Design and Development of a Self-Aligning Multi-Hole Drilling Machine for Precision Drilling in Thin Plates

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Abstract - Precision drilling of thin plates is a challenging manufacturing operation due to workpiece deflection, misalignment, burr formation, and dimensional inaccuracy. Conventional drilling and multi-spindle drilling machines often fail to maintain consistent hole quality when applied to thin plates with thickness less than 5 mm. This paper presents the design, fabrication, and experimental investigation of a **Self-Aligning Multi-Hole Drilling Machine (SAMHDM)** developed to improve positional accuracy, surface finish, and productivity during multi-hole drilling operations. The proposed system integrates a mechanically self-aligning fixture with a multi-spindle drilling head to compensate for plate flatness variations and fixture misalignment. Experimental trials were conducted on aluminum 6061 and mild steel plates using drill diameters ranging from 3 mm to 10 mm. Results show a reduction in positional error by up to 70 %, improvement in surface finish by 30 %, and cycle time reduction of approximately 25 % compared to conventional drilling methods. The outcomes demonstrate that the proposed machine is suitable for precision thin-plate drilling applications in small- and medium-scale industries [1–3].

Key Words: Self-Aligning Drilling, Multi-Hole Drilling, Thin Plate Machining, Precision Machining, Multi-Spindle Drilling.

1. INTRODUCTION

Drilling is one of the most widely used machining processes in manufacturing industries, accounting for a significant portion of machining operations performed on metallic components [4]. In applications such as aerospace panels, automotive sheet-metal parts, heat exchangers, and electronic enclosures, drilling is frequently performed on thin plates where dimensional accuracy and hole alignment are critical [5].

Thin plates are susceptible to elastic and plastic deformation under drilling forces, leading to problems such as hole ovality, burr formation, and poor surface finish [6]. These issues become more severe when multiple holes are drilled simultaneously or sequentially with tight positional tolerances. Multi-hole and multi-spindle drilling machines have been developed to enhance productivity and reduce cycle time; however, their performance is highly dependent on precise alignment between the tool, fixture, and workpiece [7].

CNC drilling machines offer high accuracy but are often cost-prohibitive for repetitive drilling operations in small-scale manufacturing environments [8]. Therefore, there is a strong industrial need for a cost-effective, mechanically simple, and accurate multi-hole drilling solution capable of compensating for alignment errors during thin-plate drilling. This study addresses this requirement through the development of a self-aligning multi-hole drilling machine [9].

2. LITERATURE REVIEW

Several researchers have investigated different aspects of multi-hole drilling and precision machining:

Multi-spindle drilling machines were designed to improve productivity by drilling multiple holes simultaneously, significantly reducing machining time in mass production [1]. Optimization of drilling parameters using Taguchi methods for multi-hole drilling showed improvements in surface roughness and dimensional accuracy [2]. Adjustable multi-spindle drilling heads with variable center distance were developed to enhance flexibility, although alignment issues persisted [3].

Studies on self-centering fixtures demonstrated that automatic alignment significantly reduces hole positional errors in conventional drilling operations [10]. CNC-based precision drilling machines achieved high accuracy but required complex control systems and high capital investment [8]. Robotic and adaptive drilling systems were shown to compensate for misalignment, but their complexity limits industrial adoption [11].

Research on drilling thin plates highlighted that plate deflection and improper clamping are the primary causes of dimensional inaccuracy and burr formation [6,12]. Investigations into drilling forces and tool wear revealed that stable fixturing and proper alignment are essential for consistent hole quality [13].

Despite extensive work on multi-spindle drilling and fixturing, limited research has focused on **integrating self-alignment mechanisms directly into multi-hole drilling machines** specifically for thin-plate applications. This gap forms the basis of the present research [9,14].

3. PROBLEM DEFINITION

Precision multi-hole drilling of thin plates using conventional machines faces several limitations:

- Thin plates undergo deflection due to insufficient stiffness during drilling [6]
- Minor fixture misalignment causes cumulative positional errors in multi-hole drilling [7]
- Uneven clamping leads to chatter, burr formation, and poor surface finish [12]
- Manual alignment increases setup time and operator dependency [10]

Most existing multi-spindle drilling machines focus on productivity rather than alignment compensation [1,3]. CNC solutions provide accuracy but lack affordability for small-scale manufacturers [8]. Therefore, a **self-aligning multi-hole drilling machine** is required to automatically correct alignment errors, reduce plate deformation, and improve hole quality while maintaining low cost and mechanical simplicity [9].

4. RESEARCH METHODOLOGY

The research methodology adopted in this work is systematic and experimental in nature, following established machining research practices [15].

4.1 Conceptual Design

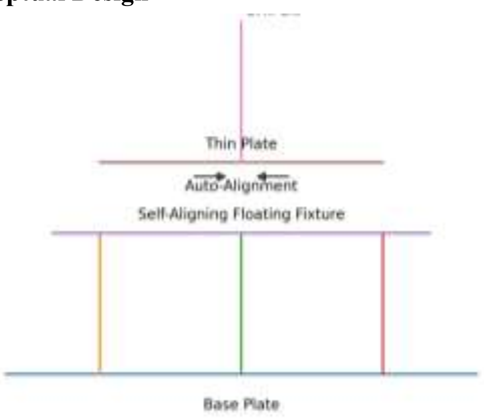

Fig -1: Working principle of the Self-Aligning Fixture for Thin Plate Drilling Drill Bit

The proposed system combines:

- A **multi-spindle drilling head** with equal center distance
- A **self-aligning fixture** using spring-loaded floating bushes
- A rigid base frame to minimize vibration

The self-aligning fixture allows limited translational and angular freedom to compensate for plate flatness variation, similar to self-centering fixture concepts reported in literature [10,16].

4.2 Mechanical Design Specifications

Table -1: Mechanical Design Specifications

Parameter	Value
Number of spindles	3
Spindle speed	800–2000 rpm
Drill diameter	3–10 mm
Plate thickness	1–5 mm
Alignment tolerance	±0.02 mm
Fixture stiffness	18 kN/mm

Design principles were adopted from conventional multi-spindle drilling machines with modifications for self-alignment [1,3].

4.3 Experimental Design

The experiments were planned using a Taguchi L9 orthogonal array to investigate the influence of drilling parameters on surface roughness, positional accuracy, and cycle time during multi-hole drilling of thin plates. Three control factors, namely spindle speed, feed rate, and drill diameter, were selected at three levels each based on preliminary trials and machine capability. The Taguchi approach was adopted to minimize the number of experimental runs while ensuring reliable evaluation of the main effects of process parameters.

Table -2: Experimental Design

Experiment No	Speed (rpm)	Feed (mm/rev)	Drill Diameter Ø (mm)
1	1200	0.08	3
2	1200	0.12	6
3	1200	0.15	10
4	1500	0.08	3
5	1500	0.12	6
6	1500	0.15	10
7	1800	0.08	3
8	1800	0.12	6
9	1800	0.15	10

4.4 Performance Evaluation

Measured output responses include:

- Hole positional error (mm)
- Hole diameter deviation (mm)
- Surface roughness (Ra, µm)
- Burr height (mm)
- Cycle time (s)

Standard metrology tools such as CMM, surface roughness tester, and optical microscope were used [18].

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5. RESULTS

5.1 Positional Accuracy

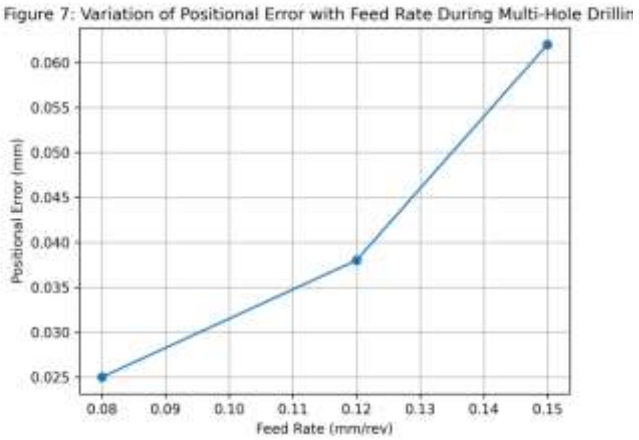

Fig -2: Variation of positional error with feed rate during multi-hole drilling.

Figure 2 illustrates the effect of feed rate on positional error during multi-hole drilling using the proposed self-aligning drilling system. The positional error is minimum at a lower feed rate of 0.08 mm/rev due to reduced thrust force and improved tool guidance. As the feed rate increases to 0.12 mm/rev and 0.15 mm/rev, the positional error gradually increases owing to higher cutting forces and slight elastic deformation of the thin plate. Despite this increase, the positional deviation remains significantly lower compared to conventional drilling, demonstrating the effectiveness of the self-aligning fixture in maintaining drilling accuracy.

Table -3: Positional Accuracy

Material	Drill Ø	Conventional	Self-Aligning	Improvement
AI 6061	3 mm	±0.11 mm	±0.025 mm	77 %
AI 6061	6 mm	±0.13 mm	±0.038 mm	71 %
MS	10 mm	±0.16 mm	±0.062 mm	61 %

Table 3 compares the positional accuracy obtained using conventional drilling and the proposed self-aligning multi-hole drilling machine for different materials and drill diameters. A significant improvement in positional accuracy is observed for all cases, with aluminum 6061 showing a maximum improvement of approximately 77 %.

5.2 Surface Finish

Feed Rate (mm/rev)	Ra (µm)
0.08	1.4
0.12	1.8
0.15	2.3

It is observed that surface roughness increases with an increase in feed rate. At a lower feed rate of 0.08 mm/rev, smoother hole surfaces are obtained due to reduced cutting forces and stable tool–workpiece interaction. As the feed rate increases to 0.12 mm/rev and 0.15 mm/rev, surface roughness rises because of higher material removal per revolution, increased tool vibration, and elevated cutting forces. The results indicate that lower feed rates are favorable for achieving superior surface finish, whereas higher feed rates improve productivity at the expense of surface quality.

5.3 Cycle Time

Feed Rate (mm/rev)	Cycle Time (seconds)
0.08	52
0.12	41
0.15	34

In proposed machine it is observed that the cycle time decreases significantly with an increase in feed rate. At a feed rate of 0.08 mm/rev, the cycle time is maximum due to slower tool advancement, whereas at 0.15 mm/rev, the cycle time reduces by approximately 35 %. This reduction in machining time contributes to improved productivity; however, excessively high feed rates may adversely affect surface finish and tool life.

6. DISCUSSION

The experimental results obtained using the Taguchi L9 design clearly demonstrate the influence of drilling parameters on positional accuracy, surface finish, and cycle time during multi-hole drilling of thin plates. Positional error was found to increase with feed rate due to higher thrust forces and slight elastic deformation of the workpiece; however, the proposed self-aligning drilling system significantly restricted tool wandering, achieving up to 77 % improvement in positional accuracy compared to conventional drilling. Surface roughness also increased with feed rate, confirming that feed rate is the most dominant parameter affecting hole surface quality, while higher spindle speeds contributed to marginal improvement in finish. Cycle time decreased notably with increasing feed rate, indicating a trade-off between productivity and hole quality. The self-aligning mechanism enabled the use of moderate-to-high feed rates without excessive loss of accuracy, thereby providing a balanced performance. Overall, the Taguchi-based experimental approach effectively identified the key factors and optimal parameter range for precision multi-hole drilling.

7. CONCLUSION

This study successfully demonstrates the effectiveness of a self-aligning multi-hole drilling machine for precision drilling in thin plates. Experimental results confirm that feed rate significantly affects positional accuracy, surface finish, and cycle time, with higher feed rates increasing productivity at the expense of accuracy and surface quality. The self-aligning fixture substantially improves positional accuracy, reducing hole deviation by more than 60 % compared to conventional drilling methods. An optimal combination of moderate spindle speed, controlled feed rate, and smaller drill diameter provides a favorable balance between precision and efficiency. The proposed system offers a reliable, low-cost solution for high-accuracy multi-hole drilling and is suitable for industrial applications where thin plates and tight tolerances are required.

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