Design of Low Cost Compact Modular Small Scale(CMSS)-CNC Lathe Machine

Abstract

The emerging of micro factories technology has encourages the development of CNC machine into small scale design. It purposes is to create a smaller machine to save some space, reduce production cost, and lower energy consumption. Without reducing its precision level, this research conduct a design of CNC lathe machine consist of head stock, main spindle, X-Z axis, bed, tool holder, and X-Z motor actuators. The design was using three jaw chuck holding method and DC brushless motor as electric actuator for each axis. Additional harmonic gear was used as the transmission system. The design was provided in a compact design at 329 mm x 483 mm, assembled in modular design consist several of several module, and can be considered as low cost module with high availability component even in domestic market. It was calculated that the resolution of this Compact Modular Small Scale CNC Lathe machine could achieve 55.5 nm. It is believed that this design would be able to support many applied industries especially those who need high precision small component with low production cost.

Keywords: CNC Machine, small scale, lathe, compact, modular, low cost

Introduction

Micro factories are one of the popular emerging technologies having a lot development within this two decade [1-9]. This popularity was because of the increased demand of mechanical component into a smaller dimension up to micro or nano scale for many applications such as electronics control, automobile component, medical component, etc. [9].

Days before, conventional industries on big and small mechanical components was produced by standard large equipment. This large equipment means larger space and higher energy consumption [10] emerging an increased production cost. Japan was one of the first countries to propose the reducing of machining size proportional to the size of the produced components [1, 9]. This proposal is to reduce the production cost, save the energy consumption, spare some space, and keep every resource correspond to the initial size of produced component [9]. Moreover, the concept can facilitate higher precision mechanism and simpler equipment than conventional machine. Hence, the concept suits for high precision industry for small component such as micro censor or micro actuator [9]. This defines the low cost micro mechanical devices for reducing the production cost.

For the present decades, many researches has conducted to develop micro machine for many application even in academicals scale or laboratorial scale [11-20]. In Yamanaka Article [12], it was described about the using of different operation and geometric precision for lathe process according to the size of the produced part. Detailed explanation pointed out that when the size of the machine changes, the precision will also be altered and concluded that creating one small component is more advantageous when using one high precision machine [11-12]. In Ojima et al. (2007) [21], graphical computation on the position of the tool is provided using CCD camera pointing to the end of the tool. This technique allows position feedback to the control unit and possible the detection of any dimensional disturbance in the lathe. Further research by Ojima introduced the use of electron microscope and SEM (scanning electron microscope) to provide greater detail and higher accuracy. Later of their researches [11] report a positioning errors correction in the order of 6 micrometers, and depths of cut of the order of 150 microns. McIntosh, Cordell and Johnson [22] also studied tissue engineering to produce implants with controlled architecture that can satisfy bioactivity demands and shaping requirements. Yarlagadda, Chandrasekharan and Shyan [11,23] assist cells attachment and growth in the interaction surface. Dunn et al [24] discussed the terms of the in vitro interaction and the in vivo bio-distribution in some animal models to investigate micro implants for drug delivery. Biomedical purpose is one of the developing segment as for the production of bone-polymer and boneceramic composite implants, as well as the development of special purpose machines (Quiroga, 2004 [25]; Rodríguez and Rojas, 2004 [26]; Neira, 2005 [27]; Quevedo, Rojas and Sanabria, 2006 [28]). Rojas (2002) [11,29] has reported about producing designated screw for joining human bone fracture or other medical application which need advanced fabrication of composite biomaterials. Jackson etal. (2005) [30] also studying micromachining in order to carefully handle the surface of microbeams with proper biocompatibility. Jackson et al used 70 micrometers in diameter rotating tool with speeds of up to 360,000 rpm, depths of cut of 50 to 100 micrometers, feed of 0.3 m/min and cutting speeds of 100 m/min to generate chips with a lamellar type structure in consistent with the high induced deformation rates. It’s created an optimal surface texture and increase the speed of the tool up to 1 million rpm. The whole previous research justify that micromachining is important to be developed to support many application.

Proposed design in this paper is a Compact Modular Small Scale (CMSS)-CNC Lathe Machine with two axes and one spindle module with the order of accuracy up to 2 μm. designated machine would verify machinability of medical architectural level at 100-300 μm [29].

CNC Lathe System Design

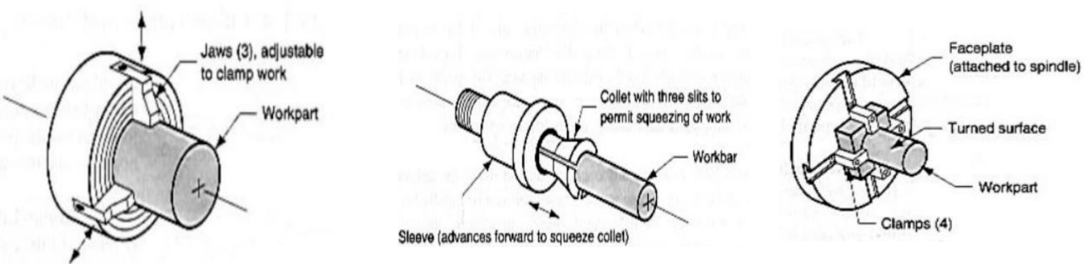
A lathe system is a machine tool that rotates the workpiece against a tool to produce cylindrical or conical component and can also be used for drilling process or boring holes in cylindrical parts [31-32]. Computerized numerical control (CNC) is one method to control the position and velocity of each motor actuator of machining tool in the lathe based on numerical data from operators. Hence, CNC lathe is a computerized controlled lathe system. The main parts of CNC lathe i.e. head stock, main spindle, X-Z axis, bed, tool holder, and X-Z motor actuator.

Head Stock

Headstock is a part of CNC Lathe machine serves to hold the electric motor and the transmission. Its powers the spindle and controls the spindle on designated rotary variety.

Main Spindle

Spindle is the part of lathe machine to hold the workpiece and rotate along with the workpiece during the lathe process. Angular velocity of spindle rotation was powered by adjustable electric motor via transmission system. Working piece was held in several holding ways i.e. three jaws chuck, collets, and four clamps (shown in figure 1) [31]. In this present design, used model for holding the work piece is three jaws chuck because its component has a high availability on domestic market, simple, and easier in centering process.



a b c

Figure 1. Working piece holding types on lathe machine; (a) Three Jaws Chuck;(b)

collets; (c) four clamps

X axis and Z axis platform

Axis platform is CNC lathe component serves as the base of tool holder which can move on two axes; x axis and z axis. Both axes were moved by the electric motor on linear trajectory along its respective axis. To achieve the linear movement along each axis, it is needed to dispatch a motion converter from rotary motion to linear translation along the working axis. Moreover, a motor driver is also needed to achieve more precise and more rigid movement. The axes use ball screw and linear guide to achieve the designated movement. Figure 2 shows the component of linear guide and ball screw.

a b

Figure 2. Component for converting motor rotary movement into linear X-Z axis movement; (a) ball screw; (b) linear guide

Tool Holder

Tool holder was attached in the X-Z axis platform (carriage) serves as the base of the cutting tool on this lathe machine. This part is move along with the X-Z axis platform during the lathe process.

Bed

This part is the supporting part of the CNC-Lathe machine which needs to be designed to present a solid base to hold the entire machine and also eliminate any possible interference vibration.

Motor Actuator

On the design process of CMSS-CNC Lathe machine, the movement of X and Z axis was powered from oriental motor DC motor brushless. The usage of this motor is because of it favorable feature i.e. [33]:

1) High efficiency because using permanent magnet rotor and have less secondary losses

2) Reducible rotor inertia and high velocity response.

3) Because of its high efficiency, it is possible to reduce motor size.

4) Ability to fluctuate its velocity for even slight load changes

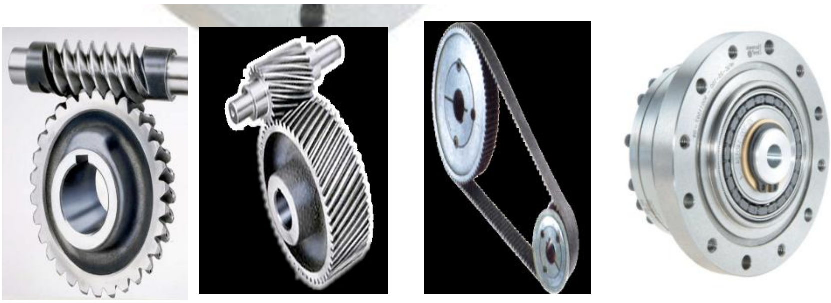
Beside all of the technical consideration mentioned above, affordable price also become one of the primary consideration. With all those feature, the price of this motor was considered cheap compared with other motor. Table 1 shows the comparison of motor DC brushless, motor stepper, and motor servo at the same power.

Table 1. Comparison of motor DC brushless, motor stepper, and motor servo

Feature	**DC Brushless**	**Stepper**	**AC Servo**
Power	30 Watt	30 Watt	30 Watt
Speed Control	Available	Available	Available
Position Control	N/A	Available	Available
Feedback Signa	Available	N/A	Available
Prediction Price	IDR	IDR	IDR

Transmission (Harmonic Gear)

Before attached to X and Y axes of CNC Lathe, generated power from motor actuator was passed through the transmission system. Transmission system serves to transmit the power, reduce the velocity, increase the torque, and escalate the movement precision along X-Z axis. Possible transmission types to be used in this design are worm-gear, gear-pinion, belt-pulley, and harmonic gear. Figure 3 shows the description of those four transmission type. Harmonic gear transmission type was chosen for this design because of its advantages i.e. more rigid, big ratio for compact size, very low backlash, low losses, etc.



a b c d

Figure 3. Transmission system types; (a) worm-gear; (b) pinion-gear; (c) beltpulley;(d) harmonic gear

CMSS-CNC Lathe Prototyping Result and Discussion

CMSS-CNC Lathe present design was resulted in a technical prototype consist of head stock, main spindle, x-z axis platform, spindle motor, tool positioning motor actuator, tool holder, and bed. This CMSS-CNC Lathe design was based on modular concept to match small scale factories and capable to achieve micro and nano scale precision. Nano scale precision will be achieved with high rigidity and low vibration.

Compact Design

Compact design of CMSS-CNC lathe means that its dimension was optimally designed compatible to the size of the size of the produced work piece. In this present design, the CMSS-CNC lathe is at the size of A4 paper (329 mm x 483mm). Detailed specification of the dimension of designed CMSS-CNC lathe machine was shown in Table 2.

Table 2. Dimension specification of CMSS-CNC Lathe machine

Specification	Size	Unit
Length	440	mm
Width	230	mm
Height	200	mm
Weight	27	kg
X axis maximum stroke	60	mm
Z axis maximum stroke	60	mm

Modular Design

Modular design can be described that the whole module can be divided into several smaller modules which can independently work under different system [34].This prototype was designed in several separate modules which can be easily assembled into one module of CMSS-CNC Lathe. furthermore, each separate module of this CMSS-CNC Lathe can be substituted by another module, can be powered up, can be scaled up, and can also configured to serve another different system. Figure 4 shows the exploded view of CMSS-CNC Lathe machine build upon its composite parts. Figure 5 shows another configuration from another unit with replacing the headstock spindle unit with mill cutting tool module, and can also with replacing tool holder module with workpiece holder module. It is proven that reconfiguration is possible to upgrade this designed CMSS-CNC Lathe into much more axes. Figure 6 shows the complete technical prototype of the CNC Lathe machine

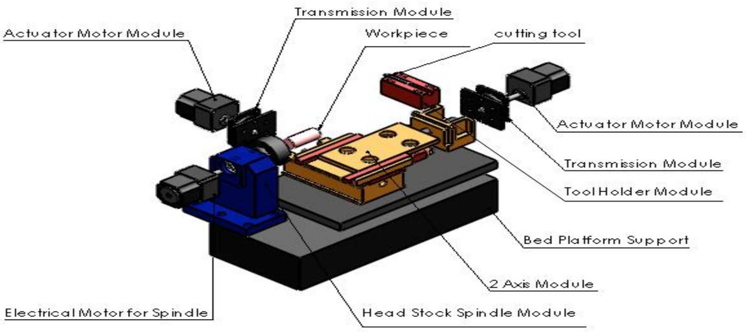


Figure 4. Exploded view of the CMSS-CNC Lathe machine system bases on the compiling unit

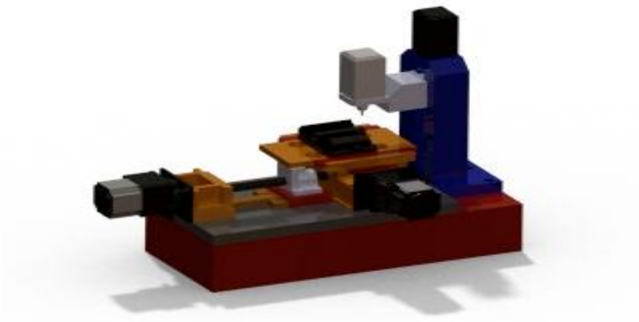


Figure 5. Another possible configuration of CMSS-CNC Lathe using modular design become 3-axis portable milling machine

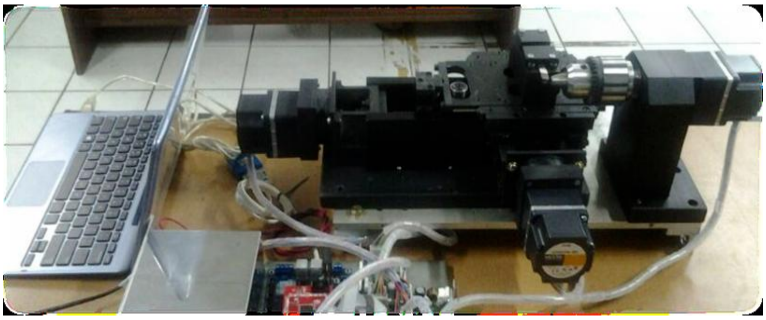


Figure 6. CNC Lathe Machine complete technical prototype

Small Scale Resolution

Resolution calculation on the smallest movement for this CMSS-CNC lathe design was using equation (1). Table 3 shows the specification on resolutions and ratio of the CMSS-CNC components.

Rm=MRxTRxCR (1)

where: Rm = Resolution of the machine / machine precision (mm)

MR = Resolution of the motor / motor precision (rad)

TR = Transmission ratio (rad/rad)

CR = Converter ratio (mm/rad)

Table 3. Specification of CMSS-CNC components

Component Type	**Parameter**	**Specification**
DC Brushless Motor	Motor Resolution	2π rad /30
Harmonic Gear	Transmission Resolution	1/600 rad/rad
Ball Screw	Converter Resolution	10 mm / 2π rad

Working resolution of the designed CMSS-CNC Lathe machine can be obtained by entering the specification data from Table 3 to equation (1):

It is shown that, theoretically, the working resolution of this designed CMSS-CNC Lathe machine could reach out until 55.5 nm. It is considered that it can be called nano machining.

Low Cost

The economical aspect analysis shows that the software can be self-developed and the dominant cost emerged are for the portable PC as the main processing unit and the hardware. Table 4 shows the price list and the availability of the component of this CNC lathe machine.

Table 4. Component price list and availability

	Component	**Price**	**Availability**
1	Main Processing Hardware	3.000.000 IDR	Available in domestic market
2	Main Processing Software	N/A	Can be self-developed
3	Secondary Processing Hardware	2.000.000 IDR	Available in domestic market
4	Secondary Processing Software	N/A	Can be self-developed
5	Mechanical Raw Material	5.000.000 IDR	Available in domestic market
6	Mechanical Machining Process	5.000.000 IDR	Available in domestic market
7	X-Y Actuator	8.000.000 IDR	Available in domestic market
8	Spindle Actuator	4.000.000 IDR	Available in domestic market
9	Transmission system	8.000.000 IDR	Available in domestic market
	TOTAL	**35.000.000 IDR**	

Overall, the cost of the whole processing system is approximately 35 million IDR and the availability is high even in domestic market. This production cost considered low because it can achieve micro scale accuracy and even nano scale accuracy. The average cost for CNC lathe machine for micro scale for the other brand is approximately 30 million and increased to 50 million for nano scale machine. So, this design can save about 15 to 20 million IDR and can save muchmore when it produced in mass production.

Conclusion

This research concludes that the design of CMSS-CNC lathe consist of head stock, main spindle, X-Z axis, bed, tool holder, and X-Z motor actuators. This design can provide advantages such as compact design, modular machine with low production cost, and being able to perform lathe process up to 55.5 nm. This design can be upgraded into 3-axis portable milling machine or even more axes. The production cost is considered low because it was approximately 35million IDR and its component have high availability in domestic market so it won't need any additional custom charges. When the resolution has achieved nano scale, further researches will be needed for reducing any environment interference.

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