NIST RAMP Competition 2018: Lathe Analysis

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Product and Process Information

Product Specifications:

Equipment:
KLR-200 Series 2-Axis CNC Lathe
CNMG 321-PM 4325 Tool Insert

Product Specifications:
Cylindrical steel shaft with keyrings slots and varying diameters to fit several bearing types.

Process Specifications:
Turning and grooving with CNC lathe that is operate through G-Code.

Variables for Transformation Equations:

N [rev/min] = Rotational speed of workpiece
f [in/rev] = Feed
v [in/min] = Feed rate
V [in/min] = Surface speed of workpiece
L [in] = Length of cut
D_o [in] = Original diameter of workpiece
D_f [in] = Final diameter of workpiece
D_{avg} [in] = Average diameter of workpiece
d [in] = Depth of cut
A_s [in^2] = Area of shear plane
S [psi] = Shear strength
F_c [N] = Cutting force
α [°] = Rake angle
β [°] = Clearance angle
φ [°] = Shear plane angle
t [min] = Cutting time
MRR [in^3/min] = Material removal rate
T [lb-ft] = Torque
P [hp] = Power
n [] = Taylor's tool life exponent
C [in/min] = Taylor constant
TL [min] = Tool life

Input

Electrical Energy: 20 hph
Material: Steel

Transformation Equations

Feed Rate: $v = fN$
Avg. Diameter of Workpiece: $D_{avg} = (D_o + D_f)/2$
Maximum Surface Speed: $V = \pi D_o N$
Average Surface Speed: $Vavg = \pi D_{avg} N$
Depth of Cut: $d = (D_o - D_f)/2$
Cutting Time: $t = L/fN$
Material Removal Rate: $MRR = \pi D_{avg} N f d$
Shear Plane Angle: $\varphi = 45 + \alpha/2 - \beta/2$ m
Area of Shear Plane: $A_s = fd/\sin\varphi$
Shear Force: $F_s = SA_s$
Cutting Force: $F_c = F_s \cos(\beta - \alpha) / \cos(\varphi + \beta - \alpha)$
Torque: $T = F_c D_{avg}/2$
Power: $P = F_c V/33{,}000$
Tool Life: $T_L = (C/V)^{1/n}$

Output

Completed Shaft
Material Removed: 31.1837 in^3

Resources

Equipment: KLR-200 Series 2-Axis CNC Lathe
Tools: Turning tool with CNMG 321-PM 4325 Tool Insert
Software: CNC with G-Code

Transformation Functions for Lathes

Feed rate: $v = fN$ **Average diameter of workpiece:** $D_{avg} = (D_o + D_f) / 2$ **Surface speed of workpiece (Maximum):** $V = \pi D_o N$ **Surface speed of workpiece (Average):** $V = \pi D_{avg} N$ **Depth of cut:** $d = (D_o - D_f) / 2$ **Cutting time:** $t = L/fN$ **Material removal rate:** $MRR = \pi D_{avg} v d$	**Shear plane angle:** $\phi = 45 + \frac{\alpha}{2} - \frac{\beta}{2}$ **Area of shear plane:** $A_s = \frac{fd}{sin\phi}$ **Shear force:** $F_s = SA_s$ **Cutting force:** $F_C = \frac{F_s cos(\beta - \alpha)}{cos(\phi + \beta - \alpha)}$ **Torque:** $T = F_c D_{avg}/2$ **Power:** $P = \frac{F_c v}{33000}$ **Cutting tool life:** $T_L = (C/V)^{1/n}$

Description of Nomenclature

N [rev/min] = Rotational speed of workpiece

f [in/rev] = Feed

v [in/min] = Feed rate

V [ft/min] = Surface speed of workpiece

L [in] = Length of cut

D_o [in] = Original diameter of workpiece

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β [°] = Clearance angle

ϕ [°] = Shear plane angle

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MRR [in^3/min] = Material removal rate

T [lb•ft] = Torque

P [hp] = Power

n [] = Taylor's tool life exponent

C [in/min] = Taylor constant

T_L [min] = Tool life

Read Me

This report analyzes the parameters involved with the production of a steel shaft using a KLR-200 Series 2-Axis CNC Lathe. Our objective is to develop a model and find the optimal means of production such that the machine tool life is maximized.

MATLAB codes used to perform calculations based on different machine settings can be found below. In the code the rake angle that produces the largest cutting force was calculated as well as the the rake angle that produces the minimum cutting force. The relationship between spindle speed and power consumption was also found. Finally the effects of changes in spindle speed on tool life were explored.

ZIP folder directory includes:

1. SBU_Submission.pdf - PDF file that includes all submission requirements
2. Shaft - Picture of the shaft we designed
3. Shaftdrw - drawing of the shaft
4. angle_vs_Force - MATLAB code to compare the cutting force and rake angle
5. feed_vs_Power - MATLAB code to compare the power and the cutting speed
6. feed_vs_ToolLife - MATLAB code to compare the tool life and cutting speed
7. UMP(1)- graph

Brief Narrative

In order to combat environmental issues, our goals are to reduce mechanical waste increase savings associated with the prolonging of tool life in a given manufacturing process. It is imperative that industries are knowledgeable about production waste and how tool life can be maximized. The important factors that play in the tool life of a machine include but are not limited to the machine selection, the rotational speed, feed, and power. By investigating how these parameters affect power consumption and tool life, we can obtain valuable information on the minimization of mechanical waste and the maximization of the efficiency of the machine.

The manufacturing machine under investigation is the KLR-200 Series 2-Axis CNC Lathe by Kent CNC [7]. In our investigation, we hypothesized that the rotational speed of a workpiece directly affects the power output of the CNC lathe. With higher rotational speeds, the CNC lathe will generate a high power output, which may not necessarily be cost-effective or energy efficient. Higher rotational speeds will also increase the material removal rate, which leads to an increase in the production of material waste in the form of chips. An increase in feed will also increase the material removal rate as it is also a parameter.

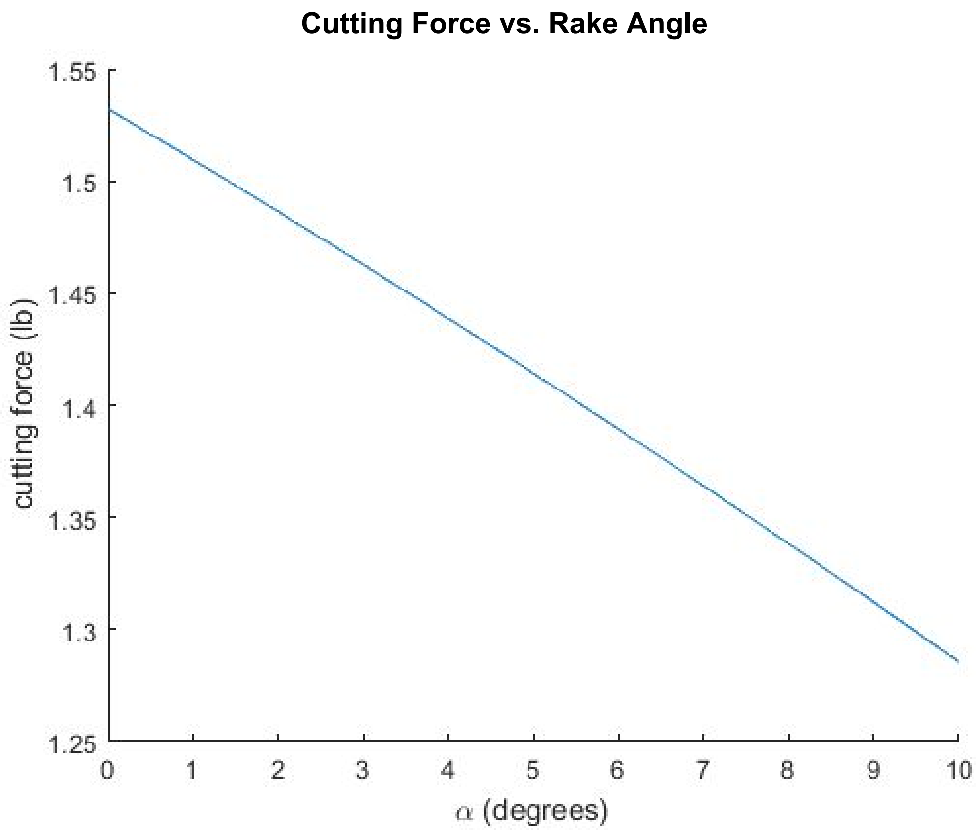


Fig. 1: Cutting force and rake angle of the KLR-200 Series 2-Axis CNC Lathe

Based on the plot of the cutting force and the rake angle, the rake angle that produces the optimal cutting force is at 0°. The range of the rake angle was from 0° to 10° as the angle of insert of the cutting tool was 80°. The clearance angle is the complementary angle to the angle containing the sum of the rake angle and angle of insertion of the tool. Although a rake angle of 0° produces the most cutting force which would lead to a desirable cut, it is also the angle that would lead to the most power consumption of the lathe and is therefore not the most efficient angle to place the cutting tool. However, a rake angle of 10° produces the least cutting force. At this angle, power consumption is the least and the process is the most efficient. The calculation of the power consumptions are as follows:

Calculation of the maximum cutting force:

$$\phi = 45 + \frac{\alpha}{2} - \frac{\beta}{2} = 45 + \frac{0°}{2} - \frac{90° - 80° - 0°}{2} = 40°$$

$$F_{max} = \frac{F_s cos(\beta - \alpha)}{cos(\phi + \beta - \alpha)} = \frac{(1\ lb)cos((90° - 0° - 80°) - 0°)}{cos(40° + (90° - 0° - 80°) - 0°)} = 1.5321\ lb$$

Calculation of the minimum cutting force:

$$\phi = 45 + \frac{\alpha}{2} - \frac{\beta}{2} = 45 + \frac{10°}{2} - \frac{90° - 80° - 10°}{2} = 50°$$

$$F_{min} = \frac{F_s cos(\beta - \alpha)}{cos(\phi + \beta - \alpha)} = \frac{(1\ lb)cos((90° - 10° - 80°) - 1\ 0°)}{cos(50° + (90° - 10° - 80°) - 10°)} = 1.2856\ lb$$

However, the cutting forces calculated in this design utilized an arbitrary shear force. As a result, these cutting forces are not the true values when the KLR-200 Series 2-Axis CNC Lathe is used. A ratio of the maximum and minimum cutting forces can be used to describe an accurate representation of the discrepancy.

Ratio of the maximum and minimum cutting forces:

$$R = \frac{F_{max}}{F_{min}} = \frac{1.5321\ lb}{1.2856\ lb} = 1.1918$$

We can expect a maximum cutting force approximately 1.2 times greater than the minimum cutting force exerted by the KLR-200 Series 2-Axis CNC Lathe.

Despite the difference in force, the minimum cutting force is sufficient for the removal of material. Thus, to minimize the use of power, it is more optimal to use a rake angle of 10° than a rake angle of 0°.

As expected, Fig. 2 indicates that the cutting speed and the power are proportional. As the cutting speed increases, the power also increases, and this creates a linear relationship. Therefore, an increase in the cutting speed will lead to more power consumption and lower efficiency.

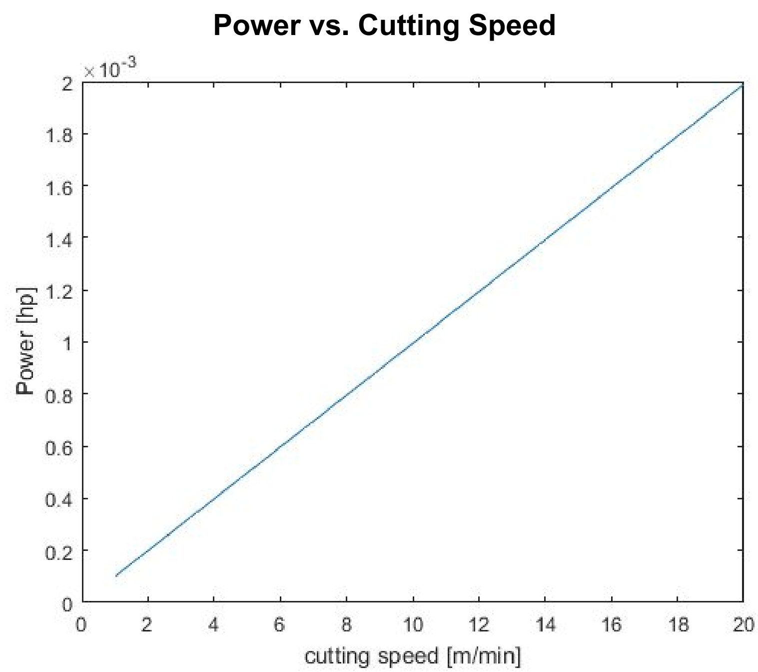


Fig. 2: Plot of the relationship between power and cutting speed of the KLR-200 Series 2-Axis CNC Lathe

Another factor that was considered was the tool life of the cutting tool. The result shows that the tool experiences a reduction in its tool life with an increase in cutting speed. There is an apparent power relationship between the tool life of the cutting tool and its cutting speed.

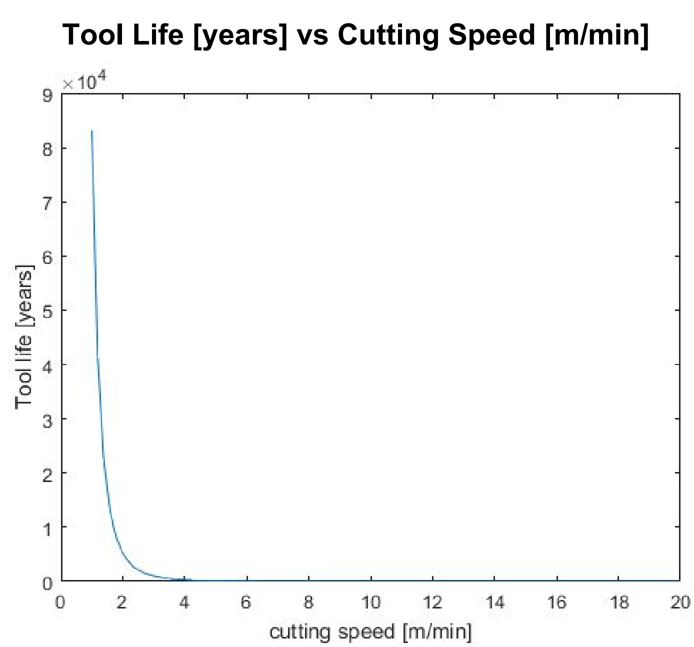
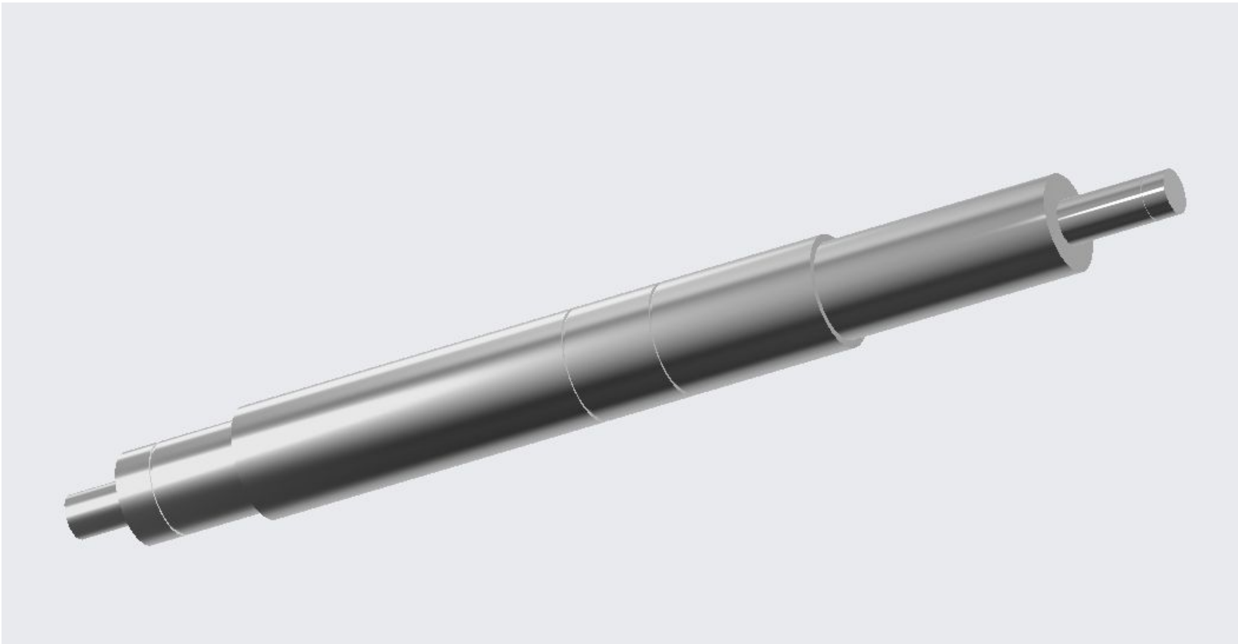
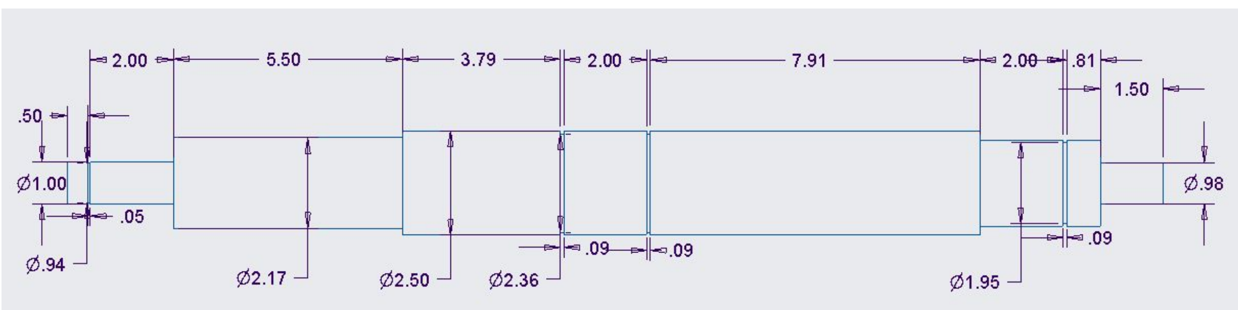


Fig. 3: Plot of the relationship between tool life and cutting speed of the CNMG 321-PM 4325 Tool Insert

Based on the results from our investigation, the rake angle of 10° is the optimal angle for prolonging tool life as it produces the least cutting force, and therefore requires less power to operate the lathe. Since the power and cutting speed is a linear function, reducing the power will always decrease the cutting speed. In Fig. 3, when the cutting speed decreases, the tool life increases. By extending the tool life, and by using lower cutting speed, the waste production from the wear particles and worn tools will be reduced. Fig. 3 also suggests that the cutting speed should be within approximately 4.1 m/min as any speed greater would result in an immediate death of the tool.

Appendix A - Shaft Design and Dimensions





Appendix B - G Code

```
G90 G20
M06 T1
M04 S4000
G00 X0 Z0 M08
G01 X0.94 F
G01 Z2.0
G01 X2.1659
G01 Z7.0
G01 X2.5
G01 Z10.79
G01 X2.36
G01 Z20.70
G01 X1.95
G01 Z22.70
G01 X2.062
G01 Z23.51
G01 X0.9846
G01 Z25.01
M05
M30
```

Appendix B - MATLAB Codes

Cutting Force vs. Rake Angle

```
clear
close all
clc

alpha = 0:0.1:10;
Angle_Insert = 80;
shear_force = 1; %constant just for comparison
deg_per_rad = 180/pi;

beta = 90-alpha-Angle_Insert;
phi = 45+alpha/2-beta/2;
cutting_force = (shear_force.*cosd(beta-alpha)./cosd(phi+beta-alpha));

figure
hold on
plot(alpha,cutting_force)
hold off
xlabel('\alpha (degrees)');
ylabel('cutting force (lb)');
```

Power vs. Cutting Speed

```
clear
close all
clc

F=1;  %constant just for comparison
v_m = linspace(1,20);  %[m/min]
v_ft = v_m*(3.280839895);  %ft/min
P = F*v_ft/33000;  %hp

figure
plot(v_m,P);
xlabel('cutting speed [m/min]')
ylabel('Power [hp]')
```

Tool Life vs. Cutting Speed

```
clear
close all
clc

C = 1500;    %[ft/min]
v_m = linspace(1,20);    %[m/min]
n = 0.25;
v_ft = v_m*(3.280839895);    %[ft/min]

TL = (C./v_ft).^(1/n)/(60*24*365);

figure
plot(v_m,TL);
xlabel('cutting speed [m/min]')
ylabel('Tool life [years]')
```

References

[1] “A36 Steel Round Bar,” *MetalsDepot*. https://www.metalsdepot.com/steel-products/steel-round-bar. [Accessed: 20-Apr-2018].

[2] Chang, Q., 2018, *Machining Operations and Machine Tools.* Stony Brook University. Stony Brook, New York.

[3] Chang, Q., 2018, *MEC325/580 Handout: CNC Machining.* Stony Brook University. Stony Brook, New York.

[4] Chang, Q., 2018, *SME Video: Turning & Lathe Basics.* Stony Brook University. Stony Brook, New York.

[5] Chang, Q., 2018, *Theory of Metal Machining.* Stony Brook University. Stony Brook, New York.

[6] “CNMG 09 03 04-PM 4325.” [Online]. Available: https://www.sandvik.coromant.com/en-us/products/pages/productdetails.aspx?c=cnmg 321-pm 4325. [Accessed: 20-Apr-2018].

[7] “KLR-200 Series 2-Axis CNC Lathe - Turning Center,” Kent CNC, 17-Feb-2016. https://www.kentcnc.com/products/cnc-lathe/2-axis-cnc-lathe-turning-center/klr-200-2-axis-cnc-lathe-turning-center/

[8] “KLR Series Slant-Bed CNC Turning Center.” http://library.kentusa.com/kentcnc/HTC/Kent%20CNC%20KLR%20Slant%20Bed%20Lathes-S.pdf [Accessed: 20-Apr-2018].