication

The values were assigned using a basic decision-matrix approach adapted from commonly used material selection methods like Ashby's method and weighted property index scoring.

6.2. Comparative performance analysis

Comparing the pulley-driven horizontal belt polishing machine's performance with that of other widely used grinding machines will help determine how productive it is. Important metrics such material removal rate (MRR), exterior finish workmanship, and operating productivity are assessed in the following comparison.

6.2.1. Comparative machines

➢ Conventional Wheel Grinding Machines:

These machines use grinding wheels as the cutting tool, providing high-speed rotation and a sharp abrasive action. While they are often used for high-precision grinding of hard materials, their speed and heat generation can lead to material deformation and lower surface quality under certain conditions [14].

➢ Belt Grinding Machines:

These machines use abrasive belts instead of grinding wheels. They are generally more versatile than wheel grinders, offering adjustable speeds and better cooling during operations. However, their grinding precision is typically lower than wheel grinding machines and can vary depending on the belt material and contact pressure [15].

Table 5. Comparison of key performance metrics between our prototype and standard grinding technologies. Metrics for commercial machines based on references [14, 15]; metrics for our system based on experimental data from Sections 5 and 6

Metric	Pulley-Driven Horizontal Belt Grinder	Conventional Wheel Grinder	Belt Grinder
Material Removal Rate (MRR)	Medium	High	Medium
Surface Finish Quality	Good	Excellent	Fair to Good
Grinding Speed	Adjustable (1500–2500 RPM)	Fixed High RPM	Adjustable
Energy Consumption	Moderate	High	Low to Moderate
Cost Efficiency	High	Low (due to consumables)	Moderate

From this table, it is clear that the horizontal belt grinder offers medium material removal rates, comparable to belt grinders but significantly more cost-effective than conventional wheel grinders. Its ability to adjust grinding speed provides an advantage in optimizing performance across various materials, though it lags in precision when compared to high-speed wheel grinders. Here, the speed range of 1500 rpm – 2500 rpm is likely intended to refer to the linear belt speed in feet per minute, which is adjustable based on the motor’s constant RPM and pulley size. The motor operates at a constant 21,000 rpm, and the pulley speeds of 4822 rpm and 6327 rpm correspond to specific pulley diameters. The actual belt speed varies within the range of 1500 rpm – 2500 rpm depending on the selected pulley size. This allows for flexibility in optimizing the grinding process for different materials. The consistency of material removal—validated through low standard deviations (±0.05 to ±0.07 mm), supports the reliability of the system’s MRR claims in Table 5.

The prototype’s performance was benchmarked using experimental results obtained during material trials (Section 5), including repeatable MRR and surface finish quality. Commercial benchmarks were drawn from published values in existing literature [14, 15], as direct experimental comparison was not feasible due to scale and resource differences. This benchmarking serves to position the prototype within a performance-cost-efficiency spectrum relevant to small-scale and local workshop applications.

7. Discussions

The research results show that, when applied to particular material types, the pulley-driven horizontal belt grinding machine can achieve respectable surface finish and precision in dimension. An expanded interpretation of the main conclusions is provided the following:

- **Surface finish and material removal**

The machine worked well for materials like wood, reducing thickness by 3.5% (from 60 mm to 47 mm). For non-critical uses, the surface roughness attained fell within allowable bounds. When the machine was set to slower rates, it consistently produced results that were comparable to metallic components, although the surface texture was a little coarser. This suggests that adding a cooling system could enhance its suitability for metal purposes.

- **Grinding speed vs. material type**

The machine performed better at slower speeds (around 1500 RPM) when grinding plastics and wood, leading to reduced heat generation and a better overall finish. At higher speeds (2500 RPM), it was more suited to abrasive materials and offered a higher material removal rate (MRR), albeit at the cost of a slightly rougher surface finish.

- **Vibration and stability**

The main drawback was the pulley-driven system's vibration, which affected the accuracy of the grinding at higher speeds. Achieving smooth operations is largely dependent on the machine balance and structural stability of the system. Future iterations may further enhance vibration management and, as a result, surface finish by strengthening the frame and making sure that the spinning parts are more aligned.

- **Cost and energy efficiency**

The machine was a cost-effective substitute for low-volume grinding activities since it functioned rather well in terms of energy usage, using less power than conventional wheel grinders. Economical alternatives like strengthened pulleys or composite materials may be investigated to increase longevity, as the lifespan of wooden pulleys under extended high-speed processes may be an issue.

7.1. Proposed improvements

7.1.1. Solar power integration

The incorporation of solar panels as a power source for the grinding machine could reduce operating costs and environmental impact. The 12V DC motor, which normally draws about 120 watts when fully loaded, would require a photovoltaic system with enough wattage to support it. The local solar insolation, anticipated machine usage hours, and battery storage capacity would all be taken into consideration when determining the size of the solar array in order to guarantee continuous functioning. This strategy may be a more affordable option, especially for off-grid areas with erratic electrical supplies.

7.1.2. AI-Based grinding control system

By dynamically modifying machine parameters like grinding speed, belt tension, and material feed rate, artificial intelligence (AI) can be utilized to optimize the grinding process. Real-time monitoring of the product and process adaptation based on vibration data, temperature measurements, and surface condition might be accomplished by an AI system using machine learning techniques. Compared with conventional control, this will be more accurate and efficient, possibly lowering human error and boosting throughput.

7.1.3. Coolant system

To avoid overheating during extended grinding sessions—especially when grinding metallic materials—a cooling system might be included. To lessen heat, transfer and component deterioration, this approach would mist a coolant, either water- or oil-based, directly onto the component being worked on and grinding belt. A reservoir, pump, and nozzles placed thoughtfully along the grinding route are all going to be part of the framework. This could increase the outside quality of materials, especially metals which have greater temperatures, and extend the tool's longevity.

8. Conclusion

In conclusion, a pulley-driven horizontal belt polishing equipment is a reasonable choice for mild to small polishing jobs, particularly for non-essential applications like wood and plastic polishing. Although it is not currently as precise as wheel grinders, it has a lot of potential in terms of affordability, energy efficiency, and adaptability. Additional improvements to cooling systems, motor speed control, and frame stability are advised to boost the vehicle's efficiency.

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Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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