Simulation on the spindle of a five-axis multifunctional CNC machine using finite element method

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Abstract. Computer Numerically Control (CNC) machines are manufacturing machines that are capable of cutting materials with many axes and various types of equipment and operations controlled using a computer. The analysis system used in this software is static structural with linear analysis, because the main focus is to get the value of the stress on the fastening bolts and the stress on the end mill when doing the milling process. The results of the stiffness simulation at the end mill, get the smallest stress results of 0.93783 MPa at a variation depth of feed 1 mm, and get the highest stress results of 5.6272 MPa at a variation depth of feed 6 mm. The result of spindle bolt stiffness simulation shows that the lowest value occurs at 1 mm variation depth of feed, about 1456.4 MPa for equivalent stress, 196.62 MPa for shear stress, and 0.036601 mm for total deformation. Meanwhile, the highest value occurred at the 6 mm variation depth of feed, about 1456.9 MPa for equivalent stress, 196.69 MPa for shear stress, and 0.03664 mm for total deformation. The greater the force that occurs, the greater the stress that occurs on the object, but the stress can also be smaller if the cross-sectional area is larger.

Keywords: simulation, spindle CNC 5 axis, finite element method

1. Introduction
The machining industry, especially machine tools, is currently facing increasingly severe challenges. This industry is required to produce cheaper, more precise, mass products with faster production times [1]. The more sophisticated the technology used, starting from the system and the dimensions of the tools used are getting smaller.

CNC (Computer Numerically Control) machines are manufacturing machines that are capable of cutting materials with many axes and various types of equipment and operations controlled using a computer [2]. CNC machines are a modification of conventional machine tools by adding a motor to move the chisel as material cutting. In the material cutting process, there are several ways that can be used, namely milling, drilling, boring, turning, shaping, planning, grinding and blanking [3]. In a multi-axis CNC machine, the five axis of the drive will be used to move the workpiece so that the production time is relatively shorter and the waste material can be minimized because the movement of the workpiece is controlled and calculated using a computer [4]. According to some construction researchers on a machine, a numerical calculation or simulation of the loading force that will be applied to the machine must be carried out to find out
the limitations of loading in using the machine so that the machine's service life is longer and reduces unwanted events [5], [6]. In this research, it is focused on examining the value of the stiffness that occurs in the spindle bolt of the machine and also the stiffness value of the end mill when doing the milling process.

2. Experimental method
Analytical calculations carried out in this study include cutting forces, force distribution on the Z-axis, and calculating bolt strength on the Z-axis. Then design a five-axis multifunctional CNC machine using Autodesk Inventor software. After the design has become an integrated machine, then the data is imported into the software finite element method to simulate the forces that occur in the construction of the machine. The software finite element method used is ANSYS 18.2. The analysis system used in this software is static structural with linear analysis, because the main focus of this research is to get the value of the stress on the fastening bolts and the stress on the end mill when doing the milling process. The stress value to be generated is still in the elastic zone of the bolt material, therefore the simulation in this study uses linear analysis.

The simulations carried out in this study used a spindle that has a maximum collet chuck size specification for an end mill of ø6 mm, so that in this study the diameter of the end mill used was ø6 mm. The in feed depth measurement is obtained from the end mill catalogue which states that the maximum recommended in feed depth for ø6 mm end mill is 6 mm.

![Figure 1. Loading simulation on a CNC machine spindle](image)

2.1 End mill material
The end mill in this simulation process uses tungsten carbide material where the material has a yield stress value of 370 MPa [7].

2.2 Spindle fixing bolts material
The bolt on the spindle uses a class 8.8 bolt where in that class the material used for the bolt is quenched and tempered alloy steel which has a yield stress value of 640 MPa [8].

3. Result and discussion

3.1 Simulation on end mill
The simulation results were carried out to determine how much stress value that occurs at the end mill with different infeed depth variations. The smallest stress occurs at a variation of the infeed
depth of 1 mm workpiece of 0.93783 MPa, and the highest stress occurs at a variation of the infeed depth of 6 mm of 5.6272 MPa.

![Figure 2. Result simulation on end mill](image)

| No. | Depth of Feed (mm) | Stress Von Mises (MPa) |
|-----|--------------------|------------------------|
| 1   | 1                  | 0.93783                |
| 2   | 2                  | 1.8758                 |
| 3   | 3                  | 2.8137                 |
| 4   | 4                  | 3.7515                 |
| 5   | 5                  | 4.6894                 |
| 6   | 6                  | 5.6272                 |

3.2 Simulation on spindle bolt
The simulation results show the value of the von Mises stress and the shear stress that occurs in the spindle bolt. The smallest von mises stress occurs at a variation of the infeed depth of the workpiece 1 mm at 1456.4 MPa, and the largest von mises stress value occurs at the 6 mm infeed depth variation of 1456.9 MPa. Meanwhile, the smallest value of shear stress is at an infeed depth of 1 mm with a value of 196.62 MPa, and the largest value is at an infeed depth of 6 mm with a value of 196.69 MPa. By comparing the simulation results of the maximum shear stress and the results of the calculation of allowable stress, it can be said that the bolts of this class can accommodate quite well on the spindle of a five-axis multifunctional CNC machine that produces a maximum shear stress value of 196.69 MPa.
Figure 3. Result Simulation Shear Stress on Spindle Bolt

Figure 4. Result simulation total deformation on spindle bolt

Table 2. Result Simulation on Spindle Bolt with Variation Depth of Feed

| No. | Depth of Feed (mm) | Cutting Force (N) | Shear Stress (MPa) | Total Deformation (mm) |
|-----|--------------------|-------------------|--------------------|------------------------|
| 1   | 1                  | 3.5142            | 196.62             | 0.036601               |
| 2   | 2                  | 7.0284            | 196.63             | 0.036609               |
| 3   | 3                  | 10.5426           | 196.65             | 0.036617               |
| 4   | 4                  | 14.0568           | 196.66             | 0.036625               |
| 5   | 5                  | 17.571            | 196.67             | 0.036632               |
| 6   | 6                  | 21.0852           | 196.69             | 0.03664                |

4. Conclusion

Stress is the intensity of the force that is distributed in a certain part [9]. A material that receives an external force will react with the same force in the opposite direction. According to research by Hong C. [6], the stress value depends on the amount of force that occurs in the material, but is inversely proportional to the cross-sectional area of the material. The results of the stiffness simulation at the end mill, get the smallest stress results of 0.93783 MPa at a variation depth of feed 1 mm, and get the highest stress results of 5.6272 MPa at a variation depth of feed 6 mm. The result of spindle bolt stiffness simulation shows that the lowest value occurs at 1 mm variation depth of feed, about 196.62 MPa for shear stress, and 0.036601 mm for total deformation. Meanwhile, the highest value occurred at the 6 mm variation depth of feed, about 196.69 MPa for
shear stress, and 0.03664 mm for total deformation. Therefore, the greater the force that occurs, the greater the stress that occurs on the object, but the stress can also be smaller if the cross-sectional area is [10]. From the simulation results of feeding the workpiece with the maximum depth, the stress that occurs at the end mill is still below the yield stress of the end mill material. However, in actual conditions, the stress that occurs at the end mill can exceed the value obtained in the simulation [11]. This happens because there are several factors that can affect the stress at the end mill to increase, among others, the thermal effect and the propagation of tool wear [12]. Both of these factors can be solved by using coolant when infusing the workpiece [13]. In addition, the effect of using an end mill with a maximum infeed depth in the milling machining process is wear on the tool edges [14]. The greater the infeed depth value in the milling process, the greater the surface area eroded by the end mill. With the increase in the surface area eroded by the end mill, it will result in a rougher workpiece surface [14].

5. Reference

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