Chapter 15: Manufacturing Engineering

15-1. Discuss the building materials used by the three little pigs (straw, sticks, and bricks). Why were they chosen? Why did they fail? What was the environmental impact?

**Need:** A discussion of the choice of building materials by the “Three Little Pigs”.

**Know:** They chose to use straw, sticks, and bricks to build their houses.

**How:** Use your knowledge of this children’s story and your understanding of these materials.

**Solve:** Since this story is likely of medieval origin when wild animals and other predictors stalked villages, both straw and sticks were inexpensive and easily obtained. Straw and stick mud houses were common, but sun-dried mud brick houses were more labor intensive and expensive. Straw is weaker than sticks, and both are weaker than bricks. A strong wind (or wolf) could easily damage straw and stick houses, but was less likely to damage brick dwellings. Since all three building materials were available from the local environment, the use of straw and sticks would eventually deplete their supply, but the use of sun-dried mud bricks would have little impact on the pig’s environment.
15-2. A **casting process** involves pouring molten metal into a mold, letting the metal cool and solidify, and removing the part from the mold. The solidification time is a function of the casting volume and its surface area, known as **Chvorinov’s rule**.

\[
\text{Solidification Time} = K \times \left( \frac{\text{Volume}}{\text{Surface area}} \right)^2
\]

where \( K \) is a constant that depends on the metal. Three parts are to be cast that have the same total volume of \(0.015 \text{ m}^3\), but different shapes. The first is a sphere of radius \( R_{\text{sph}} \), the second is a cube with a side length \( L_{\text{cube}} \), and the third is a circular cylinder with its height equal to its diameter \((H_{\text{cyl}} = D_{\text{cyl}} = 2R_{\text{cyl}})\). All the castings are to be made from the same metal, so \( K \) has the same value for all three parts. Which piece will solidify the fastest?

The following table gives the equations for the volume and surface area of these parts.

<table>
<thead>
<tr>
<th>Object</th>
<th>Surface area</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sphere</td>
<td>(4\pi R_{\text{sph}}^2)</td>
<td>((4/3)\pi R_{\text{sph}}^3)</td>
</tr>
<tr>
<td>Cube</td>
<td>(6L_{\text{cube}}^2)</td>
<td>(L_{\text{cube}}^3)</td>
</tr>
<tr>
<td>Cylinder</td>
<td>(2\pi R_{\text{cyl}}^2 + 2\pi R_{\text{cyl}} H_{\text{cyl}} = 6\pi R_{\text{cyl}}^2)</td>
<td>(\pi R_{\text{cyl}}^2 H_{\text{cyl}} = 2\pi R_{\text{cyl}}^3)</td>
</tr>
</tbody>
</table>

**Need:** The solidification times of objects to determine which solidifies the quickest.

**Know:** Chvorinov’s rule.

**How:** Solidification Time \( ST = K \times \left( \frac{\text{Volume}}{\text{Surface area}} \right)^2 \)

**Solve:**

\[
ST_{\text{sphere}} = K \times \left( \frac{4/3}{4\pi R_{\text{sph}}^3 / 4\pi R_{\text{sph}}^2} \right)^2 = K \times \left( \frac{R_{\text{sph}}}{3} \right)^2
\]

\[
ST_{\text{cube}} = K \times \left( \frac{L_{\text{cube}}^3 / L_{\text{cube}}^2}{L_{\text{cube}}^2 / 6} \right)^2 = K \times \left( \frac{L_{\text{cube}}}{6} \right)^2
\]

\[
ST_{\text{cyl}} = K \times \left( \frac{2\pi R_{\text{cyl}}^3 / 6\pi R_{\text{cyl}}^2}{\pi R_{\text{cyl}}^2 H_{\text{cyl}} / 2\pi} \right)^2 = K \times \left( \frac{R_{\text{cyl}}}{3} \right)^2
\]

where \( R_{\text{sph}} = (3 \times \text{Volume} / 4\pi)^{1/3} = (3 \times 0.015 / 4 \pi)^{1/3} = 0.15 \text{ m} \)
\( L_{\text{cube}} = (\text{volume})^{1/3} = (0.015)^{1/3} = 0.25 \text{ m} \)
\( R_{\text{cyl}} = (\text{Volume} / 2\pi)^{1/3} = (0.015 / 2\pi)^{1/3} = 0.13 \text{ m} \)

For comparison we can divide by \( K \) to get:

\[
ST_{\text{sphere}} / K = (R_{\text{sph}} / 3)^2 = (0.15/3)^2 = 0.0025
\]
\[
ST_{\text{cube}} / K = (L_{\text{cube}} / 6)^2 = (0.25/6)^2 = 0.0017
\]
\[
ST_{\text{cyl}} / K = (R_{\text{cyl}} / 3)^2 = (0.13/3)^2 = 0.0020
\]

**So the cube cools the fastest.** (\( \text{A:} \) The cube will solidify the fastest and the sphere will solidify the slowest.)
15-3. For a particular casting process the constant $K$ in Chvorinov’s equation in exercise 2 is $3.00 \text{ s/mm}^2$ for a cylindrical casting $150. \text{ mm}$ high and $100. \text{ mm}$ in diameter. Determine the solidification time for this casting.

**Need:** The solidification time for a casting with $K = 3.00 \text{ s/mm}^2$.

**Know:** Chvorinov’s rule: Solidification Time = $K \times (\text{Volume} / \text{Surface area})^2$

**How:** Use Chvorinov’s rule with $K = 3.00 \text{ s/mm}^2$, $H_{cyl} = 150. \text{ mm}$, $R_{cyl} = 100./2 = 50.0 \text{ mm}$.

**Solve:** Solidification Time = $K \times (\text{Volume} / \text{Surface area})^2$,
where the surface area = $2\pi R_{cyl}^2 + 2\pi R_{cyl} H_{cyl}$

$$= 2\pi \times (50.0 \text{ mm})^2 + 2\pi \times (50.0 \text{ mm})(150. \text{ mm})$$

$$= 6.28 \times 10^4 \text{ mm}^2$$

and the volume = $\pi R_{cyl}^2 H_{cyl} = \pi (50.0 \text{ mm})^2 \times 150. \text{ mm} = 1.18 \times 10^6 \text{ mm}^3$

Then the solidification time = $(3.00 \text{ s/mm}^2)(1.18 \times 10^6 \text{ mm}^3 / 6.28 \times 10^4 \text{ mm}^2)^2 = 1060 \text{ s} = 17.7 \text{ minutes}$
15-4. **Tool wear** is a major consideration in machining operations. The following relation was developed by F. W. Taylor for the machining of steels:

\[ VT^n = C \]

where \( V \) is the cutting speed; \( T \) is the tool life; the exponent \( n \) depends on the tool, the material being cut, and the cutting conditions; and \( C \) is a constant. If \( n = 0.5 \) and \( C = 400 \text{ mm/min}^{0.5} \) in the equation, determine the percentage increase in tool life when the cutting speed is reduced by 50%.

(A: The tool life increases by 300%.)

**Need:** The percentage increase in tool life when the cutting speed is reduced by 50%.

**Know:** The F. W. Taylor’s tool life formula \( VT^n = C \), so \( T = (C/V)^{1/n} \)

**How:** For \( n = 0.5 \), \( T_1 = (C/V_1)^{1/0.5} = (C/V_1)^2 \) and \( T_2 = (C/V_2)^2 \).

**Solve:** \( V_2 = V_1/2 \), so \( T_2 = (C/V_2)^2 = (2C/V_1)^2 = 4(C/V_1)^2 = 4T_1 \). The tool life increases by a factor of 4 and its **percentage increase** is \([ (T_2 - T_1)/T_1 ] \times 100 = 300\% \)
15-5. For a particular machining operation \( n = 0.60 \) and \( C = 350 \text{ mm/min}^{0.5} \) in the Taylor equation given in Exercise 4. What is the percentage increase in tool life when the cutting speed \( V \) is reduced by (a) 25% and (b) 74%?

**Need:** The percentage increase in tool life when the cutting speed is reduced by (a) 25% and (b) 74%?

**Know:** The F. W. Taylor’s tool life formula \( VT^n = C \), so \( T = (C/V)^{1/n} \)

**How:** For \( n = 0.6 \), \( T_1 = (C/V_1)^{1/0.6} = (C/V_1)^{1.7} \) and \( T_2 = (C/V_2)^{1.7} \).

**Solve:**

a) \( V_2 = (1 - 0.25) \times V_1 = 3/4 \times V_1 \), so \( T_2 = (C/V_2)^{1.7} = (4C/3V_1)^{1.7} = (4/3)^{1.7} (C/V_1)^{1.7} = (4/3)^{1.7} T_1 = 1.6 T_1 \).

The tool life increases by a factor of 1.6 and its percentage increase is \([(T_2 - T_1)/T_1] \times 100 = 60\% \).

b) \( V_2 = (1 - 0.74) \times V_1 = 0.26 \times V_1 \), so \( T_2 = (C/V_2)^{1.7} = (C/0.26V_1)^{1.7} = (1/0.26)^{1.7} (C/V_1)^{1.7} = (3.85)^{1.7} T_1 = 9.9 T_1 \).

The tool life increases by a factor of 9.9 and its percentage increase is \([(T_2 - T_1)/T_1] \times 100 = 890\% \).
15-6. Using Taylor’s equation in Exercise 4, show that tool wear and cutting speed are related by \( T_2 = T_1(V_1/V_2)^{1/n} \).

**Need:** Show that \( T_2 = T_1(V_1/V_2)^{1/n} \).

**Know:** The F. W. Taylor’s tool life formula \( VT^n = C \)

**How:** We can insert the constant \( C = V_1T_1^n \) into the equation for \( T_2 \).

**Solve:** \( T_2 = (C/V_2)^{1/n} = (V_1T_1^n/V_2)^{1/n} = T_1(V_1/V_2)^{1/n} \)
15-7. A shaft 150. mm long with an initial diameter of 15. mm is to be turned to a diameter of 13.0 mm in a lathe. The shaft rotated at 750. RPM in the lathe and the cutting tool feed rate is 100. mm/minute. Determine:

a. The cutting speed
b. The material removal rate
c. The time required to machine the shaft

**Need:** The cutting speed \( V_{cutting} \), material removal rate \( MRR \), and the machining time \( t_{machining} \).

**Know:** Equation (15.3) gives the cutting speed \( V_{cutting} = \pi \overline{D}N \); equation (15.2) gives \( MRR_{turning} = \pi \overline{D}f dN \); and Equation (15.6) provides the machining time \( t_{machining} = L/FR \).

**How:** Equation (15.1) gives \( \overline{D} = (D_o + D_f)/2 \); \( f \) is the feed; \( d \) is the depth of cut (1.0 mm); \( N \) is the rotational speed (750 RPM); \( L \) is the length of cut (150. mm); and \( FR \) is the feed rate (100. mm/min).

**Solve:**

(a) \( \overline{D} = (D_o + D_f)/2 = (15. + 13.)/2 = 14. \text{ mm}. \)

Then \( V_{cutting} = \pi \overline{D}N = \pi (14 \text{ mm})(750 \text{ RPM}) = 3.3 \times 10^4 \text{ mm/min}. \)

(b) \( f = FR/N = (100. \text{ mm/min})/(750 \text{ RPM}) = 0.13 \text{ mm/rev} \), then \( MRR_{turning} = \pi \overline{D}f dN = \pi (14. \text{ mm})(0.13 \text{ mm/rev})(1.0 \text{ mm})(750 \text{ RPM}) \)
\[ \therefore f = 4.3 \times 10^3 \text{ mm}^3/\text{min} \]

(c) \( t_{machining} = L/FR = (150. \text{ mm})/100. \text{ mm/minute} = 1.5 \text{ min}. \)
15-8. Repeat the calculations in Example 15.2 in this chapter for a magnesium alloy being machined at 700. RPM.

**Need:** The machining power \( P_{\text{machining}} \) and the cutting torque \( T_{\text{cutting}} \)

**Know:** From Example 15.2, but with a magnesium alloy; \( N = 700 \) RPM; \( L = 6 \) in; \( D_o = 0.5 \) in; \( D_f = 0.48 \) in; \( FR = 4.0 \) in/min; and Table 1 gives the average machining energy per unit volume = 0.15 HP·min/in\(^3\)

**How:** Equation (15.7) gives: \( P_{\text{machining}} = (\text{Average Machining Energy Per Unit Volume}) \times (\text{Material Removal Rate}) \), and equation (15.8) gives: \( T_{\text{cutting}} = \frac{P_{\text{machining}}}{2\pi N} \)

**Solve:** \( d = \frac{(D_o - D_f)}{2} = 0.010 \) in; \( f = \frac{FR}{N} = 0.0057 \) in/rev and \( D_{\text{avg}} = \frac{(D_o + D_f)}{2} = 0.49 \) inches.

Then, **Material Removal Rate (MRR) in turning** = \( \pi D_{\text{avg}} f d N = 0.061 \) in\(^3\)/min

\[ P_{\text{machining}} = (\text{Average Machining Energy per Unit Volume}) \times \text{MRR} = (0.15 \text{ HP·min/in}^3)(0.062 \text{ in}^3/\text{min}) = 0.0093 \text{ HP} \]

\[ T_{\text{cutting}} = \frac{P_{\text{machining}}}{2\pi N} = \left[\frac{(0.0093 \text{ HP})/(2\pi \times 700 \text{ RPM})}{(33000 \text{ ft·lbf/min})/(1 \text{ HP})}\right] = 0.070 \text{ ft·lbf} \]
15-9. Determine the machining power and cutting torque required to machine a magnesium shaft on a lathe if the material removal rate \((MRR)\) is 0.10 in\(^3\)/min and \(N = 900\) RPM.

**Need:** The machining power \((P_{\text{machining}})\) and the cutting torque \((T_{\text{cutting}})\)

**Know:** The material is a magnesium alloy; \(MRR_{\text{turning}} = 0.10\) in\(^3\)/min; \(N = 900\) RPM; and from Table 1, the average machining energy/unit volume = 0.15 HP·min/in\(^3\)

**How:** Equation (15.7) gives: \(P_{\text{machining}} = (\text{Average Machining Energy Per Unit Volume}) \times (\text{Material Removal Rate})\), and equation (15.8) gives: \(T_{\text{cutting}} = \frac{P_{\text{machining}}}{2\pi N}\)

**Solve:** From equation (15.7), \(P_{\text{machining}} = (0.15 \text{ HPmin/in}^3)(0.10 \text{ in}^3\text{/min}) = 0.015 \text{ HP}\)

Then, equation (15.8) gives: \(T_{\text{cutting}} = \frac{(0.015 \text{ HP})}{[2\pi(900. \text{ RPM})]} \times (33000 \text{ ft·lbf/HP}) = 0.086 \text{ ft·lbf}\)
15-10. Determine the machining time required to turn a 0.20 m long shaft rotating at 300 RPM at a tool feed of 0.20 mm/rev.

**Need:** The machining time, $t_{\text{machining}}$.

**Know:** $L = 0.20$ m; $N = 300$. RPM; $f = 0.20$ mm/rev; $FR = fN = (0.20$ mm/rev) $\times$ (300. RPM) = 60. mm/min = 0.060 m/min

**How:** Equation (15.6) gives $t_{\text{machining}} = L/FR$.

**Solve:** Equation (15.6) gives: $t_{\text{machining}} = L/FR = 0.20$ m / 0.060 m/min = 3.3 min
15-11. A lathe is powered by a 5.0 HP electric motor and is running at 500. RPM. It is turning a 1.0 inch cast iron shaft with a depth of cut of 0.035 in. What is the maximum feed rate that can be used before the lathe stalls?

**Need:** Maximum feed rate \((FR)\) before stalling the lathe.

**Know:** Lathe motor is 5.0 HP and it is running at \(N = 500\). RPM. The material is a \(D_o = 1.0\) inch cast iron shaft and the cutting depth is \(d = 0.035\) inches.

**How:** Equation (15.7) gives the power required to operate the lathe as:

\[
P_{\text{machining}} = \text{(Average Machining Energy Per Unit Volume)} \times \text{(Material Removal Rate)}
\]

**Solve:** From Table 1, the Average Machining Energy per Unit Volume of cast iron is 1.2 HP·min/in\(^3\). Then, \(D_f = D_o - 2d = 1.0 - 2(0.035) = 0.93\) inches, and \(D_{\text{avg}} = (D_o + D_f)/2 = 0.97\) inches.

Equation (15.7) gives the material removal rate as: \(MRR_{\text{lathe}} = (5.0\ \text{HP})/(1.2\ \text{HP} \cdot \text{min}/\text{in}^3) = 4.2\ \text{in}^3/\text{min}\), and then equation (15.2) gives \(MRR_{\text{turning}} = \pi D_{\text{avg}} fdN\).

The corresponding tool feed is \(f = (MRR_{\text{turning}})/(\pi D_{\text{avg}} fdN)\)

\[
= (4.2\ \text{in}^3/\text{min})/((\pi \times (0.97\ \text{in}))(1.0\ \text{in})(500.\ \text{RPM})) = 0.0027\ \text{in/rev},
\]

and the maximum possible feed rate is:

\[
FR = f \times N = 0.0027 \times 500\ [\text{in/rev}][\text{rev/min}] = 1.35\ \text{in/min}.
\]
15-12. A 2.0 inch diameter carbon steel shaft is to be turned on a lathe at 500. RPM with a 0.20 inch depth of cut and a feed of 0.030 in/rev. What is the minimum horsepower and torque that the lathe must have to complete this operation?

**Need:** The minimum power and torque required.

**Know:** The material is carbon steel; \( D_o = 2.0 \) in; \( N = 500. \) RPM; \( d = 0.20 \) in; and \( f = 0.30 \) in/rev.

**How:** The lathe power and torque are given by equations (15.7), and (15.8) respectively.

**Solve:** \( D_f = D_o - 2d = 2.0 - 2(0.20 \text{ in}) = 1.6 \) inches, and \( D_{avg} = (D_o + D_f)/2 = 1.8 \) inches.

From equation (15.2), \( MRR_{turning} = \pi D_{avg}fdN = (\pi \times 1.8 \text{ in})(0.030 \text{ in/rev})(0.20 \text{ in})(500. \text{ RPM}) = 17. \text{ in}^3/\text{min}. \)

Then, equation (15.7) gives \( P_{drilling} = MRR_{drilling} \times (\text{Average Machining Energy Per Unit Volume}), \) or \( P_{drilling} = 17. \text{ in}^3/\text{min} \times 2.1 \text{ HP} \cdot \text{min}/\text{in}^3 = 36 \text{ HP}. \)

Equation (15.8) gives \( T_{drilling} = P_{drilling}/(2\pi N) = (36 \text{ HP})/(2\pi \times 500. \text{ RPM}) \times (33000 \text{ ft} \cdot \text{lbf}/\text{HP}) = 380 \text{ ft} \cdot \text{lbf} \)
15-13. Suppose the material used in Example 15.3 was an aluminum alloy and the drill rotational speed was 500. RPM. Recalculate the material removal rate, the power required, and the torque on the drill.

**Need:** The material removal rate, power and torque required in Example 15.3 for an aluminum alloy.

**Know:** The material is an aluminum alloy; \( D = 10. \text{ mm}; \) \( f = 0.20 \text{ mm/rev}; \) and \( N = 500. \text{ RPM}. \)

**How:** The material removal rate, power and torque are given by equations (15.10), (15.7), and (15.8) respectively.

**Solve:**

a) From equation (15.10), \( MRR_{\text{drilling}} = (\pi D^2/4)fN = (\pi \times 10.2/4 \text{ mm}^3) \times (0.20 \text{ mm/rev})(500. \text{ RPM}) = 7,900 \text{ mm}^3/\text{min}. \)

b) From equation (15.7), \( P_{\text{drilling}} = MRR_{\text{drilling}} \times (\text{Average Machining Energy Per Unit Volume}) = 7,900 \text{ mm}^3/\text{min} \times 0.70 \text{ W·s/mm}^3 \times 1 \text{ min/60 s} = 92. \text{ Watts} \)

c) From equation (15.8), \( T_{\text{drilling}} = P_{\text{drilling}}/(2\pi N) = (92. \text{ W})/(2\pi \times 500. \text{ RPM}) = 0.029 \text{ W·min} = 1.8 \text{ W·s} = 1.8 \text{ N·m} \)
15-14. A drill press with a 0.375 inch diameter drill bit is running at 300. RPM with a feed of 0.010 in/rev. What is the material removal rate?

**Need:** Material removal rate in drilling ($MRR_{drilling}$).

**Know:** $D = 0.375$ in; $N = 300$. RPM; $FR = 0.010$ in/rev

**How:** The drilling material removal rate is given by equations (15.10).

**Solve:** From equation (15.10),

$$MRR_{drilling} = \left(\pi D^2/4\right)F = \left(\pi \times 0.375^2/4\right)(0.010 \text{ in/rev})(300. \text{ RPM}) = 0.33 \text{ in}^3/\text{min}.$$
15-15. You need to drill a 20. mm hole in a piece of stainless steel. The drill feed is 0.10 mm/revolution and its rotational speed is 400. RPM. Determine:

- The material removal rate
- The power required
- The torque on the drill

**Need:** the drilling material removal rate, power, and torque required.

**Know:** Drilling in stainless steel; \( D = 20. \text{ mm} \); \( f = 0.10 \text{ mm/rev} \); \( N = 400. \text{ RPM} \).

**How:** The drilling material removal rate, power and torque are given by equations (15.10), (15.7), and (15.8) respectively.

**Solve:**

a) From equation (15.10),
\[
MRR_{\text{drilling}} = \frac{\pi D^2}{4} f N = \left( \frac{\pi \times 20^2}{4} \text{ mm}^2 \right) (0.10 \text{ mm/rev})(400. \text{ RPM}) = 1.3 \times 10^4 \text{ mm}^3/\text{min}.
\]

b) From equation (15.7),
\[
P_{\text{drilling}} = MRR_{\text{drilling}} \times (\text{Average Machining Energy Per Unit Volume}) = 1.3 \times 10^4 \text{ mm}^3/\text{min} \times 3.5 \text{ W·s/mm}^3 \times 1 \text{ min/60 s} = 760 \text{ Watts}
\]

c) From equation (15.8),
\[
T_{\text{drilling}} = \frac{P_{\text{drilling}}}{2\pi N} = \frac{(760 \text{ W})}{(2\pi \times 400. \text{ RPM})} = 0.30 \text{ W·min} = 18. \text{ W·s = 18. N·m}
\]
15-16. Repeat the calculations in Example 15.4 for stainless steel instead of cast iron. Use the same material dimensions and operating conditions, and compare the machining times for the two materials.

**Need:** Repeat the calculations in Example 15.4 using stainless steel instead of cast iron.

**Know:** The material is stainless steel; \( w = 4.0 \text{ in} \); \( L = 15. \text{ in} \); \( FR = 20. \text{ in/min} \); \( d = 0.10 \text{ in} \); and \( N = 100. \text{ RPM} \).

**How:** The material removal rate power and torque required are given by equations (15.13), (15.7) and (15.8). The milling time is given by equation (15.6).

**Solve:**

a) From equation (15.13), \( MRR_{\text{milling}} = (4.0 \text{ in} \times 0.10 \text{ in}) \times (20. \text{ in/min}) = 8.0 \text{ in}^3/\text{min} \)

b) From equation (15.7) and Table 1, \( P_{\text{milling}} = MRR_{\text{milling}} \times \text{(Average Machining Energy Per Unit Volume)} = (8.0 \text{ in}^3/\text{min})(1.4 \text{ HP min/in}^3) = 11. \text{ HP} \)

c) From equation (15.8), \( T_{\text{milling}} = P_{\text{milling}}/(2\pi N) = (11. \text{ HP})/(2 \times 100. \text{ RPM}) = 0.018 \text{ HP·min} \)

d) From equation (15.6), \( t_{\text{milling}} = L/FR = 15./20. = 0.75 \text{ min} = 45 \text{ seconds} \).
15-17. A flat piece of cast iron 100. mm wide and 150. mm long is to milled with a feed rate of 200. mm/minute with a depth of cut of 1.0 mm. The milling cutter rotates at 100. RPM, and is wider than the workpiece. Determine:

   a. The material removal rate
   b. The machining power required
   c. The machining torque required
   d. The time required to machine the workpiece

   **Need:** a) Material removal rate \( (MRR_{milling}) \)
   b) Machining power required \( (P_{milling}) \)
   c) Machining torque required \( (T_{milling}) \)
   d) Time required to machine the workpiece \( (t_{milling}) \)

   **Know:** The material is cast iron; width \( W = 100. \text{ mm} \); length \( L = 150. \text{ mm} \); feed rate \( FR = 200. \text{ mm/min} \); depth of cut \( d = 1.0 \text{ mm} \); rotating at \( N = 100. \text{ RPM} \).

   **How:** The material removal rate, power and torque required are given by equations (15.13), (15.7) and (15.8). The milling time is given by equation (15.6).

   **Solve:** a) From equation (15.13), \( MRR_{milling} = \text{width} \times \text{depth of cut} \times \text{feed rate} = 100. \text{ mm} \times 1.0 \text{ mm} \times 200. \text{ mm/min} = 2.0 \times 10^4 \text{ mm}^3/\text{min} \)

b) From equation (15.7) and Table 1, \( P_{maching} = \text{average machining energy per unit volume} \times MRR = 3.3 \text{ W·s/mm}^2 \times 2.0 \times 10^4 \text{ mm}^3/\text{min} \times 1 \text{ min/60 sec} = 1100 \text{ W} \)

c) From equation (15.8), \( T_{(maching)} = P_{(maching)} / (2\pi N) = (1100 \text{ W} / (2\pi \times 100. \text{ RPM})) \times (60 \text{ sec/min}) \times (1 \text{ N·m/s})/(1\text{W}) = 110 \text{ N·m} \)

d) From equation (15.6), \( t_{maching} = \text{length/ feed rate} = 150. \text{ mm/ 200. mm/min} = 0.800 \text{ min} \)
15-18. A milling operation is carried out on a 10. inch long, 3.0 inch wide slab of aluminum alloy. The cutter feed is 0.01 in/tooth, and the depth of cut is 0.125 inches. The cutter is wider than the slab and the diameter is 2.0 inches. It has 25 teeth and rotates at 150 RPM. Calculate:

a. The material removal rate
b. The power required
c. The torque at the cutter

**Need:**

a) Material Removal Rate  
   b) Machining Power Required  
   c) Machining Torque Required

**Know:** Slab milling machine, aluminum alloy, width $W = 3.0$ in, length $L = 10.$ in, depth of cut $d = 0.125$ in, feed $f = 0.01$ in/tooth, cutter diameter $D = 2.0$ in, number of teeth $n = 25$ teeth, rotating at $N = 150$ RPM.

**How:** The material removal rate power and torque required are given by equations (15.13), (15.7) and (15.8).

**Solve:**

a) From equation (15.13), $MRR_{milling} = \text{width} \times \text{depth of cut} \times \text{feed/tooth} \times \text{rotational speed} \times \text{number of teeth} = 3.0 \text{ in} \times 0.125 \text{ in} \times 0.01 \text{ in/tooth} \times 150 \text{ rev/min} \times 25 \text{ teeth} = 14. \text{ in}^3/\text{min}$

b) From equation (15.7), $P_{\text{machining}} = \frac{\text{average machining energy per unit volume} \times \text{MRR}}{1.2 \text{ HP·min/in}^3}$ $= 17. \text{ HP}$

c) From equation (15.8), $T_{\text{machining}} = \frac{P_{\text{machining}}}{(2\pi N)} = 17. \frac{\text{HP}}{2\pi \times 150 \text{ RPM}} \times (33000 \text{ ft lbf / HP·min}) = 6.0 \times 10^2 \text{ ft·lb}$
15-19. A part 275. mm long and 75. mm wide is to be milled with a 10-toothed cutter 75. mm in diameter using a feed of 0.10 mm/tooth at a cutting speed of 40.×10³ mm/min. The depth of cut is 5.0 mm. Determine the material removal rate and the time required to machine the part.

**Need:** The material removal rate \(MRR_{\text{milling}}\) and the machining time \(t_{\text{milling}}\).

**Know:** \(L = 275. \text{ mm}; \ W = 75. \text{ mm}; \ n = 10 \text{ teeth}; \ D = 75. \text{ mm}; \ f = 0.10 \text{ mm/tooth}; \ V_{\text{milling}} = 40. \times 10^3 \text{ mm/min}; \ d = 5.0 \text{ mm}.\)

**How:** The material removal rate and milling time are given by equations (15.13) and (15.14).

**Solve:** We can solve for the rotational speed of the cutter as: \(N = V_{\text{milling}}/(\pi D) = (40. \times 10^3 \text{ mm/min})/(\pi \times 75. \text{ mm}) = 530 \text{ RPM}.\)

Then, equation (15.12) gives the feed rate as: \(FR = fNn = (0.10 \text{ mm/tooth})(530 \text{ RPM})(10 \text{ teeth}) = 530 \text{ mm/min}.\)

Now, equation (15.13) gives \(MRR_{\text{milling}} = wdFR = (75. \text{ mm})(5.0 \text{ mm})(530 \text{ mm/min}) = 20. \times 10^4 \text{ mm}^3/\text{min}.\)

The milling time is given by equation (15.14) as: \(t_{\text{milling}} = L/FR = (275. \text{ mm})/(530 \text{ mm}^3/\text{min}) = 0.52 \text{ min}.\)
15-20. In the face-milling operation shown below the cutter is 1.5 inches in diameter and the cast iron workpiece is 7.0 inches long and 3.75 inches wide. The cutter has 8 teeth and rotates at 350 RPM. The feed is 0.005 in/tooth and the depth of cut is 0.125 inches. Assuming that only 70.\% of the cutter diameter is engaged in the cutting, determine the material removal rate and the machining power required.

Need: The material removal rate \( (MRR_{\text{milling}}) \) and the machining power \( (P_{\text{milling}}) \).

Know: the material is cast iron; \( D = 1.5 \text{ in} \); \( L = 7.0 \text{ in} \); \( W = 3.75 \text{ in} \); \( n = 8 \) teeth; \( N = 350 \text{ RPM} \); \( f = 0.05 \text{ in/tooth} \); \( d = 0.125 \text{ inches} \).

How: The material removal rate and machining power are given by equations (15.13) and (15.7).

Solve: Equation (15.12) gives the feed rate as: \( FR = fNn = (0.05 \text{ in/tooth})(350 \text{ RPM})(8 \text{ teeth}) = 140 \text{ in/min} \).

Equation (15.13) gives \( MRR_{\text{milling}} = wdFR \), but in face milling \( W = \) the percentage of the cutter diameter engaged in cutting, which is 70.\% here. So, \( w = 0.70D = 0.70(1.5) = 1.1 \text{ inches} \).

Then, \( MRR_{\text{milling}} = (1.1 \text{ in})(0.125 \text{ in})(140 \text{ in/min}) = 19. \text{ in}^3/\text{min} \).

The machining power is given by equation (15.7) as: \( P_{\text{milling}} = (\text{average machining energy per unit volume}) \times MRR_{\text{milling}} = (1.2 \text{ HP/min/in}^3)(19. \text{ in}^3/\text{min}) = 23. \text{ HP} \).
15-21. In Example 15.5, we did not take into account recycling or disposal costs or benefits. Do you think his conclusions would change if these were included? Plot the net energy per use vs. the number of uses for the reusable and disposable cups.

**Need:** An opinion regarding the effect of recycling and disposal costs on the results of Example 15.5, plus a plot of the net energy per use vs. the number of uses of reusable and disposable cups.

**Know:** The results from example 15.5.

**How:** This requires an opinion about the financial effects of recycling and disposal of the plastic, paper, and foam cups. These cups are mostly disposed in landfills with few recycled. Since these costs are currently relatively low, their disposal would have little effect on the results reached in Example 15.5.

**Solve:** Draw conclusions from everyday experience regarding packaging and disposal costs. In the U.S. today, these would have little effect on the conclusions reached in Example 15.5.
15-22. The equation for a normal error curve is:

\[
\frac{\exp\left(-\frac{1}{2} \left(\frac{x - \mu}{\sigma}\right)^2\right)}{\sigma \sqrt{2\pi}}
\]

or in spreadsheet script:

\[
\exp(-0.5 * ((x - \mu) / \sigma)^2) / (\sigma * \text{sqrt}(2 * \text{pi}())
\]

Plot a normal distribution curve for the set of 100 numbers from 0 to 99. (Hint: Use the Chart–Column graphical representation. Observe its shape and calculate its mean and standard distribution. See exercise 23).

**Need**: Plot of a normal distribution & μ and σ for set of numbers from 0 to 100.

**Know**: Functional form of normal error curve:

\[
\frac{\exp\left(-\frac{1}{2} \left(\frac{x - \mu}{\sigma}\right)^2\right)}{\sigma \sqrt{2\pi}}
\]

**How**: Spreadsheet, using exp (-0.5 * ((x - μ) / σ)^2) / (σ * sqrt(2 * pi()))

**Solve**: 
<table>
<thead>
<tr>
<th></th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>x (normal distribution)</td>
<td>Normal, %</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>3.18E-03</td>
<td>3.18E-01</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>3.37E-03</td>
<td>3.37E-01</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>3.57E-03</td>
<td>3.57E-01</td>
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<tr>
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<td>5</td>
<td>4.21E-03</td>
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<th>B</th>
<th>C</th>
<th>D</th>
</tr>
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<td>97</td>
<td>3.57E-03</td>
<td>3.57E-01</td>
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<tr>
<td>100</td>
<td>98</td>
<td>3.37E-03</td>
<td>3.37E-01</td>
</tr>
<tr>
<td>101</td>
<td>99</td>
<td>3.18E-03</td>
<td>3.18E-01</td>
</tr>
<tr>
<td>102</td>
<td>μ</td>
<td>=49.5</td>
<td></td>
</tr>
<tr>
<td>103</td>
<td>σ</td>
<td>=28.9</td>
<td></td>
</tr>
</tbody>
</table>

<table>
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<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
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<tr>
<td>99</td>
<td>=1+B98</td>
<td>=EXP(-0.5 * (B99-B$102)) =C99*100</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>=1+B99</td>
<td>=EXP(-0.5 * (B100-B$102)) =C100*100</td>
<td></td>
</tr>
<tr>
<td>101</td>
<td>=1+B100</td>
<td>=EXP(-0.5 * (B101-B$102)) =C101*100</td>
<td></td>
</tr>
<tr>
<td>102</td>
<td>μ =</td>
<td>=AVERAGE(B2:B101)</td>
<td></td>
</tr>
<tr>
<td>103</td>
<td>σ =</td>
<td>=STDEV(B2:B101)</td>
<td></td>
</tr>
</tbody>
</table>

**Normal distribution**

- Frequency, %
- x value
15-23. Students often are confused by the difference between a normal distribution curve, as in exercise 22, and a random distribution. Excel has a variable rand() that will generate random numbers between 0 and 1. (See the Excel Help menu to see how to use it.) Plot a random curve for the set of 100 numbers from 0 to 99.

(Hint: Use the Chart–Column representation. Observe its shape and calculate its mean and standard distribution.)

**Need:** Side by side graphs of a list of random numbers and a normal distribution.

**Know:** rand() will create random numbers between 0 & 1. The equation for a normal distribution is:

$$
\exp\left(-\frac{1}{2}\left(\frac{x - \mu}{\sigma}\right)^2\right) / \sigma \sqrt{2\pi}
$$

**How:** Use a Spreadsheet – it will give average(data), stdevp(data) and to generate a random real number between $a$ and $b$, use:

$$
\text{RAND()}*(b-a) + a.
$$

**Solve:**

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
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<td></td>
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<td>96</td>
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<td>51.7</td>
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<td>28.9</td>
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<td>27.3</td>
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<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>=EXP(-0.5 <em>( (B2-B$102)/B$103)^2)/(B$103</em>SQRT(2*PI())))</td>
<td>=C2*100</td>
<td>=RAND()*(B$101-B$2)+B$2</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>=1+B2</td>
<td>=EXP(-0.5 <em>( (B3-B$102)/B$103)^2)/(B$103</em>SQRT(2*PI())))</td>
<td>=C3*100</td>
<td>=RAND()*(B$101-B$2)+B$2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>=EXP(-0.5 <em>( (B4-B$102)/B$103)^2)/(B$103</em>SQRT(2*PI())))</td>
<td>=C4*100</td>
<td>=RAND()*(B$101-B$2)+B$2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>=EXP(-0.5 <em>( (B5-B$102)/B$103)^2)/(B$103</em>SQRT(2*PI())))</td>
<td>=C5*100</td>
<td>=RAND()*(B$101-B$2)+B$2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>=EXP(-0.5 <em>( (B6-B$102)/B$103)^2)/(B$103</em>SQRT(2*PI())))</td>
<td>=C6*100</td>
<td>=RAND()*(B$101-B$2)+B$2</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>=EXP(-0.5 <em>( (B7-B$102)/B$103)^2)/(B$103</em>SQRT(2*PI())))</td>
<td>=C7*100</td>
<td>=RAND()*(B$101-B$2)+B$2</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>=EXP(-0.5 <em>( (B8-B$102)/B$103)^2)/(B$103</em>SQRT(2*PI())))</td>
<td>=C8*100</td>
<td>=RAND()*(B$101-B$2)+B$2</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>=EXP(-0.5 <em>( (B9-B$102)/B$103)^2)/(B$103</em>SQRT(2*PI())))</td>
<td>=C9*100</td>
<td>=RAND()*(B$101-B$2)+B$2</td>
<td></td>
</tr>
</tbody>
</table>

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The shapes of the curves are quite different. The normally distributed case can be thought of as a dart player aiming always for the bull’s eye. The hits will cluster around the bull’s eye and tail off around the edge of the dart board. On the other hand the random case is simply throwing the darts at haphazardly with no aim at all. There’s an equal probability the darts will land anywhere.

Note both curves have approximately the same means (49.5 and 50.8) and std. deviations (28.9 and 29.7); however, for the random case, it will vary for each particular set of 100 random numbers. Had we had 10,000 random numbers it would vary much less.
15-24. Three hundred widgets are manufactured with the following normal error distribution statistics: mean = 123 units, standard deviation is (a) 23 units, (b) 32.5 units, and (c) 41 units. How many will measure less than 140. units?

**Need:** For three distributions of 300 widgets with \( \sigma = 23, 32.5, \) and 41 “units”, the number < 140. units = ________?

**Know - How:** Since distribution is normal error, can use Excel functions NORMDIST or NORMSDIST, the former for data in non-standard form, the latter in standard form.

**Solve:** **Method 1** Use NORMDIST \((x, \mu, \sigma, \text{TRUE})\) in which \(x\) is the value you want to test with a mean \(\mu\), a standard deviation \(\sigma\) and a variable set to “TRUE” so that NORMDIST returns the probability that the value will be less than or equal to \(x\).

\[
\text{NORMDIST}(x, \text{mean}, \text{standard}_\text{dev}, \text{cumulative})
\]

See: [http://www.exceluser.com/explore/statsnormal.htm](http://www.exceluser.com/explore/statsnormal.htm)

NORMDIST gives the probability that a number falls at or below a given value of a normal distribution. It's the unshaded area on the chart.

x -- The value you want to test.

\text{mean} -- The average value of the distribution.

\text{standard}_\text{dev} -- The standard deviation of the distribution.

\text{cumulative} -- If FALSE or zero, returns the probability that \(x\) will occur;

if TRUE or non-zero, returns the probability that the value will be less than or equal to \(x\).

Example: The distribution of heights of American women aged 18 to 24 is approximately normally distributed with a mean of 65.5 inches (166.37 cm) and a standard deviation of 2.5 inches (6.35 cm).

What percentage of these women is taller than 5' 8", that is, 68 inches (172.72 cm)?
The percentage of women less than or equal to 68 inches is:

\[
=\text{NORMDIST}(68, 65.5, 2.5, \text{TRUE}) = 84.13\% 
\]

Therefore, the percentage of women taller than 68 inches is 1 - 84.13%, or approximately 15.87%.

This value is represented by the shaded area in the chart above.

<table>
<thead>
<tr>
<th>Method 1: NORMDIST</th>
<th>(N)</th>
<th>(\mu)</th>
<th>(\sigma)</th>
<th>(x), Cutoff</th>
<th>Fraction (&lt;= x)</th>
<th>Number (&lt;= x)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case a)</td>
<td>300</td>
<td>123</td>
<td>23</td>
<td>140</td>
<td>0.770</td>
<td>231</td>
</tr>
<tr>
<td>Case b)</td>
<td>300</td>
<td>123</td>
<td>32.5</td>
<td>140</td>
<td>0.700</td>
<td>210</td>
</tr>
<tr>
<td>Case c)</td>
<td>300</td>
<td>123</td>
<td>41</td>
<td>140</td>
<td>0.661</td>
<td>198</td>
</tr>
<tr>
<td>Method 1: NORMDIST</td>
<td>N</td>
<td>μ</td>
<td>σ</td>
<td>x, Cutoff</td>
<td>Fraction &lt;= x</td>
<td>Number &lt;= x</td>
</tr>
<tr>
<td>-------------------</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>-----------</td>
<td>---------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Case a)</td>
<td>300</td>
<td>123</td>
<td>23</td>
<td>140</td>
<td>=NORMDIST(E39, C39, D39, TRUE)</td>
<td>=B39*F39</td>
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<tr>
<td>Case b)</td>
<td>300</td>
<td>123</td>
<td>32.5</td>
<td>140</td>
<td>=NORMDIST(E40, C40, D40, TRUE)</td>
<td>=B40*F40</td>
</tr>
<tr>
<td>Case c)</td>
<td>300</td>
<td>123</td>
<td>41</td>
<td>140</td>
<td>=NORMDIST(E41, C41, D41, TRUE)</td>
<td>=B41*F41</td>
</tr>
</tbody>
</table>

Method 2) Uses NORMSDIST (z)

See: [http://www.exceluser.com/explore/statsnormal.htm](http://www.exceluser.com/explore/statsnormal.htm)

**NORMSDIST(z)**

NORMSDIST translates the number of standard deviations (z) into cumulative probabilities. It's the unshaded area on the first chart.

To illustrate:

= NORMSDIST(-1) = 15.87%

Therefore, the probability of a value being within one standard deviation of the mean is the difference between these values, or 68.27%.

This range is represented by the shaded area of the second chart.

<table>
<thead>
<tr>
<th>Method 2: NORMDIST</th>
<th>N</th>
<th>μ</th>
<th>σ</th>
<th>x, Cutoff</th>
<th>Z value</th>
<th>Fraction &lt;= x</th>
<th>Number &lt;= x</th>
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</thead>
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<td>0.770</td>
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<tr>
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<td>140</td>
<td>0.523</td>
<td>0.700</td>
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</tr>
<tr>
<td>Case c)</td>
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<td>41</td>
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<td>0.415</td>
<td>0.661</td>
<td>198</td>
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<thead>
<tr>
<th>Method 2: NORMSDIST</th>
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<th>μ</th>
<th>σ</th>
<th>x, Cutoff</th>
<th>Z value</th>
<th>Fraction &lt;= x</th>
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<tr>
<td>Case a)</td>
<td>300</td>
<td>123</td>
<td>23</td>
<td>140</td>
<td>= (E69-C69)/D69</td>
<td>=NORMSDIST(F69)</td>
<td>=B69*G69</td>
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<tr>
<td>Case b)</td>
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<td>123</td>
<td>32.5</td>
<td>140</td>
<td>= (E70-C70)/D70</td>
<td>=NORMSDIST(F70)</td>
<td>=B70*G70</td>
</tr>
<tr>
<td>Case c)</td>
<td>300</td>
<td>123</td>
<td>41</td>
<td>140</td>
<td>= (E71-C71)/D71</td>
<td>=NORMSDIST(F71)</td>
<td>=B71*G71</td>
</tr>
</tbody>
</table>
15-25. We wish to fit steel rods \( (\mu = 21.2 \text{ mm}, \sigma = 0.20 \text{ mm}) \) into the following jig in order to make sure we can meet specifications. The process requires that 97.5\% of all rods are to be within specifications. (Presume that no rod is so short that it cannot pass specifications.) What is the appropriate size \( L \text{ mm} \) of the jaws of the jig?

**Hint:** 95\% of (two-sided) normally distributed data are found within \( \pm 2\sigma \) from the mean and therefore 2.5\% of the rods are too large.

\[
21.2 \pm \text{ mm}
\]

Need: Jig jaws size, \( L = \) ____________ mm.

Know: For the rods, \( \mu = 21.2 \text{ mm}, \sigma = 0.20 \text{ mm} \). Assume distribution follows a normal curve.

How: First make a quick sketch of the histogram.

Only a rough sketch is all that is needed.
**Solve:** On the standard normal distribution curve, $Z = \pm 2$ has 95% of the data within $2\sigma$ and therefore 97.5% of the data for $Z \leq 2$.

Since $Z = \frac{L - \mu}{\sigma}$, $L = 2 \times 0.20 + 21.2 = 21.6 \text{ mm}$

This size jig will have 2.5% of the widgets larger than 21.6 mm and fail the quality test. Obviously there are rods as large as 21.6 mm passing the quality test. The only way to improve this is to tighten up machining practices to reduce $\sigma$. 
15-26. The jig in exercise 25 is now OK, except we are now getting too many undersized rods passing specifications. The manufacturing section of your company wants to eliminate all rods 0.2 mm or more that are undersized so that \( L = 21.0 \) mm is the lower cutoff. What fraction will now pass specifications?

**Need:** Percentage of rods passing specification = __________%  

**Know:** For the rods, \( \mu = 21.2 \) mm, \( \sigma = 0.20 \) mm. Assume distribution follows a normal curve.

**How:** First sketch the histogram that represents the problem.

![Histogram](image)

**Solve:** All we need is the fraction of rods failing whose length is less than 21.0 mm. Use NORMSDIST or NORMDIST. That answer is that 15.9% fail for being too small. Total failures: 15.9 + 2.5 = 18.4%.
15-27. You perform 100 tests on one of two prototypes of the X15-24 line of products and a colleague performs another 100 tests on the other prototype.

<table>
<thead>
<tr>
<th>Test set Statistic</th>
<th>Your test</th>
<th>Colleague’s test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean, μ</td>
<td>125.7</td>
<td>123.5</td>
</tr>
<tr>
<td>Std Dev, σ</td>
<td>1.50</td>
<td>13.3</td>
</tr>
</tbody>
</table>

Graphing of the tests is similar with your data as circles and your colleagues as crosses:

Your colleague notes that because the means of the measurements are virtually identical, there is no difference between the two prototypes and that therefore hers should be used because it will be cheaper to manufacture (which you concede). What counterarguments can you muster?

**Need:** Arguments as to why X15-24 widgets would be better if they are built with smaller standard deviations in manufacturing them.

**Know:** Larger σ would be cheaper to manufacture

**How:** Cost of rejects increases with increasing σ

**Solve:** Do a comparison between here and yours.
For your colleague’s data at \( Z = 2 \), \( Z = \frac{x - \mu}{\sigma}, \quad x = \pm 2 \times 13.3 + 123.5 \)

and the accepted range of \( x \) is 96.9 to 150.1

Your statistics are \( x = \pm 2 \times 1.5 + 125.7 \) and the accepted range of your data is 120.5 to 126.5.

Can the application for the X15-24’s really work with her large spread?

If so, concede; if not, yours is the better product.
15-28. Quality control is more personal when the products are hand grenades and it’s your turn to learn how to throw one. You understand that once you pull the pin, if you hold on too long you might be severely injured or killed. However, if the fuse burns too long after you have thrown it, the enemy might have time to pick it up and throw it back at you with results similar to holding it too long. Suppose the fuse burn time is designed to be 4.00 s with a standard deviation of 0.2 s, and the grenade has been made to Six Sigma standards. What is the variability you can expect on the time for it to detonate after pulling its safety pin?

**Need:** Six Sigma limits on time to explode, \( t = \) ______ s..

**Know:** \( \mu = 4.00 \) s and \( \sigma = 0.1 \) s. The Six Sigma limits are at \( Z = \pm 6 \).

**How:** \( Z = (x_i - \mu) / \sigma \)

**Solve:** \( \text{time} = x_i = 4.00 \pm 6 \times 0.1 = 3.4 \text{ to } 4.6 \text{ s.} \)

If you want a narrower range (and I would) the only way to achieve it is to make better hand grenades with a smaller \( \sigma \), say 0.01 s rather than 0.1 s so that then \( x_i = 4 \pm 6 \times 0.01 = 3.94 \) to 4.06 s.
15-29. You are a new quality control engineer at a company that manufactures bottled drinking water. All the bottles and the filling water are checked hourly to make sure that there are no contaminants. Monday morning you notice that for some reason the water that was used to wash the bottles before filling was not tested over the weekend. Now you have several carloads of product ready to be shipped. What do you do?

a. Have the shipment destroyed and start filling them over again.
b. Test random samples for the shipment and if they pass send the shipment.
c. Tell your supervisor and let him or her decide what to do.
d. Since the wash water has never been contaminated in the past, do nothing and release the shipment.

Use the Engineering Ethics Matrix.

1) In Engineering Ethics Matrix format:

<table>
<thead>
<tr>
<th>Options</th>
<th>a) Destroy and refill</th>
<th>b) Test random samples</th>
<th>c) Tell supervisor</th>
<th>d) Do nothing-release shipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hold paramount the safety, health and welfare of the public.</td>
<td>Meets canon</td>
<td>May not meet canon unless random sampling has been verified as assuring safety</td>
<td>Meets canon</td>
<td>Does not meet canon</td>
</tr>
<tr>
<td>Perform services only in the area of your competence</td>
<td>Meets canon</td>
<td>May not meet canon if you are not the company’s safety authority</td>
<td>Meets canon</td>
<td>Does not meet canon</td>
</tr>
<tr>
<td>Issue public statements only in an objective and truthful manner</td>
<td>Does not apply</td>
<td>Does not apply</td>
<td>Does not apply</td>
<td>Does not apply</td>
</tr>
<tr>
<td>Act for each employer or client as faithful agents or trustees</td>
<td>Does not meet canon unless this is what you have been instructed to</td>
<td>Does not meet canon unless this is what you have been instructed to</td>
<td>Meets canon</td>
<td>Does not meet canon</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Avoid deceptive acts</th>
<th>Meets canon</th>
<th>May meet canon if this is policy</th>
<th>Meets canon</th>
<th>Does not meet canon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conduct themselves honorably …</td>
<td>Meets canon</td>
<td>May meet canon</td>
<td>Meets canon</td>
<td>Does not meet canon</td>
</tr>
</tbody>
</table>

Do c). Pass the buck – tell your supervisor (that’s what he is there for!)
As a young engineer, you have been told not to trust the machinists who work for you. They will make up excuses for bad parts that aren’t true because they are lazy or incompetent. One day a machinist tells you his milling machine is “out of calibration,” and that he can’t make parts to specification unless the machine is repaired. What do you do?

a. Replace him with a more competent machinist.

b. Ask the machine shop supervisor to check the milling machine to see if there is a problem.

c. Ask the machinist to show you exactly what he means by demonstrating the problem.

d. Tell your supervisor you need a raise if you have to work with idiots like this.

Use the Engineering Ethics Matrix.

1) In Engineering Ethics Matrix format:

<table>
<thead>
<tr>
<th>Options</th>
<th>a) Replace</th>
<th>b) Ask supervisor to check</th>
<th>c) Ask machinist to show what he means</th>
<th>d) Tell supervisor you need raise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canons</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hold paramount the safety, health and welfare of the public.</td>
<td>Does not apply</td>
<td>Does not apply</td>
<td>Does not apply</td>
<td>Does not apply</td>
</tr>
<tr>
<td>Perform services only in the area of your competence</td>
<td>Does not meet canon</td>
<td>Meets canon</td>
<td>Meets canon</td>
<td>Does not apply</td>
</tr>
<tr>
<td>Issue public statements only in an objective and truthful manner</td>
<td>Does not apply</td>
<td>Does not apply</td>
<td>Does not apply</td>
<td>Does not apply</td>
</tr>
<tr>
<td>Act for each employer or client as faithful agents or trustees</td>
<td>Does not meet canon- might cause a union problem as well</td>
<td>Meets canon</td>
<td>Meets canon unless union or other shop rules forbid it</td>
<td>Does not apply</td>
</tr>
<tr>
<td>Avoid deceptive acts</td>
<td>Does not apply</td>
<td>Meets canon</td>
<td>Meets canon</td>
<td>Does not apply</td>
</tr>
<tr>
<td>Conduct themselves honorably …</td>
<td>Does not meet canon</td>
<td>Meets canon</td>
<td>Meets canon</td>
<td>Does not apply</td>
</tr>
</tbody>
</table>
In this case you should consider b) or c).