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Design, Fabrication, and Analysis of a Precision Drilling Jig for Waste Reduction: A Low-cost Solution

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ABSTRACT

The modern assemblies of various machines such as engines, gears trains, and body panels require a highly precise drilling operation. These precisely drilled holes not only ensure the efficiency by constrained motions of these machines' parts but also ensure longer service life. Moreover, precision drilling shall also ensure no subsequent requirement of reaming resulting in time and cost-saving. The precise drilling operation cannot be achieved unless highly precise machinery (CNC) is being utilized requiring higher initial investment (Pkr 1000000), or highly skilled workers demanding about twice the labor than the semi-skilled person. Being a small-sized industry, for profitability, a low-cost solution was proposed in this current work. To obtain precise drilling operation by the application of a drilling jig (Pkr 3000) on the manual bench drill machine (Pkr 15000), by a semi-skilled worker. In this work, a drilling jig has been designed, fabricated, and analyzed. This jig also can rotate the workpiece in clockwise/counter-clockwise directions. The drilled holes measurements provided the evidence that under the spindle speeds of 340, 700, and 1000 rpm, the closer dimensional values (~0.1mm) can be obtained, resulting in the elimination of rework and extra cost, along with the setup-time reduction by eliminating marking and center punching process, with the application of jig. It was concluded that the jig is quite applicable and can be substituted with high-cost CNC machines as a low-cost solution to the local small and medium-scale manufacturing industries.

Keywords: Design and fabrication; drilling jig; low cost; precise hole location; waste/rework reduction

INTRODUCTION

In the manufacturing of various machines, assembly processes are usually mandatory, starting from the simpler machines such as a lawnmower, bench drills, rice mills, and blower fans, to medium complicated machines which are manual shapers, manual lathes and manual milling machines, to highly sophisticated and complex machines such as automobiles and aerospace vehicles, are always produced in various parts, to be assembled in a single unit by an assembly process.

The complexity of the assembly depends upon the number and types of the parts which are being assembled by the fastening and joining of different parts having variable sizes, thicknesses, complicated shapes, and different geometries (Ezugwu et al. 2023; Khan et al 2023: Liu et al. 2022; Othman et al. 2022; Glaissa et al. 2020). The fastening process demands a very precise drilling process for any kind of rivet or bolt joining. The location and quality of the drilled hole directly affect the service life and efficiency of the assembled parts (Eguti et al. 2012; Ple et al. 2011; Webb et al. 2006; Webb et al. 2001; Mangus et al. 1996).

The application of the precision drilling process is not limited to assemblies but is also critically required in various simple parts joining such as chain sprocket, and engine exhaust joints (Haider et al. 2022; Zhu et al. 2019; Wąsik et al. 2017; Zhu et al. 2014; Ramesh et al. 2000).

In this current work, a small-sized manufacturing and assembling unit of cooking gas cylinder stove was analyzed for product quality and production improvement, as these small-sized industries play an important role in the economy of underdeveloped countries (Ijaz et al. 2023: Ye et al. 2020; Eastwood et al. 2010).

For a small-level industry, there were two challenges faced, either an expensive CNC drilling machine was to be required for precise drilling which was un-affordable, secondly if a low-cost manual drill machine was being utilized, a highly skilled and experienced worker was mandatory to obtain the necessary level of accuracy of holes. As the highly skilled worker also demands around twice the labor charges in comparison to the semiskilled worker, there was a requirement for some low-cost solution for this problem. As some modifications in any machine can greatly enhance its capability, avoiding the requirement of purchasing newer equipment (Haider et al 2021). The drilling jig can also provide the required accuracy level for the drilling holes.

Moreover, being a small-sized manufacturing and assembling unit, to gain good profitability there is an essential requirement of waste reduction either in terms of elimination of non-value-added activities or by reduction the defective part productions. As a lot of rework was being performed, when the drilled hole locations were not precise, usually one or two holes were drilled again and in a few cases, all four holes were drilled again in new locations of plate resulting in more time and energy consumption and reduced production.

Considering the economic constrained of the unit, the semiskilled workers and manual machines were found to be the most suitable solution to attain the sustainability of the business. Initially, there was a lot of rework and rejected parts observed, due to the drilled hole misalignments, lower skill level, and poor precise machinery.

To overcome this issue a low-cost solution was proposed, a precision drilling jig. Precision drilling has the following advantages in comparison to common drilling practice, firstly there was no more requirement of marking and center punching on each workpiece, resulting in time-saving, secondly drilling jig was able to hold the workpiece rigidly resulting in the precise hole location, and avoiding any misalignment. This not only solved the rework problem but also ensured the elimination of defective part production which was causing scrap production.

As the assembly bolts of the upper plate of the stove are directly fastened to the bottom plate, through the means of threading in the drilled holes, the stove assemblage requires the precise hole location in the bottom mild steel thick plate, figure 1 represents the assembly of the upper and bottom plates of the stove. The jig provides the right points to the tool regarding the workpiece, any deviation can be prevented.

There are many cases where the drilling jigs have advantages, such as when vendors are more than one or when the part complexity is much higher and specialized tool costs are higher. Moreover, by utilizing a drilling template, a simple bench drill can also provide dimensional accuracy with very close tolerance at a relatively lower cost.

The drilling jigs application resolves any potential inaccuracy of the drilled holes and unreliable assemblies. The alternative name of the drilling jig is a drilling template, which is a type of work-holding device that is extensively valued in the drilling process to make precise holes in any assembly of components. The drilling jigs hold the parts upright so that the drilling tools can be appropriately guided to the specific location for the hole-making process in the smaller structural applications and large parts assemblies such as the fuselage of airplanes (Mei et al. 2021; B. Mei 2019; Mosqueira et al. 2012; Oberg et al. 2000; Liu et al. 1995).

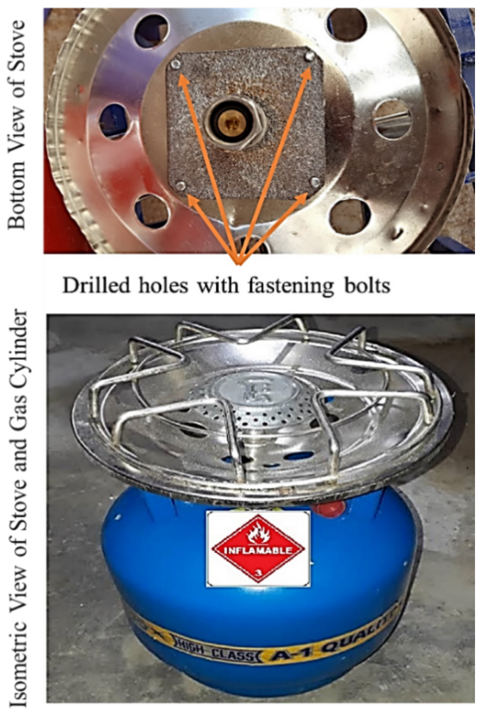


FIGURE 1. Assembly of upper and bottom plates of stove.

Typically, these drilling jigs consist of a horizontal metallic plate along with a pattern of drilled holes. For drilling holes, the pattern provides a guide to the drilling tools and an accurate hole-making process. Before the drilling process, the template is clamped to the workpiece while after the drilling, when the template is removed, the workpiece has duplicate holes as the template (B. Mei et al. 2019; Zhu et al. 2014; Yuan 2007).

Due to the higher requirements and broad application of drilling jigs, many researchers have made contributions to the design considerations for drilling jigs. Robinson (2003) provided many techniques and applicable principles for drilling jigs. Similarly, Jayaweera (2011) defined the construction and validation of a flexible tooling process. Wiemann (2007) presented a different type of drilling jig, that having the ability to gain the shape of the workpiece for many kinds of drilling.

Lostlen (1998) also introduced a flexible drilling jig, which could be adjusted according to the application. Many of the researchers have emphasized the core principle and methodologies for designing generalized drilling jigs that have the capability of holding workpieces and providing a guide to the drilling holes for different kinds of hole applications.

In this work a precise drilling jig was designed, this jig was aimed to be utilized on the manual and conventional types of machines such as manual drills and manual milling machines. The purpose of this effort was to produce precise holes in the parts without the requirements of the marking and center punch operations, resulting in a higher production rate. Moreover, it also ensured the dimensional accuracy of the holes without the requirement of the CNC machine and highly skilled workers, reducing the initial investment and higher labor cost.

The design of the jig was aimed to be robust so it could be further applied to a few other machines such as a radial drill. Figure 2 represents the schematic illustration of a drilling process, along with the defects associated with the misalignment of the workpiece during the drilling process.

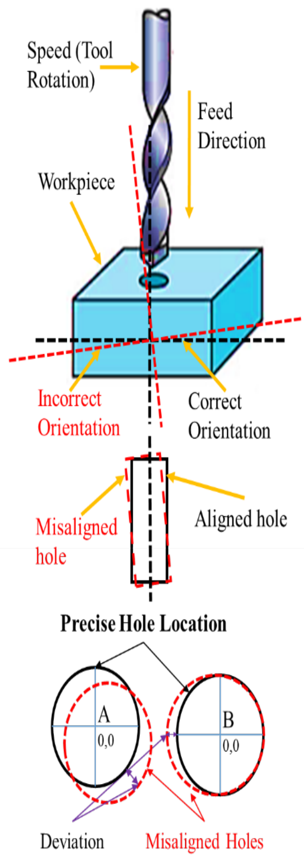


FIGURE 2. Schematic illustration of drilling mechanism.

This drilling jig has the capability of settling on the bench of the manual bench drill while gripping the workpiece inside it, whereas the hole template can be keyed on its upper surface to guide the drill bit. Moreover, this template also had the capability of revolving on its central axis, as only one drilling tool/bit is available in a bench drill for drilling at a spot. After each drilled hole, the jig possesses the ability to rotate on its central axis to make the other spot of the workpiece available for drilling holes.

DESIGN AND FABRICATION OF DRILLING JIG

The design fabrication and analysis of the designed drilling jig have consisted of the following steps; (a) CAD design of the drilling jig followed by the assembly of its parts on Solids-Works. (b) A prototype of the designed jig model is made of wood to avoid possible defects and initial costs. (c) Analysis of the wooden prototype and fabrication of the practical model (Mild Steel) of the jig. (d) Performance evaluation of the fabricated practical model of the drilling jig, by analyzing the drilled hole locations.

In the manufacturing sector, jigs are designed as per the requirements of a component. After need analysis, the component, which requires drilling at multiple locations, a bottom plate of the cylinder stove, was selected, and its dimensions were measured. For an extensive study on the feasibility of the drilling jig's conceptual model, the first step that was followed was the computer-aided design (CAD) of the drilling jig in Solid Works 2016. Figure 3 represents the descriptions of the major components of the drilling jig in CAD. As the jig has four major parts, a base plate (figure 3 a) which has a central hole for bush support and four curved slots for the chip removal, above that, two middle plates (figure 3 b) the upper middle plate, empty form the center, and a lower middle plate with holes for chip removal, both of plates combined for holding and gripping the work piece during the drilling process.

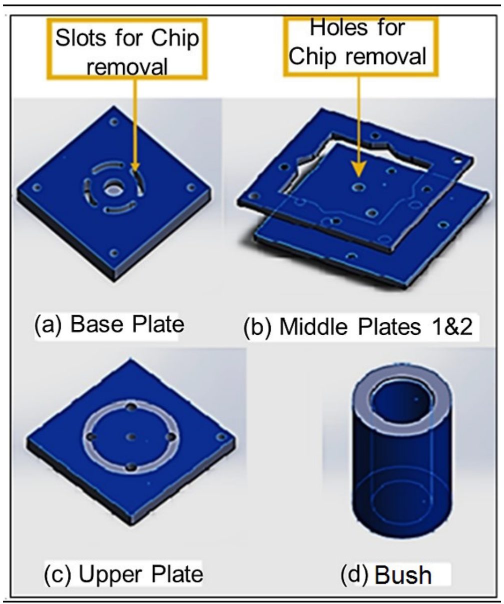
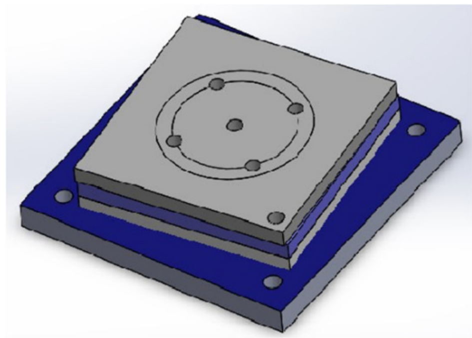


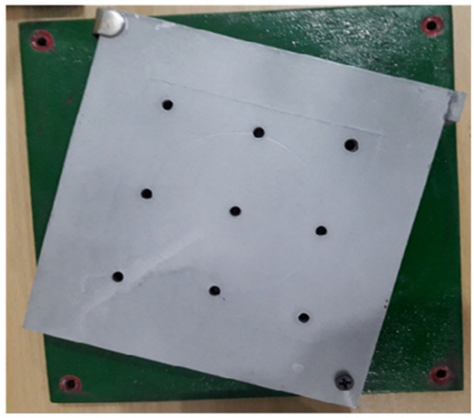
FIGURE 3. Major components of drilling jig.

Furthermore, a upper covering plate (figure 3 c) for securing the workpiece inside the jig during the drilling process, this plate has hole pattern in which holes are required to be produced on workpiece. Lastly, a central bush (figure 3 d) responsible for constrained rotation of the jig's middle and upper plates for rotating the workpiece, during the drilling process.

Whereas in figure 4 the assembly drawing of the drilling jig is shown.



(a) Assembled Drilling Jig



(b) Drilling Jig (Wooden Prototype)

FIGURE 4. Drilling Jig Finalized Design and Prototype.

After designing the CAD model, a wooden prototype was prepared to efficiently resolve design issues (figure 4 b) before making the final Product. After inspection and testing of this prototype, the drilling jig's fabrication was clear in many aspects, such as the material requirements, the thickness of the metallic plate, the dimensions of each plate, and the required type of machining for the final finish product.

Figure 5, illustrates the schematic of the drilling operation, performed by utilizing drilling jig, the position of the jig on bench drill table and the hole location on drilling jig for precision drilling process.

Figure 6, represents a conventional bench drill along with labelled components for understanding. The bench drill details are mentioned in table 1.

TABLE 1. Specifications of the bench drill machine

Maximum Drilling Capacity	25 mm
Spindle Travel	125 mm
Spindle Speed Range	340-1800 rpm
Table Diameter	290 mm
Base Worktable	335 x 335 mm
Voltage	230V
Motor Power	750 w

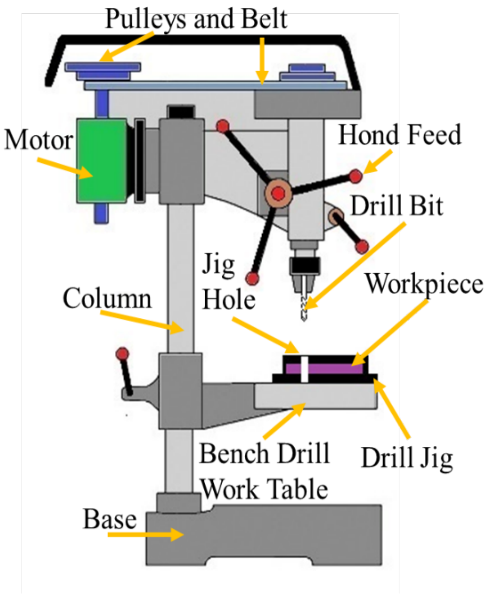


FIGURE 5. Drilling Jig on bench drill (Schematic Illustration).

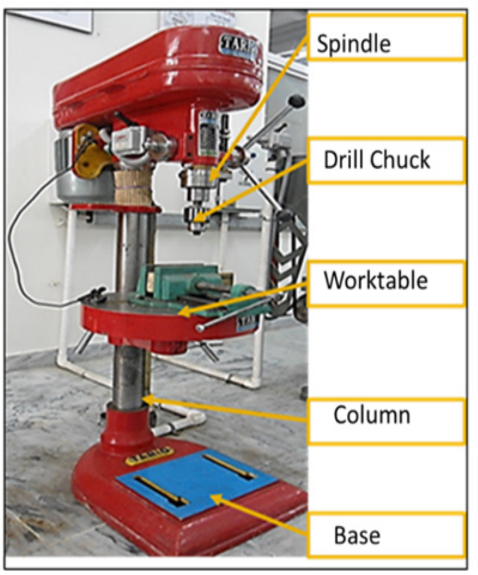


FIGURE 6. A Conventional Bench Drill.

The drilling jig was designed to work by placing it on the worktable of the bench drill, so the suitability of the jig was also ensured after analyzing the wooden prototype on the bench drill.

FABRICATION METHODOLOGY

The fabrication methodology of the drilling jig contains many manufacturing operations performed in sequential order for preparing the operational drilling jig. The drilling jig was designed and fabricated after an in-depth study of the available literature on jigs and fixtures (Mei et al. 2019; Jayaweera et al. 2011; Wiemann et al. 2007). The jig has four main components i.e., base plate, middle plate, top plate, and the bushes (Figure 3).

After finalizing the required components, initially, the 2D drawing of the jig was made, which was then transformed into a 3D model (figure 4 a) of the assembled jig. Afterward, the 3D model was utilized to produce a wooden prototype of the drilling jig (figure 4 b). The wooden prototype made clear a lot of aspects related to the drilling jig fabrication. The wooden prototype was also evaluated for its suitability on the work table of the bench drill. In case of any required changes required the process was rectified and repeated from the 2D drawing of the jig.

After ensuring the prototype's acceptability the jig components were fabricated with mild steel. Almost all four components of the jig were prepared by performing similar kinds of operations except a few dissimilar operations. The material that was selected for drilling the jig was mild steel, due to its lower cost, easier availability, and higher machinability.

The shearing operations were performed on the power hacksaw, and shaper, and turning on the lathe machine. The holes were made via the drilling process. The precision of each machined component was ensured via a calibrated instrument (digital vernier caliper). The electro-discharge machining was also performed to ensure a proper alignment of the plates and bush. Furthermore, the electroplating was done on the plate surfaces to avoid corrosion. After preparing all components, the jig was assembled by joining the three square plates, base, middle, and upper, were joined by mechanical fastenings, and was tested for precision hole drilling.

The alloying constituents of mild steel are mentioned in table 2.

TABLE 2.Composition of Mild Steel

Weight (%)	C	Fe	S	Mn	P
Min.	0.14	98.8	*	0.6	-
Max.	0.2	99.3	0.05	0.9	0.04

The base plate has one hole in the middle to enable the rotation of the middle and upper plate, and there were four holes 10 mm in diameter for fastening the jig on the bed of the bench drill. The base plate also contains four slots for the removal of chips produced during the drilling operation.

There were two middle plates, the lower one to be fastened on the base plate and the upper plate having a cavity inside in it, to hold work of circular, square, and octagonal geometry with the dimensions of (100 x 100 x 15 mm). Both were fastened together to avoid any misalignment. Dimensions of different Jig components are provided in Table 3.

TABLE 3. Dimensions of Different Jig Components

Component Name	Dimensions (mm)
Base Plate	200 x 200 x 15
Middle Plate 1	150 x 150 x 10
Middle Plate 2	150 x 150 x 15 (Internal Cavity: 100 x 100 x 15)
Top Plate	150 x 150 x 10
Bush	Outer Dia.: 10, Inner Dia.: 06, Height: 10

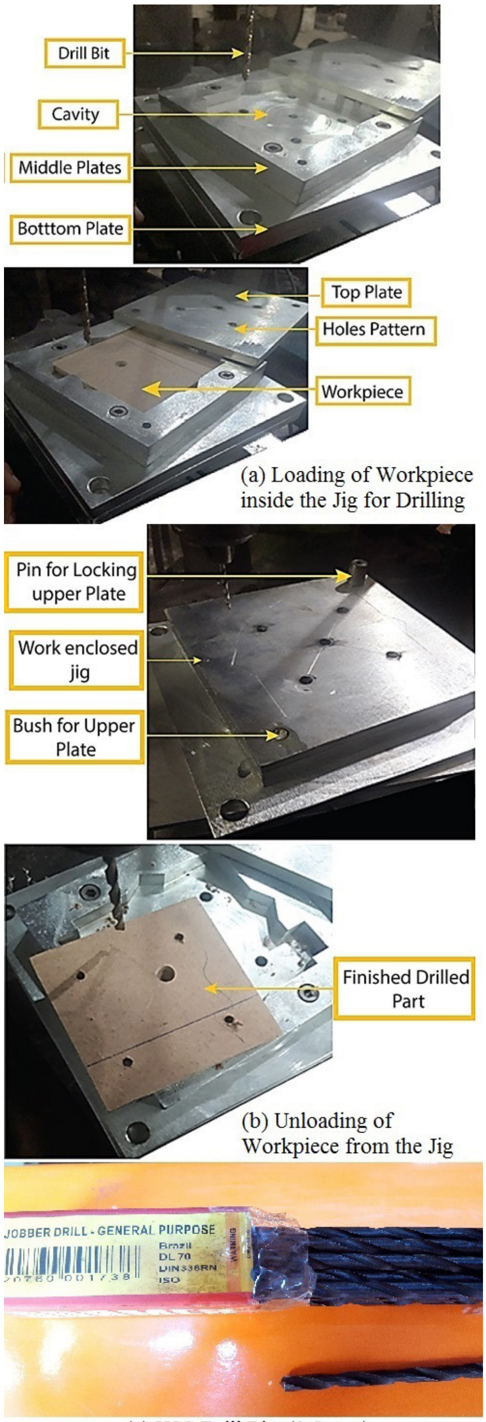
Like the base plate, the lower middle plate also contains four holes. The purpose of these holes is the removal of drilling chips for uninterrupted operation. The upper plate, which was utilized for covering and holding the work rigidly into the middle plate cavity, can revolve on a corner pin for loading and unloading the workpiece with the application of bush and afterward keyed to be positioned on its place.

A HSS twist drill bit of 5 mm diameter (figure 7 c) was utilized for the drilling purposes in the hardboard, and mild steel plate. The drill bit was positioned in the chuck of the drill machine and was able to reach the workpiece for a through-hole drilling process, either in the application of the jig or without the jig.

Moreover, there was a hole pattern in the upper plate to guide the drill bit in work. The whole jig was able to rotate on its central axis to make a hole in different locations of the workpiece. Figure 8 & 9 shows the drilling jig's real images during the operation and the drilled part after the hole has been drilled.

TESTING AND VALIDATION

For the performance evaluation of the fabricated drilling jig, experiments were performed, there were thirty drilling experiments performed in the absence of the drilling jig and thirty were performed in the utilization of the drilling jig (figure 7 a & b). The collected data of these two cases was compared to evaluate the precision achieved by the drilling jig.



(a) Loading of Workpiece inside the Jig for Drilling

(b) Unloading of Workpiece from the Jig

(c) HSS Drill Bits (0.5 mm)

Figure 7. Mechanism of the drill jig (working).

A locking pin is also utilized to ensure the fixed position of the upper plate during the drilling process. After performing the drilling process the upper plate is again displaced by removing the locking pin and the finished workpiece is removed from the jig.

Figure 7(a, b) explains the geometry, parts, and the mechanism of drilling jig during the process. Initially, the upper plate of the jig is displaced via rotation, and the workpiece is placed inside the cavity of the jig, afterwards, the upper plate is returned back to the initial position, closing the jig.

The drilling experiments were performed under three spindle speeds of the bench drill 340, 700, and 1000 rpm. At each speed there were ten experiments performed. The values of spindle speed were changed by the selection of the different pulley combinations in bench drill machine.

An HSS drill bit having a diameter of 5 mm was utilized for the drilling of 10 holes in each experiment. To avoid any variation caused by the tool wear each experiment was performed with the new tool (figure 7 c). A mild steel square plate (100x100x15 mm) was selected for the workpiece, as this material is very common in local manufacturing industries and this jig was aimed to produce higher precise holes in the mild steel parts.

The recommended speed of drilling the mild steel is 1000 rpm for the bench drill so the spindle speed was kept lower than 1000 rpm. A semi-skilled worker was assigned to perform the experimentation on the bench drill, either in the absence of the drilling jig or in the application of the jig for producing holes in the mild steel. The ascending order of the spindle speed was selected and in the first step, the holes were produced without utilizing the drilling jig. Once all thirty holes without jig were produced, the jig was placed on the bench of the drill machine to produce precise drilled holes.

Figure 8(a) represents the essential steps of conventional manual drilling practices compared to the drilling process with a jig application. As in the absence of the drilling jig, there is a mandatory requirement of the marking (step 1), center punching (step 2), drilling the workpiece (step 3), and the finished workpiece (step 4). Whereas, the jig application eliminates the first two steps of the manual drilling process and reduces the setup time, figure 8 (b). In the jig application, step 1, is to open the jig, step 2 is workpiece placement, step 3 is the drilling operation and in step 4, the finished workpiece is obtained.

First, the jig was placed and fastened onto the workbench of the bench drill, a dial gauge was also utilized to ensure the alignment of the drilling jig on the bench of the drill machine, after removing the upper covering plate of the jig, the work was placed in the cavity of the middle plate after placing the square mild steel work-piece (100 x 100 x 15mm) the upper plate was replaced and keyed. The holes were made according to the drilled hole pattern in the upper plate. During the whole process, the different aspects were ensured, such as the alignment of the drilling jig on the drill bench, meshing of plates on each other, rotation of middle and top plates, and work holding (Figure 8b).

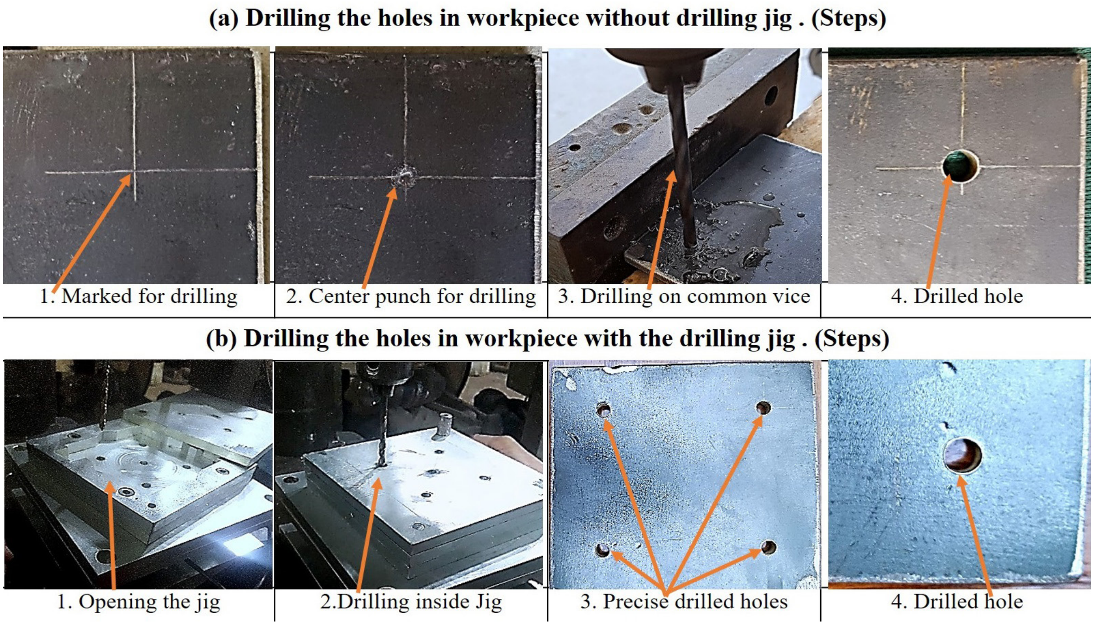


FIGURE 8. Drilling process with and without drilling jig

As the holes were produced, the maximum values of deviations were measured for each hole via a calibrated instrument (digital vernier calipers). For deviation measurement the drilled hole position was measured with the reference to the central point to which the hole was required to be produced, the location was measured in three directions, in which two were measured with respect to the nearest edges of the plate and one with respect to the nearest corner of the plate for each hole. Deviations were measured for both conditions, without the jig application (figure 9 a) and with the application of the jig (figure 9 b). A dowel pin was inserted inside the hole and a calibrated tool (digital vernier calipers) was utilized to find the distance between the hole and the two nearest edges of the plate, moreover, the distance between the hole and the edge corner was also measured for each hole.

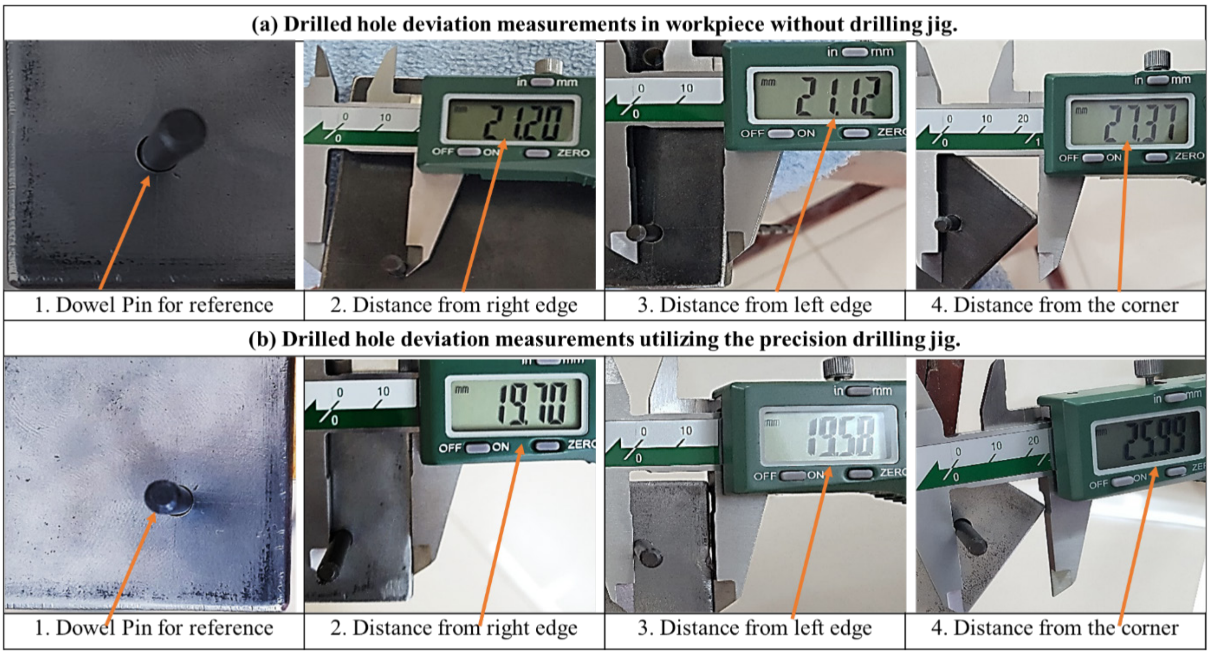


FIGURE 9. Location measurement of drilled holes, drilled with and without drilling jig.

In this methodology, all holes were measured for the deviation, from the position where the holes were aimed to be produced. For convenience the center of the aimed hole was referred to as x = 0, y = 0, from the nearest edges, and xy = 0 from the nearest corner (figure 2). The maximum measured deviation value (±) in either direction (x, y or xy) was plotted for each hole with respect to drill spindle speed, for each condition either holes were made without jig application or with the application of the jig.

On each value of the spindle speed, 10 drilling experiments were performed to gain certainty in the results, figure 10 (a), (b) and (c), represents the values of deviations in the drilled holes from the marked positions on the steel plate, when the holes were drilled without and with the application of drilling jig. The deviations were measured via a calibrated instrument (digital vernier calipers) having a least count of 0.01 mm. From each hole, the maximum value of deviation was linearly measured, as it is shown in Figure 2.

In comparison to the CNC drilling machines having a precision value of 0.01~0.02mm, this drilling jig has a precision value of 0.1~0.5 mm which is quite less, however, the cost (~1000000 Pkr) of CNC machines is unaffordable for a small sized production unit, furthermore this value of precision 0.1~0.5 mm is acceptable for this required assembly.

Moreover, the accuracy requirements for the aircraft's and automobiles parts assembly usually have a very high tolerance value, for smaller parts such as engine valves, so these are being machined by CNC machines having precision values more than ±0.0127 mm, and for bigger parts such as body panels a higher value of tolerance of ±2 mm is also acceptable (Quellmalz 2007). So, this type of jig having a precision value of ±0.5 mm can also be applied to the bigger part assemblies of automobiles and aircraft, for economic purposes.

RESULT AND DISCUSSION

From the results, it was found that without the application of a jig, the higher values of spindle speeds resulted in higher values of deviation in comparison to the lower values of the spindle speeds. As on the higher values of the spindle, the chance of misalignment and dislocation of the workpiece is higher.

Whenever the workpiece is misaligned the drilled hole shall also be misaligned and the dislocation of the workpiece shall result in the poor precision of the drilled hole. As it has been shown in Figure 2.

The deviation in the hole location makes assembly difficult or in many cases holes were required to be again drilled on the plate. For the assembly of this stove plate, an acceptable tolerance was 0.5 mm and when the deviation was more than 0.5 mm the rework, depending upon the number of misaligned holes was required.

As if there were only one or two holes misaligned those were enlarged in diameter and the stove was assembled with the help of additional washers and nuts, rather than directly assembling with the presence of internal threading in correctly positioned holes. Moreover, if more than two holes were misaligned, those were also rectified by drilling again all four holes in the plate.

This requirement of rework and additional washer and nuts resulted in lower production and additional cost. It was observed that a semiskilled worker was able to produce only 50% to 65% drilled plates in comparison to the skilled worker during a shift due to rework requirements.

The requirement of additional washers and nuts was causing lower profitability and poor aesthetics, as a bigger-sized screw was required to join the stove assembly.

On the contrary, when the jig was applied for the drilling process, it was found that the jig not only solved the problems of inaccurate hole locations and misalignments but also enabled the drilling process on a higher spindle speed of 1000 rpm.

As for the measured data it was found that by utilizing the drilling jig the location inaccuracy was lowered when the spindle speed was increased.

This phenomenon was observed due to a rigidly gripped workpiece in the jig which was drilled under the speed of 1000 rpm resulting in a very short workpiece and tool contact. As the rotating tool has a higher speed, it produced the hole quickly, smaller contact time with the workpiece the hole ensured the entering and exiting of the drill bit within a short time, the hole dimension was not disturbed.

On the completion of the experimentation, obtained results were found quite satisfactory in comparison to the drilled holes in the absence of the drill jig. The accuracy of the hole position was appreciable, as almost all hole positions were precise up to 0.1-0.3 mm concerning the drilled hole pattern on the top plate of the drilling jig.

Figure 10, (a), (b) and (c) represents the comparison of the values of deviation in the drilled holes, produced with and without drilling jig and under three different spindle speeds.

Starting from the spindle speed of 340 rpm there were 10 holes drilled in the mild steel workpiece in both conditions (with and without drilling jig) after completion of the experimentation the drilled holes were analyzed and the location of the holes was verified by the calibrated instrument (digital calipers).

The maximum derivation of each hole was noted and a comparison was drawn in the graphical representation for better understanding. Figure 10 (a) represents the measured deviations of holes produced under the speed of 340 rpm. From the results it was found that the maximum value deviation which was observed without the jig, was 1.55 mm whereas the maximum value of the deviation which was measured with the jig was 0.5mm, furthermore, the closest tolerance of location was 0.17 mm was also achieved by the jig application.

In the second step of experimentation, the next 10 holes were produced under the spindle speed of 700 rpm, in the absence and under the utilization of the jig (figure 10 b). As the spindle speed was almost double the previous step the higher values of deviation were also observed. The maximum deviation value of hole location was 1.78 mm in the absence of a jig, whereas the application jig reduced this up to 0.4 mm and the most precise value was 0.03 mm.

Lastly, 10 holes were drilled on the spindle speed of 1000 rpm. Likewise the rest of experiments ten experiments were performed without jig and ten with jig utilization (figure 10 c). From the obtained results it was obvious that the highest value of hole location deviation was 2.4 mm without jig application, which was reduced to the value of 0.5 mm after the application of the jig. Moreover, the closest tolerance value under the jig utilization was 0.01 mm, in the measured values.

From the experimentation, it was quite obvious that, on the higher values of spindle speed the deviation was more obvious as compared to those experiments in which spindle speed was kept lower. However, in all three cases of different spindle speeds, the application of the jig resulted in closer tolerance of the hole location.

Based on this research and obtained results, it was found that this designed drill jig can increase the machining accuracy and can drill precise holes while utilizing any ordinary type of bench drill. Thus, as a low-cost solution compared to high-cost CNC machines, it can be successfully applied where parts need to be held tightly via a mechanical fastening.

The measured values of deviations of holes were also analyzed, under the spindle speed variations without jig application, and it was found that on increasing spindle speed, there was an increase in the values of deviation regarding the hole locations—figure 11 (a).

Figure 11 (a) and (b), represents the comparison of the deviations in the hole location when the hole was produced under the application of the drilling jig.

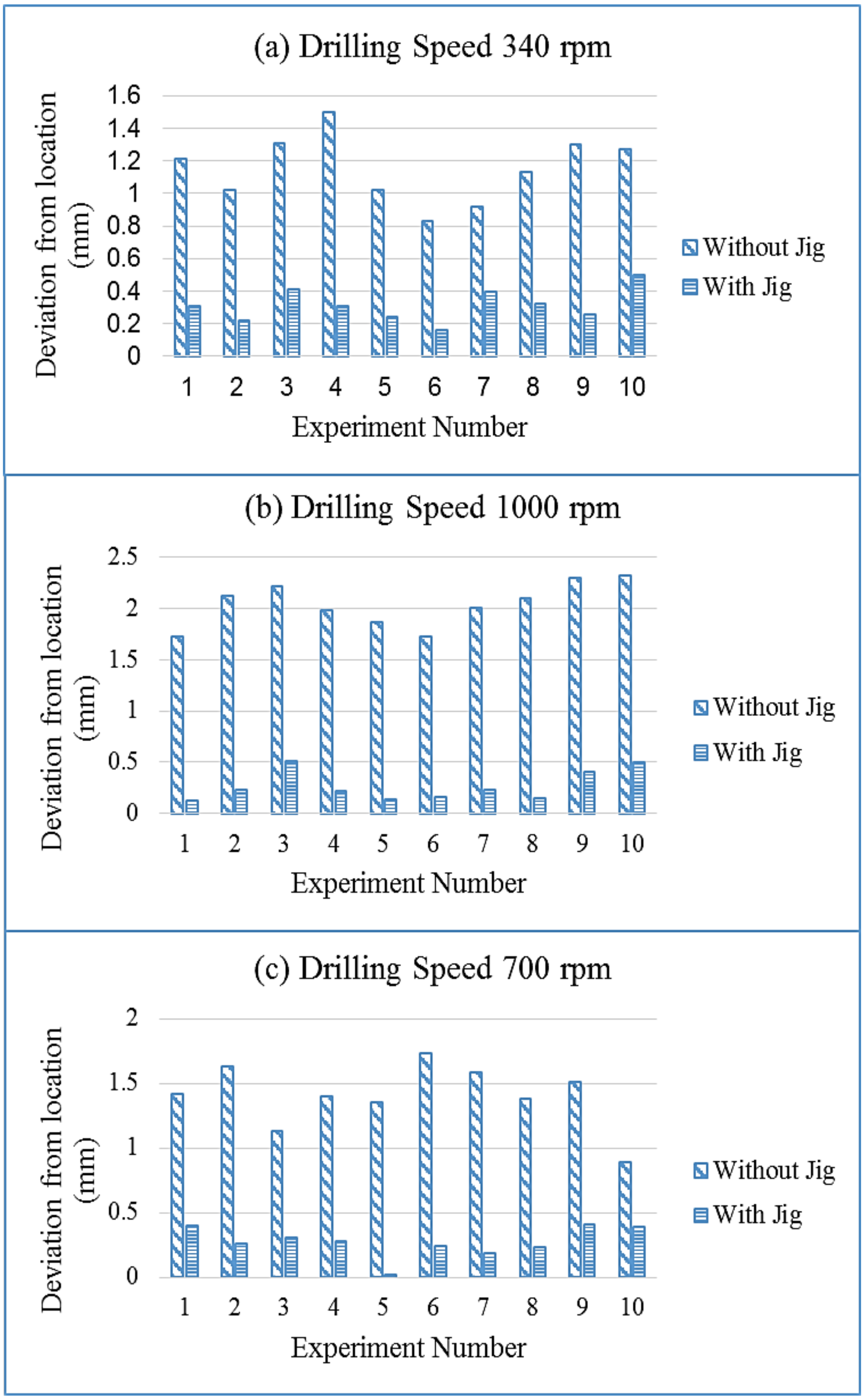


FIGURE 10. Values of deviation in drilled holes (with/without jig)

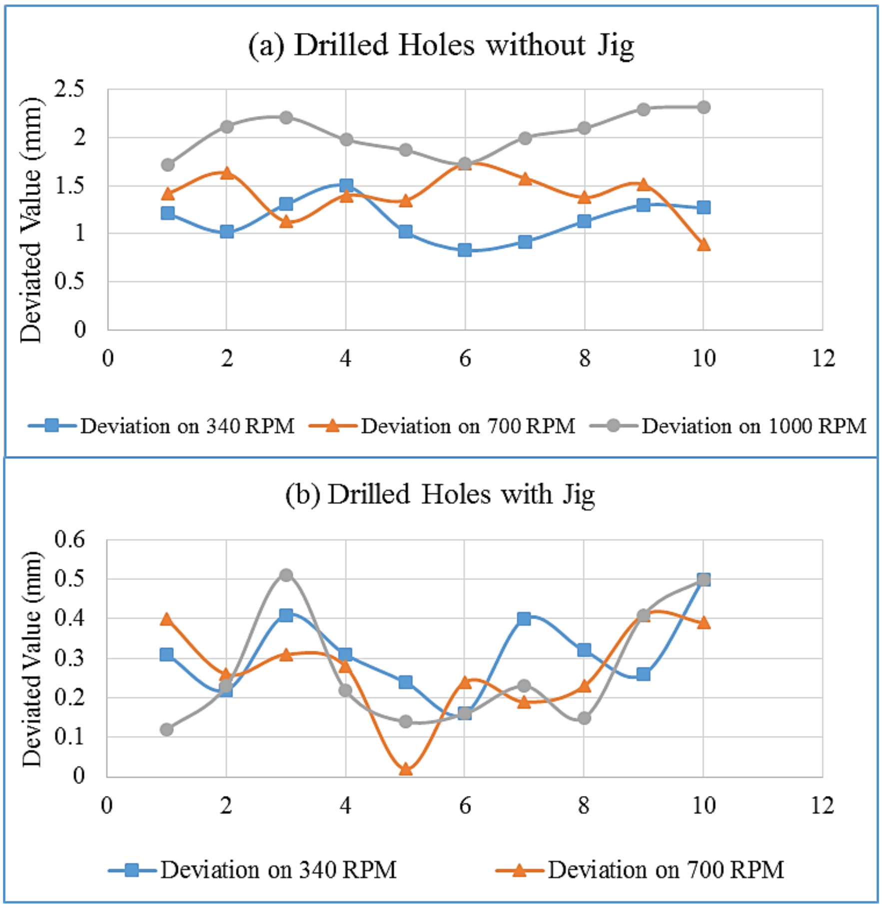


FIGURE 11. Values of deviation in drilled holes (With /without drill jig)

However, it was found that the values of deviation were reducing as the spindle speed was increased in each step when the drilling jig was applied.

This phenomenon can be explained as when the workpiece was held rigidly on the drill jig the drill bit was unable to displace it and the hole was produced rapidly due to higher spindle speed and the bit was returned to its position quickly. As the bit was not in contact with the workpiece for much time the hole did not deviated considerably.

Another finding of this work was that this drilling jig only ensures the precise alignment of the workpiece inside, but the alignment of the jig is required to be ensured initially on the bench drill table via calibrated instruments. Moreover, as this jig was made of mild steel, the same material as the workpiece, the initial poorly aligned jig placements on the bench drill also resulted in the degradation of the hole entrance of the jig's upper plate. This highlighted that the fabrication material for the jig should have more hardness, such as die steel.

CONCLUSION

This work presents the design fabrication and analysis of a precise drilling jig for manual machines as a cost-effective solution. This jig is highly applicable for the different types of materials and hole locations. The currently designed drilling jig has been proven to be a low-cost solution in comparison to the high-cost CNC machines and higher wage requirement of skilled workers.

As this jig requires only the placement of the workpiece and drilling can be performed conveniently, this eliminates the requirement of marking and center punch for drilling holes. The deviation in the drilled hole locations measured, be accurate up to 0.28 mm in comparison to the hole drilled without jig having an accuracy of 1.55 mm. It is providing the evidence of closer tolerance achievement by utilizing drilling jig.

The elimination of rework (waste) was the main objective for the application of drill jig which was successfully obtained as drilled holes were produced within the required tolerance of 0.5 mm.

The jig also provided the option of high spindle speed drilling (1000 rpm) for higher production speed. Without jig spindle speed of 1000 rpm was creating too many dimensional errors.

The overall cost required to produce one jig on the experimental scale was Pkr 3000 which shall be further reduced to Pkr 2000, in mass production, making it further cost-effective. The standard design of the jig has been introduced; however, the design can be modified for any other requirements. The current design idea has been analyzed and fabricated and the comprehensive details of all components with illustrations.

This jig design can be utilized in different drilling applications. The precision drilling jig provides a low-cost solution for drilling accurate holes in different types of materials and geometries. Compared with other traditional tools such as CNC drilling machines, this precise drilling jig provides several benefits i.e., simpler in design, lower manufacturing cost, easy to operation, and insurance to assembly precision.

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DECLARATION OF COMPETING INTEREST

None.

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