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

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DOI: 10.29322/IJSRP.9.08.2019.p9259
http://dx.doi.org/10.29322/IJSRP.9.08.2019.p9259

Abstract

The CNC Lathe machines are constructed based 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 for material parts 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 nose 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 slides 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 capability 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.
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.

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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

**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 = \[
\frac{\text{Output speed}}{\text{Input speed}}
\]

\[
TV = \frac{N_B}{N_A} \times \frac{N_C}{N_B} \times \frac{N_E}{N_D} \times \frac{N_H}{N_I} \times \frac{N_N}{N_L}
\]

\[
= \frac{36}{50} \times \frac{36}{36} \times \frac{42}{42} \times \frac{68}{72} \times \frac{18}{18}
\]

\[
= -11.52
\]

Input Speed = TV \times \text{Output Speed}

\[
= 11.52 \times 100 \\
= 1152 \text{ rpm}
\]

\[(\text{rpm})_A = (\text{rpm})_p = 1152 \text{ rpm}
\]

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

\[s = 5\%
\]

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

\[= 2188.8 \text{ rpm}
\]

\[= 2189 \text{ rpm}
\]

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

SO = 140 MN/m²

BHN = 400

\[E_P = 200 \times 10^9 \text{ N/m}^2
\]

\[E_g = 200 \times 10^9 \text{ N/m}^2
\]

\[C = \text{precision cut}
\]

\[(rpm)_P = 1600 \text{ rpm}
\]

\[VR = 1.388
\]

\[N_P = 36
\]

\[D_P = 108 \text{ mm}
\]

\[N_g = 50
\]

\[D_g = \frac{50}{36} \times 108 = 150 \text{ mm}
\]

\[(\text{rpm})_P = 1600 \text{ rpm}
\]

\[(\text{rpm})_g = \frac{36}{36} = 1152 \text{ rpm}
\]

\[(\text{rpm})_g = \frac{1152 \text{ rpm}}{36}
\]

Gear and pinion are same material.
Base design on pinion.

Strength Check

Known diameter case

\[ \frac{1}{m^2y_{all}} = \frac{S_{all} \pi^2}{F_t} \]

\[ V = \frac{\pi \times D_p \times (rpm)_p}{60} = \frac{\pi \times 0.108 \times 1600}{60} = 9.048 \text{ m/s} < 10 \text{ m/s} \]

\[ S_{all} = S_o \left[ \frac{3}{3 + V} \right] = 140 \left[ \frac{3}{3 + V} \right] = 34.861 \text{ MN/m}^2 \]

\[ F_t = \frac{9550 \times kW}{(rpm)_p \times D_{p/2}} = \frac{9550 \times 10}{1600 \times 0.108} = 1105.324 \text{ N} \]

Let \( k_{(max)} = 4 \)

\[ \frac{1}{m^2y_{all}} = \frac{34.861 \times 4 \times \pi^2}{1105342} = 1.245 \text{ MN/m}^2 \]

Assume, \( y = 0.1 \)

\[ \frac{1}{m^2y_{all}} = 1.245 \times 10^6 \]

\( m = 2.834 \text{ mm} \)

Standard module series, 1, 1.25, 1.5, 2, 2.5, 3, 4, 5, ...

Try, \( m = 2.5 \)

\( N_p = \frac{108}{2.5} = 43.2 \text{ \# integer} \)

Try, \( m = 3 \)

\( N_p = \frac{108}{3} = 36 \)

\( N_p = 36, y_p = 0.12 \text{ (From form factor Table)} \)

\[ \frac{1}{m^2y_{indu}} = \frac{1}{(0.003)^2 \times 0.12} = 0.926 \text{ MN/m}^2 \]

\[ \frac{1}{m^2y_{all}} > \frac{1}{m^2y_{indu}} \]

Design Satisfactory

Choose, \( m = 3 \)

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

\[ = 4 \times \frac{0.926}{1.254} = 2.975 \]

Face width, \( b = k_{redu} \times \pi \times m \)

\[ = 2.975 \times \pi \times 3 \]

\[ = 28.053 \text{ mm} \]

Dynamic Check

Endurance Force

\[ F_o = S_o \beta_\gamma \pi m \]

\[ = 140 \times 10^6 \times 0.028 \times 0.12 \times \pi \times 0.003 = 4433 \text{ N} \]

\( m = 3, \text{ Tooth Error} = 0.01 \)

\( C = 114 \text{ (from Table 4.2)} \)

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

\[ = \frac{1105.324 + 21 \times 9.048(0.028 \times 114 + 1105.324)}{21 \times 9.048 + \sqrt{0.028 \times 114 + 1105.324}} = 2048.560 \text{ N} \]

Wear Force,

\( F_w = D_p b K Q \]

\[ = \frac{2N_g}{N_g + N_p} = \frac{2 \times 50}{50 + 36} = 1.163 \]

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

\[ = [2.75(400) - 70] = 1030 \text{ MN/m}^2 \]

\[ S_{es}^2 \sin \phi \left[ \frac{1}{E_p} + \frac{1}{E_g} \right] \]

\[ K = \frac{1.4}{(1030 \times 10^6)^2 \sin 20^\circ \left[ \frac{2}{200 \times 10^3} \right]} = 1.4 \]

\[ = 2591.779 \text{ kN/m}^2 \]

\[ F_w = 0.108 \times 0.028 \times 2591.779 \times 10^3 \times 1.163 = 9115.059 \text{ N} \]

\( F_o > F_d, F_w > F_d \)

\( \therefore \text{ Design is Satisfactory.} \)

III. Design calculation of shafts for gear arrangement at 0-100 RPM

2nd Shaft

\( D_c = 108 \text{ mm}, D_D = 126 \text{ mm} \)

\( (rpm)_c = 1600 \text{ rpm} \)

Power = 10 kW

\[ M_t = \frac{9550 \times kW}{rpm} = \frac{9550 \times 10}{1600} = 59.688 \text{ Nm} \]

\( F_{t1} = 1105.33 \text{ N}, F_{t1} = F_{t1} \tan 20^\circ = 402.307 \text{ N} \)

\( F_{t2} = 947.429 \text{ N}, F_{t2} = F_{t2} \tan 20^\circ = 344.836 \text{ N} \)

From HLD

Taking moment about \( R_1 \),

\[ \sum M_{R_1} = 0 \]

\[ - R_{2x} \times 0.3335 + 947.429 \times 0.139 + 1105.33 \times 0.05 = 0 \]
\[ R_2 = 560.597 \text{ N} \]

\[ [\Sigma F_y \uparrow = 0] \]
\[ R_1 + R_2 - 947.429 - 1105.33 = 0 \]
\[ R_1 = 1492.162 \text{ N} \]

From H.B.M.D
\[ M_1 = 1492.162 \times 0.05 = 74.608 \text{ Nm} \]
\[ M_2 = 560.597 \times 0.1945 = 109.036 \text{ Nm} \]

From V.L.D

Taking moment about \( R_3 \)
\[ \Sigma M_{R_3} = 0 \]
\[ R_4 \times 0.3335 - 344.836 \times 0.139 + 402.307 \times 0.05 = 0 \]
\[ R_3 = 140.88 \text{ N} \]

From V.B.M.D
\[ M_3 = 140.88 \times 0.05 = 7.044 \text{ Nm} \]
\[ M_4 = 83.409 \times 0.1945 = 16.223 \text{ Nm} \]

\[ k_b = 1.5, k_i = 1 \]

Max, \( M_b = 110.236 \text{ Nm} \)

\[ S_s = 40 \text{ MN/m}^2 \]
\[ d^3 = \frac{16}{\pi S_s} \sqrt{(k_b M_b)^2 + (k_i M_i)^2} \]
\[ = \frac{16}{\pi \times 40 \times 10^6} \sqrt{(1.5 \times 110.236)^2 + (1 \times 59.688)^2} \]
\[ d^3 = 0.02818 \text{ m} \]
\[ = 28.18 \text{ mm} \]

Std, \( d = 29 \text{ mm} \)

\[ \text{Fig(4) Bending Moment diagram} \]

| Table 1 Results of Spur Gear Design |
| Detail | Gear A | Gear B | Gear C | Gear D | Gear E |
| Type | Spur | Spur | Spur | Spur | Spur |
| Material | Cast Steel | Cast Steel | Cast Steel | Cast Steel | Cast Steel |
| \( S_o \) | 140 MN/m² | 140 MN/m² | 140 MN/m² | 140 MN/m² | 140 MN/m² |
| BHN | 400 | 400 | 400 | 400 | 400 |
| Diameter | 150 mm | 108 mm | 108 mm | 126 mm | 126 mm |
| \( \phi \) | 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 |
Table 3 Strength Check in Gear Design

<table>
<thead>
<tr>
<th>Material</th>
<th>Cast Steel</th>
<th>Cast Steel</th>
<th>Cast Steel</th>
<th>Cast Steel</th>
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</thead>
<tbody>
<tr>
<td>$S_o$</td>
<td>140 MN/m²</td>
<td>140 MN/m²</td>
<td>140 MN/m²</td>
<td>140 MN/m²</td>
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<tr>
<td>BHN</td>
<td>400</td>
<td>400</td>
<td>400</td>
<td>400</td>
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<tr>
<td>Diameter</td>
<td>204 mm</td>
<td>51 mm</td>
<td>72 mm</td>
<td>288 mm</td>
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<td>$\phi$</td>
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<td>20 Stub</td>
<td>20 Stub</td>
<td>20 Stub</td>
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<tr>
<td>V.R</td>
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<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>R.P.M</td>
<td>400</td>
<td>1600</td>
<td>400</td>
<td>100</td>
</tr>
<tr>
<td>Type</td>
<td>Precision cut</td>
<td>Precision cut</td>
<td>Precision cut</td>
<td>Precision cut</td>
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</tbody>
</table>

Table 4 Dynamic Check in Gear Design

<table>
<thead>
<tr>
<th>$F_o$</th>
<th>$F_w$</th>
<th>$F_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st gear</td>
<td>4433.416 N</td>
<td>9115.059 N</td>
</tr>
<tr>
<td>2nd gear</td>
<td>4433.416 N</td>
<td>9115.059 N</td>
</tr>
<tr>
<td>3rd gear</td>
<td>2638.938 N</td>
<td>5225.026 N</td>
</tr>
<tr>
<td>4th gear</td>
<td>5711.981 N</td>
<td>7825.099 N</td>
</tr>
<tr>
<td>5th gear</td>
<td>9922.406 N</td>
<td>14032.92 N</td>
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</table>

Table 5 Results of Shafts Design

<table>
<thead>
<tr>
<th>Type of Shaft</th>
<th>2nd Shaft</th>
<th>3rd Shaft</th>
<th>4th Shaft</th>
<th>Spindle shaft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Commercial</td>
<td>Commercial</td>
<td>Commercial</td>
<td>Commercial</td>
</tr>
</tbody>
</table>

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 ball screw, servomotor and computer. In this paper, my portion is Design Calculation of Gear that is arranged to transfer the range 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.

ACKNOWLEDGMENT

We would like to sincerely acknowledge the encourageous efforts of our department of mechanical engineering, Technological University (Mawlamyine). I wish to express my sincere thanks to all my friends for their goodwill and constructive ideas.

REFERENCES


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