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Innovative Design Idea of the Shaft Drilling Jigs and Fixture for Better Machining and Fabrication

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ABSTRACT

This project focuses on enhancing precision and efficiency in the manufacturing process by optimizing the selection and design of jigs and fixtures, specifically aimed at reducing cycle time in pinion production. The methodology incorporates product design using Solidworks and Surfcam, encompassing the development of a detailed fabrication flow, process planning, selection of machines and tools, material choices, and manufacturing methods. Implementing shaft drilling jigs is crucial in improving operational efficiency, safety, and product quality. Key recommendations emphasize the importance of jig rigidity, adaptability, secure clamping, precise guiding, ergonomics, safety features, and thorough documentation. The enhanced jigs successfully improved machinability and prevented shaft slippage. Future recommendations suggest exploring the use of advanced materials, integrating automation, and fostering collaborative efforts.

Keywords: Shaft drilling, Surfcam, Jigs and fixtures, Machining and fabrication.

1. INTRODUCTION

Jigs and fixtures play a vital role in manufacturing processes [1], directly influencing production's precision, efficiency, and cost-effectiveness. These tools are essential for ensuring that components are consistently manufactured to the required specifications, reducing the likelihood of errors [2], and streamlining the production process. However, selecting the most appropriate jig and fixture for a specific component is often complex and challenging. This difficulty arises from the vast array of available options, each with its unique features, as well as the varying preferences and expertise of designers who may prioritize different aspects such as cost, ease of use, or adaptability. Despite the significant impact that the correct choice of jigs and fixtures can have on manufacturing outcomes, there is currently no standardized or universally accepted procedure for making these selections [3]. Although numerous strategies and guidelines have been proposed in the literature, they often cater to specific scenarios or industries, leaving a gap in providing a comprehensive, accessible, and adaptable selection framework that can be applied across different manufacturing contexts.

Deokar [4] significantly reduced the cycle time of post-manufacture machining for pinions by leveraging mechanical engineering expertise, specifically through jigs and fixtures. He reported that only 5-6 pinions were machined per shift on a YASDA 800N CNC machine. This process is both time-consuming and reliant on highly skilled labor. The existing procedure involves manually mounting the pinion on a V-clamp fixture, followed by precise measurement for oil hole drilling, which is the most time-intensive step. After drilling, the pinion must be demounted and

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remounted on a different fixture for tapping and spot-facing operations, requiring continuous use of overhead cranes. The project proposes radical changes to this system to streamline the process, aiming to increase productivity and efficiency. Pandit [5] explored the essential principles of jig and fixture design, emphasizing their ongoing relevance in improving productivity and machining accuracy, even as manufacturing technologies evolve. While standard machine tools can be transformed into specialized tools using jigs and fixtures, a unified approach to fixture design is still lacking. The fundamentals of location, clamping, and automation in fixture design are crucial for developing effective solutions. A well-designed fixture enhances productivity and repeatability and addresses issues, such as workpiece distortion caused by clamping and cutting forces. Despite advances in machine tools, these principles remain central to successful jig and fixture design. Pachbhai and Raut [6] reviewed different clamping methodologies used in machining fixtures to minimize workpiece deformation and maintain accuracy. It highlights the need for optimal placement of fixturing elements like locators and clamps and the manual nature of current fixture setups, which increases cycle time. Developing systems to improve productivity and reduce operation time is emphasized as a critical area for advancement in fixture design.

Mohammed and Tariq [7] mentioned that to stay competitive in an increasingly demanding market, industrialists must aim for higher production and enhanced quality while reducing costs. Automation and tooling aids such as jigs and fixtures offer cost-effective solutions with lower initial investment and higher productivity. They explored the design and analysis of drill jigs using PRO E for modeling and ANSYS software for performance evaluation, highlighting these tools' efficiency and cost-saving potential in manufacturing. Kengle et al. [8] emphasized that a fixture is crucial for locating, holding, and supporting a workpiece during various manufacturing operations, particularly in automated production, inspection, and assembly processes. It ensures the workpiece is accurately positioned and securely clamped for precise interaction with tools or other components, maintaining consistency throughout the operation. They conducted experimental and theoretical analyses of fixtures with variable shaft diameters, focusing on their accuracy and clearance during use. Patel et al. [9] reported that mass production focuses on achieving high productivity and ensuring interchangeability for easy assembly, which can be accomplished through jigs. Jigs, equipped with tool-guiding elements like drill bushes, streamline operations by enhancing accuracy and reducing the need for manual positioning and frequent checks. They designed and analyzed drill jig plates for drilling at various angles and positions to ensure precision and efficiency. Using drill jigs increased productivity by automating tools' locating, clamping, and guiding, minimizing repetitive tasks, and providing consistent drill operations.

Sim and Lee [10] focused on designing and constructing a drilling jig for mass production, utilizing tools like AutoCAD and database management. The first part of their study covers key aspects such as part drawing analysis, jig planning, and design. Drilling jigs are critical in meeting industrial demands for mass production, especially in machining, welding, and assembly. The design and application of jigs and fixtures are crucial in preventing production defects, making them essential in optimizing manufacturing processes. This requires a thorough analysis of factors such as machine tool operations, jig and fixture structures, machining conditions, and material properties, including heat treatment of components. Reddy et al. [11] modeled and analyzed a drill jig. The modeling was completed using advanced software, while the analysis was performed using Finite Element Analysis (FEA) through Ansys. A bottom-up methodology was employed to model both individual components and their assembly. Modal analysis was conducted to visualize the behavior of the drill jig, and static structural analysis was performed under different load conditions for various materials. The results were plotted and tabulated to determine the optimal material for the drill jig. Anand et al. [12] focused on designing and analyzing turning and drilling fixtures for an HSU component, evaluating their performance under different loading conditions experienced during the cutting process. Axial loads during turning and drilling generate stress within the fixture, and two main forces, cutting and clamping, were analyzed. Using AutoCAD for 2D drawings, CATIA for 3D modeling, and ANSYS Workbench for meshing and analysis, their study examined the stress and deformation caused by these forces. The results showed that the maximum stress observed was below the material's yield strength, indicating that the fixture design is reliable under the given conditions. These findings suggest that the design is safe and can withstand the operational loads without failure. Masurkar et al. [13] designed a custom drill jig to manufacture a critical currency counting machine component. The drill jig holds, supports, and guides the drill bit to drill equidistant holes accurately along the curved surface of a cylindrical workpiece. An indexing plate mechanism was developed to streamline the process, allowing all five holes to be drilled without repeatedly clamping and unclamping the workpiece. Solidworks was used for design, assembly, and drafting, while height gauges and Go/no-go gauges ensured hole positioning accuracy and diameter verification. Implementing this indexing drill jig significantly improved drilling accuracy, production consistency, and the overall manufacturing rate.

According to Deokar [4], the previous method took approximately 55 minutes to complete the oil hole drilling process for a single pinion. Given the high demand for pinions, we expect to develop a solution that significantly reducing the cycle time. The oil hole drilling operation has become a bottleneck in the overall pinion manufacturing process, hindering the production output. To meet the increased demand and improve productivity, it is vital to explore alternative approaches and methods to minimize the cycle time of the oil hole drilling operation. This can be achieved by modifying drilling procedures, reducing material handling time, and implementing innovative solutions. This work aims to propose and design shaft drilling jigs and fixtures to shorten the duration of drilling production. Other goals include increasing the product's machining ability and avoiding rotational shaft slippage. A cost analysis was also conducted for the proposed shaft drilling.

2. MATERIAL AND METHODS

Understanding the qualities of the materials being drilled, the behavior of the drilling equipment, and the interaction between the drill bit and the ground are all part of the theory underpinning shaft drilling. Figure 1 depicts the proposed design of shaft drilling jigs and fixtures. Figure 2 shows the multiview and exploded view of the proposed shaft drilling jigs and fixtures. The theory behind jig drilling involves using a specialized tool or fixture that holds the drill bit in a fixed position and guides its movement during the drilling process. The jig usually has pre-drilled holes or bushings that determine the location and angle of the drill bit. The fastener diameter is 10 mm, the thread pitch is 1.5 mm, the coefficient of friction is 0.15, the torque applied is 25 Nm, and the tensile strength is 400 MPa.

The thread area: $(\pi/4) \times (10\ \text{mm})^2 = 78.54\ \text{mm}^2$

The thread radius = 10 mm/2 = 5 mm

In the first stage, designing a 3D model of the project part using SolidWorks' modeling tools is the first step. This entails sketching 2D profiles, adding dimensions and restrictions, and using features like extrusions, cuts, and fillets to achieve the appropriate shape. The second stage starts the process by choosing the suitable metal material based on the desired qualities and application needs. The chosen metal is cut using a saw blade and placed in the appropriate shape and size. The third stage is forming. After being sliced into smaller pieces, the metal is processed into the required shape using techniques like drilling. The use of specialized tools and equipment may be necessary for this phase. Further machining procedures like milling, drilling, or turning may occasionally be used to attain precise measurements or produce specific characteristics on the metal surface. The fourth stage is assembly. Welding makes a solid and reliable connection when laying metal components together. The various metal components are assembled using fasteners, adhesive, or welding methods if the fabrication entails constructing a more substantial product or structure. The last stage is finishing, which prevents corrosion, enhances aesthetics, or provides valuable features, such as metal items that might be coated or painted. Several inspections and quality control procedures are used throughout the fabrication process to ensure that the finished product meets the requirements. The finished metal fabrication may go through extra finishing procedures like deburring, cleaning, or polishing to produce a high-quality product.

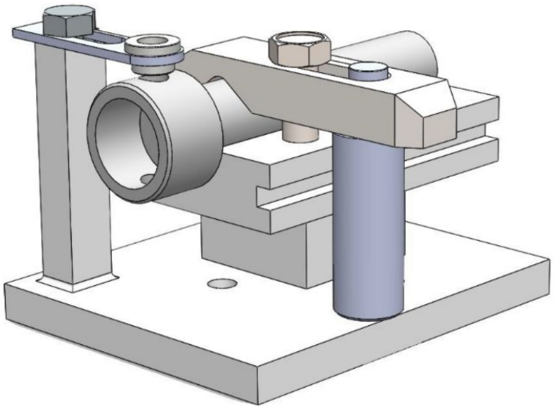

Figure 1: 3D model of proposed shaft drilling jigs and fixtures.

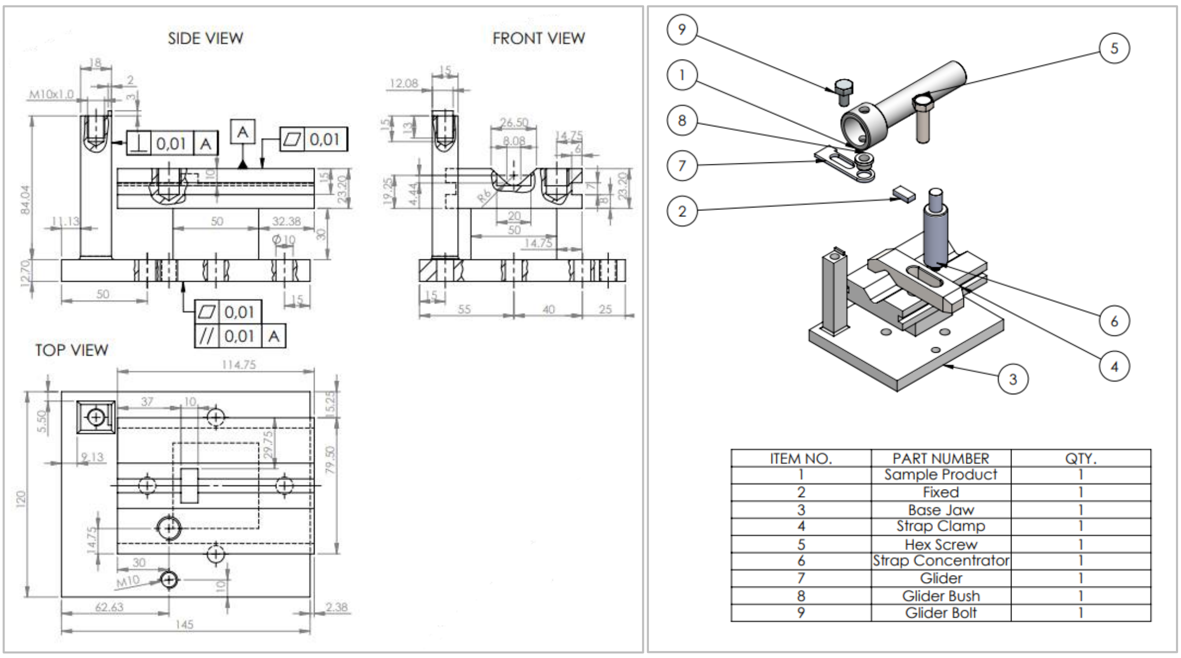

Figure 2: Multiview and exploded view of sharf drilling jigs and fixtures.

3. RESULTS AND DISCUSSION

3.1 Computer-Aided Manufacturing (CAM)

The Computer-Aided Manufacturing (CAM) procedure was studied and processed using Surfcam. The unit in Surfcam software was set to metric units. The axis in Surfcam software was set to Lathe Radius. Figure 3 shows the dimensions of the strap concentrator used in CAM. The strap concentrator part was drawn using the exact dimensions as Solidworks in Surfcam. Then, the lathe-face toolpath process was generated. The lathe-turn toolpath process was generated. The stock of the strap concentrator was set to a round lathe. The stock value was set. Lastly, the Surfcam process was checked and edited by running the simulation. The tool selection was emphasized, and CNMG4318B 0.4 mm OD Face/Turn and VNMG432B 0.4 mm OD BacFace/Turn was selected. Both types of cutting tools are diamond, and the nose radius of this cutting tool is 0.4mm. CNMG4318B 0.4 mm OD Face/Turn was used for the facing and turning. Besides, the number of cutting tools was set to 1 for the facing process and 2 and 3 for the turning process, while VNMG432B 0.4 mm OD BacFace/Turn was used for the turning process, and the number of cutting tools was set to 4 and 5 for turning process. For this strap concentrator, the stainless steel 304 material was used. A lathe face and lathe turn was carried out. There were two types of cutting simulation: facing and turning.

Facing is the process of removing metal from the end of a workpiece to produce a flat surface (Figure 4). The amount of removal during the facing process is 2 mm. Turning is a process where a cutting tool removes material from the outer diameter of a rotating workpiece (Figure 5). Four turning processes use the same cutting tool for the strap concentrator. For turning tool 2, the amount removed is 19.8 mm for the z-axis, and the diameter removed is 5.25 mm. For tool 3, the amount removed is 0.5 mm for the z-axis, and the angle is 135 degrees. For tool 4, the amount removed is 0.5 mm for the z-axis, and the angle is 225 degrees. For tool 5, the amount removed is 8.2 mm for the z-axis, and the diameter removed is 6.5 mm.

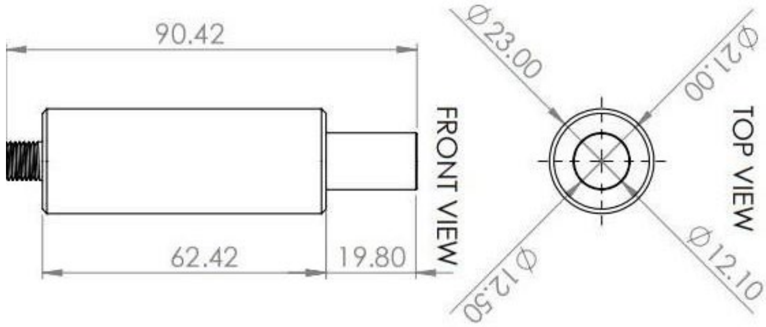

Figure 3: Strap concentrator drawing.

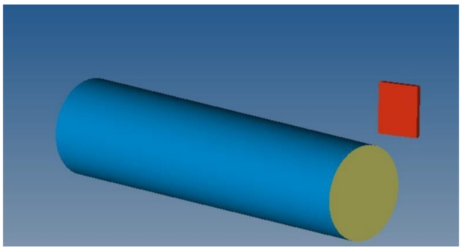

Figure 4: Facing process.

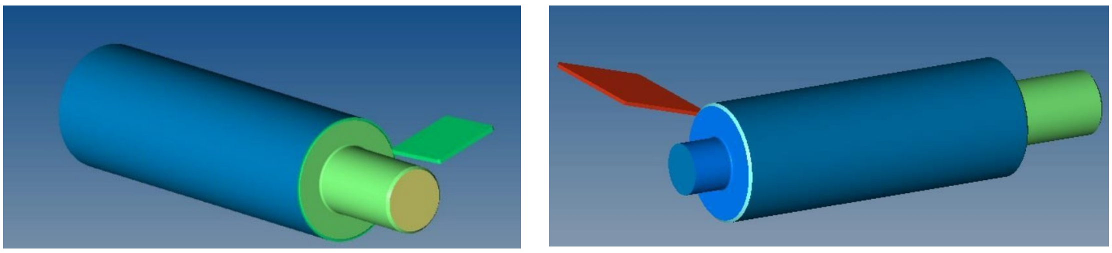

Figure 5: Turning process.

3.2 Cost Analysis

3.2.1 Direct Cost

Various sorts of machines are necessary during the production process. In terms of increased productivity, the equipment enables smart and safe labor. Table 1 show lists the costs and machine models that must be used. It would be illogical for the corporation to invest significant money in the new product before it generates revenue. To maximize profit, the monthly rental technique is chosen for short-term rentals (Table 2).

Table 1: The costs and machine models used in machining and fabrications.

Type of machine	Model	Price (RM)
Cutting off machine	Mod.ZB-355C-1	RM 168
Bench drilling machine	Z5035	RM 17,180
Vertical milling machine	ZAY7045FG	RM 5,135
MIG welding machine	220A DC AC	RM 326

Table 2: Monthly rental price.

Type of machine	Daily rental price (RM)
Cutting off machine	RM 20
Bench drilling machine	RM 20
Vertical milling machine	RM 20
MIG welding machine	RM 35
Total	RM 95

For material, stainless steel 304 (Table 3) is renowned for its corrosion resistance, high strength, and formability. It is widely used in kitchen appliances, automobiles, and other industries requiring durability. Its appealing look and ability to maintain stability at high temperatures make it an ideal choice for various applications.

Table 3: Cost of material.

Item	Cost per unit	Quantity	Total cost (RM)
304 Stainless Steel	RM 151/300 × 600mm	1	RM 151

The cost of labor is the amount spent on wages paid to employees and is calculated based on the number of hours worked per week. Employees must perform the production parts' cutting, drilling, milling, and welding processes. The employee is paid RM 7.50 per hour and works in a team of two. The daily schedule calls for 8 hours of work, which equates to RM 60 for each employee.

3.2.2 Indirect Cost

In addition to the activities on the production line, manufacturing and other running costs were included in the overhead expenditure. The term "overhead cost" is frequently used to describe utilities, sales and marketing, or maintenance expenses. It is projected to cost around RM900 per month, assuming RM30 per day. For taxes, the product will be subjected to an additional 10% good and services tax (SST) under the government of Malaysia's imposed tariffs and levies. It must be calculated along with the other expenses for the product to consider. Electrical power is necessary for utility bills, including what to perform. It is the primary supplier of functional machinery and equipment. The costing computation must take electricity usage into account.

Tenaga Nasional Berhad (TNB) is the sole electricity supplier in Malaysia. During the machining process, the cost rating of utilization will be calculated in watts per hour.

Along with the cost of water, the statement for other expenses also includes the state water supplier's rating. A rough estimate comes out to RM50 each day. For material, items not directly used in production or have any commercial value are referred to as indirect materials. It is employed in the final finishing process to give products a nice appearance and prevent oxidation. Spray paint and anti-rust primer are included in the indirect cost (Table 4). Regarding indirect costs, labor refers to employees who do not work on the production line but instead help the business administration maintain control and make improvements to meet the target.

Table 4: Spray paint and anti-rust primer cost.

Item	Cost per unit	Quantity	Total cost (RM)
Screw	RM 0.20	50 pieces	RM 10.00
Spray paint	RM 7.50	3	RM 22.50
Anti-rust spray	RM 6.80	3	RM 20.40
Total			RM 52.90

Table 5: Cost of labor.

Position	Rating per hours	Working hours	Quantity	Total cost (RM)
Supervisor	8	8	1	RM 64
Assistant	7.50	8	1	RM 60
Cleaner	5	3	1	RM 15
Total				RM 139

3.2.3 Selling Prices

Determining an accurate selling price for the product requires careful consideration of several vital factors. The pricing strategy must account for the primary production costs, which include material, labor, overhead expenses, and any additional costs related to logistics and distribution. Furthermore, applicable taxes and regulatory fees must be factored into the final price to ensure compliance with local and national laws. In addition to cost considerations, a thorough market analysis is essential. This analysis should evaluate competitors' pricing, consumer demand, and perceived value of the product within the target market. A more accurate and competitive selling price can be achieved by combining cost-based pricing with insights from market trends and customer expectations. Tables 6 - 10 outline the factors that influence estimating the product's selling price, providing a structured approach to ensure profitability while maintaining market competitiveness. Therefore, the calculated cost of the item is RM 701.90, and the suggested selling price is RM 800 per unit.

Table 6: Direct cost.

Types	Daily price (RM)
Machine	RM 95
Material	RM 151
Labor	RM 120
Total	RM 366

Table 7: Indirect cost.

Types	Daily price (RM)
Overhead	RM 30
Utility bill	RM 50
Material	RM 52.90
Labor	RM 139
Total	RM 271.90

Table 8: Fixed cost.

Types	Cost (RM)
Direct material	RM 151
Machine	RM 95
Utility bill	RM 50
Total	RM 296

Table 9: Variable cost.

Types	Cost (RM)
Overhead	RM 30
Indirect material	RM 52.90
Direct labour	RM 120
Indirect labour	RM 139
Total	RM 341.90

Table 10: Type of Cost.

Types of Cost	Cost (RM)
Fixed cost	RM 296
Variable cost	RM 341.90
Total (with 10% taxes)	RM 637.90 + RM 63.79 = RM 701.69

3.2.4 Profits

The selling price of the products would depend on the company's revenue after considering all cost factors. Profit, or the company's income, is determined by deducting costs from the selling price. The essential factor to consider is the profitability estimate as the corporation proposes to generate commercial. In addition to the profit, the product's price must be acceptable to prevent overcharging or market loss. As a result, conducting a marketing survey is necessary before determining the selling price. The suggested selling price is RM 800 per unit. The total cost is RM 701.90, and the profits of RM 98.10. Therefore, a product's profit per unit after sales would be RM 98.10.

3.2.5 Return on Investment (ROI)

The creation of a product in a business field is quite expensive. Many companies may seek out investors to raise money for their product development projects. The investor's curiosity is stimulated by the feature of ROI, which is calculated as data. The project's investment worth should be mentioned. The ROI computation and formula [14] are shown below:

$$\text{Return on Investment (ROI)} = (\text{Net Profit} / \text{Cost of Investment}) \times 100\% \quad (1)$$

$$\text{Net Profit} = \text{Profit} - \text{Cost of Investment} \quad (2)$$

Cost of Investment: RM 10000 (estimate)

Profits for 10 units (per month): RM 98.10 × 10 = RM 981.0

(Profit per month) × (12 months) = RM 11772

Therefore ROI, [(11772 – 10000) / 10000] × 100% = 17.72%

3.3 Impact and Future of the Product

3.3.1 Impact on Project Field

The use of shaft drilling jigs has significant societal and engineering impacts. Societally, these jigs enhance efficiency and productivity by reducing the time and effort required for drilling shafts. They also improve safety by securely holding the workpiece, minimizing the risk of accidents. Additionally, shaft drilling jigs contribute to higher-quality shafts, resulting in better-performing end products. From an engineering perspective, these jigs ensure accuracy and precision in drilling, leading to reliable and uniform hole placement. They also facilitate design and manufacturing efficiency, allowing engineers to optimize processes and achieve standardization and interchangeability.

3.3.2 Recommendations

Considering recommendations for shaft drilling jigs, it is essential to focus on rigidity and stability to reduce vibrations and maintain accuracy [15]. Designing jigs with flexibility and adaptability enables their use for various shaft sizes and configurations. The clamping mechanism should secure the workpiece's grip, minimizing movement or slippage. Incorporating precise guiding and positioning devices ensures accurate alignment. Ergonomics should be considered for operator comfort, and safety features [16], like protective shields and emergency stop buttons, are crucial. Finally, comprehensive documentation and user manuals aid in proper usage and safety protocols.

4. CONCLUSION

In conclusion, introducing enhanced jigs and fixtures in manufacturing has been proposed, which is expected to reduce production time, improve machinability, and mitigate issues like rotational shaft slippage. A cost analysis was conducted, and the estimated selling price for a unit of shaft drilling jigs was RM 800. The profit per unit is RM 98.1 after considering the direct, indirect, fixed, and variable costs. The estimated return on investment is 17.7%. However, ongoing research in shaft drilling jigs is essential to advance performance further and tackle future challenges. Critical areas for exploration include advanced materials, automation, adaptive designs, virtual simulation, integrated monitoring, ergonomics, sustainability, and collaborative research efforts. By pursuing these opportunities, the continuous improvement of shaft drilling jigs will lead to greater manufacturing efficiency, precision, and safety, ultimately revolutionizing precision drilling operations and boosting productivity across multiple sectors.

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