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Design and Calculation of 2-Axis CNC Lathe Machine (Spindle and Shaft)

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Abstract- The main aim of this research paper deals with the design of spindle for 2-axis CNC lathe machine. The spindle axis is horizontal in lathe machine. The speed of spindle can be set with levers and pulley belts to give a range of speed. Especially, spindle assembly involves design of shaft diameter, spur gear, selection of bearing and keyway. The shaft is made with commercial steel and speed is 1500 rpm. The length of the shaft is 1000 mm and outside and inside diameter of shaft are 86mm and 60.2mm. In spur gear design, pinion and gear are made with cast iron. Module and face width of the spur gear are 5mm and 63mm. The dynamic force, wear force and endurance force of the spur gear are 5751.628N, 25512.820N and 7565.505N.

Indexed Terms- spindle, CNC Lathe, shaft, module, face width.

I. INTRODUCTION

Computer Numerical Control (CNC) is among the fastest growing fields in manufacturing today. The CNC technology was applied on basic conventional machines like lathes and milling machine. In 2-axis CNC lathe machine the main four portions are as following,

1) Design of spindle assembly
2) Design of carriage and tool post
3) Design of bed-way and
4) Design of axis drive system

In this research paper is how to design of spindle assembly.

II. CNC MACHINE COMPONENTS

The controllable components of CNC machine are feed axis system, feed drive unit, machine work spindle drive unit, spindle chuck unit, tool turret and tool changer, tailstock and CNC control unit as shown in Fig. 1.

Fig. 1.CNC Lathe Machine [4]

III. SPINDLE DRIVE UNIT

Spindle assembly contain shaft, spur gear, bearings and key as shown in Fig. 2.

Fig. 2. Spindle Assembly

The work spindle generates workpiece rotation of turning lathe and tool rotation of milling and drilling machines. The spindle can be driven by a three-phase AC or DC motor. In three-phrase AC drives spindle speed selection is obtained through the gearbox.

However, in most case the work spindle of CNC machines are driven by DC motors whose speed is infinitely variable by means of a tach generator.

Work holding equipment is provided to secure the workpiece to the work table (milling) or the spindle (turning). On turning lathe the jaws generally can be opened and closed by the NC program, and it is possible to set various clamping pressure. Since CNC machines are frequently work with very high speeds and since chucking pressure cannot be increased at will on account of workpiece distortion.

IV. FUNCTION OF MACHINE SPINDLE

A spindle may locate and hold the workpiece or the outer and rotate the same. A spindle is a shaft which mounted on bearing supported in the machine tool housing. In order to avoid deflection and run out, the spindle have to be well supported in true bearing. Any slackness in the bearings will clearly affect the location of the spindle.

V. MANUFACTURING PROCESS OF SPINDLE SHAFT

The spindle shaft is manufactured by pipe system. Stainless steel shaft up to 48 inches in diameter to be used as boiler headers and other high pressure purpose is made by forging and drawing. The hollow forging is then transferred to the draw bench, where it is placed over a mandrel and forced through a die to be reduced and elongated. Except for some size limitation, any casting or metal may be centrifugally cast.

a.Spur Gear Design

The calculation of spur gear is done as follow:

$$F_t = \frac{9550\,kW}{rpm_p \times D_p / 2} \quad (1)$$

Where, F_t = tangential force (N)

kW = power (kW)

rpm_p = speed of pinion (rpm)

D_p = diameter of pinion (mm)

$$v = \frac{\pi D_p\, rpm_p}{60}$$

(2)

Where, v = pitch line velocity (m/s)

$$S = S_o \times \left(\frac{3}{3+v}\right) \text{For v less than 10 m/s}$$

(3)

$$S = S_o \times \left(\frac{6}{6+v}\right) \text{For v to 10 to 20 m/s}$$

(4) $$S = S_o \times \left(\frac{5.6}{5.6+\sqrt{v}}\right) \text{ for v greater than 20 m/s}$$

(5)

$$\left(\frac{1}{m^2 y}\right)_{all} = \frac{Sk\pi^2}{F_t}$$

(6)

Where, m = module (mm)

y = form factor (unitless)

S = allowable tooth stress (N/m^2)

S_o = endurance stress (N/m^2)

b= $k_{red}\,\pi\,m$

(7)

$$k_{red} = k_{max} \times \frac{\left(\frac{1}{m^2 y}\right)_{ind}}{\left(\frac{1}{m^2 y}\right)_{all}}$$

(8)

Where, b = face width (mm)

$k_{max} = 4$

$$F_o = S_o\, b\, y\, \pi\, m$$

(9)

Where, F_o = endurance force (N)

$$F_w = D_p b K Q$$

(10)

Where, F_w = wear force (N)

$$Q = \frac{2D_g}{D_p + D_g}$$

K= stress fatigue factor (kN/m^2)

$$F_d = F_t + \frac{21v(bc + F_t)}{21v + \sqrt{bc + F_t}}$$

(11)

Where, F_d = dynamic force (N)

c = deformation factor (kN / m)

b. Shaft Design

The equations for shaft design are as follow:

$$M_t = \frac{9550\,kW}{rpm}$$

(12)

Where, M_t = tangential moment (Nmm)

$$F_t = \frac{M_t}{D/2}$$

(13)

$$F_r = F_t \tan\phi$$

(14)

Where, F_t=tangential force (N)

F_r =radial force (N)

ASME Code equation for hollow shaft with axial load,

$$d_o^{\,3} = \frac{16}{\pi S_s(1-K^4)}\sqrt{\left[K_b M_b + \frac{\alpha F_a d_o}{8}(1+K^2)\right]^2 + [K_t M_t]^2}$$

Where, d_o = outside diameter of hollow shaft (mm)

S_s = allowable shear stress (MN/m^2)

$K = \frac{d_i}{d_o}$

M_b= bending moment (Nmm)

α = column-action factor= $\frac{1}{1-0.0044(L/k)}$

F_a = axial force (N)

K_b= combined shock and fatigue factor applied tobending moment

K_t= combined shock and fatigue factor applied totorsional moment

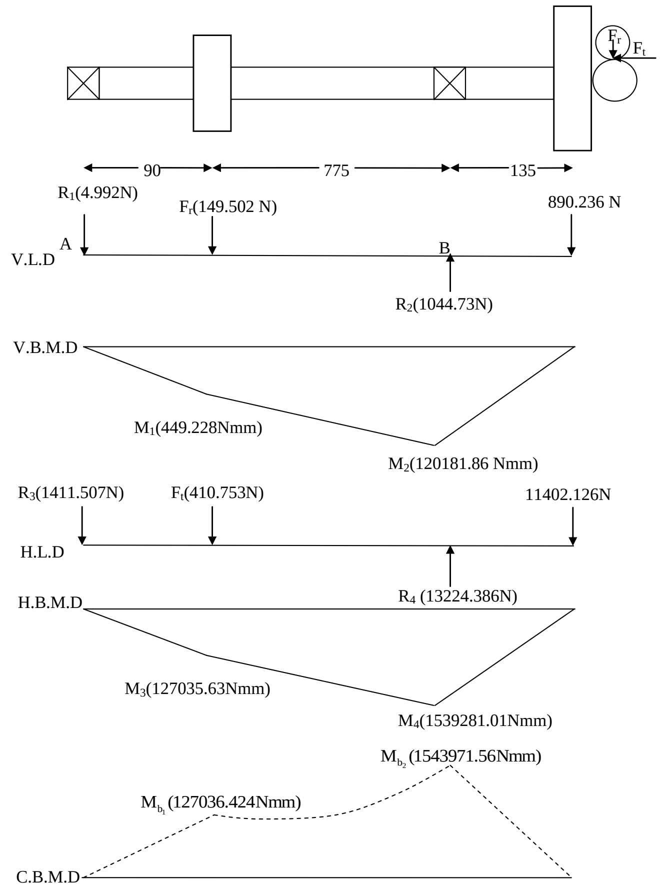

Fig. 3. Result of Shaft Design

The outside and inside diameter of shaft are 86mm and 60.2mm.

c. Bearing Design

If a significant axial load is applied to a bearing along with a radial load, perform with the following steps:

(1) Assume the value of Y from Table A.7. The value Y= 1.05 is reasonable, being about the middle of the range of the possible values.
(2) Compute P= $XV F_r + YF_a$.
(3) Compute the required basic dynamic load rating C.
(4) Select a candidate bearing having a value of C at least equal to the required value.
(5) For the selected bearing, determine C_o .
(6) Compute F_a / C_o .
(7) From Table A.7, determine e.
(8) If $(F_a / VF_r) \rangle e$, then X and Y value from Table A.7.

(9) If the new value of Y is different from that assumed in step 1, repeat the problem.

(10) If $(F_a / VF_r) \langle e$ use equation $P = VF_r$ to compute P and proceed as for a pure radial load.

d. Key Design

The calculation of key is done as follow:

Key in shear,

$$T_s = S_s \times B \times L \times d_o / 2 \qquad (16)$$

Where, T_s = the shaft torque that the key can sustain from the stand point of shear (Nmm)

S_s = shear stress ($0.6S_y$/F.S) (N/mm^2)

B = width of key (mm)

L = length of key (mm)

d_o = outside diameter of shaft (mm)

S_y = yield stress (N/mm^2)

F.S = factor of safety

Key in compression,

$$T_c = S_c \times (t/2) \times L \times (d_o / 2) \qquad (17)$$

Where, T_c= the shaft torque that the key can sustain from the stand point of compression (Nmm)

S_c= compressive stress S_y/F.S (N/mm^2)

t = thickness of key (mm)

$$L_s = 0.877mm \quad and \quad L_c = 2.105mm$$

Design key length is less than gear face width .Thus choose key length=63mm.

e. Deflection of Spindle Axis

The total deflection of spindle nose consists of:

(1) Deflection y_1 of the spindle axis due to bending forces P_1 and P_2 as shown in Fig . 6.

(2) Deflection y_2 of the spindle axis due to compliance of spindle support as shown in Fig . 7.

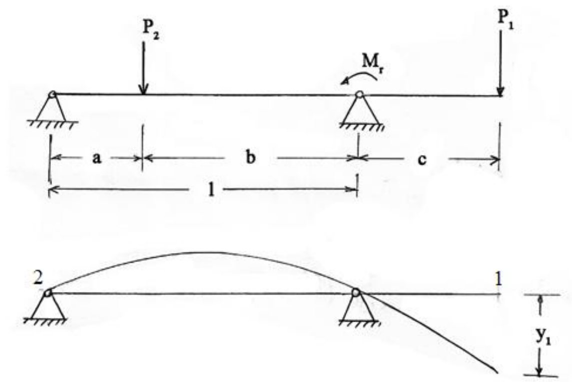

Fig .4. Deflected Axis of the Spindle due toBending Forces

$$y_1 = \frac{1}{3EI}\left[P_1 q^2 (l+q) - 0.5P_2 opq(1 - o/l) - M_r lq\right] \qquad (18)$$

$$M_r = k_c M_b \qquad (19)$$

$$I = \frac{\pi}{64}(d_o{}^4 - d_i{}^4) \qquad (20)$$

Where,

E = modulus of elasticity of the spindle material (N/mm^2)

I =moment of inertia of the spindle shaft (mm^2)

M_r= reactive moment (Nmm)

k_c = coefficient that varies from 0 at small load to 0.3 to 0.35

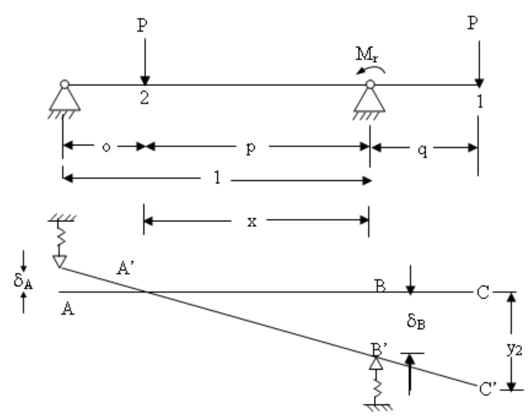

Fig. 5. Deflected axis of the Spindle due to Compliance of the Spindle Support

$$y_2 = \frac{P_2 o - M_r + P_1(l+q)}{lK_B}(l + \frac{q}{l}) + \frac{P_2 p + M_r - P_1 q}{lK_A}(\frac{q}{l}) \qquad (21)$$

Where,

K_A and K_B are stiffness at support A and B.

The total deflection of the spindle, $yt = y_1+y_2$ (22)

Table 1.Design Specifications

Item	Data	Portion
Material	Stainless steel	Shaft
Power	5kW	
Speed	1500rpm	
Cutting force P_z	11402.126 N	
Cutting force P_y	2985.324N	
Cutting force P_x	5240.35 N	
Chuck weight	265.56N	
Workpiece weight	3610N	
Material of pinion	Cast iron	Spur
Material of gear	Cast iron	
Speed of pinion	1500 rpm	
Diameter of pinion	155 mm	
Allowable stress	55 MN/m^2	
Power	5kW	
Pressure angle	20 deg,stub	
Velocity ratio	2	
Material	AISI cold-drawn	Key
$T_s=T_c$	steel	
B	31.833x10^3Nmm	
t	20mm	
S_y	10mm	
F.S	351.633MPa	
	5	
Left bearing of the shaft	Tapered	Bearing
Type of bearing	roller bearing	
Speed	1500rpm	
Axial load F_a	5240.35 N	
Radial load F_r	1411.516N	
Life	30000hr	
Loading ratio	10.601	
Right bearing of the shaft	Tapered	
Type of bearing	roller bearing	
Radial load F_r	13265.589N	
Bending force P_1	11436.826N	Deflection
Bending force P_2	437.114N	
Distance, o	90mm	
Distance, p	775mm	
Distance, q	135mm	
Distance, l	865mm	
Reactive moment M_r	540.390x10^3Nmm	
Modulus of elasticity E	206.01x10^3N/mm^2	
Moment of inertia I	2.040x$10^6$$mm^4$	
Stiffness, K_A	3000kg/mm	
Stiffness, K_B	4000 kg/mm	

Table 8.Results Data

Item	Data	Portion
Bearing Number	30216	Bearing
Inner diameter	80mm	
Outer diameter	140mm	
Right bearing of the shaft		
Bearing Number	30220	
Inner diameter	100mm	
Outer diameter	180mm	
Module	5 mm	Spur
Face width	63 mm	
Dynamic force	5751.628 N	
Wear force	25512.820N	
Endurance force	7565.505 N	
y_1	0.133mm	Deflection
y_2	o.367mm	
y_t	0.480mm	

VI. CONCLUSION

The design of Spindle assembly for CNC lathe machine was fabricated by using Fagor CNC lathe machine. Design of machine plants is concentrated on cutting for aluminium and stainless steel, because only 5kW load and available stepper motor can drive. The dimension of workpiece to be operated on designed CNC lathe machine are 200mm in diameter and 1500mm in length. Spindle assembly contains shaft, gear, bearing, key and chuck. All design calculations are dependent on shaft design. Shaft is hollow shaft and made of stainless steel. In spur gear design, pinion and gear are made with cast iron. Taper roller bearings are used in this system and give high rotating accuracy. In Key design, rectangular key is used. Key is made with AISI cold- drawn steel.

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