Reverse engineering of wörner type drilling machine structure.

A Wibowo, I Belly, R Ilhamsyah, Indrawanto and Y Yuwana
Faculty of Mechanical and Aerospace Engineering, Institut Teknologi Bandung
Jalan Ganesa 10 Bandung, 40132 Indonesia

Email : a_wibowo_m@yahoo.com

Abstract. A product design needs to be modified based on the conditions of production facilities and existing resource capabilities without reducing the functional aspects of the product itself. This paper describes the reverse engineering process of the main structure of the wörner type drilling machine to obtain a machine structure design that can be made by resources with limited ability by using simple processes. Some structural, functional and the work mechanism analyzes have been performed to understand the function and role of each basic components. The process of dismantling of the drilling machine and measuring each of the basic components was performed to obtain sets of the geometry and size data of each component. The geometric model of each structure components and the machine assembly were built to facilitate the simulation process and machine performance analysis that refers to ISO standard of drilling machine. The tolerance stackup analysis also performed to determine the type and value of geometrical and dimensional tolerances, which could affect the ease of the components to be manufactured and assembled.

1. Introduction
Forward engineering is the traditional process of moving from high-level abstractions and logical designs to the physical implementation of a system. In some situations, there may be a physical part/product without any technical details, such as drawings, bills-of-material, or without engineering data. The process of duplicating an existing part, subassembly, or product, without drawings, documentation, or a computer model is known as reverse engineering [1]. Reverse engineering has several objectives, which one of them is learning to design and make a product with the correct procedure. The reverse engineering process can be performed in seven stages [2]. The seven stages of reverse engineering are the collection of information, the analysis of product functions, dimensional measurement, and modeling, functionality, reliability and manufacturability analysis, product embodiment, testing, evaluation and final improvement. The problem after the completion of the solid CAD model with detailed feature is the accommodation of tolerance and constrains to the dimensional and geometrical values and to the surface features. [3]

As a part of functionality, reliability and manufacturability analysis in reverse engineering, the stack up analysis was perform. The purpose of stack up analysis is to establish the dimensional relationship within a part or assembly. It enables part tolerance to be achieved. One of the most important reason for using stack analysis is that problem can be discovered and solved on paper rather than in the prototype or production, and thus evaluation and modification can be done at early stage of design [4].
The general purpose of this reverse engineering process is to study the reverse engineering by emphasizing how to recognize the precision requirements of machine geometry and the process of establishing tolerances, so the Worner B13 type drilling machine was chosen because it has relatively simple construction and relatively few components. The final objective of this reverse engineering process is to build the drill machine design with the easiness of manufacturing and assembly process, so the machine can be made with simple manufacturing facilities, and limited operator skills. The discussion in this paper will be limited to the process of identifying the requirement for the geometric accuracy of each component of machine structure so that the overall accuracy of the machine can be achieved. The drilling machine structure component consists of worktable, column based, column, and head.

2. Initial information and product function analysis
The Worner B13 type drilling machine can be seen in Figure 1. The initial information of Worner B13 type drilling machine was obtained from the information attached or measured on the machine. The initial information can be seen on the Table 1.

Table 1. Specifications of Worner B13 type drilling machine

| Specification      | Value                          |
|--------------------|--------------------------------|
| Power              | 0.75 HP                        |
| Spindle Speed      | 560 - 3500 rpm                 |
| Spindle stroke     | 120 mm                        |
| Worktable size     | 330 mm x 430 mm                |

Figure 1. The Worner B13 type drilling machine

Like other drilling machines, in general this machine is used to make holes. Beside the maximum volume of the workpiece, there are no information is available about the range of cutting operation of this machine. Spindle speed analysis and power analysis are performed to estimate the cutting operation range. Spindle speed analysis is performed for the spindle speed range of 560 rpm. up to 3500 rpm. Based on the table of recommended rotary speed for various tools material [5]. Spindle speed range of 560 rpm. up to 3500 rpm. are suitable for HSS tool with the diameter of 3.175 mm. up to 6.35 mm. Larger tool diameters can be used up to 10.16 mm. in diameter for limited workpiece material. Furthermore, the adequacy of power analysis has been performed to ensure that the power requirements of the cutting process with the variation of tools diameter variations can be supplied by the motor. Based
on the power analysis it has been found that with a motor power of 0.75 HP, the range of possible tool diameter variations is only tools of diameter of 3.175 mm up to a diameter of 6.35 mm.

The main structure of the drilling machine can be seen in Figure 2. Next, the function of each major component of the drilling machine structure will be identified. The drilling machine worktable is a part of the base of the machine. The function of the worktable is to place the workpiece during the cutting process. Another function of machine base is to be the support of the machine column through the column base. The column base connects the column and machine base and supports the column in such a way that the column can move up and down and perpendicular to the worktable surface. Column supports and carries the head up and down. The machine head is the location of the motor, transmission system, and spindle. Spindle system must be able to move up and down (feeding stroke) and the movement is perpendicular to the worktable surface.

![Exploded drawing of the Drilling Machine Structure](image)

**Figure 2.** Exploded drawing of the Drilling Machine Structure

| No. | Component name                  |
|-----|---------------------------------|
| 1   | Machine base with worktable     |
| 2   | Column base screw               |
| 3   | Column base                     |
| 4   | Column                          |
| 5   | Column – Head screw             |
| 6   | Head                            |

3. **Measurement and modeling**

The shape of the drilling machine structure component is not too complex, so the geometry and dimensions of the component can be known by measurement using simple dimensional measuring equipment. All information related to the shape and dimensions of each component obtained is used for modeling. The ST42W material is selected for the main components of the drilling machine structure because it has a high machinability. The load simulation due to torque, gravity, and compressive force is carried out on the structure of drilling machine. The simulation results shows that the maximum deformation is about 0.00619 mm as shows in the Figure 3. Figure 4 shows that maximum stress occurs in the fillet area of 1.4 MPa. Furthermore, the simulation results have been used to calculate the angular error of the machine structure in the tolerance analysis.
4. Functionality and geometric requirement.
As a machine tool, the accuracy of drilling machines when functioning is very important. In addition to the rigidity of drilling machine structure, geometric accuracy of each component of drilling machine structure play an important role in realizing the overall accuracy of the machine. The geometry accuracy of each component is determined refer to the expected accuracy of the drill machine. The accuracy of the drilling machine cannot be obtained directly from the machine, in this case the geometric accuracy information of the drilling machine is obtained from ISO 2773 [6]. The squareness of spindle axis of drilling machine to the worktable surface is 0.06/300 mm.

The tolerance stackup analysis is performed to determine the accuracy and tolerance of each component so that the final accuracy of the drilling machine can be achieved. The datum reference frame (DRF) is generated for each component based on guides from ASME Y14.5 [7] and becomes a reference when performing a tolerance stackup analysis. At the assembly level, the DRF for the drilling machine is placed at the middle of machine worktable feature as seen in Figure 5.
The tolerance stackup analysis has been performed based on two reference planes: X-Z plane and Y-Z plane. The budget tolerance as shown in Table 2, is determined for machine structure, spindle system, and deflection to be used as a tolerance limit on tolerance stackup analysis. The total budget is obtained from the conversion of the squareness tolerance value to the maximum permissible angular error at the location and orientation of the DRF. Only the tolerance stackup analysis for the machine structure to be discussed in this paper. The proportion of the tolerance budget for machine structure subsystem and spindle subsystem was determined based on the number of parts in each subsystems. The number of parts in the machine structure subsystem is 6, whereas in spindle subsystem is 4 so the budget ratio of 6:4.

Table 2. The Budget Tolerance

| No. | Tolerance component       | Budget for X-Z (E) | Budget for Y-Z (E) |
|-----|--------------------------|--------------------|--------------------|
| 1   | Machine Structure        | 0.0110             | 0.0070             |
| 2   | Spindle System           | 0.0074             | 0.0041             |
| 3   | Deflection               | 0.0006             | 0                   |
|     | **Total Budget**         | **0.019**          | **0.011**          |

The tolerance stackup for machine drilling was perform by using the worst case method. Geometric tolerances as result of the tolerance stackup analysis for drilling machine structure components can be seen in Table 3.

Table 3. Geometric tolerances of structure components

| No. | Geometric Feature Correlations | X – Z Plane | Y – Z Plane |
|-----|--------------------------------|------------|------------|
|     |                                | Sensitivity (E/mm) | Tolerance (mm) | Sensitivity (E/mm) | Tolerance (mm) |
| 1   | Parallelism between the column base pad and the worktable | 0.41 | 0.001 | 0.28 | 0.002 |
| 2   | Flatness of each paired surface between column base pad and pad on base | 0.41 | 0.002 | 0.28 | 0.002 |
| 3   | Perpendicularity of cylindrical axis and column base pad. | 0.29 | 0.004 | 0.29 | 0.002 |
Cylindricity of each paired cylinders on the column base and the column  | 0.29  | 0.004  | 0.29  | 0.002  
Perpendicularity the head mating surface to the axis of the column cylinder | 0.14  | 0.005  | 0.14  | 0.003  
Flatness of each paired surface between the column head mating surface base | 0.32  | 0.004  | 0.47  | 0.002  
Perpendicularity between the main axis of the spindle system and the head mating surface | 0.57  | 0.003  | 0.47  | 0.002  

The result of the tolerance stackup analysis becomes a geometric specification on each component of the machine structure, which according to the specification will be determined the production process and the appropriate production equipment. The tolerance value can be compromised by some iteration processes in the tolerance stackup analysis, due to the possibility to looking for the easier manufacturing processes and the simpler production equipments. The result of the tolerance stackup analysis can be used as reference to do some design modification as alternative to meet the strict specifications.

5. Conclusions
The reverse engineering process has been performed on The Worner B13 type drilling machine up to the stage of identifying the requirements for the geometric accuracy of each component of machine structure so that the overall accuracy of the machine can be achieved. The geometric accuracy of machine structure component were obtained by the tolerance stackup analysis with considering the results of the modeling and simulation process. The geometric accuracy for each component can be used as a basis for production planning processes or making some design modifications. By conducting the tolerance stackup analysis, the adjustment of tolerance values is possible according to the existing component relationships, so that the compromises related to the process and equipment to be used can be performed.

References

[1] Raja V, Fernandesh K 2008 Reverse Engineering (London: Springer-Verlag).
[2] Rochim T 2012 Tujuh Tahapan Reverse Engineering (Indonesia: Teknik Produksi Mesin-ITB)
[3] Jamshidi J, Mileham A R and Owen G W 2006 Dimensional Tolerance Approximation for Reverse Engineering Applications (International Design Conference – Design)
[4] Sahani A K, Jain P K and Sharma S C 2013 Geometrical Tolerance Stack Up Technologies (DAAAM International Scientific Book 2013 pp. 875-872 Chapter 52)
[5] Oberg, Erik, Franklin D. Jones, Holbrook L. Horton, Henry H. Ryffel, 29th Edition Machinery’s Handbook, New York. 2012.
[6] ISO 2773/1 1973 Test Conditions for Pillar Type Vertical Drilling Machines — Testing accuracy — Part I: Geometrical Test (Switzerland: ISO)
[7] ASME Y14.5 2009 Dimensioning and Tolerancing (USA: American Society of Mechanical Engineering)