Experimental Investigation on Feedback System of CNC Turning Center

Vishalkumar B Golaviya1, Nayan N Jariwala2, Jay A Gandhi1, Keval M Vareliya3, Jignesh G Vaghasiya4

Address for Correspondence
1UG student, 2Associate Professor, Mechanical engineering Department, Shree Swami Atmanand Saraswati Institute of Technology, Surat-395006

ABSTRACT

Computer Numerical Control (CNC) is the latest technology and lots of research and innovative work is going on it. CNC machine offers lots of advantage compared to traditional machines as CNC machine give better accuracy, flexibility, lower cost of production and also reduces process time. The CNC machine feedback system consists of encoder, shaft, bearing, coupling and housing assembly. The encoder gives feedback of spindle speed to controller of CNC machine. In this project, the problem is frequent failure of bearing and coupling due to which the encoder stop working in the feedback system which is driven by belt drive mechanism, so this problem was taken as analysis and calculation of different forces and torque which are transmitted to the coupling and bearing. In order to increase performance of the system and eliminate the stoppage of the entire machining system due to feedback issue, this project presents a new idea to modify the feedback system of CNC turning centers. After successions on the experimental set up performance was checked and it was found that machine’s feedback system responses very accurately and works for longer period than before. Nevertheless, the main advantage of this experimental project is to improve the feedback system of CNC machines which stops due to feedback system response problem and to reduce the replacement cost of components.

KEYWORDS: Encoder, Feedback, Frequent failure, Drive mechanism, Coupling, Bearing

1. INTRODUCTION

Numerical control (NC) is the automation of machine tools that are operated by programmed command encoded on a storage medium, as opposed to controlled manually via hand wheels or leavers, or mechanically automated viacams. Most NC today is computer numerical control (CNC), in which worked through computer control.

A major contribution towards the development of CNC was made by John Parsons who developed a technique to machine accurate templates to manufacture helicopter blades. Subsequent developments in electronics and VLSI design led to the development of present generation CNC machines and computer aided manufacturing technology. The efforts to integrate CAD and CAM and later all other activities connected with manufacture resulted in the development of Computer Integrated Manufacturing (CIM). It can be said that the path breaking development of John Parsons is the beginning of the CIM technology. In modern CNC system, end to end component design is highly automated using computer-aided design (CAD) and computer-aided manufacturing (CAM) programs. The programs produce a computer file that is interpreted to extract the commands needed to operate a particular machine via a postprocessor and then loaded into the CNC machines for production.

2.1 WHAT IS FEEDBACK SYSTEM?

It is a dynamic control system that is designed to efficiently cut the shape you design or program. In that system it will account for the material its cutting and select the proper spindle speed and move rate, some do tool path and have functions for tool wear. CNC machine feedback system consists of housing assembly, encoder, shaft, bearing, coupling, belt drive mechanism, etc

Encoder: A device used to convert linear or rotational position information into an electrical output signal.

How does encoder works?

- Outer track is used to determine position.
- Middle track is used to measure the direction of rotation.
- Inner track is used to indicate the complete revolution.
- Integrated counter circuits are used to count leading and falling edges of pulse.

In the feedback system the motor rpm is transferred by means of belt drive and from belt drive the motion is given to the shaft and then to encoder of CNC which is joint with the housing. The housing consists of a shaft, bearings, coupling and spacer. There is problem in the feedback system of rotary encoder and where it is mounted. Due to this, there was frequent failure of bearing, coupling and also misalignment shaft is occurring. There is immediate stopping of the spindle which results in sudden stoppage of the machine.
2.2 Types of feedback system:

Closed and Semi-Closed Loop for feedback System

In some systems, only one encoder is used and it serves as both position and velocity feedback unit. The encoder is mounted at the back of the servomotor (semi-closed loop system). This is illustrated in Fig.1. In other systems (closed loop system illustrated in Fig. 2.), separate feedback units for position and velocity are used. In this case, the position feedback is derived position feedback is obtained this way, errors due to backlash, pitch error, ball screw compliance etc. can be eliminated.

![Fig. 2.1 - Semi Closed Loop System](image1)

CNC machine tools employ AC motors (DC motors in older versions of CNC machines), which offer infinite variation of spindle speeds over a wide range of speeds. Digital technology is used in the modern AC drives. AC motors are capable of delivering high power at low base speeds. The main advantages of AC motors are their ruggedness and low cost.

2.3 Line diagram of CNC turning center

![Fig. 2.2- Closed Loop System](image2)

ANALYSIS METHODOLOGY

2.1 Force Analysis of Feedback System

The feedback system of the CNC turning center consists of different mechanisms for power transmission. Different elements of this feedback system are belt drive (V-Belt and Timing Belt), housing assembly. To find out the reason for the failure of the coupling and bearing in the housing assembly we analyze the force transmitted by the V-belt drive to timing belt drive and then to bearing and coupling.

3.1.1 Analysis of V-Belt Tensions

Notations: P1 = force in Tight Side of Belt, P2 = force in Slack side of Belt, \( l_p \) = Pitch Width of Pulley Groove or Pitch Width of Belt, \( b \) = Minimum Height of Groove above the Pitch Line, \( h \) = Minimum Depth of Groove below the Pitch Line, \( E \) = Centre Distance of Adjacent Grooves, \( F \) = Distance of the Edge of Pulley to First Groove Centre

\[
\begin{align*}
\alpha &= \text{Groove Angle},
\quad dp = \text{Pitch Diameter of Pulley},
\quad G = \text{Minimum top Width of the Groove} \\
D &= \text{Diameter of Driving Pulley},
\quad d &= \text{Diameter of Driven Pulley},
\quad M &= \text{Mass of Belt} \\
\mu &= \text{Co-Efficient of Friction},
\quad T1 &= \text{Tension in Tight Side} \\
T2 &= \text{Tension in Slack side} \\
R &= \text{Radius of Shaft},
\quad \sigma_b &= \text{Bending Stress}
\end{align*}
\]
Table 1 - Selection of V-Belt Parameter

<table>
<thead>
<tr>
<th>Groove Section</th>
<th>dp mm</th>
<th>B Mm</th>
<th>H mm</th>
<th>e mm</th>
<th>F mm</th>
<th>α</th>
<th>dp Mm</th>
<th>g mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>8.5</td>
<td>2.00</td>
<td>9</td>
<td>12.6</td>
<td>0.39</td>
<td>7.9</td>
<td>150</td>
<td>9.7</td>
</tr>
<tr>
<td>B</td>
<td>11.2</td>
<td>2.75</td>
<td>11</td>
<td>15.0</td>
<td>0.3</td>
<td>9.12</td>
<td>140</td>
<td>12.7</td>
</tr>
<tr>
<td>C</td>
<td>14.0</td>
<td>3.50</td>
<td>14</td>
<td>19.0</td>
<td>0.4</td>
<td>11.5</td>
<td>140</td>
<td>16.1</td>
</tr>
<tr>
<td>D</td>
<td>19.0</td>
<td>4.80</td>
<td>19</td>
<td>25.5</td>
<td>0.5</td>
<td>16.0</td>
<td>140</td>
<td>21.9</td>
</tr>
<tr>
<td>E</td>
<td>27.0</td>
<td>8.10</td>
<td>19</td>
<td>37.6</td>
<td>0.6</td>
<td>23.7</td>
<td>140</td>
<td>21.9</td>
</tr>
<tr>
<td>F</td>
<td>32.0</td>
<td>9.60</td>
<td>23</td>
<td>24.2</td>
<td>0.6</td>
<td>7.83</td>
<td>140</td>
<td>38.2</td>
</tr>
</tbody>
</table>

Table 2 - Arc of contact Correction Factor \( f_d \)

<table>
<thead>
<tr>
<th>( f_d )</th>
<th>0.77</th>
<th>0.80</th>
<th>0.82</th>
<th>0.83</th>
<th>0.87</th>
<th>0.89</th>
<th>0.91</th>
<th>0.95</th>
<th>0.96</th>
<th>0.97</th>
<th>0.99</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arc of contact</td>
<td>106°</td>
<td>113°</td>
<td>120°</td>
<td>127°</td>
<td>133°</td>
<td>139°</td>
<td>145°</td>
<td>151°</td>
<td>157°</td>
<td>163°</td>
<td>169°</td>
<td>174°</td>
</tr>
</tbody>
</table>

\[ b = 3.5 \text{ mm}, \ h = 14 \text{ mm}, \ e = 19 \pm 0.4, \ f = 11.5-14.5, \quad \alpha = 34°, \ dp = \text{ up to } 190, \ g = 16.1, \text{ Outside diameter } = \]

\[ dp + 7.0, \ d = 80 \text{ mm}, \ D = 126 \text{ mm}, \ m = 0.5 \text{ kg/m}, \mu = 0.2, \ n = 5000 \text{ rpm}, \ p = 5.5 \text{ kW}, \]

\[ T_1 = \text{ Torque at Spindle}, \ T_2 = \text{ Torque at Coupling} \]

\[ \text{Step 1: Correct centre distance; } \]

\[ L = 2C + \frac{\pi (D+d)}{2} + \frac{(D-d)^2}{4C} \]

\[ 1395 = 2C + \frac{\pi (126+80)}{2} + \frac{(126-80)^2}{4C} \]

\[ 2C^2 - 1071.42C + 529 = 0 \]

\[ \text{The correct centre distance } C = 535.21 \text{ mm} \]

\[ \text{Step 2: Correction factor for arc of contact } (f_d) \]

\[ \alpha_s = 180 - 2\sin^{-1}\left(\frac{D-d}{2C}\right) = 174° \]

\[ \text{Take, } f_d \text{ is } 0.99 \]

\[ \text{Step 3: Belt tension; } \]

\[ \frac{f_{a}}{\sin\left(\frac{\alpha}{2}\right)} = \frac{30.2 (\frac{141}{13})}{2 \sin\left(\frac{174}{2}\right)} \]

\[ \epsilon^{0.775} = 5.64 \]

\[ \nu = \frac{mdn}{60 \times 10^9} = 20.94 \text{ m/s} \]

\[ m \nu^2 = 0.5*(20.94)^2 = 219.32 \]

\[ \left(P - \frac{m \nu^2}{2} \right) = \frac{f_a}{\sin(\theta/2)} \]

\[ P_1 - 5.64P_2 + 1017.58 = 0 \]

\[ \text{Power transmitted; } \text{kW} = \frac{1000}{(P_1 - P_2) + \nu^2} \]

\[ \text{kW} = \frac{1000}{(5.64P_2 - 1017.59 - P_2) + 20.94} \]

\[ \text{so, } P_1 = 538.57 \]

\[ P_2 = 275.90 \text{ N} \]

\[ \text{Torque } (T_2) = \frac{P}{w} = \frac{5.5 \times 10^3 \times 60}{2 \times 3000} = 17.5 \text{ Nm } \]

3.1.2 Bearing Force Analysis

\[ \text{Bearing Specifications: Bearing number } = 6003, \text{ Dynamic load } (C) = 6050 \text{ N } \]

\[ \text{Total maximum Force; } \]

\[ P_{\max} = P_1 + P_2 = 538.57 + 275.9 = 814.47 \text{ N } \]

\[ \text{Step: 1 Equivalent Radial Load but Bearing is subjected to purely radial load.} \]

\[ F_r = 814.47 \text{ N} \]

\[ \text{Step: 2 Bearing Life } (L_{10}) ; P = \left(\frac{L}{10^6}\right)^{0.3} \]

\[ L_{10} = \frac{6050}{814.47}; L_{10} = 799.71 \text{ million rev } \]

\[ \text{Step: 3 Working Life of Bearing but The relationship between life in million revolutions and life in working hours is given by } ; L_{10} = \left(\frac{60 \times n + L_{10}}{10^6}\right) \]

\[ L_{10\text{th}} = 4442.83 \text{ hrs.} \]

\[ \text{For the bearing no. 6003 we calculated that the expected life is 4442.83 hours (eq. 13) so it should work for at least 4 months if it works 10 hour a day but in service the bearing is failing once in every 2-3 months during working of 10 hours a day. So to find the reason we analyzed other components of the system.} \]

3.1.3 Coupling Torque Analysis

\[ \text{N} \]

Fig 3.3 - Schematic Diagram of Coupling

Where, A= ø6 mm, B= ø6 mm, D= ø19 mm, L= 22.2 mm

Maximum torque that can be sustained by coupling = 2.3 Nm (Table 3)........... (14)

From Table 7 the maximum peak torque that the coupling can sustain is 2.3 Nm for coupling size of ø19 mm. Now there might be possibility failure of coupling due to the higher torque transmitted by the timing belt drive. So we will analyze the maximum torque transmitted by the timing belt drive on coupling.

3.1.4 Analysis of Timing Belt (Synchronous Belt)

Table 4 - Belt Designation

<table>
<thead>
<tr>
<th>Size Designation</th>
<th>Ø60</th>
<th>Ø65</th>
<th>Ø70</th>
<th>Ø75</th>
<th>Ø80</th>
<th>Ø85</th>
<th>Ø90</th>
<th>Ø95</th>
<th>Ø100</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm</td>
<td>60</td>
<td>65</td>
<td>70</td>
<td>75</td>
<td>80</td>
<td>85</td>
<td>90</td>
<td>95</td>
<td>100</td>
</tr>
</tbody>
</table>

The belt used in as per our experiment is light duty belt (L322) which is 13 mm wide.
3.1.5 Shaft Design

\[ T_1 = 538.57 \text{ N}, \quad T_2 = 275.9 \text{ N} \]

Torque \( (T) = (T_1 - T_2) \times R = (538.57 - 275.9) \times 0.0095 = 2.495 \text{ Nm} \) ............ (15)

Now this is the maximum torque that can be transferred by the timing belt drive mechanism to coupling and bearing. At peak capacity and peak load conditions this maximum torque is transferred to the coupling.

The maximum torque capacity of coupling is 2.3 Nm (eq. 14) which is less than the maximum torque transferred by the timing belt. This maximum torque causes the failure of the coupling.

Hence, we can conclude that the belt of lesser width should be used for the above purpose which does not cause the failure of the coupling and it is easier to change the belt then to change a coupling.

3. CONCLUSION

In this project work a preliminary investigation is carried out to study on feedback system of CNC machining centres.

1. From the analysis of timing belt and coupling torque the maximum torque transmitted by the timing belt is 14.112 Nm and the maximum torque capacity of helical coupling is 2.3 Nm. So the torque transmitted is higher than capacity of coupling, result in the failure of coupling.

2. From calculation of bearing life the estimated bearing life 4442.83 hours. Due to failure of coupling at higher torque then its capacity there will be misalignment of shaft which results in the failure of bearing.

3. The failure of bearing and coupling causes the failure of feedback system of CNC this result in stopping of the system.

4. As it is easy to replace the belt so the use of belt of thinner width so it will restrict the belt to transfer load of higher value. During peak load conditions the belt will fail first and prevent the failure of bearing and coupling. It will reduce the down time for the machine as replacement and procurement of belt is much easier.

5. There is one other possibility for preventing this failure is to use an encoder which does not require to use coupling. The shaft will directly fit into the encoder. As we do not need to use coupling to join shaft and encoder. So, it will not cause the breakdown of feedback system due to failure of coupling which will result into reduction of downtime of the machine.

6. To use the bearing of higher number to increase strength. i.e. 6203

**REFERENCE**


Table 5- Selection Parameter for Timing Belt

<table>
<thead>
<tr>
<th>Belt Type</th>
<th>Stock Width</th>
<th>Rated Working Tension</th>
<th>Maximum Available Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>LXL (200%)</td>
<td>5.00</td>
<td>13</td>
<td>24.5</td>
</tr>
<tr>
<td>L (3/4&quot;)</td>
<td>6.00</td>
<td>16</td>
<td>26.5</td>
</tr>
<tr>
<td>L (1&quot;)</td>
<td>8.00</td>
<td>20</td>
<td>29.5</td>
</tr>
<tr>
<td>L (1 3/8&quot;)</td>
<td>10.00</td>
<td>24</td>
<td>31.5</td>
</tr>
</tbody>
</table>

From table for the belt size of L322, Rated working tension T1 = 112 N (Maximum), To find maximum torque considering T2 = 0 N

\[ T = (T_1 - T_2) \times R = (112 - 0) \times 0.0126 = 14.112 \text{ Nm} \]