Analysis of Gear Box Design in Head Stock for CNC Lathe Machine

Ye Myint [1]
Department of Mechanical Engineering
Technological University (Mawlamyine)
yemyint5@gmail.com

Zaw Maw Oo [2]
Department of Mechanical Engineering
Technological University (Meiktila)
zawmawoo11@gmail.com

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Abstract

The CNC Lathe machines are constructed base on conventional lathe machine. This paper is the conventional lathe can be modified to CNC lathe machine. For 2.5 m length conventional lathe machine to be CNC lathe machine, reassembling is done. With the disloged parts of conventional lathe, some changes, substitutions and necessary parts construction is done to be CNC. For converting to CNC, some necessary parts for changes and substitutions fagor materials are used. Gear box design of the spindle unit in CNC lathe machine and design calculation of Gears and Shafts in Head Stock are expressed. This study is including Gear Train, Gear Design, Strength Check, Dynamic Check and Shaft design material.

Keyword; Gear Train, Gear Design, Strength Check, Dynamic Check, Shaft design

I. INTRODUCTION

A lathe is machine tool for producing cylindrical, conical and flat surfaces. It can be used for drilling and boring holes which may be cylindrical or conical shape.

In its operation the lathe holds a piece of material between two rigid supports called centers, or by some other device such as a chuck or face plate, screwed or secured to the norse or end of the spindle.

The tool post is supported on a cross-slide which moves perpendicular to the spindle axis whilst the cross-slide is integral with a carriage which sliders along the bed of the lathe. The spindle axis is parallel with the slideways of the bed, so that movement of the carriage along the bed causes the tool to move parallel with the spindle axis.

The CNC system are constructed with an NC unit integrated with a programmable logic controller (PLC) and sometimes with on additional external PLC (non-integrated).The NC controls the spindle movement and the speeds and feeds in machining. It calculates the traversing paths of the axes as defined by inputs. The PLC controls the peripheral actuating elements of the machine such as solenoids, relay coils, etc. Working together, the NC and PLC enable the machine tool to operate automatically. Positioning and part accuracy depend on the CNC system's computer control algorithms, the system resolution and the basic mechanical machine inaccuracies.

By utilizing computers as an integral of the control system, modern manufacturing technique and industrial production become advanced and developed. Computer Numerical Control (CNC) is one of the major development in Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) technology. It is the process of manufacturing machine parts in a production environment to control and allocate by a computerized controller. Due to the digital technology used in such controller, the design of automation systems have more flexibility which is the keyword to characterize the manufacturing system. With the programs of computer technology and programming technique, CNC machines enable to automate the machining process with flexibility. This means capacity in a short time. As a consequence, CNC machines are economical for mass, batch and in many cases single-item production. It can provide the higher productively rate, better quality, accuracy of manufactured parts and stabilization to produce complex or otherwise impossible jobs.

The main purpose of this study is to design a CNC lathe machine modified from a conventional lathe.

The carriage movements are made by hand wheel via a lead screw (ACME thread) in conventional lathe. Whereas these movements are driven by stepper motor in CNC lathe machine. These motor can be controlled for exact revolutions. And the ball screw is more efficient than ACME thread. The surface finish of CNC lathe is more precise than that of the conventional lathe and power losses is significantly decreased.

The gearing system and pulleys are required in conventional lathe to speed up and down the spindle of lathe. But in CNC lathe machine speed up and down can be adjusted by the voltage control of the spindle motor. So efficiency the process of increases because power transmission losses decreases.

The following figure (1) is Gear Trains in Head Stock at Conventional lathe machine. Gears arrangement and shafts rotation are shown in figure

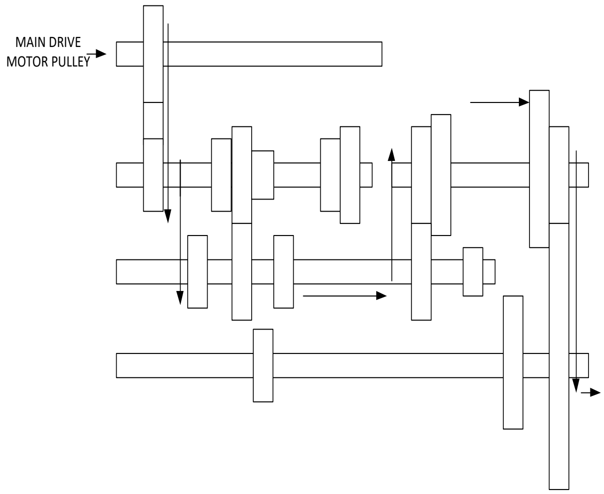


Figure (1) Gear Trains in Head Stock at Conventional Lathe

To get the desired three speed ranges gear trains in conventional lathe machine was changed, figure (2) is gear trains in Head Stock at CNC lathe machine.

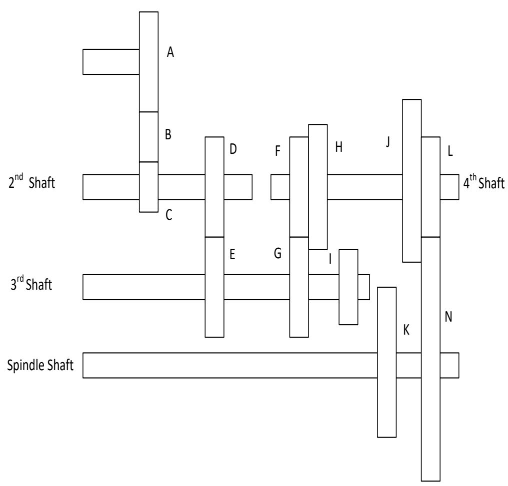


Figure (2) Gear Trains in Head Stock at CNC Lathe Machine

The desired three speed ranges are 0-100 RPM at low speed position, 0-500 RPM at middle speed position and 0-1500 RPM at high speed position

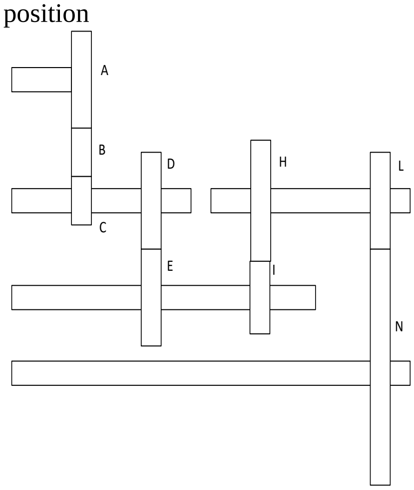


Figure (3) Gear Arrangement at 0-100 RPM

II.DESIGN CALCULATION OF GEAR TRAINS

Calculation of Input Shaft Speed
For Gear Arrangement at 0-100 rpm
Output speed of Spindle = 100 rpm

Train Value, TV = $\dfrac{\text{Input speed}}{\text{Output speed}}$

$$TV = -\,\frac{N_B}{N_A}\times\frac{N_C}{N_B}\times\frac{N_E}{N_D}\times\frac{N_H}{N_I}\times\frac{N_N}{N_L}$$

$$= -\,\frac{36}{50}\times\frac{36}{36}\times\frac{42}{42}\times\frac{68}{17}\times\frac{72}{18}$$

= - 11. 52
= 11.52 (opposite direction)

Input Speed = TV × Output Speed
= 11. 52 × 100
= 1152 rpm

$$(\text{rpm})_A = (\text{rpm})_P = 1152 \text{ rpm}$$

$$\frac{(\text{rpm})_{\text{motor}}}{(\text{rpm})_{\text{pulley}}} = \frac{D_P}{D_m}\times\frac{(100-s)}{100}$$

Slip (0-5 %)
Maximum slip, s = 5%

$$(\text{rpm})_{\text{motor}} = 1152 \times 2 \times \frac{100-5}{100}$$

= 2188. 8 rpm
= 2189 rpm

The theoretical desired meter speed = 22189 rpm

Design Calculation of Spur Gear
Pinion (B) on Idler Shaft and Gear (A) on 1st Shaft
Input power = 10 kW (motor)
Material = Cast Steel
S_O = 140 MN/m^2
BHN = 400
E_P = 200 × 109 N/m2
E_g = 200 × 109 N/m2
C = precision cut
$(\text{rpm})_p$ = 1600 rpm

VR = 1.388
N_P = 36
D_P = 108 mm
N_g = 50

$$D_g = \frac{50}{36}\times 108 = 150\,\text{mm}$$

$$\frac{(\text{rpm})_P}{(\text{rpm})_g} = \frac{1600}{(\text{rpm})g} = \frac{50}{36}$$

$(\text{rpm})_g$ = 1152 rpm

Gear and pinion are same material.

Base design on pinion.
Strength Check
Known diameter case

$$\left[\frac{1}{m^2 y}\right]_{all} = \frac{S_{all} k \pi^2}{F_t}$$

$$V = \frac{\pi \times D_P \times (rpm)_P}{60} = \frac{\pi \times 0.108 \times 1600}{60}$$

= 9.048 m/s < 10 m/s

$$S_{all} = S_o \left[\frac{3}{3+V}\right]$$

$$= 140 \left[\frac{3}{3+V}\right] = 34.861 MN/m^2$$

$$F_t = \frac{9550 \times kW}{(rpm)_P \times D_{P/2}} = \frac{9550 \times 10}{1600 \times \frac{0.108}{2}} = 1105.324 N$$

Let $k_{(max)}$ = 4

$$\left[\frac{1}{m^2 y}\right]_{all} = \frac{34.861 \times 4 \times \pi^2}{1105.342} = 1.245 MN/m^2$$

Assume, y = 0.1

$$\left[\frac{1}{m^2 \times 0.1}\right] = 1.245 \times 10^6$$

m = 2.834 mm

Standard module series, 1, 1.25, 1.5, 2, 2.5, 3, 4, 5, …
Try, m = 2.5

$$N_P = \frac{108}{2.5} = 43.2 \neq \text{integer}$$

Try, m = 3

$$N_P = \frac{108}{3} = 36$$

N_P = 36, y_P = 0.12 (From form factor Table)

$$\left[\frac{1}{m^2 y}\right]_{indu} = \frac{1}{(0.003)^2 \times 0.12} = 0.926 MN/m^2$$

$$\left[\frac{1}{m^2 y}\right]_{all} > \left[\frac{1}{m^2 y}\right]_{indu}$$

Design Satisfactory
Choose, m = 3

$$k_{redu} = k_{(max)} \times \frac{\left[\frac{1}{m^2 y}\right]_{indu}}{\left[\frac{1}{m^2 y}\right]_{all}}$$

$$= 4 \times \frac{0.926}{1.254} = 2.975$$

$$\text{face width}, b = k_{redu} \times \pi \times m$$

$$= 2.975 \times \pi \times 3$$

$$= 28.039 \, mm$$

$$= 28 \, mm$$

Dynamic Check
Endurance Force

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

= 140 x 10^6 0.028 x 0.12x π x0.003

= 4433N

m = 3, Tooth Error = 0.01
C = 114 (from Table 4.2)

Dynamic Force

$$F_d = F_t + \frac{21V(bC + F_t)}{21V + \sqrt{bC + F_t}}$$

$$= 1105.324 + \frac{21 \times 9.048(0.028 \times 114 + 1105.324}{21 \times 9.048 + \sqrt{0.028 \times 114 + 1105.324}}$$

$$= 2048.560 \, N$$

Wear Fore,
$F_w = D_P \, b \, K \, Q$

$$Q = \frac{2N_g}{N_g + N_P} = \frac{2 \times 50}{50 + 36} = 1.163$$

$$S_{es} = [2.75(BHN) - 70] MN/m^2$$

$$= [2.75(400) - 70] = 1030 MN/m^2$$

$$K = \frac{S^2{}_{es} \sin\phi \left[\frac{1}{E_p} + \frac{1}{E_g}\right]}{1.4}$$

$$= \frac{(1030 \times 10^6)^2 \sin 20^\circ \left[\frac{2}{200 \times 10^9}\right]}{1.4}$$

$$= 2591.779 \, kN/m^2$$

F_w = 0.108 × 0.028 × 2591.779 × 10^3 ×1.163
= 9115. 059 N

$F_o > F_d$, $F_w > F_d$

∴ Design is Satisfactory.

III.DESIGN CALCULATION OF SHAFTS FOR GEAR ARRANGEMENT AT 0-100 RPM

2^{nd} Shaft
D_{c} = 108 mm, D_D = 126 mm
$(rpm)_c$ = 1600 rpm
Power = 10 kW

$$M_t = \frac{9550 \times kW}{rpm} = \frac{9550 \times 10}{1600} = 59.688 Nm$$

F_{t_1} = 1105.33 N, F_{r_1} = F_{t_1} tan 20° = 402.307 N

F_{t_2} = 947.429 N, F_{r_2} = F_{t_2} tan 20° = 344.836 N

From HLD
Taking moment about R_1,

$$\sum M_{R_1} = 0 \, [\circlearrowright +]$$

- R_2 × 0.3335 + 947.429 × 0.139 + 1105.33 ×0.05 = 0

$R_2 = 560.597$ N

$[\sum Fy \uparrow = 0]$

$R_1 + R_2 - 947.429 - 1105.33 = 0$

$R_1 = 1492.162$ N

From H.B.M.D

$M_1 = 1492.162 \times 0.05 = 74.608$ Nm

$M_2 = 560.597 \times 0.1945 = 109.036$ Nm

From VLD

Taking moment about R_3

$$\sum M_{R_3} = 0 [\circlearrowleft +]$$

$R_4 \times 0.3335 - 344.836 \times 0.139 + 402.307 \times 0.05 = 0$

$R_3 = 140.88$ N

From V.B.M.D

$M_3 = 140.88 \times 0.05 = 7.044$ Nm

$M_4 = 83.409 \times 0.1945 = 16.223$ Nm

$$M_{R_1} = \sqrt{M_1^2 + M_3^2} = 74.939 \text{ Nm}$$

$$M_{R_2} = \sqrt{M_2^2 + M_4^2} = 110.236 \text{ Nm}$$

$$k_b = 1.5, k_t = 1$$

$$\text{Max}: M_b = 110.236 \text{ Nm}$$

$$S_s = 40 \text{ MN/m}^2$$

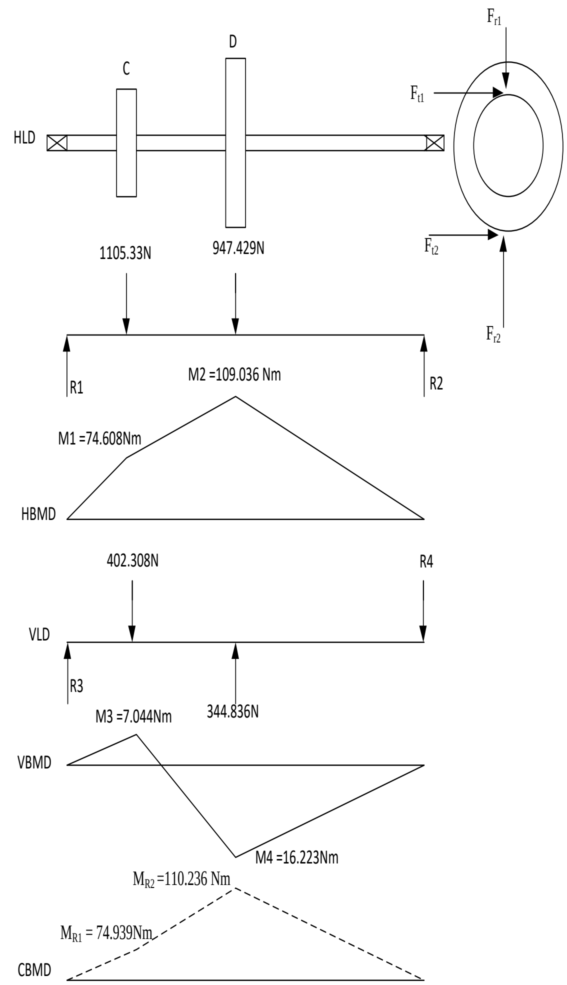
$$d^3 = \frac{16}{\pi S_s}\sqrt{(k_b M_b)^2 + (k_t M_t)^2}$$

$$= \frac{16}{\pi \times 40 \times 10^6}\sqrt{(1.5 \times 110.236)^2 + (1 \times 59.688)^2}$$

$d^3 = 0.02818$ m

$= 28.18$ mm

Std, d = 29 mm



Fig(4) Bending Moment diagram

Table.1 Results of Spur Gear Design

Detail	GearA	GearB	GearC	GearD	GearE
Type	Spur	Spur	Spur	Spur	Spur
Material	Cast Steel	Cast Steel	Cast Steel	Cast Steel	Cast Steel
S_o	140 MN/m^2	140 MN/m^2	140 MN/m^2	140 MN/m^2	140 MN/m^2
BHN	400	400	400	400	400
Diameter	150 mm	108 mm	108 mm	126 mm	126 mm
ϕ	20 Full Depth	20 Full Depth	20 Full Depth	20 Full Depth	20 Full Depth
V.R	1.388	1	1	1	1
R.P.M	1152	1600	1600	1600	1600
Type of Cut	Precision cut	Precision cut	Precision cut	Precision cut	Precision cut

Table.2 Results of Spur Gear Design

Detail	Gear H	Gear I	Gear L	Gear N
Type	Spur	Spur	Spur	Spur

Material	Cast Steel	Cast Steel	Cast Steel	Cast Steel
S_o	140 MN/m^2	140 MN/m^2	140 MN/m^2	140 MN/m^2
BHN	400	400	400	400
Diameter	204 mm	51 mm	72 mm	288 mm
ϕ	20 Stub	20 Stub	20 Stub	20 Stub
V.R	4	4	4	4
R.P.M	400	1600	400	100
Type	Precision cut	Precision cut	Precision cut	Precision cut

Table. 3 Strength Check in Gear Design

	b	m	$(1/m^2y)_{all}$	$(1/m^2y)_{indu}$	No. of teeth	
					Pinion	Gear
1st gear (A,B)	28 mm	3	1.245 MN/m^2	0.926 MN/m^2	36	50
2nd gear (B,C)	28 mm	3	1.245 MN/m^2	0.926 MN/m^2	36	36
3rd gear (D,E)	16 mm	3	2.114 MN/m^2	0.887 MN/m^2	42	42
4th gear (H,I)	37 mm	3	0.974 MN/m^2	0.949 MN/m^2	17	68
5th gear (L,N)	47 mm	4	0.555 MN/m^2	0.521 MN/m^2	18	72

Table.4 Dynamic Check in Gear Design

	F_o	F_w	F_d
1st gear	4433.416 N	9115.059 N	2048.560
2nd gear	4433.416 N	9115.059 N	2048.560
3rd gear	2638.938 N	5225.026 N	1780.833 N
4th gear	5711.981 N	7825.099 N	3863.798 N
5th gear	9922.406 N	14032.92 N	8490.313 N

Table.5 Results of Shafts Design

Type of Shaft	2nd Shaft	3rd Shaft	4th Shaft	Spindle shaft
Material	Commercial steel	Commercial steel	Commercial steel	Commercial steel
Ss (MN/m^2)	40	40	40	40
RPM	1600	1600	400	100
Diameter (mm)	29 mm	27 mm	47 mm	d_i = 71 mm d_o= 91 mm
Length (mm)	333.5 mm	515.5 mm	377.5 mm	865 mm

IV.CONCLUSION

The main aim of this paper is to help in reassembling from conventional lathe machine to CNC lathe Machine. The modified CNC Lathe was fabricated by using 2.5 meter local conventional lathe machine. The modified machine is made of parts, such as ballscrew, servomotor and computer. In this paper, my portion is Design Calculation of Gear that is arranged to transfer the ranges of spindle. There were 18 ranges in the lathe deal with. But in CNC Lathe, there are only three wide ranges. The three speed ranges in CNC are low speed position 0-100 rpm and, middle speed position 0-500 rpm and high speed position 0-1500 rpm. In figure (1), it is the gear arrangement of Head Stock in Conventional Lathe Machine and in figure (2), it is transferring for Gear Arrangement of CNC Lathe Machine. In this paper, the calculation on appropriate diameter of Shafts and Gears design has been made.

The required design calculation of Spur Gears can be calculated through both Strength and Dynamic check and it involves many steps. In design calculation of shaft, it requires rotational speed of shaft must be known. The ASME Code Equation is used to calculate the design of shafts. In this paper, design calculation results for gear and shaft are satisfied machine design. The results of gears and shafts are described with tables.

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AUTHORS

First Author – Ye Myint, Lecturer, Department of Mechanical Engineering , Technological University (MawlaMyine), yemyint5@gmail.come

Second Author –Zaw Maw Oo, Lecturer, Department of Mechanical Engineering, Technological University (Meiktila), zawmawoo11@gmail.com

Correspondence Author – Zaw Maw Oo, zawmawoo@gmail.com