Evaluation of Design Efficiency using Boothroyd Dewhurst Method for PCB Drilling Machine Products

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Abstract — **This paper presents the investigation on design efficiency of two different 3-axis printed circuit board (PCB) drilling machine products using Boothroyd Dewhurst design for manufacturing and assembly (DFMA) approach. The two products that are used as a case study named machine A and machine B products. The investigation also intends to analyze on the total operation time, and total parts of the two existing machine products. A comparative study was done for both products that give better results for machine A in term of design efficiency and total operation time compared to machine B. However, the total parts of machine A is still higher than machine B. Therefore, the modified machine A is proposed to improve the design efficiency by minimizing the total parts of machine A. The Boothroyd Dewhurst DFMA technique is then utilizedd to analyze the proposed modified machine A. As results, the design efficiency of the proposed modified machine A improves from 5.81% to 9.24%.**

Keywords - Boothroyd Dewhurst Method, PCB Drilling Machine, Design for Manufacturing and Assembly (DFMA)

I. Introduction

With the growth of a variety of products nowadays, a modern production design method is significantly important to improve the efficiency of assembly processes that will cause high finish good quality products. To compete in current manufacturing industries, manufactures must generate excellent quality of finish good product at minimum cost with complete good lifecycle [1].

Design for manufacturing and assembly (DFMA) is a method in the development of product design in order to minimize the production costs of product as to compete with others manufacturer while increasing the profit margin. Most of the manufacturers prefer to reduce the production cost by using traditional processes in which it not employ any optimization methods. Moreover, the product design stage is just determined by either the cost is higher or lower [2]. The utilization of DFMA method is not only measures the higher and lower costs but it is able to measure and also optimize the total number of part, operation times, and design efficiency, as well. Design for assembly (DFA) and design for manufacturing (DFM) are two important aspects of DFMA. DFA is an approach to optimize the components in product design. DFM is a technique to optimize the manufacturing processes in term of design component [3]. DFA will cause some parts to be diminished while DFM will reduce the number of total parts [4]. Applying the concept of DFA and DFM will give significant advantages including rearrangements of items, reducing manufacturing and assembling costs, and enhancement value and time reduction of products [5]. Generally, the aim of DFA is to make the assembly processes easily and also assist designers to solve the assembly issue problems [6]. False design selection will affect a higher production and manufacturing costs of a product. The essential standards of DFMA are to diminish parts. It is a key part in item improvement, particularly in certain manufacturing industries such as aeronautics, in which variety in segment geometry is accessible. Then, that is imperative to implement in any manufacturing industries to enhance efficiency and their capacity to satisfy their client necessity without neglecting the delivery of the product quality.

Applying DFA guidelines will enable the manufacturer to understand general possible design guidelines to gain manufacturing knowledge and help the designer in the form of simple rules to be followed when creating a product design. According to Geoffrey Boothroyd [9], the process of manual assembly is divided by two. First is handling by means of moving, acquiring and orienting parts. Secondly is an insertion by means of mating a part to another part or group of parts.

II. Methodology

A. Product Selection

In this study, a printed circuit board (PCB) drilling machine is chosen as a case study. Before the design is simplified, general review on this machine is been done. The design concept of the PCB drilling machine is similar to the mechanical design of the coordinate measuring machine (CMM) as both of this application consists of 3-axis component and mechanism. The difference is on the use of the CMM itself. CMM is an instrument that provided with the probing system that moving in order to

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determine the coordinates on the part surface being measure [7]. The application of this CMM structural design been applied to the 3-axis PCB drilling machine. There are six main design structures as shown in Figure 1.

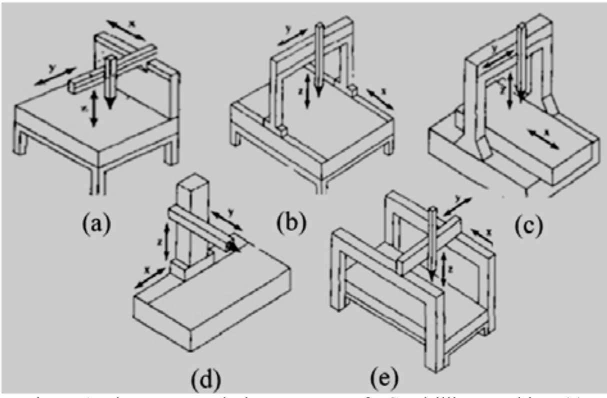
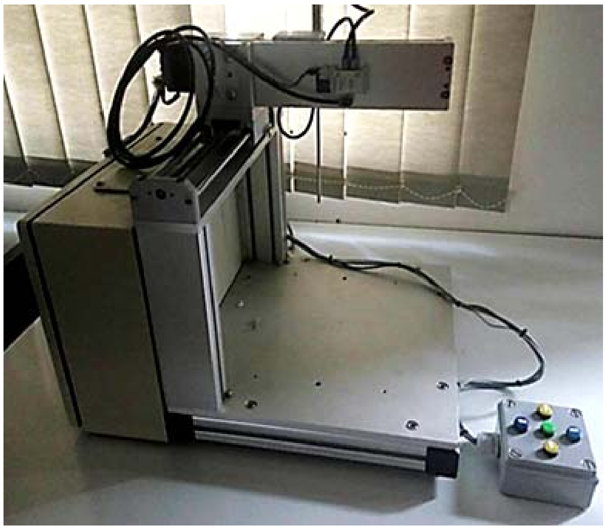


Figure 1. The common design structure of PCB drilling machine. (a) Cantilever (b) Moving bridge (c) Fixed bridge (d) Horizontal arm (e) Gantry

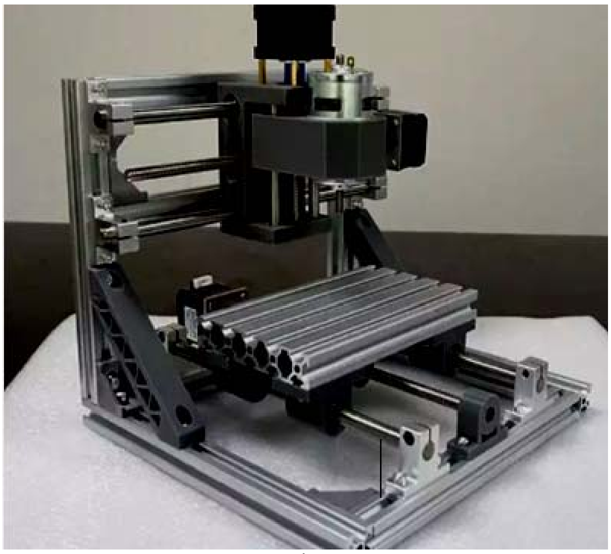
Referring to [10], the morphologic matrix framework is utilized to arrange all conceivable plan arrangements, for every item work, characterized at the practical displaying stage. Figure beneath demonstrates the morphological framework found for this item. Every single conceivable origination is then broken down and contrasted with the objective prerequisites to check whether they satisfy them or not. Table 1 shows the possible mechanisms used by the researcher while designing the PCB drilling machine.

Two type of PCB drilling machines are chosen as a case study. These two machines are called as PCB drilling Machine A and PCB drilling machine B as shown in Figure 2. These PCB drilling machines are selected because of its uniqueness, as it is a custom machine for drilling in order to locate an electronic component after the drilling component process has been completed. As the goal for this to compare both of this machine regarding on its design efficiency, the influence of the use of electrical usage was disregard.

Firstly, the machine was dismantled and all of the single product parts was measured using the measuring `tools including a vernier caliper. CATIA V5 modeling software was used to develop the detail drawing of each component as to generally observe the each of the component parts. Boothroyd Dewhurst DFMA method is used to generate the design efficiency of both machines. Design efficiency will potentially reduce the product costs. Costs also include handling the cost, assembly cost, and development time.



-a.

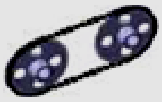
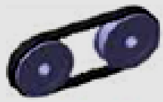
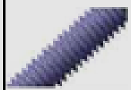
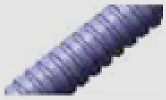
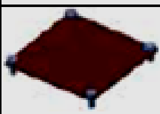
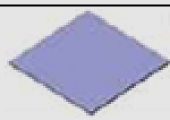
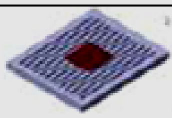
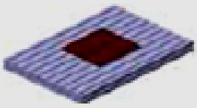
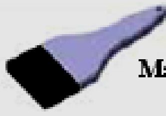
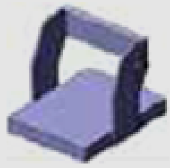


-b.

Figure 2. (a) Machine A; (b) Machine B

Theoretically, the least number of products will indicate a higher design efficiency that reduces fabrication and assembly steps.

TABLE 1. MECHANISM AVAILABLE FOR PCB DRILLING MACHINE

Function	Possible Mechanism		
Motor Actuation	 Screws	 Chai n	 Belt
Tool Actuation	 Belt	 Dc motor	 Gear
Axis moving	 Lead screw	 Metric screw	 Ball screw
Board Fixture	 Fasteners	 Holding plate	 Moon holder
Noise Insulation	 Foam	 Styrofoam	 Felt
Board Support	 Oblong	 Aluminum pro	 Holes
Splinter Removal	 Suction	 Manual	
Tool Fixture	 Set-screw	 Conic	 Chuck key
Structure Reinforcement	 Laser cut piece	 Aluminum pro	 Machined

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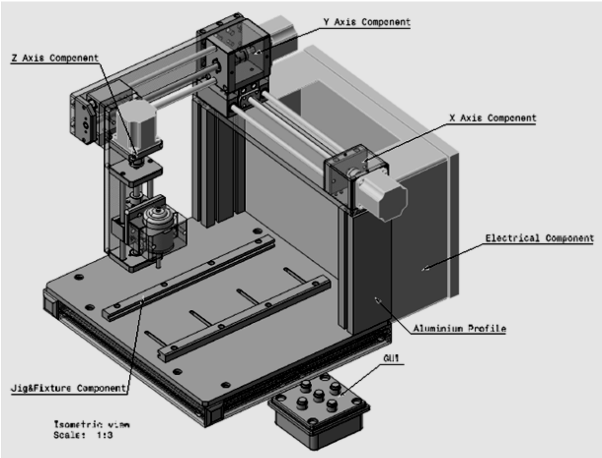


Figure 3. CATIA modelling machine A

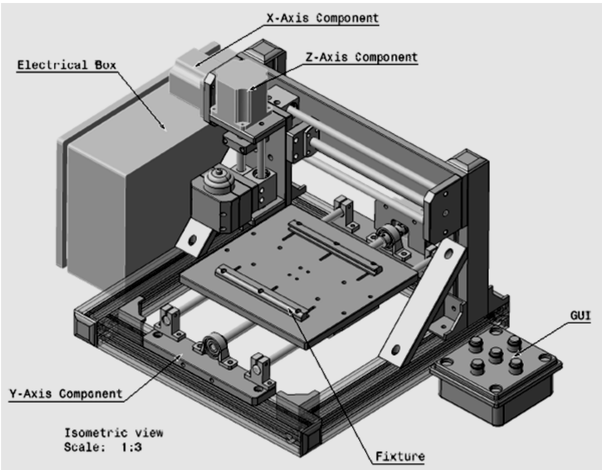


Figure 4. CATIA modelling machine B

B. Overall Step and Block Diagram

There are two factors need to look forward in order to analyze the design efficiency. The first factor is the possibilities to eliminate the parts or combination of parts. The second factors are an estimation of time taken to insert, grasp and manipulate the part. Both of these factors have to be considered in order to get the design efficiency of the machine. The current items are distinguished, gotten and the detail plans of the items duplicated with the guide of CATIA. Figure 3 and Figure 4 show the current existing design by using the aid of CATIA software.

C. Design Efficiency Equation

The design efficiency is based on an equation as follows,

$$EM = NM*TA / TM \qquad (1)$$

where, EM = design efficiency, NM = estimation for the theoretical minimum part, and TM = Assembly time, TA = is taken as 3, based on the average value of theoretical assembly time.

D. Theoretical Minimum Parts Count

The theoretical minimum part count represents an ideal situation in which separate parts are combined into a single part unless one of the criteria above is met. There are three criteria in total which are:

1. Criteria 1 is regarding on part movement, the parts move relatively to all others parts already assembled during the normal operating mode of the final product.
2. Criteria 2 is regarding on part isolation, the part must be made of different material than other parts already assembled in the system.
3. Criteria 3 is regarding on adjustment or replacement, the part must be separate from all other assemble parts.

These three criteria are important to identify and analyze the theoretical minimum part count for the machine. As example Table 2, LM10UU bearing is theoretically considered as non-necessary part as not met all the criteria meanwhile the lead screw is considered as necessary part as met all the criteria. Referring to Table 2, when the criteria are met thus number “1” is entered in column A8 as a necessary part and if criteria not met thus number “0” is entered as not necessary part.

TABLE 2. EXAMPLE OF THE THEORETICAL PART COUNT FOR PCB DRILLING MACHINE

Part	Criteria 1	Criteria 2	Criteria 3	Theo. part
Screw	No	No	No	✗
Lead screw	Yes	Yes	Yes	✓
Holder	No	No	No	✗

TABLE 3. EXAMPLE OF DESIGN EFFICIENCY

PI	A1	A2	A3	A4	A5	A6	A7	A8
Screw	360	1	11	1.50	38	6.0	7.5	0
Lead	720	1	35	2.73	06	5.5	8.23	1
……………………………………………………… Analyze for all product parts								
Holder	720	1	30	1.95	59	12	13.9	0
Motor	720	1	35	2.73	08	6.5	9.23	1
EM = 3*42 / 2165.45							TM	NM

PI = Part item; A1= angle of symmetry; A2= No. of items; A3= Manual handling code; A4= Handling time per item, A5= Manual insertion code, A6= Insertion time per item; A7= total operation time (A4+A6); A8= Theoretical minimum parts.

E. Design Efficiency Table

Next step is to fulfill the column A1 through A7 by following the standard theoretical values as shown in Table 3. In order to full fill the column A1 trough A7 standard procedure as in [9]. The selected time is taken for manual handling and manual insertion manual handling of the part was stated in the standard table that was provided in which is based on theoretical value. The analysis is done for both Machine A and Machine B then was repeated for the newly improved designs for internal validation and the result of the analysis.

According to Sudin [10], improvement of the product study can be carried out by considering two ways below:

Step 1: If the value in column 8 (A8) less than the value in column 2 (A2), then the opportunity to lessen the number of parts considered.

Step 2: Check columns 4 (A4) and 6 (A6). These figures indicate the potential for assembly time reduction.

As stated in step by step before, the method and technique are applied in order to identify the design efficiency on PCB drilling machine.

III. Results and Discussions

A. Design Efficiency of PCB Drilling Machine

PCB drilling machine A and B product are analyzed using Boothroyd Dewhurst DFMA methods for manual assembly. Equation (1) is used in order to calculate and determine the design efficiency. As for information PCB drilling machine A consist of 63 parts while PCB drilling machine B consists of 51 parts in total where all the screw, aluminum profile slotter, aluminum profile and dowel pin is considered as one single part. Table 4 shows an analysis result of Machine A and B.

As the clarification above, the theoretical minimum number of the part is one of the tools to describe potential simplification in the part product design. In Figure 5, the lead screw holder, the criteria for the separate part are to be applied after the slider base, LM10UU bearing, nutleadscrew, solid round bar and leadscrew is been assembled.

1. Lead screw holder relatively does not move to these parts, thus it can be considered that lead screw can be theoretically combined.
2. Lead screw holder and nut lead screw are both are a different material, but it actually can be the same material. Thus, theoretically can be combined.
3. The lead screw holder does not have to be separate with nutleadscrew in order to allow assembly of the nutleadscrew.

Since these criteria are not valid, thus the leadscrew holder can be possibly combined with nut lead screw. After the theoretical number of parts counted, the next step is to define its insertion and handling time. According to the analysis, the theoretical part count for machine A and B are the same but total part number of machine A is higher compared to part B. Even the total part number of design A is higher compared to B, but the total operation time for Machine A is lower than machine B. Therefore, the higher number of parts does not mean longer time is needed to assemble the machine but it depends on the machine design itself. Design efficiency of machine A 5.81% which is higher than machine B that is 5.56%. Based on this result it shows that the design of machine A is more efficient compared to design B.

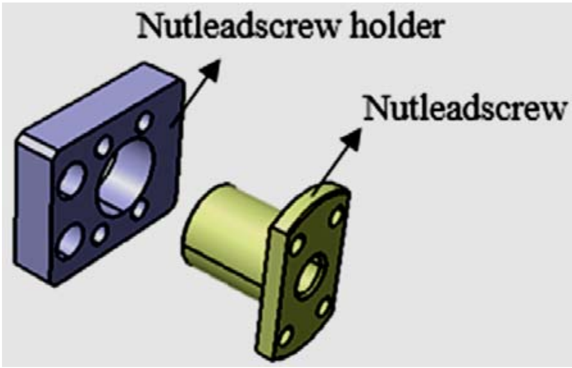


Figure 5. Example of a product part of machine A

TABLE 4. THE RESULT OF DESIGN EFFICIENCY FOR MACHINE A AND MACHINE B

Product	Total item no.	Total op. Time(s) (A4+A6)	Theoretical no. part count	Design Efficiency
Machine A	63	2165.45	42	5.81%
Machine B	51	2262.39	42	5.56%

TABLE 5. SUGGESTION FOR REDESIGN OF MACHINE A

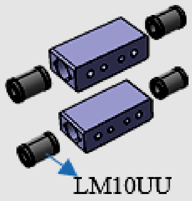
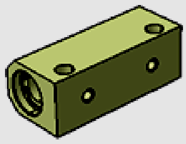
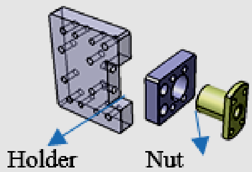
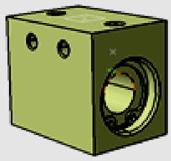
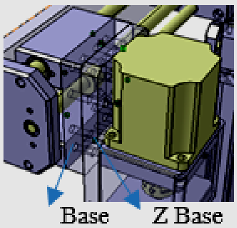
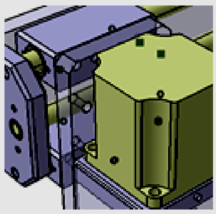
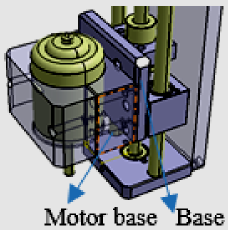
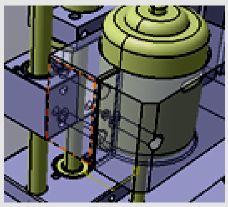
Existing	Improve	Justification
		Change the two parts into single part by using standard component by Misumi.
		Change the nut into single part by using standard component by Misumi.
		Eliminate the base and directly attach the Z base directly to the tail block.
		Eliminate the base and directly attach the motor base directly to the tail block.

TABLE 6. EXISTING DESIGN AND MODIFIED DESIGN OF MACHINE A

Product	Total part no.	Total op. Time(s) (A4+A6)	Theoretical no. part count	Design Efficiency
Machine A	63	2165.45	42	5.81%
Modified machine A	51	1495.86	47	9.42%

B. Design Improvement of Machine A

PCB drilling machine A consist of four general modules which are X axis module, Y axis module, Z axis module and a general module that including all the aluminum profiles, jigs, fixtures and few more components. The re-outlined model of the Machine A was conveyed out thinking about the simplicity of getting together and diminishment in material and assembling process.

Based on the results in Table 4, the alteration for the design that need improve is applied on machine A is based on the analysis of DFMA. As a rule, a portion of the parts was proposed to be disposed of and a few changes have been actualized in the components. For machine A there are few part components that will be eliminated or change such as nut lead screw holder, LM10UU bearing, slider block screws, dowel pin and others few components.

Table 5 demonstrates the proposed adjustment for the PCB penetrating machine plan. The first plan and new outline are inscribed and recorded in the table. The justification of the adjustment between existing and improve parts are briefly explained in the table. It clearly indicates that the proposed adjustment satisfies the expected outcomes in term of the number of total parts.

In Table 5, most of the modification is by combining the single part and becoming one part. As an example the LM10UU bearing and the slider block is changed with standard part by Misumi where this mechanism used in Z-axis, Y-axis and X-axis components. When these parts are changed, the number of screws is reduced to a new part. It will use less screw compared to the previous design.

Nut and nut holder also can be combining into one single part, so that the number of screws can be reduced. In order to attach the Z base into the slider block, the base will be eliminated by directly attaching Z base to the slider block. Similar situation with motor base and Z base, the modification needs to be made to the Z base and motor base to meet the hole within the standard part. Table 6 shows the comparison between machine A and modified machine A. Before modification, the design efficiency of machine A is 5.81%. Then after done the modification, the efficiency rises up to 9.42%.

C. Comparison between Machine A, Machine B and Modified Machine A

After comparing all of the machines, the DFMA analysis results show that machine B has the lowest design efficiency worth of 5.56% compared to machine A which is 5.81%. Thus machine A is chosen for modification. Figure 6 shows the comparison on design efficiency. After modification of machine A design efficiency increased by 3.61% and rise up 9.42%.

Figure 7 shows the operation time of modified machine A is less compared to Machine A and B. Number of components of machine A consist of 63 components and modified Machine A consist of 51 parts after modification as shown in Figure 8. Portions of these parts joined as a single component and some superfluous segments/highlights were diminished. The new PCB drilling machine increases the design efficiency by 3.61 % by actual value is 9.42%.

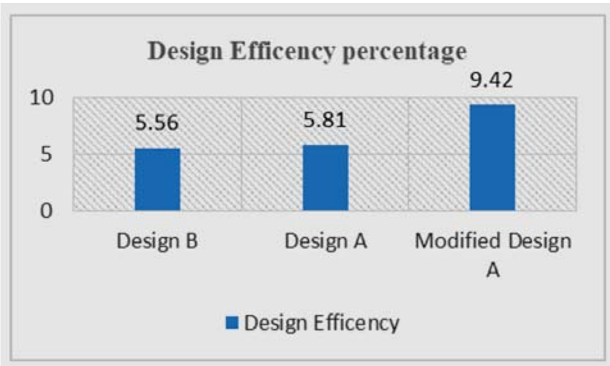


Figure 6. Comparison on design efficiency percentage

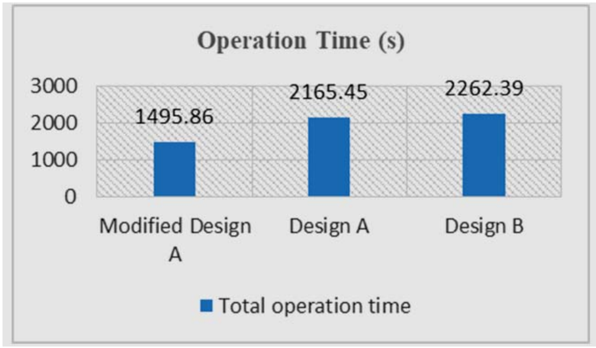


Figure 7. Comparison on operation time (s)

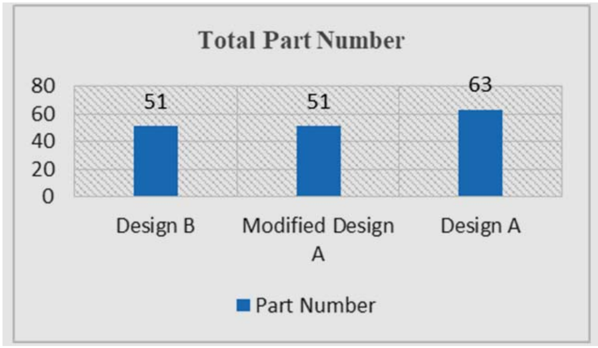


Figure 8. Total part number

IV. CONCLUSION

The number of part components and assembly strategy are the imperative components influencing the planned productivity of a product. The number of total components of the new PCB drilling machine was reduced from 63 components to 51 with the application of the DFMA analysis. The total assembly operation time reduced from 2165.45s to 1495.86s. It obviously shortens the assembly time by about 669.59 s or 3.61%. The reduction of assembly time is contributed by the elimination and combination of certain components based on DFMA analysis result. This reduction in the component will ultimately improve design efficiency.

ACKNOWLEDGEMENT

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