Perwira Journal of Sains & Engineering (PJSE), Vol. 3 (1) 2023, 38-42
https://ejournal.unperba.ac.id/index.php/pjse

ISSN Online 2775-8486, DOI : *10.54199/pjse.v3i1*

Design and Finite Element Analysis of Small Conventional Lathe Frame for Regular Manufacturing Works

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ABSTRACT
A lathe is a machine that plays an important role in manufacturing works. The existence of this machine is needed in the work of cylindrical workpieces with precise dimensions. Therefore, a lathe with a high degree of accuracy is an important requirement in the process of manufacturing works. In general, lathes have a large frame which is related to the stability of the turning process. In this study, the design and analysis of finite elements on a small lathe frame for general manufacturing work is carried out. Finite element analysis is performed on the components of force, pressure, and shift in each of the axis x, y, z directions with a predetermined nominal cutting depth and feed rate.

KEYWORDS Lathe; design; analysis; manufacturing.

1. INTRODUCTION

Historically, lathe is the basic machine for the production of any cylindrical part to produce required dimension form with a required surface finish, from the smallest workshop to the largest production line [1–4]. The development of machine performance has been impressive, from the simple hand-operated machine developed by Henry Maudslay in the early 1800s to the new lathes [2]. The standard form of lathes in use today began in 1965 when the British company Colchester Lathe Co. Ltd introduced the Mascot 1600 lathe. The Colchester Mascot 1600 lathe has the principal parts, the base, the headstock including controls, legend plate, the carriage or saddle including controls and tool holder, and the tailstock. The design features of Mascot lathes had to exhibit a solid, familiar business style suitable for machines of various size and proportions [1].

The purpose of the turning process is to achieve the proper consistency of machined parts by eliminating high material volumes. However, this performance in the cutting process depends on the following: machine rigidity, fixing rigidity, tool rigidity, and good vibration damping capability [2,5–8]. Machine manufacturers are experienced in multi-tasking machines of the small to medium size and other Western manufacturers dominates to retain a leading position on the international market, which lies in building heavy machines, without losing precision. That's why most of the lathes have large frame sizes [2]. Manufacturers need to build machines to cope with the high mechanical and thermal stress while taking a minimum quantity of material and energy. In other hand, the machines demanded to remain stable and rigid throughout the turning process in maximum performance [2]. The operating conditions (work material, operations and tools) are a major factor in determining the level of stability and stiffness of a lathe frame body [9]. Frame bodies are machine tool elements that link simple assemblies and mechanisms to a structure. Its function is to ensure a clear shared place for other sections and assemblies. Generally, the main body frame consists of the main support system and any or hundreds smaller parts, which are connected (bolted, welded or sliding) to the main body and form an entire machine tool [10].

2. DESIGN AND METHODS

The design of the lathe was made using the Autodesk Inventor software by applying cast iron material as the body frame material. The size of the lathe refers to the Taiwan BV-20 lathe with adjustments. Finite element analysis was applied to the fully assembled body frame. Finite element analysis on this body frame was carried out using analysis software that is included in the Autodesk Inventor software. Various feed rate and depth of cut was applied to determine forces, von mises stresses, and displacements of the body frame.

The lathe frame design was simulated using cast iron material, which is a conventional material commonly used in lathe body frames. Cast iron is a high carbon alloy made of carbonated iron, typically often containing silicon, manganese, arsenic, sulfur and other ingredients. Contains cementite or graphite from 2.11 to 4.3% carbon. The lamellar graphite present in CI offers positive damping and compressive strength characteristics [4,10]. The simulated workpiece material is stainless steel 316L, which is a material used as a test material and a common product in medical equipment. The characteristics of the stainless-steel material in this simulation that have been adjusted using the Kennametal Turning Calculator are:

Stainless Steel 316L	
Diameter (D) mm	10
Hardness (HB)	147
Power Constant (p)	0,03322

While the constant cutting conditions used in this simulation that have been adjusted using the Kennametal Turning Calculator are:

Cutting Conditions	
Length of cut (L) mm	20
Cutting Speed (Vc) m/min	25,125
Spindle Speed (n) Rpm	800
Machine Tool Efficiency Factor (E)	0,8

The various feed rates and cutting depths of the simulation are determined referring to the cut commonly used during the turning process. The feed rate and depth of cut used in this simulation are:

Simulation num	**Feed rate (mm/rev)**	**depth of cut (mm)**
1	0,10	1,00
2	0,15	1,00
3	0,20	1,00
4	0,25	1,00
5	0,30	1,00
6	0,30	0,25
7	0,30	0,50
8	0,30	0,75
9	0,30	1,00
10	0,30	1,25

3. RESULTS AND DISCUSSION

3.1 Conceptual Design

The objectives of the proposed design are to obtain and demonstrate the result of the simulation during the turning process. The design of this small lathe is used as a reference for how well the body frame can withstand forces during the turning process. The design can be seen in **Fig. 1**.

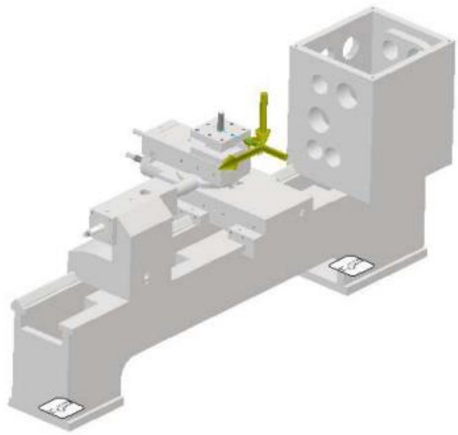

Fig. 1 Conceptual design of small conventional lathe with the force directions

3.2 Applied Turning Forces

The cutting is assumed to be uniform and the cutting forces are going to be found in the directions of the velocity and the feed rate (f). These two forces are called Tangential Force (Ft) and Feed force (Ff). Only orthogonal two-dimensional cut is being explained by now, in oblique cutting a third force appears due to the inclination angle (i) of the cutting edge. This force acts in the radial direction, Radial Force (Fr) [11]. A diagram of the standard turning process forces is shown in the **Fig. 2** below, where it can also be seen the parallel direction of the cutting tool and the spindle velocity.

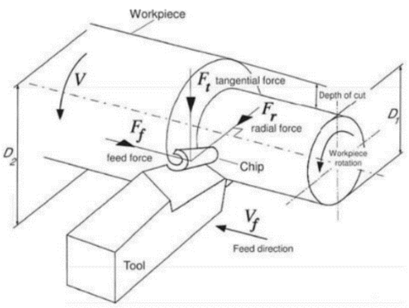

Fig. 2 Geometry of a turning process [11]

The standard tool geometry and important geometric parameters influencing in the turning process. These parameters are the nose radius, side rake angle, back rake angle and side cutting edge angle. As an important introduction, it is assumed that the chip produced in the turning operation comes off and slides on the rake face of the tool. Positive rake angles make higher shear angles, so the cutting forces are reduced, and the chip can flow easily, hence it leaves a better surface finish [11]. Since this is a simulation, the parameters of the actual turning process are ignored resulting in a pure force for each component.

The force is calculated using the Kennametal Turning Calculator based on the characteristic of Stainless-Steel 316L material and cutting conditions as well as the predefined feed rate and depth of cut parameters in each of the simulation. The results are shown in **Fig. 3** which shows that in simulations 1-5 there is an increase constantly in each force as the feed rate increases. The minimum forces generated are feed force: 34.8 N, radial force: 170.9 N, tangential force:

199.32 N, resultant force: 264.85 N generated in simulation 1. While the maximum forces generated are feed force: 244.87 N, radial force: 228.7 N, tangential force: 597.96 N, resultant force: 685.44 N generated in simulation 5.

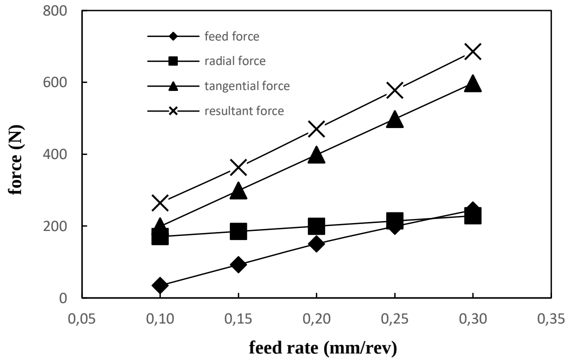

Fig. 3 Forces simulated in simulation 1-5

There is also a constant increase of each force in simulation 6-10 as the depth of cut is increased as shown in **Fig. 4**. The minimum forces generated are feed force: 39.47 N, radial force: 163.68 N, tangential force: 149.49 N, resultant force: 225.16 N generated in simulation 6. The maximum forces generated are feed force: 313.33 N, radial force: 250.38 N, tangential force: 747.45 N, resultant force: 848.26 N generated in simulation 10.

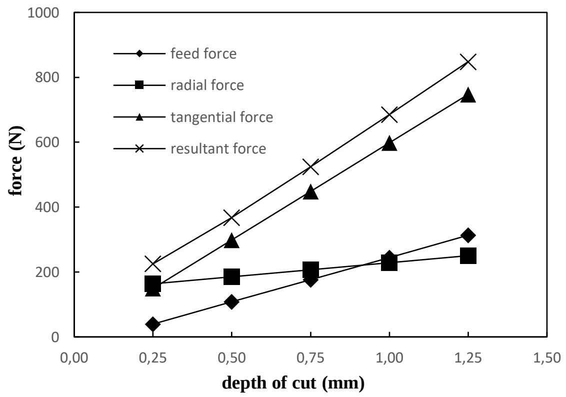

Fig. 4 Forces simulated in simulation 6-10

3.3 Stress Distributed in Frame

The finite element method is widely accepted for the analysis of static and dynamic stress allows the most realistic assumptions [6]. The procedure for the FEA consist of simplify the model into a single solid or divide the model into smaller subsets. For this simulation, the model is being simplified into one single integrated solid. An example of a simulation is shown in **Fig. 5** which is the result of the FEA simulation in simulation 1.

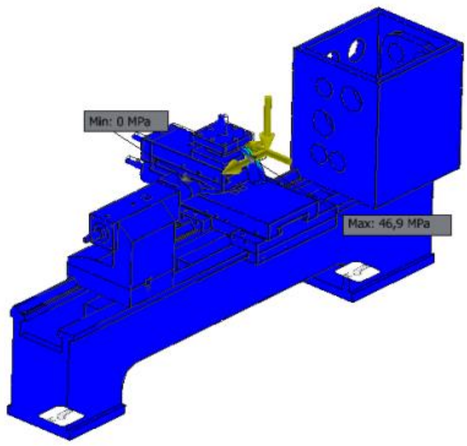

Fig. 5 FEA of simulation 1

Based on the FEA in the Autodesk Inventor software, the results of simulation 1-5 are constant increase in von misses stress along with an increase in the feed rate as shown in **Fig. 6**. The minimum von misses stress is 46.9 MPa at a feed rate of 0.10 mm/rev, while the maximum von misses stress is 186.7 MPa at a feed rate of 0.30 mm/rev.

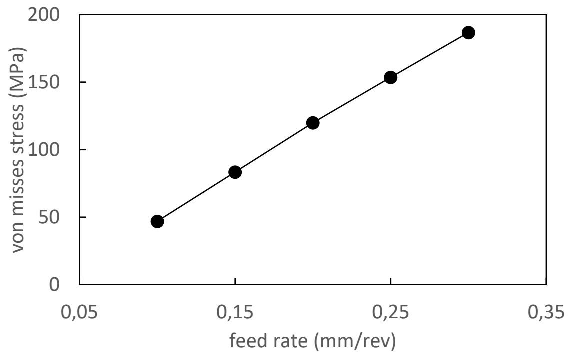

Fig. 6 Von misses stress at simulation 1-5

The results of the analysis in simulation 6-10 also show a constant increase in von mises stress along with the increase in feed rate as shown in **Fig. 7**. The minimum von misses stress is 38.08 MPa at a depth of cut of 0.25 mm, while the maximum von misses stress is 236.2 MPa at a depth of cut of 1.25 mm.

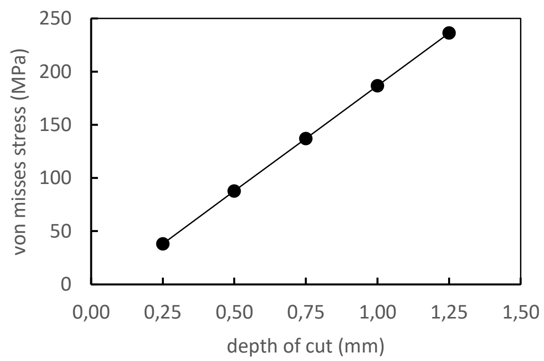

Fig. 7 Von misses stress at simulation 6-10

3.4 Displacement of Simulated Frame

The application of force to the frame body model results in deformation which affects the displacement for each frame component that is subjected to the force. The displacement from this simulation analysis consists of 4 displacement components, namely x, y, z, and combination. Generally, displacement x is influenced by tangential force, displacement y is influenced by radial force, displacement z is influenced by feed force. An example of a displacement simulation is shown in **Fig. 8** which is the result of the FEA combination displacement in simulation 1.

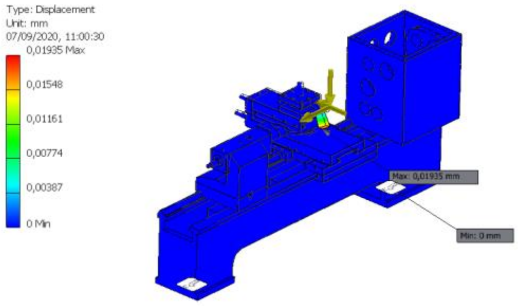

Fig. 8 Displacement in simulation 1

The displacements from simulation 1-5 based on the simulation results using Autodesk Inventor shows that the results constantly increase with the increase of feed rate shown in **Fig. 9**. The smallest displacement occurs in simulation 1 with the maximum displacement of 0.01935 mm. While the largest displacement occurred in simulation 5 with a maximum displacement of 0.06319 mm. Based on **Fig. 9**, it can be seen that the largest displacement occurs in the y direction which is the result of displacement affected by radial force.

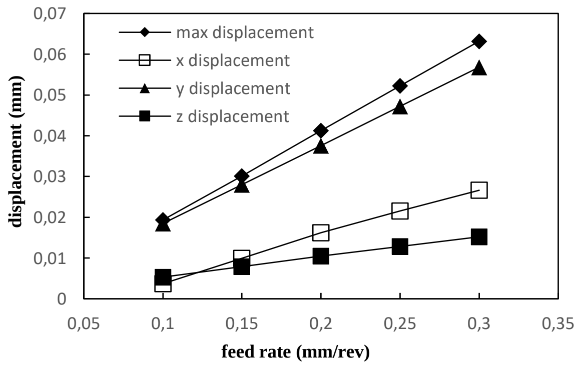

Fig. 9 Displacement results in simulation 1-5

The displacements from simulation 6-10 based on the simulation results using Autodesk Inventor shows that the results constantly increase with the increase of feed rate shown in **Fig. 10**. The smallest displacement occurs in simulation 6 with the maximum displacement of 0.01447 mm. While the largest displacement occurred in simulation 5 with a maximum displacement of 0.07978 mm.

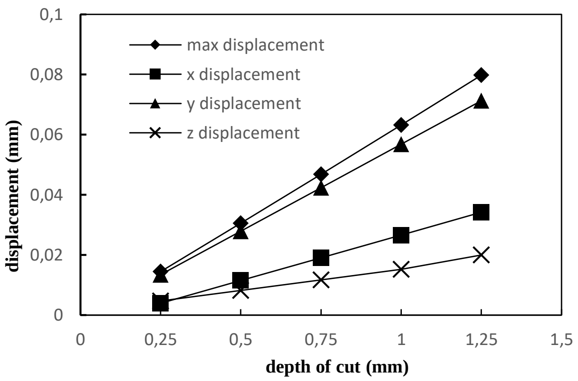

Fig. 10 Displacement results in simulation 6-10

4. CONCLUSION

The study of conceptual design and finite element analysis from small lathes for manufacturing work generally produces data in the form of forces, von misses stress, and displacement. The conclusions of these results are:

a) The objectives of the proposed design are to obtain and demonstrate the result of the simulation during the turning process.
b) The minimum forces generated in simulation 1, which are feed force: 34.8 N, radial force: 170.9 N, tangential force: 199.32 N, resultant force: 264.85 N.
c) The maximum forces generated in simulation 10, which are feed force: 313.33 N, radial force: 250.38 N, tangential force: 747.45 N, resultant force: 848.26 N.
d) The minimum von misses stress is 38.08 MPa which is generated in simulation 6 at a depth of cut of 0.25 mm.
e) The maximum von misses stress is 236.2 MPa which is generated in simulation 10 at a depth of cut of 1.25 mm.
f) The smallest displacement occurs in simulation 6 with the maximum displacement of 0.01447 mm.
g) The largest displacement occurred in simulation 5 with a maximum displacement of 0.07978 mm.
h) The largest displacement occurs in the y direction which is the result of displacement affected by radial force.

5. ACKNOWLEDGMENT

The authors would like show appreciation to Mechanical and Industrial Engineering Department, Gadjah Mada University and Science and Technology Faculty, Perwira Purbalingga University for the support to the study.

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