

1. The diameters of some shafts and holes to be assembled were measured and the results are given in the table below.

	1	2	3	4	5	6	7	8	9	10	average	std
Shaft	4.875	4.756	4.91	4.922	4.786	4.888	4.913	4.875	4.999	4.932	4.886	0.0704
Hole	5.012	5.111	5.035	5.123	4.986	5.002	5.026	5.022	5.111	5.123	5.055	0.0550

Unit: mm

- (a) Express the dimensional tolerance of the shafts and holes using the bilateral and unilateral notations. For the unilateral notation, use 0 as the lower tolerance limit for the holes and 0 as the upper tolerance limit for the shafts. (Hint: they must represent the same ranges)

Bilateral

shafts:  $4.886 \pm 0.211$ , or  $9.872 \pm 0.303$  (if the divided-by-n formula is used).  
 holes:  $5.055 \pm 0.165$ , or  $10.063 \pm 0.126$  (if the divided-by-n formula is used)

Unilateral

shafts:  $5.097^0_{-0.422}$ , or  $10.175^0_{-0.606}$  (if the divided-by-n formula is used).  
 holes:  $4.89^{+0.33}_0$ , or  $9.937^{+0.252}_0$  (if the divided-by-n formula is used).

- (b) For the manufacturing process making the shaft, assuming USL = 5.0 and LSL = 4.7, determine the process capability  $C_{pk}$ .

$$C_{pk} = \frac{\min(|5-4.886|, |4.7-4.886|)}{3 \times 0.0704} = \frac{\min(0.117, 0.186)}{3 \times 0.0704} = 0.55$$

Or

$$C_{pk} = \frac{\min(|10.14-9.872|, |9.5-9.872|)}{3 \times 0.101} = 0.88$$

(if the divided-by-n formula is used)

- (c) This problem is related to surface roughness. The surface roughness was measured on a milled piece in the diagonal direction against the feed direction with the following values. Calculate the arithmetic surface roughness  $R_a$  value with the cutoff length of 0.8 mm. (unit in micron)

1	2	3	4	5	6	7	8	9	10	11	12	average
-0.23	0.42	-0.76	-1.2	-0.36	0.78	0.85	-0.55	-0.88	0.66	1.42	0.22	0.03

$$R_a = \frac{\sum |y_i - \bar{y}|}{N} = \frac{0.26 + 0.39 + 0.79 + 1.23 + 0.75 + 0.82 + 0.58 + 0.91 + 0.63 + 1.39 + 0.19}{12}$$

$$= \frac{8.48}{12} = 0.707$$

2. For a given type of metal material, its strain hardening index is  $n = 0.12$ . In a tensile test for the material sample, necking occurs at a true strain of  $\varepsilon = 0.12$  and fracture occurs at a true strain of  $\varepsilon = 0.22$ . The toughness of the material is 60 MPa.

(a) Determine the material strength coefficient  $K$ .

$$\int_0^{0.22} K\varepsilon^n d\varepsilon = 60 \text{ MPa}$$

Thus:  **$K = 366.32 \text{ MPa}$**

(b) Determine the material ultimate tensile strength  $\sigma_u$  (in terms of true stress).

$$\sigma_u = K0.12^{0.12} = \mathbf{284 \text{ MPa}}$$

(c) When necking occurs, what is the corresponding engineering stress and strain of the specimen?

$$\varepsilon_e = e^{\varepsilon_t} - 1 = e^{0.12} - 1 = \mathbf{0.127}$$

$$\sigma_e = \sigma_t e^{-\varepsilon_t} = \mathbf{251.9 \text{ MPa}}$$

3. A cutting tool is used in a turning process on a cylindrical steel workpiece. The cutting tool nose radius is 0.7 mm. The depth of cut is 1 mm. After turning, the workpiece surface roughness (after being cut) is  $R_a = 1.5 \mu\text{m}$ . The workpiece specific cutting energy is  $4 \text{ J/mm}^3$ .
- a) Determine the feed  $f_r$  in the unit of mm/rev.

$$R_a = \frac{R_t}{4} = \frac{f_r^2}{32CR}, \text{ Thus: } f_r = 0.183 \text{ mm/rev}$$

- b) Determine the cutting force F in the unit of Newton.

$$U = 4 \text{ J/mm}^3, t = 1 \text{ mm.}$$

$$F = U f_r t = 732 \text{ N}$$

4. A tool life experiment of a turning process was carried out with a cutting tool and the following machining conditions. The tool life equation was established.

*feed: 0.025 in/rev*

*depth of cut: 0.015 in*

*workpiece diameter: 4 in*

*length of the cut: 10 in*

*C<sub>o</sub>: operating cost (\$90/hour)*

*T<sub>c</sub>: time to change the tool (120 seconds)*

*C<sub>i</sub>: initial cost of the tool (\$20 for each cutting tool edge)*

- (a) Tool life was determined to be 60 min and 10 min for the cutting speed of 350 fpm and 500 fpm. Determine the Taylor tool life equation parameters.  $VT^n=C$ , where V and T are in the unit of fpm and minutes, respectively.

Taylor's tool life equation,  $VT^n = C$

$$350 \times 60^n = C$$

$$500 \times 10^n = C$$

$$6^n = 1.43 \Rightarrow n = 0.2$$

$$C = 350 \times 60^{0.2} = 793.8$$

- (b) Calculate the optimal cutting speed for this operation to yield the minimum machining cost per part. (Hint: pay attention to the units).

$$T_{\min} = \left( \frac{1}{n} - 1 \right) \left( \frac{C_t + T_c C_o}{C_o} \right) = \left( \frac{1}{0.2} - 1 \right) \left( \frac{20 + 2 \times 1.5}{1.5} \right)$$

$$= 61.33 \text{ min}$$

$$V_{\min} = \frac{C}{T_{\min}^n} = \frac{793.8}{61.33^{0.2}} = 348.5 \text{ fpm}$$

- (c) Calculate the cost per part at the optimal cutting speed calculated in part (b), assuming that the loading and unloading time per part is 120 seconds in total.

$$CT = \frac{L}{f_m} = \frac{L}{f_r N} = \frac{L \pi D}{f_r 12V} = \frac{10 \times \pi \times 4}{0.025 \times 12 \times 348.5} = 1.2 \text{ min}$$

$$C = CT \cdot \left( C_o + \frac{C_t + C_o T_c}{T} \right) + \$2 \times 1.5$$

$$= 1.2 \times \left( 1.5 + \frac{20 + 2 \times 1.5}{61.33} \right) + \$1.5 \times 2$$

$$= \$5.25$$

## 5. CNC programming problem.

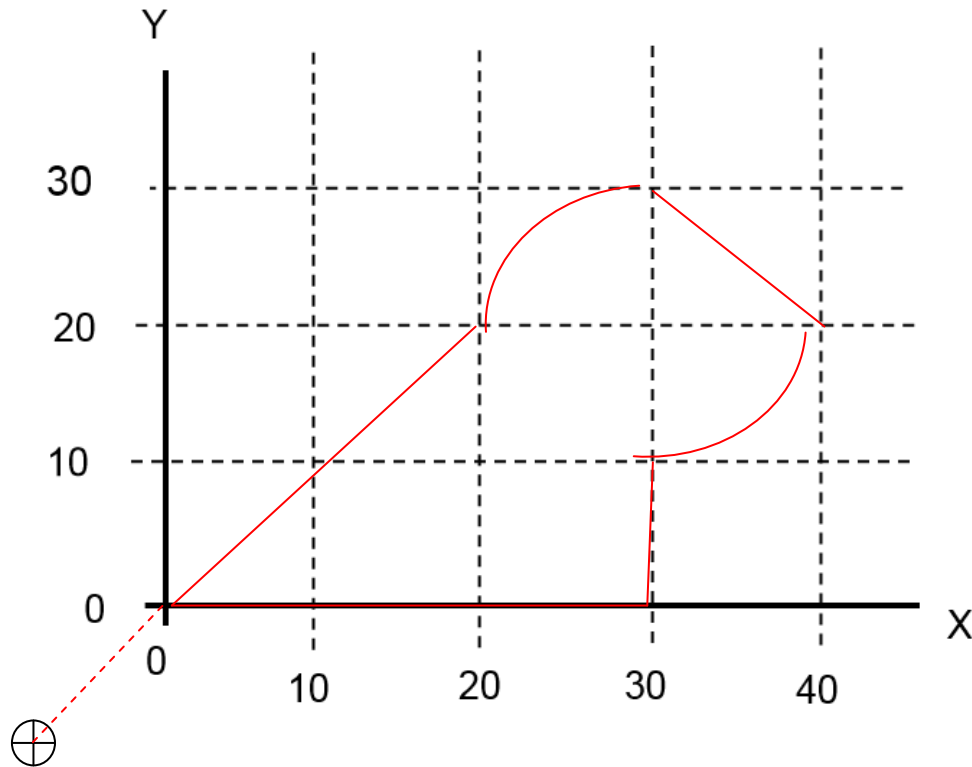
**G & M code**

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G01	Linear interpolation
G02	Circular interpolation, CW
G03	Circular interpolation, CCW
G06	Spline execution command
G17	XY plane selection
G40	Cancellation of tool radius compensation
G41	Tool radius compensation to the left of profile
G42	Tool radius compensation to the right of profile
G48	Beginning of spline curve definition
G70	Data input in inches
G71	Data input in metrics
G77	Unconditional call or jump with return
G79	Conditional or unconditional jump to a sequence without return
G90	Absolute dimension programming
G91	Relative dimension programming
G94	Feed rate in mm/min
G95	Feed in mm/rev
M02	End of program
M03	Clockwise spindle rotation
M04	Anti-clockwise spindle rotation
M05	Spindle stop

- (a) Draw the tool trajectory that will be produced by the following CNC program. The tool traveling speed in the rapid linear motion mode (G0) is 120 mm/min. The tool is assume to be at (-10,-10) before this cycle starts. Start your drawing from the point of (-10, -10). All the units are given in mm. Please draw your answer in the plot given below.

```
N10 G90 XY G17 G71
N20 T1 D1 G94 F10 S1000 M03
N30 G0 X0 Y0
N40 G01 X20 Y20
N50 G02 X30 Y30 I30 J20
N60 G91 G01 X10Y-10
N70 G90 G02 X30 Y10 R10
N80 G01 X30 Y0
N90 G01 X0 Y0
N100 M02
```



- (b) Estimate the total cycle time of this operation (i.e., the time it takes the tool to travel through the trajectory), ignoring the time taken for acceleration and deceleration. Start your calculation from the point of (-10, -10).

distance by linear and circular interpolation with feed rate of 10 mm/min (from F10)

$$= \sqrt{20^2 + 20^2} + \sqrt{10^2 + 10^2} + 3.14 \times 20 / 2 + 40$$

$$= 28.28 + 14.14 + 31.4 + 40 = 113.82$$

rapid mode from (-10,-10) to (0,0) with feed rate of 120 mm/min

$$= \frac{14.14}{120}$$

Total time

$$= \frac{113.82}{10} + \frac{14.14}{120} = 11.38 + 0.12 = 11.5 \text{ min}$$



- F. Which of the following statements about cutting tools is definitely correct?
- (a) A tungsten carbide cutting tool has no metallic component.
  - (b) To produce surface coating on a high-speed-steel cutting tool, people can use either physical vapor deposition or chemical vapor deposition.
  - (c) A polycrystalline diamond cutting tool can be suitably used to cut aluminum alloys.
  - (d) A Sialon cutting tool can be suitably used to cut steels.
- G. Which one of the following workpiece properties is NOT a critical factor to machinability?
- (a) Hardness
  - (b) Chemistry
  - (c) Fatigue strength
  - (d) Compatibility with cutting tool material
- H. Which one of the following mechanical properties describes the ability of a material to absorb the mechanical energy while in elastic range?
- (a) Yield strain
  - (b) Resilience
  - (c) Young's modulus
  - (d) Hardness
- I. Which one of the following hardness tester is not based on the indentation area?
- (a) Brinell
  - (b) Rockwell
  - (c) Vickers
  - (d) Knoop
- J. Which one of the followings is NOT the benefit of high speed machining?
- (a) Easy chip removal
  - (b) Improved surface finish
  - (c) Higher cutting force
  - (d) Lower thermal distortion