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Design and Development of a Compact Drilling Machine for Small-scale Industries

Muhammad Azreen Syafeezy Azhar [1], Siti Nur Mariani Mohd Yunos[1]*

[1] *Faculty of Mechanical and Manufacturing Engineering*
Universiti Tun Hussein Onn Malaysia, Parit Raja, Johor, 86400, MALAYSIA

*Corresponding Author: nmariani@uthm.edu.my
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Abstract

In modern manufacturing, drilling machines play a crucial role in material processing and component fabrication. However, conventional drilling machines are often large, costly, and logistically challenging for smaller workshops. This study focuses on the design and development of a compact bench press drilling machine tailored for small-scale industries and workshops based on do-it-yourself concept. Key limitations of existing machines were identified using fishbone diagram. A morphological chart was employed to generate and evaluate design concepts, leading to the selection of an optimal mechanism. The final design was developed using SolidWorks, and a prototype was fabricated and tested by experienced industrial professionals. The results demonstrate the performance of the miniature drilling machine, highlighting its potential to address the challenges faced by smaller enterprises. Comparison with conventional models highlights the prototype's strengths, and recommendations for further refinement are proposed to enhance its performance and applicability.

1. Introduction

Drilling machines are fundamental tools across industries, with applications ranging from construction to manufacturing. They facilitate material processing and component fabrication, making them indispensable in various sectors. The drilling machine cut holes in metal with a twist drill. They also use a variety of other cutting tools to perform the following basic hole-machining operations like reaming, boring, counterboring, countersinking, and tapping internal threads with the use of a tapping attachment. However, small-scale industries often face challenges in acquiring cost-effective, compact, and versatile drilling machines due to budget constraints, limited space, and the specific demands of their operations.

Compact drilling machines address these challenges by integrating precision, flexibility, and affordability into their design. Recent advancements in this field have focused on enhancing automation, reducing noise levels, and improving control mechanisms to meet diverse industrial requirements. Numerous studies have emphasized the role of compact drilling machines in enhancing productivity and operational efficiency. For instance, Egeland et al. [1] designed a miniature robotic drilling rig aimed at advancing automation for research and educational purposes, demonstrating the feasibility of compact and efficient drilling systems. Similarly, Bijwe et al[2] introduced a 360-degree flexible drilling machine capable of operating in any direction, which significantly improved the adaptability of drilling operations in confined spaces.

Vertical press drilling machines are versatile solutions for various applications, offering precise and efficient operations in a compact form factor. These robust tools are primarily used in industrial settings for precision drilling. Designed with a sturdy column, a stable base, and a movable worktable that can be adjusted for height and angle, they are well-suited to handle large and heavy workpieces. Equipped with high-power motors, vertical press drilling machines provide the necessary torque to drill through tough materials such as metal, wood, and plastic. Their solid construction minimizes vibrations, ensuring precise and clean drilling results. Many models come with advanced features like variable speed control, depth stops, and coolant systems, which enhance performance and prolong the lifespan of the tool. These machines are valued and widely utilized in manufacturing, metalworking, and woodworking industries, for their stability and accuracy. They accommodate various drill bits and accessories, enabling a wide range of tasks, from simple hole drilling to more complex operations such as tapping and countersinking.

CNC technology has further underscored the importance of integrating multiple machining processes into a single setup, thereby reducing labour intensity and production costs. The development of specialized CNC turret vertical drilling machines has shown the potential for completing various operations—such as drilling, reaming, and tapping—within a single clamping cycle, significantly enhancing efficiency [3].

For small-scale industries, the development of PC-controlled PCB drilling machines offers a cost-effective alternative to expensive CNC machines. These machines utilize software to generate coordinates for drilling, significantly reducing manual labor and increasing precision. The integration of microprocessors and stepper motors allows for automated and accurate drilling processes, making them highly practical for small-scale operations [4]. Additionally, Niranjan et al. [5] explored automated drilling machines with depth controllability, highlighting their potential for precision drilling in small-scale workshops. These innovations align with the requirements of small-scale industries for high precision and controlled operations.

Manual drilling machines, on the other hand, are particularly beneficial for rural and less privileged areas. They offer a practical solution for drilling operations in regions with limited access to electricity and high-tech equipment. These machines contribute to local economy by enabling small-scale production and reducing dependency on expensive machinery [6].

Portable drilling machines offer flexibility and adaptability, enabling operations in diverse settings, from workshops to field applications. They are extensively used in maintenance and repair work across various industries, providing flexibility in performing drilling tasks. Design considerations typically include factors such as weight, ease of use, and the ability to perform multiple functions without compromising performance. Sun et al. [7] highlighted the effectiveness of portable systems in achieving high-quality drilling outcomes while maintaining user-friendly interfaces.

Most workshops use portable drilling machine because they are the cheapest option. However, these machines have limitations, as they require force to drill into materials and the material must be held on the table by hand or with an external clamp. Portable drilling machines can be equipped with accessories to mimic bench press drilling machines, but this will only increase the cost of the tools. On the other hand, bench press drilling machines are expensive for small workshops.

This paper aims to design and develop a compact, do-it-yourself (DIY) drilling machine specifically for small-scale industries, by considering insights from existing innovations to address the constraints faced by these industries. The research identifies and addresses the primary limitations inherent in existing drilling machines. Subsequently, a morphological chart is utilized to explore and evaluate potential solutions, culminating in the creation of a prototype. The prototype was tested for its performance.

2. Methodology

The study was structured into two primary phases: the design phase and the assessment phase. The design process begins by defining the problem, which identifies common issues associated with conventional drilling machines, such as bulkiness, high costs, excessive noise, vibration, safety concerns and high energy consumption. These issues are systematically categorized and analyzed using a fishbone diagram to understand their root causes, as indicated in Fig. 1.

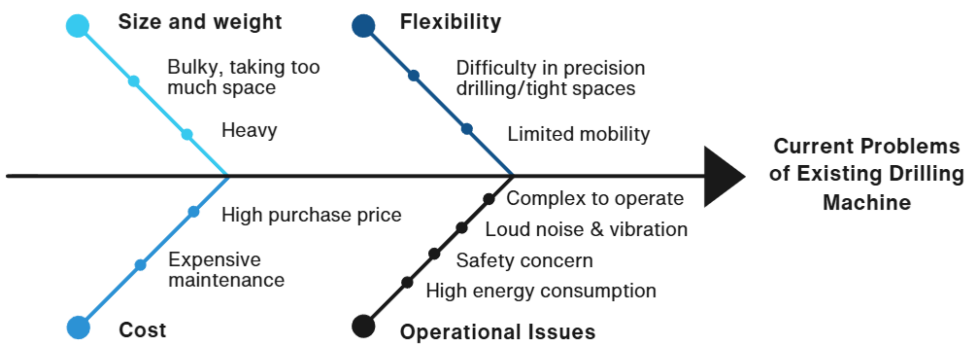


Fig. 1 *Common issues of conventional drilling machines*

Detailed requirements and limitations specific to small-scale industries and workshops were gathered, as well as reviewing existing solutions and technologies used in portable and compact drilling machines. By utilizing a morphological chart, potential solutions were generated by exploring and organizing different combinations of drilling machines characteristics. The morphological chart is given in Table 1.

Table 1 *Morphological chart of the drilling machines*

Characteristics	Material			
	Wood	**Steel**	**Plastic**	**Aluminum**
Power Source	Battery	Battery	Wall Plug-in	DC Power Supply
Jig Process	Thread shaft	Manual		Manual
Movement mechanism	Drawer slide	Gear	Rail guide	Gear
Movement of machine	Y axis	Static	X-Y-Z axis	Static
Handler's shape	cuboid	Cylinder	wheel	Cylinder

Several design concepts were proposed, and a design evaluation was performed to analyze the overall quality of each concept. The evaluation focused on key criteria such as functionality, rigidity, ease of assembly, simplicity, practicality, troubleshooting, cost, safety, and appearance. This process involved systematically inspecting the design aspects to identify strengths, weaknesses, and areas for improvement, ensuring that each design met the objectives and adhered to relevant standards and specifications

To visualize the mechanism, movement, and dimensions of the proposed designs, virtual product design and simulation were conducted using SolidWorks. Fig. 2 shows the component of the proposed design. Considering the aim of this study was to produce a compact, DIY drilling machine, the prototype was fabricated using wood. Adhesives were chosen based on the materials being joined: glue was used for all wooden assembly parts, metal epoxy for metal-to-metal connections, and Argol bond adhesive for metal-to-wood assemblies. The Argol bond adhesive was specifically selected for its suitability in bonding dissimilar materials.

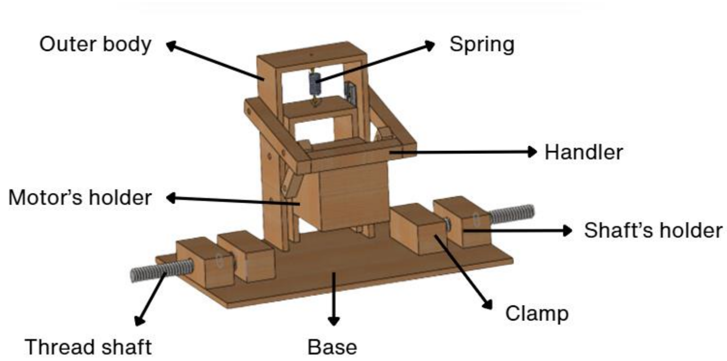


Fig. 2 *3D drawing of the miniature drilling machine*

Several key parameters must be considered for the effective use of a drilling machine: cutting speed, feed rate, machine power, and machining time. These variables are crucial for the machine's performance. The cutting speed refers to the speed of the cutting tool's edge in meters per minute when drilling into the material. The typical range for cutting speed is between 10 and 90 meters per minute. The cutting speed, A, can be calculated using Eq. 1.

$$A = \frac{\pi \times drill\ diameter\ (mm)\ \times motor\ rpm}{1000} \tag{1}$$

The feed range is between 0.05 mm to 0.35mm. The cutting speed and feed have an impact on how much the workpiece is removed. The machining time, T, can be calculated using Eq. 2 where f is the per revolution of the drill, N is the drill's rpm, L is the depth of the hole in mm.

$$T = \frac{L}{(N \times f)} \tag{2}$$

3. Result and discussion

3.1 Drilling speed

The prototype was equipped with a motor capable of a rotational speed ranging from 3500 to 7200 rpm. A 5 mm diameter drill bit was used to test the machine's power. Using Eq. 1, the rotational speed of the miniature drilling machine was calculated to be between 55 and 113 rpm. A comparison of rotational speeds with other types of drilling machines is presented in Table 2. The table indicates that the miniature drilling machine has a higher rotational speed than certain other drilling machines.

Table 2 *Comparison of drilling speeds for various machines*

Types of drilling machine	Motor rpm	Drilling machine spindle speed (rpm)
Portable drilling machine	1500	30
Hydraulic oil drilling machine	2100 – 9200	185 – 809
Micro drill press	1 – 1400	13
Pillar drilling machine	365 – 3150	23 – 198
Miniature drilling machine prototype	3500 – 7200	55 – 113
3500 – 7200		
55 – 113		

3.2 Drilling test

The prototype was tested and compared with the BOSCH GSR 120-Li Cordless Drill, a commonly used portable drilling machine. Both machines were tested by drilling into wood panels and aluminium plates of varying thickness. Table 3 presents the results of the drilling tests for each machine.

Table 3 *Comparison of drilling tests between the prototype and a cordless drill*

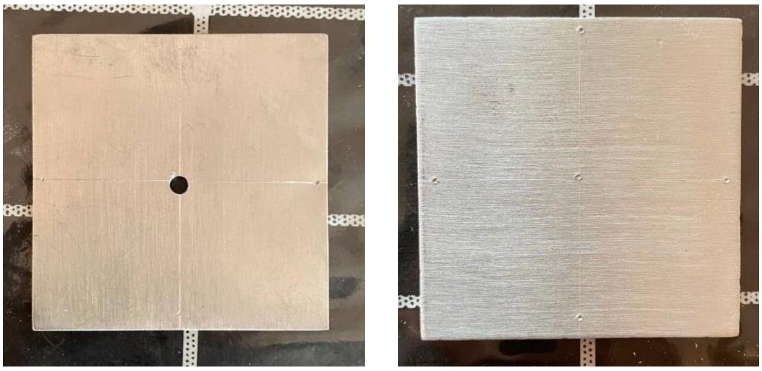
Material	Miniature drilling machine prototype	BOSCH GSR 120-Li Cordless Drill
Wood Panel (5 mm)	Penetrate	Penetrate
Wood Panel (10 mm)	Penetrate	Penetrate
Wood Panel (15 mm)	Penetrate	Penetrate
Aluminum Sheet (1mm)	Penetrate	Failed
Aluminum Sheet (3mm)	Penetrate	Failed
Aluminum Sheet (5mm)	Penetrate	Failed

A wood panel and an aluminum sheet, each measuring 70 mm × 70 mm, were used to evaluate the drilling performance of both models. The prototype successfully drilled through all the test panels without any issues, while the BOSCH GSR 120-LI was unable to penetrate even the thinnest aluminum sheet. For the wood panel, the prototype produced cleaner and more accurate holes compared to the hand drill. As shown in Fig. 3, the prototype achieved a smoother finish at the end of the hole, whereas the cordless drill left wood chips that were harder and rougher around the edges.

(a) **(b)**

Fig. 3 *Wood panel drilled by **(a)** the prototype and **(b)** BOSCH GSR 120-Li Cordless Drill*

The results for the aluminum sheets are shown in Fig. 4. It can be observed that the miniature drilling machine prototype managed to drill through the sheet, while the cordless drill machine was unable to do so.



(a) **(b)**

Fig. 4 *Aluminum panels drilled by **(a)** the prototype and **(b)** BOSCH GSR 120-Li Cordless Drill*

3.3 Discussion

3.3.1 Prototype construction

During the construction and assembly of the drilling machine's body, several challenges were identified. One major issue was with the spring used to support the outer body and motor. The weight of these components exceeded the spring's stiffness, causing it to surpass its yield point and preventing it from returning to its original position. This issue compromised the functionality of the machine.

Another significant problem was the initial placement of the motor outside the block, which posed a substantial safety hazard during operation. The exposed motor increased the risk of injury to users, particularly during drilling tasks. Additionally, the outer body of the drilling machine lacked stability during operation. When pushed down, it skewed inward and moved outward, reducing both its precision and operational stability. These challenges highlighted the need for modifications to enhance the machine's safety, reliability, and performance.

To address these issues, several improvements were implemented. The motor was repositioned inside the outer box, enhancing safety by covering the motor and minimizing the risk of injury during operation. This new placement also provided better protection and functionality. The initial spring was replaced with one of greater tensile strength and larger dimensions. This upgrade resolved the weight-bearing issue, allowing the spring to support the components and return to its original position after being compressed. The body parts were securely glued to the base and reinforced with L-brackets to ensure a tighter and more stable assembly. Most components were fastened using screws, while the handler and connector parts were attached with hex bolts and hex nuts to allow for movement. After implementing these improvements, the body parts were mounted on the base, and the final assembly of the mini drilling machine's prototype was completed.

3.3.2 Performance

Although the prototype successfully drilled through the aluminum sheet, its accuracy fell short of expectations due to an inadequate clamping mechanism. During the drilling process, the clamp failed to hold the material securely, as the clamp block lifted and shifted.

In contrast, the cordless drill demonstrated significant safety concerns. It also lacked a clamping mechanism, requiring the operator to manually hold the material in place. While attempting to penetrate the aluminum sheet, the operator had to apply additional force with one hand to push the drill down. This not only increased the risk of injury but also caused the material to shift or potentially be propelled away, posing further safety hazards.

3.3.3 Advantages

The mini drilling machine offers several key strengths, making it ideal for professional and small-scale use. Its compact and ergonomic design allows it to be placed on a workshop table, reducing worker movement and improving efficiency. Portability is another advantage, enabling the machine to be used in various locations, unlike larger, stationary drills.

Safety is another critical feature of the miniature drilling machine. The motor is enclosed within the machine's housing, protecting users from exposure to moving parts and electrical components. The machine is also user-friendly, with simple controls for easy operation, minimizing the need for extensive training and boosting productivity.

3.3.4 Disadvantages

Despite its strengths, the mini drilling machine has several notable limitations that reduce its overall effectiveness. One significant drawback is the absence of an auto coolant system, a feature common in hydraulic drilling machines. The lack of this system increases the risk of overheating, potentially damaging materials during prolonged drilling operations.

Another limitation is the restricted range of axis movements, particularly along the Z-axis, which is critical for precise drilling operations. This, combined with the absence of integrated measuring tools, makes it difficult to position materials accurately based on 2D drawings, further compromising precision.

The machine is also limited in its capacity, as it can handle only small parts due to its compact size and restricted chuck range. This makes it unsuitable for drilling larger materials, unlike hydraulic drilling machines that accommodate various chuck sizes. Additionally, its DIY construction, including the use of drawer slides instead of linear guides for movement and springs for feedback mechanisms require further improvement. Replacing the drawer slide with a linear guide for the movement mechanism can significantly enhance the smoothness of operation. Although the linear guide may be more expensive, its superior performance will improve the efficiency of the drilling process by ensuring smoother and more precise movements.

4. Conclusions

This study focused on the design, development, and performance evaluation of a mini-drilling machine aimed at addressing the limitations of traditional drilling machines. Utilizing low-cost materials commonly found in woodworking, metalworking, and DIY projects, a prototype was developed using SolidWorks. The prototype demonstrated strong performance in terms of drilling speed (55–113 rpm), accuracy, and stability, effectively meeting a variety of drilling needs. Its compact size, lightweight construction, and portability enhance efficiency by allowing workers to transport it easily between workstations.

However, the mini-drilling machine has limitations that reduce its suitability for industrial applications. Key areas for improvement include the incorporation of a linear guide to replace the drawer slide, ensuring smoother and more precise movement. Upgrading the motor to a higher voltage model could increase rotational speed and improve performance when drilling solid materials, thereby enhancing accuracy. Additionally, the clamping mechanism, a critical component of the drilling process, requires reinforcement. The existing block clamp should be replaced with a sturdier and stronger design to prevent movement during operation, and an additional front clamp on the base should be included to provide extra support.

With these targeted enhancements, the mini-drilling machine has significant potential to evolve into a more versatile, efficient, and practical tool, making it suitable for a broader range of applications, including industrial use.

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Author Contribution

The authors confirm contribution to the paper as follows: ***study conception, data collection, analysis and interpretation of results:*** *Muhammad Azreen Syafeezy Azhar;* ***draft manuscript preparation:*** *Muhammad Azreen Syafeezy Azhar, Siti Nur Mariani Mohd Yunos;* ***proofread and final manuscript:*** *Siti Nur Mariani Mohd Yunos. All authors reviewed the results and approved the final version of the manuscript.*

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