NATURAL FREQUENCY ANALYSIS ON THE BASE STRUCTURE OF THE CNC MILLING MACHINE USING SIMULATION AND EXPERIMENTAL METHODS

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ABSTRACT

The development of national machine tools needs special attention in order to compete with foreign products. Government agency cooperates with industry partners to develop precision CNC milling tools at competitive prices in today's manufacturing industry. One of the problems that often occur in the machine structure is the vibration caused by the resonance between the components that make up the machine, which results in inaccurate machining products. Therefore, it is necessary to do a natural frequency analysis on the milling machine prototype. This research was conducted on the base structure which is the most basic component as a holder for other components. Natural frequency analysis on the base structure uses two methods, namely experimental and numerical simulation using FEA. The results of the two methods are then compared and analyzed for errors that occur. Research parameter so that design does not resonate is that rotational velocity should be 15% above or below the natural frequency. The results show comparison natural frequency error value of numerical simulation method with experimental method and analysis of safety base design against resonance.

Keywords : base structure; natural frequency; experimental; simulation
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INTRODUCTION

Improving the quality and productivity of a product is currently a challenge for the manufacturing and machinery industry [1]. For this reason, it is necessary to develop machine tool designs that have low production costs and high machining precision [2]. One of factors that affect the Machining precision level is the occurrence of vibration caused by rotation of motor or movements of other components that cause resonance. So that the designer needs to consider the optimal level of structural rigidity.

Machine tools play an important role in the manufacturing system. Too many vibrations will reduce the precision level of product dimensions and surface finish. Many losses occur due to vibration, such as reducing tool life, component joints loose, causing noise and production failure due to wear and cracking [3]. One of sources of this vibration comes from resonance due to its natural frequency similarity.

Every component of a machine or other tool has a certain natural frequency or is often interpreted as its favorite frequency whose value is influenced by mass and stiffness [4]. Likewise, the base structure of the milling machine used in this research has its own natural frequency.

The problem that is often faced in designing machine tool structures is the resonance that occurs at critical speed. Critical speed occurs when the natural frequency of the machine component is between the rotational frequency of the motor. This resonance will cause engine vibration increases [5].

Mathematically natural frequency can be determined by formula no-1:

$$fn = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \qquad (1)$$

Where *fn* is natural frequency of the base structure. *k* is stiffness of the base structure. *m* is the mass of base structure.

Stiffness is resistance of a material to elastic deformation. The value of material stiffness can be assessed from its modulus elasticity. The modulus of elasticity is the ratio between stress and strain. Finite element method (FEM) requires material properties such as modulus of elasticity of material used in the test object [6].

The aim of this study is to compare the natural frequency error between two methods, namely experimental and simulation. In addition, this study is also to ensure that the design of machine tools, especially the design of the base structure on the milling machine, is still safe from resonance at critical speed.

Figure 1 is prototype of milling machine. It is a result of research and development for the design machine tools which will be discussed in this journal.

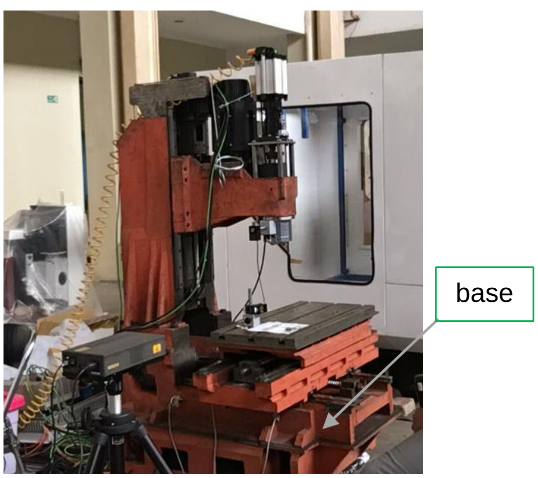

Figure 1. WAGE 645 CNC Milling.

METHODS

The method used to complete this research include:

1. Numerical simulation using computational software. simulation is an approximation method used to determine the value of the natural frequency component. The steps are
   1.1. Literature Studies
   Conducted a literature review in accordance with the research to understand the process of designing the base structure of the CNC milling machine and the properties of the materials used.
   1.2. Designing using CAD (computer aided design)
   Conceptual designs are made based on DR&O (Design Requirements and Objectives). Next step, we make embodiment design based on optimization design of conseptual designs using CAD software.
   1.3. Numerical simulation
   Simulations were carried out using FEA (Finite element analysis) software.
   1.4. Discussion
   Discussions with research team and all parties to analyze and find solutions to determine further steps.
2. The experimental method is called the bump test with the free play method, the steps that have been carried out are:
   2.1. Discussion
   Discussions with research team colleagues and various parties to analyze and find solutions to determine further steps.
   2.2. Create test base layout
   The base to be tested is a crane so that the base is free or free fly [7] to reduce damping.
   2.3. Perform bump test
   The test was carried out at 4 measurement points. Each point is tested 5 times.
   2.4. Record test results
   Test results is automatically saved in the internal memory.
   2.5. Discussion
   Discussions with research team and all parties to analyze and find solutions.

RESULTS AND DISCUSSION

Research Results

The simulation uses FEA software to determine natural frequency of the CAD design that has been made as shown in Figure 2. Figure 2 is the initial design based on the design concept.

Concept design is the result of DR&O development, such as problem definition, collecting information, concept creation and evaluation [8].

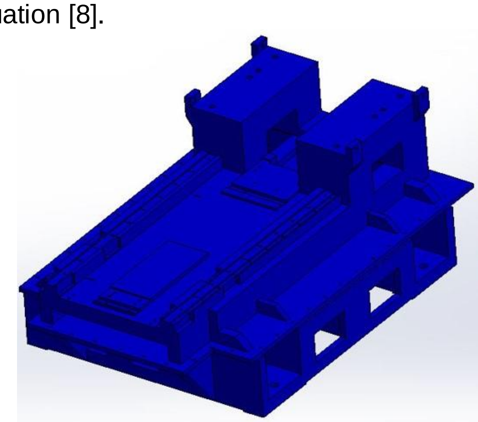

Figure 2. Milling Machine Base CAD Design.

The design of base structure using CAD is simulated by incorporating material properties of FC20. This material is widely used because of its ease in the manufacturing process, capable of mass production and competitive process costs, etc [9]. FC 20 material properties can be seen in table 1 below.

Table 1. Material properties of base structure [10].

Item	Value	Unit
Elastic Modulus	1	MPa
Thermal conduction coefficient (heat)	54	Watt/ (m.Grade)
Density	7100	kg/m3
Tensile strength	200	MPa

In this simulation, several assumptions will be made as boundary conditions to facilitate the calculation and analysis process, such as:

1. The model is simulated without providing a fixture function, so it is assumed free fly.
2. Modelling is simulated without providing external force loading function.

Numerical simulation of natural frequency using FEA software, it is necessary to determine the boundary conditions and the value of the material properties. In Figure 3-6, is the mode shape of the CNC milling machine base structure.

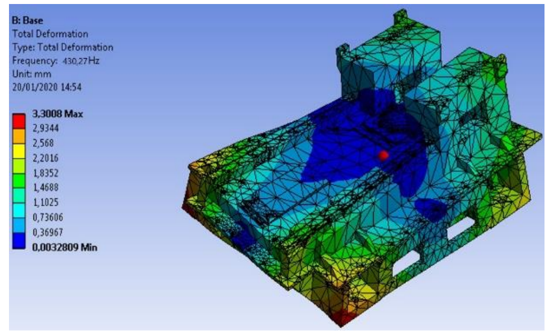

Figure 3. Mode Shape 1.

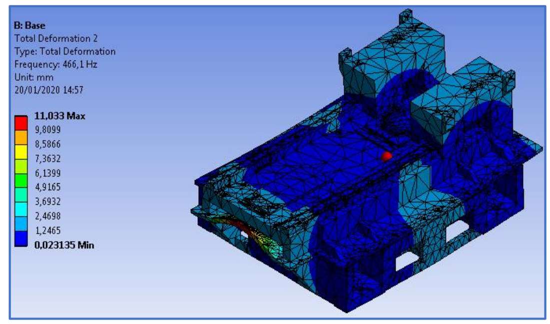

Figure 4. Mode Shape 2.

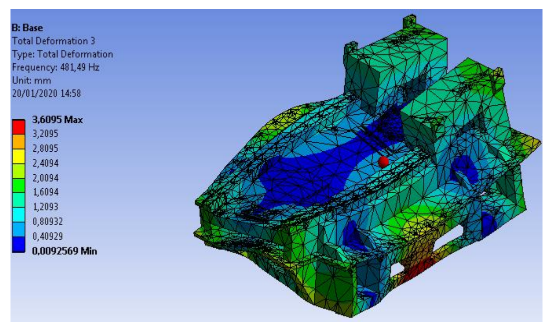

Figure 5. Mode Shape 3.

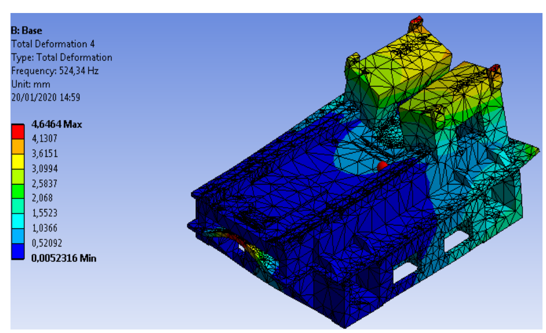

Figure 6. Mode Shape 4.

Table 2 is simulation results of the base structure. It will show the mode, frequency and deformation.

Table 2. Simulation results of the base structure.

Mode	Frequency (Hz)
Mode 1	430.27
Mode 2	466.10
Mode 3	481.49
Mode 4	524.34

Figure 7 is a Bump Test, the aim of Bump Test is to measure the natural frequency value of the base component of the CNC machine.

Figure 7. Bump test of base component.

By knowing the natural frequency of each components, we want resonance problems can be identified and prevented early, by increasing stiffness or avoiding the rotational speed of the machine so that it is not close to the natural frequency of each component. According to the recommended rotational speed should be 15% above or below the natural frequency.

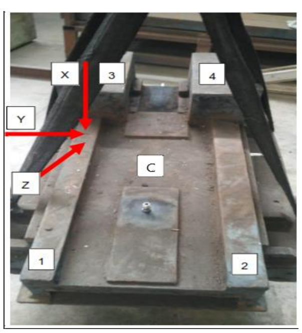

Figure 8. Base test layout.

Figure 8 is the layout of the test base. The specimen is hung using an overhead crane as shown in the picture. There are 4 test points, each point is tested in X-axis direction or vertical direction.

By knowing the natural frequency of a structure and the source of its vibration excitation, we can estimate whether the structure is susceptible to resonance or not. Table 3 is a table of frequency margins assuming the CNC machine operates at a maximum speed of 6000 rpm.

Table 3. Frequency margin.

RPM	**Order**	**Freq Margin -15%**	**Frequency (Hz)**	**Freq Margin -15%**
6000	1x	85	100	115
12000	2x	170	200	230
18000	3x	255	300	345
24000	4x	340	400	460
30000	5x	425	500	575

The data from the bump test results can be seen in table 4. The test was carried out at 4 points according to Figure 8. The test was carried out 5 times so that 5 peak frequencies were obtained.

Table 4. Bump test results.

Measuring point	**Peak 1**	**Peak 2**	**Peak 3**	**Peak 4**	**Peak 5**
	Freq	**Freq**	**Freq**	**Freq**	**Freq**
Point 1	140	420	480	640	700
Point 2	110	410	480	640	700
Point 3	140	410	480	650	730
Point 4	140	410	480	540	730

Table 5 is the data obtained from the simulation and the test results are then compared and it can be seen the error which is the difference between the two methods. At point 4 the biggest error occurred, namely 12%. At point 3 the smallest error is 0.1%.

From the data that has been recorded, further analysis is carried out. This analysis will be a recommendation in the development of the base structure design of the next milling machine.

Table 5. Error Value Between Test And Simulation.

Measuring point	Testing Average	Simulation	Error (%)
Point 1	476	430.27	9.6%
Point 2	468	466.1	0.4%
Point 3	482	481.49	0.1%
Point 4	460	524.34	12%

From the results and discussion in the previous chapter, it can be concluded that the design of the base structure of the milling machine from the simulation and experiment/test results has an error which is the difference between the simulation and test results. This can occur due to interference when conducting direct testing or data collection. Interference can occur due to noise around the data collection area.

The analysis obtained from both methods can be used to determine whether the base structure design is still safe from critical speed resonance or not. From DR&O and motor specifications we can assume the CNC machine operates at a maximum speed of 6000 rpm. Table 3 shows the frequency margin for motor rotation. For a motor rotation of 6000 rpm the frequency is 100 Hz.

According to the recommended rotational velocity should be 15% above or below the natural frequency. For 6000 rpm motor rotation speed, it means that the frequency of other components will resonate if the natural frequency of other components is between 85 Hz-115 Hz.

CONCLUSION

From the test and simulation data, it can be concluded shall be the following. The minimum error value from the comparison of the two methods is 0.1% and a maximum is 12% due to interference when conducting direct testing and noise around the data collection area. The base structure design of the CNC milling machine is still safe from resonance because its natural frequency value is not within the critical speed frequency margin.

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