Answer. (b) and (d).

Problems

Cutting Operations

20.1 A power shears is used to cut soft cold-rolled steel that is 4.75 mm thick. At what clearance should the shears be set to yield an optimum cut?

Solution: From Table 20.1, A_c = 0.060. Thus, $c = A_c t$ = 0.060(4.75) = **0.285 mm**

20.2 A blanking operation is to be performed on 2.0 mm thick cold-rolled steel (half hard). The part is circular with diameter = 75.0 mm. Determine the appropriate punch and die sizes for this operation.

Solution: From Table 20.1, A_c = 0.075. Thus, c = 0.075(2.0) = 0.15 mm.
Punch diameter = D_b - 2c = 75.0 - 2(0.15) = **74.70 mm**.
Die diameter = D_b = **75.0 mm.**

20.3 A compound die will be used to blank and punch a large washer out of 6061ST aluminum alloy sheet stock 3.50 mm thick. The outside diameter of the washer is 50.0 mm and the inside diameter is 15.0 mm. Determine (a) the punch and die sizes for the blanking operation, and (b) the punch and die sizes for the punching operation.

Solution: From Table 20.1, A_c = 0.060. Thus, c = 0.060(3.50) = 0.210 mm

(a) Blanking punch diameter = D_b - 2c = 50 - 2(0.21) = **49.58 mm**
Blanking die diameter = D_b = **50.00 mm**

(b) Punching punch diameter = D_h = **15.00 mm**
Punching die diameter = D_h + 2c = 30 + 2(0.210) = **15.42 mm**

20.4 A blanking die is to be designed to blank the part outline shown in Figure P20.4. The material is 4 mm thick stainless steel (half hard). Determine the dimensions of the blanking punch and the die opening.

Solution: From Table 20.1, A_c = 0.075. Thus, c = 0.075(4.0) = 0.30 mm
Blanking die: dimensions are the same as for the part in Figure P20.4.
Blanking punch: 85 mm length dimension = 85 - 2(0.3) = **84.4 mm**
50 mm width dimension = 50 - 2(0.3) = **49.4 mm**
Top and bottom 25 mm extension widths = 25 - 2(0.3) = **24.4 mm**
The 25 mm inset dimension remains the same.

20.5 Determine the blanking force required in Problem 20.2, if the shear strength of the steel = 325 MPa and the tensile strength is 450 MPa.

Solution: $F = StL$
t = 2.0 mm from Problem 20.2.
$L = \pi D = 75\pi$ = 235.65 mm
F = 325(2.0)(235.65) = **153,200 N**

20.6 Determine the minimum tonnage press to perform the blanking and punching operation in Problem 20.3. The aluminum sheet metal has a tensile strength = 310 MPa, a strength coefficient of 350 MPa, and a strain-hardening exponent of 0.12. (a) Assume that blanking and punching occur simultaneously. (b) Assume the punches are staggered so that punching occurs first, then blanking.

Solution: (a) $F = 0.7(TS)tL$
t =3.5 mm from Problem 20.3.
$L = 50\pi + 15\pi = 65\pi$ = 204.2 mm
F = 0.7(310)(3.5)(235.6) = **155,100 N =** 155,1000/(4.4482*2000) tons **= 17.4 tons => 18 ton press**

(b) Longest length will determine the minimum tonnage press required.
Punching length of cut, $L = 15\pi$, blanking length of cut, $L=50\pi$ = 157.1 mm (use blanking)
F = 0.7(310)(3.5)(157.1) = **119,300 N =** 119,3000/(4.4482*2000) tons **= 13.4 tons => 14 ton press**

20.7 Determine the tonnage requirement for the blanking operation in Problem 20.4, given that the stainless steel has a yield strength = 500 MPa, a shear strength = 600 MPa, and a tensile strength = 700 MPa.

Solution: $F = StL$
t = 4 mm from Problem 20.4.
L = 85 + 50 + 25 + 25 + 35 + 25 + 25 + 50 = 320 mm
F = 600(4.0)(320) = **768,000 N.** This is about **86.3 tons**

20.8 The foreman in the pressworking section comes to you with the problem of a blanking operation that is producing parts with excessive burrs. (a) What are the possible reasons for the burrs, and (b) what can be done to correct the condition?

Solution: (a) Reasons for excessive burrs: (1) clearance between punch and die is too large for the material and stock thickness; and (2) punch and die cutting edges are worn (rounded) which has the same effect as excessive clearance.

(b) To correct the problem: (1) Check the punch and die cutting edges to see if they are worn. If they are, regrind the faces to sharpen the cutting edges. (2) If the die is not worn, measure the punch and die clearance to see if it equals the recommended value. If not, die maker must rebuild the punch and die.

Bending

20.9 A bending operation is to be performed on 5.00 mm thick cold-rolled steel. The part drawing is given in Figure P20.9. Determine the blank size required.

Solution: From drawing, α' = 40°, R = 8.50 mm
$\alpha = 180 - \alpha' = 140°$.
$A_b = 2\pi(\alpha/360)(R + K_{ba}t)$
R/t = (8.5)/(5.00) = 1.7, which is less than 2.0; therefore, K_{ba} = 0.333
A_b = 2π(140/360)(8.5 + 0.333 x 5.0) = 24.84 mm
Dimensions of starting blank: w = **35 mm,** L = 58 + 24.84 + 46.5 = **129.34 mm**

20.10 Solve Problem 20.9 except that the bend radius R = 11.35 mm.

Solution: From drawing, α' = 40°, R = 11.35 mm
$\alpha = 180 - \alpha' = 140°$.
$A_b = 2\pi(\alpha/360)(R + K_{ba}t)$
R/t = (11.35)/(5.00) = 2.270; therefore, K_{ba} = 0.5
A_b = 2π(140/360)(11.35 + 0.5 x 5.00) = 34.21 mm
Dimensions of starting blank: w = **35 mm,** L = 58 + 34.21 + 46.5 = **138.71 mm**

20.11 An L-shaped part is to be bent in a V-bending operation on a press brake from a flat blank 4.0 in by 1.5 in that is 5/32 in thick. The bend of 90° is to be made in the middle of the 4-in length. (a) Determine the dimensions of the two equal sides that will result after the bend, if the bend radius = 3/16 in. For convenience, these sides should be measured to the beginning of the bend radius. (b) Also, determine the length of the part's neutral axis after the bend. (c) Where should the machine operator set the stop on the press brake relative to the starting length of the part?

Solution: (a) R/t = (3/16)/(5/32) = 1.2. Therefore, K_{ba} = 0.33
A_b = 2π(90/360)(0.1875 + 0.33 x 0.15625) = 0.3756 in
Dimensions (lengths) of each end = 0.5(4.0 - 0.3756) = **1.8122 in**

(b) Since the metal stretches during bending, its length will be greater after the bend than before. Its length before bending = 4.000 in. The stretched length of the bend along the neutral axis will be:
Bent length = 2π(90/360)(0.1875 + 0.5 x 0.15625) = 0.4173 in
Therefore, the length of the neutral axis of the part will be 2(1.8122) + 0.4173 = **4.0417 in**

However, if stretching occurs along the neutral axis of the bend, then thinning of the stretched metal will also occur, and this will affect the preceding calculated value of the length of the bent section. The amount of thinning will be inversely proportional to the amount of stretching because volume must remain constant, before and after bending. The sheet thickness after bending (assuming uniform stretching and thinning) = (0.3756/0.4173)(0.15625) = 0.1406 in. Now let us recalculate the length of the bent section with this new value of t.

The bend radius will remain the same (R = 3/16 = 0.1875 in) because it is located at the inside of the bend. Length of neutral axis along the bend = 2π(90/360)(0.1875 + 0.5 x 0.1406) = 0.4049 in. The new final length of the neutral axis is L = 2(1.8122) + 0.4049 = 4.0293 in. The amount of stretching is less than previously determined, and so is the amount of thinning. An iterative procedure must be used to arrive at the final values of stretching and thinning.

Recalculate the thickness of the stretched sheet as (0.3756/0.4049)(0.15625) = 0.1449 in, and recalculating the length of the bent section based on this value, we have the following:
Length of neutral axis along the bend = 2π(90/360)(0.1875 + 0.5 x 0.1449) = 0.4084 in
The new final length of the neutral axis is L = 2(1.8122) + 0.4084 = 4.0328 in.

One more iteration: The thickness of the stretched sheet is (0.3756/0.4084)(0.15625) = 0.1437 in, and recalculating the length of the bent section based on this value, we have 2π(90/360)(0.1875 + 0.5 x 0.1437) = 0.4074 in. The new final length of the neutral axis is L = 2(1.8122) + 0.4074 = **4.0318 in**. Close enough and only about 0.01 in different from our previous value of 4.0417 in.

(c) The operator should set the stop so that the tip of the V-punch contacts the starting blank at a distance = 2.000 in from the end.

20.12 A bending operation is to be performed on 4.0 mm thick cold-rolled steel sheet that is 25 mm wide and 100 mm long. The sheet is bent along the 25 mm direction, so that the bend is 25 mm long. The resulting sheet metal part has an acute angle of 30° and a bend radius of 6 mm. Determine (a) the bend allowance and (b) the length of the neutral axis of the part after the bend. (Hint: the length of the neutral axis before the bend = 100.0 mm).

Solution: (a) Given that α' = 30°, R = 6.0 mm, and t = 4.0 mm
α = 180 - α' = 150°.
$A_b = 2\pi(\alpha/360)(R + K_{ba}t)$
R/t = 6/4 = 1.5, which is less than 2.0; therefore, K_{ba} = 0.333
A_b = 2π(150/360)(6.0 + 0.333 x 4.0) = 19.195 mm

(b) Due to stretching, the neutral axis of the final part will be greater than 100.0 mm. The amount of stretching will be the difference between the bend allowance and the length of the bent section, which is computed as 2π(150/360)(6.0 + 0.5 x 4.0) = 20.944.
The difference = 20.944 – 19.195 = 1.75 mm
Thus, the final length of the neutral axis will be L = 100 + 1.75 = **101.75 mm**

However, if stretching occurs along the neutral axis of the bend, then thinning of the stretched metal will also occur, and this will affect the preceding calculated value of the length of the bent section. The amount of thinning will be inversely proportional to the amount of stretching because volume must remain constant, before and after bending. The sheet thickness after bending (assuming uniform stretching and thinning) = (19.195/20.944)(4.0) = 3.67 mm. Now let us recalculate the length of the bent section with this new value of t.

The bend radius will remain the same (R = 6.0 mm) because it is located at the inside of the bend. Length of neutral axis along the bend = $2\pi(150/360)(6.0 + 0.5 \times 3.67)$ = 20.512 mm. Now the difference between the length of the bent section and the bend allowance = 20.512 – 19.195 = 1.317 mm. The new final length of the neutral axis is L = 100 + 1.32 = **101.32 mm**
The amount of stretching is less than previously determined, and so is the amount of thinning. An iterative procedure must be used to arrive at the final values of stretching and thinning.

Recalculate the thickness of the stretched sheet as (19.195/20.512)(4.0) = 3.74 mm, and recalculating the length of the bent section based on this value, we have the following:
Length of neutral axis along the bend = $2\pi(150/360)(6.0 + 0.5 \times 3.74)$ = 20.608 mm
The new difference between the length of the bent section and the bend allowance = 20.608 – 19.195 = 1.413 mm, and the new final length of the neutral axis is L = 100 + 1.41 = **101.41 mm**

One more iteration: The thickness of the stretched sheet is (19.195/20.608)(4.0) = 3.73 mm, and recalculating the length of the bent section based on this value, we have $2\pi(150/360)(6.0 + 0.5 \times 3.73)$ = 20.585 mm. The new before and after difference = 20.585 – 19.195 = 1.39 mm, and the new final length of the neutral axis is L = 100 + 1.39 = **101.39 mm**

20.13 Determine the bending force required in Problem 20.9 if the bend is to be performed in a V-die with a die opening dimension of 40 mm. The material has a tensile strength of 600 MPa and a shear strength of 430 MPa.

Solution: For V-bending, K_{bf} = 1.33.
$F = K_{bf}(TS)wt^2/D = 1.33(600)(35)(5.0)^2/40$ = **17,460 N**

20.14 Solve Problem 20.13 except that the operation is performed using a wiping die with die opening dimension = 28 mm.

Solution: For edge-bending in a wiping die, K_{bf} = 0.33.
$F = K_{bf}(TS)wt^2/D = 0.33(600)(35)(5.0)^2/28$ = **6,188 N**

20.15 Determine the bending force required in Problem 20.11 if the bend is to be performed in a V-die with a die opening width dimension = 1.25 in. The material has a tensile strength = 70,000 lb/in^2.

Solution: For V-bending, K_{bf} = 1.33.
$F = K_{bf}(TS)wt^2/D = 1.33(70{,}000)(1.5)(5/32)^2/1.25$ = **2728 lb.**

20.16 Solve Problem 20.15 except that the operation is performed using a wiping die with die opening dimension = 0.75 in.

Solution: For edge-bending in a wiping die, K_{bf} = 0.33.
$F = K_{bf}(TS)wt^2/D = 0.33(70{,}000)(1.5)(5/32)^2/0.75$ = **1128 lb.**

20.17 A sheet-metal part 3.0 mm thick and 20.0 mm long is bent to an included angle = 60° and a bend radius = 7.5 mm in a V-die. The metal has a yield strength = 220 MPa and a tensile strength = 340 MPa. Compute the required force to bend the part, given that the die opening dimension = 15 mm.

Solution: For V-bending, K_{bf} = 1.33.
$F = K_{bf}(TS)wt^2/D = 1.33(340)(20)(3)^2/15$ = **5426 N**

Drawing Operations

20.18 Derive an expression for the reduction r in drawing as a function of drawing ratio DR.

Solution: Reduction $r = (D_b - D_p)/D_b$
Drawing ratio $DR = D_b/D_p$
$r = D_b/D_b - D_p/D_b = 1 - D_p/D_b = 1 - 1/DR$

20.19 A cup is to be drawn in a deep drawing operation. The height of the cup is 75 mm and its inside diameter = 100 mm. The sheet-metal thickness = 2 mm. If the blank diameter = 225 mm, determine (a) drawing ratio, (b) reduction, and (c) thickness-to-diameter ratio. (d) Does the operation seem feasible?

Solution: (a) $DR = D_b/D_p = 225/100 =$ **2.25**

(b) $r = (D_b - D_p)/D_b = (225 - 100)/225 = 0.555 =$ **55.5%**

(c) $t/D_b = 2/225 = 0.0089 =$ **0.89%**

(d) Feasibility? **No**! DR is too large (greater than 2.0), r is too large (greater than 50%), and t/D is too small (less than 1%).

20.20 Solve Problem 20.19 except that the starting blank size diameter = 175 mm.

Solution: (a) $DR = D_b/D_p = 175/100 =$ **1.75**

(b) $r = (D_b - D_p)/D_b = (175 - 100)/175 = 0.429 =$ **42.9%**

(c) $t/D_b = 2/175 = 0.0114 =$ **1.14%**

(d) Feasibility? $DR < 2.0$, $r < 50\%$, and $t/D > 1\%$. However, the operation is not feasible because the 175 mm diameter blank size does not provide sufficient metal to draw a 75 mm cup height. The actual cup height possible with a 175 mm diameter blank can be determined by comparing surface areas (one side only for convenience) between the cup and the starting blank. Blank area = $\pi D^2/4 = \pi(175)^2/4 = 24{,}053$ mm^2. To compute the cup surface area, let us divide the cup into two sections: (1) walls, and (2) base, assuming the corner radius on the punch has a negligible effect in our calculations and there is no earing of the cup. Thus, Cup area = $\pi D_p h + \pi D_p^2/4 = 100\pi h + \pi(100)^2/4 = 100\pi h + 2500\pi = 314.16h + 7854$. Set surface area of cup = surface are of starting blank:
$314.16h + 7854 = 24{,}053$
$314.16h = 16{,}199$
$h = 51.56$ mm. This is less than the specified 75 mm height.

20.21 A deep drawing operation is performed in which the inside of the cylindrical cup has a diameter of 4.25 in and a height = 2.65 in. The stock thickness = 3/16 in, and the starting blank diameter = 7.7 in. Punch and die radii = 5/32 in. The metal has a tensile strength = 65,000 lb/in^2, a yield strength = 32,000 lb/in^2, and a shear strength of 40,000 lb/in^2. Determine (a) drawing ratio, (b) reduction, (c) drawing force, and (d) blankholder force.

Solution: (a) $DR = 7.7/4.25 =$ **1.81**

(b) $r = (D_b - D_p)/D_b = (7.7 - 4.25)/7.7 = 3.45/7.70 = 0.448 =$ **44.8%**

(c) $F = \pi D_p t(TS)(D_b/D_p - 0.7) = \pi(4.25)(0.1875)(65{,}000)(7.7/4.25 - 0.7) =$ **180,900 lb**.

(d) $F_h = 0.015Y\pi(D_b^2 - (D_p + 2.2t + 2R_d)^2)$
$F_h = 0.015(32{,}000)\pi(7.7^2 - (4.25 + 2.2 \text{ x } 0.1875 + 2 \text{ x } 0.15625)^2) = 0.015(32{,}000)\pi(7.7^2 - 4.975^2)$
$\boldsymbol{F_h = 52{,}100}$ **lb**

20.22 Solve Problem 20.21 except that the stock thickness $t = 1/8$ in.

Solution: (a) $DR = 7.7/4.25 =$ **1.81** (same as previous problem)

(b) $t/D_b = 0.125/7.7 =$ **0.01623 = 1.623%**

(c) $F = \pi D_p t(TS)(D/D_p - 0.7) = \pi(4.25)(0.125)(65{,}000)(7.7/4.25 - 0.7) =$ **120,600 lb**.

(d) $F_h = 0.015Y\pi(D^2 - (D_p + 2.2t + 2R_d)^2)$
$F_h = 0.015(32{,}000)\pi(7.7^2 - (4.25 + 2.2 \text{ x } 0.125 + 2 \text{ x } 0.15625)^2) = 0.015(32{,}000)\pi(7.7^2 - 4.8375^2)$
$\boldsymbol{F_h = 54{,}100}$ **lb**

20.23 A cup-drawing operation is performed in which the inside diameter = 80 mm and the height = 50 mm. The stock thickness = 3.0 mm, and the starting blank diameter = 150 mm. Punch and die radii = 4 mm. Tensile strength = 400 MPa and yield strength = 180 MPa for this sheet metal. Determine (a) drawing ratio, (b) reduction, (c) drawing force, and (d) blankholder force.

Solution: (a) $DR = 150/80 = \mathbf{1.875}$

(b) $r = (D_b - D_p)/D_b = (150 - 80)/150 = 70/150 = \mathbf{0.46}$

(c) $F = \pi D_p t(TS)(D_b/D_p - 0.7) = \pi(80)(3)(400)(150/80 - 0.7) =$ **354,418 N**.

(d) $F_h = 0.015Y\pi(D_b^2 - (D_p + 2.2t + 2R_d)^2)$
$F_h = 0.015(180)\pi(150^2 - (80 + 2.2 \text{ x } 3 + 2 \text{ x } 4)^2) = 0.015(180)\pi(150^2 - 94.6^2)$
$\boldsymbol{F_h}$ **= 114,942 N**

20.24 A deep drawing operation is to be performed on a sheet-metal blank that is 1/8 in thick. The height (inside dimension) of the cup = 3.8 in and the diameter (inside dimension) = 5.0 in. Assuming the punch radius = 0, compute the starting diameter of the blank to complete the operation with no material left in the flange. Is the operation feasible (ignoring the fact that the punch radius is too small)?

Solution: Use surface area computation, assuming thickness t remains constant.
Cup area = wall area + base area = $\pi D_p h + \pi D_p^2/4 = 5\pi(3.8) + 0.25\pi(5)^2 = 25.25\pi$ in^2
Blank area = $\pi D_b^2/4 = 0.25\pi D_b^2$
Setting blank area = cup area: $0.25\pi D_b^2 = 25.25\pi$
$D_b^2 = 25.25/0.25 = 101.0$
$\boldsymbol{D_b}$ **= 10.050 in**

Test for feasibility: $DR = D_b/D_p = 10.050/5.0 =$ **2.01.** Because $DR > 2.0$, this operation may not be feasible. Of course, the zero punch radius makes this operation infeasible anyway. With a rounded punch radius, the blank size would be slightly smaller, which would reduce *DR*.

20.25 Solve Problem 20.24 except use a punch radius = 0.375 in.

Solution: Use surface area computation, assuming thickness t remains constant. The surface area of the cup will be divided into three sections: (1) straight walls, whose height = 3.80 - 0.375 = 3.425 in, (2) quarter toroid formed by the 0.375 radius at the base of the cup, and (3) base, which has a diameter = 5.0 - 2 x 0.375 = 4.25 in
$A_1 = \pi D_p h = \pi(5.0)(3.425) = 53.807$ in^2
A_2 = length of the quarter circle at the base multiplied by the circumference of the circle described by the centroid (Pappus-Guldin Theorem): length of quarter circle = $\pi D/4 = 0.25\pi(2 \text{ x } 0.375) =$ 0.589 in. The centroid is located at the center of the arc, which is 0.375 sin 45 = 0.265 beyond the center of the 0.375 in radius. Thus, the diameter of the circle described by the centroid is 4.25 + 2 x 0.265 = 4.780 in
$A_2 = 4.78\pi(0.589) = 8.847$ in^2
$A_3 = \pi(4.25)^2/4 = 14.188$ in^2
Total area of cup = 53.807 + 8.847 + 14.188 = 76.842 in^2
Blank area = $\pi D_b^2/4 = 0.7855D_b^2$
Setting blank area = cup area: $0.7855D_b^2 = 76.842$
$D_b^2 = 76.842/0.7855 = 97.825$
$\boldsymbol{D_b}$ **= 9.890 in**

Test for feasibility: $DR = D_b/D_p = 9.89/5.0 =$ **1.978**, which is less than the limiting ratio of 2.0. The thickness to diameter ratio $t/D_b = 0.125/9.89 = 0.0126 = 1.26\%$, which is above the value of 1% used as a criterion of feasibility in cup drawing. Whereas the operation in Problem 20.23 was not feasible, the operation in the present problem seems feasible.

20.26 A drawing operation is performed on 3.0 mm stock. The part is a cylindrical cup with height = 50 mm and inside diameter = 70 mm. Assume the corner radius on the punch is zero. (a) Find the required starting blank size D_b. (b) Is the drawing operation feasible?

Solution: Use surface area computation, assuming thickness t remains constant.
Cup area = wall area + base area = $\pi D_p h + \pi D_p^2/4 = \pi(70)(50) + 0.25\pi(70)^2 = 14{,}846$ mm^2.
Blank area = $\pi D_b^2/4 = 0.7855 D_b^2$
Setting blank area = cup area: $0.7855 D_b^2 = 14{,}846$
$D_b^2 = 14{,}846/0.7855 = 18{,}900$
$\boldsymbol{D_b}$ **= 137.48 mm**

Test for feasibility: $DR = D_b/D_p = 137.48/70 =$ **1.964;** $t/D_b = 3/137.48 = 0.0218 =$ **2.18%.** These criteria values indicate that the operation is feasible; however, with a punch radius $R_p = 0$, this shape would be difficult to draw because the drawing punch would act on the metal like a blanking punch.

20.27 Solve Problem 20.26 except that the height = 60 mm.

Solution: Cup area = wall area + base area
Cup area = $\pi D_p h + \pi D_p^2/4 = \pi(70)(60) + 0.25\pi(70)^2 = 17{,}045$ mm^2.
Blank area = $\pi D_b^2/4 = 0.7855 D_b^2$
Setting blank area = cup area: $0.7855 D_b^2 = 17{,}045$
$D_b^2 = 17{,}045/0.7855 = 21{,}700$
$\boldsymbol{D_b}$ **= 147.31 mm.**

Test for feasibility: $DR = D_b/D_p = 147.31/70 =$ **2.10;** $t/D_b = 3/147.31 = 0.0204 =$ **2.04%.** Since the DR is greater than 2.0, this operation is considered infeasible. Also, as in the previous problem, the punch radius $R_p = 0$ would render this operation difficult if not infeasible.

20.28 Solve Problem 20.27 except that the corner radius on the punch = 10 mm.

Solution: Use surface area computation, assuming thickness t remains constant. The surface area of the cup will be divided into three sections: (1) straight walls, whose height = 60 - 10 = 50 mm, (2) quarter toroid formed by the 0.375 radius at the base of the cup, and (3) base, which has a diameter = 70 - 2 x 10 = 50 mm.
$A_1 = \pi D_p h = \pi(70)(50) = 10{,}995.6$ mm^2
A_2 = length of the quarter circle at the base multiplied by the circumference of the circle described by the centroid (Pappus-Guldin Theorem): length of quarter circle = $2\pi R_p/4 = 0.25\pi(2 \text{ x } 10) = 15.71$ mm. The centroid is located at the center of the arc, which is 10 sin 45 = 7.071 beyond the center of the 0.375 in radius. Thus, the diameter of the circle described by the centroid is 50 + 2 x 7.071 = 64.142 mm.
$A_2 = 64.142\pi(15.71) = 3166.1$ mm^2
$A_3 = \pi(50)^2/4 = 1963.8$ mm^2
Total area of cup = 10,995.6 + 3166.1 + 1963.8 = 16,125.5 mm^2
Blank area = $\pi D_b^2/4 = 0.7855 D_b^2$
Setting blank area = cup area: $0.7855 D_b^2 = 16{,}125.5$
$D_b^2 = 16{,}125.5/0.7855 = 20{,}529.0$
$\boldsymbol{D_b}$ **= 143.28 mm**

Test for feasibility: $DR = D_b/D_p = 143.28/70 =$ **2.047**. Since the DR is greater than 2.0, this operation is considered infeasible.

20.29 The foreman in the drawing section of the shop brings to you several samples of parts that have been drawn in the shop. The samples have various defects. One has ears, another has wrinkles, and still a third has torn sections at its base. What are the causes of each of these defects and what remedies would you propose?

Solution: (1) ***Ears*** are caused by sheet metal that has directional properties. The material is anisotropic. One remedy is to anneal the metal to reduce the directionality of the properties.

(2) ***Wrinkles*** are caused by compressive buckling of the flange as it is drawn inward to form the cup. There are several possible remedies: (a) increase the t/D ratio by using a thicker gage sheet metal. This may not be possible since a design change is required. (b) Increase the blankholder pressure against the work during drawing.

(3) ***Tearing*** occurs due to high tensile stresses in the walls of the cup near the base. A remedy would be to provide a large punch radius. Tearing can also occur due to a die corner radius that is too small.

20.30 A cup-shaped part is to be drawn without a blankholder from sheet metal whose thickness = 0.25 in. The inside diameter of the cup = 2.5 in, its height = 1.5 in, and the corner radius at the base = 0.375 in. (a) What is the minimum starting blank diameter that can be used, according to Eq. (20.14)? (b) Does this blank diameter provide sufficient material to complete the cup?

Solution: (a) According to Eq. (22.14), $D_b - D_p < 5t$
$D_b < 5t + D_p = 5(0.25) + 2.5 =$ **3.75 in**

(b) Because the sheet metal is rather thick, let us use volume rather than area to determine whether there is sufficient metal in a 3.75 in blank diameter. The drawn cup consists of three sections: (1) cup walls, (2) toroid at base, and (3) base.
$V_1 = (1.5 - 0.375)\pi[(2.5 + 2 \text{ x } 0.25)^2] - (2.5)^2)/4 = 1.125\pi(2.75)/4 = 2.430 \text{ in}^3$
V_2 = (cross-section of quarter toroid) x (circle made by sweep of centroid)
Cross-section of quarter toroid $= 0.25\pi[(0.375 + 0.25)^2 - (0.375)^2] = 0.1964 \text{ in}^2$
Circle made by centroid sweep has diameter = (2.5 - 2 x 0.25) + 2(0.375 + 0.25/2)sin 45 = 2.457 in
$V_2 = 2.457\pi(0.1964) = 1.516 \text{ in}^3$
$V_3 = (2.5 - 2 \text{ x } 0.375)^2\pi(0.25)/4 = 0.601 \text{ in}^3$
Total $V = V_1 + V_2 + V_3 = 2.430 + 1.516 + 0.601 = 4.547 \text{ in}^3$
Volume of blank $= \pi D_b^2 t/4 = \pi(0.25)D_b^2/4 = 0.1963D_b^2$
Setting blank volume = cup volume: $0.1963D_b^2 = 4.547$
$D_b^2 = 4.547/0.1963 = 23.16$
$D_b =$ **4.81 in.** The diameter of 3.75 in computed in (a) does not provide sufficient metal to complete the drawing.

Other Operations

20.31 A 20-in-long sheet-metal workpiece is stretched in a stretch forming operation to the dimensions shown in Figure P20.31. The thickness of the beginning stock is 3/16 in and the width is 8.5 in. The metal has a flow curve defined by a strength coefficient of 75,000 lb/in^2 and a strain hardening exponent of 0.20. The yield strength of the material is 30,000 lb/in^2. (a) Find the stretching force F required near the beginning of the operation when yielding first occurs. Determine (b) true strain experienced by the metal, (c) stretching force F, and (d) die force F_{die} at the very end when the part is formed as indicated in Figure P20.31(b).

Solution: (a) Use $\varepsilon = 0.002$ as start of yielding.
$F = LtY_f$
$Y_f = 75{,}000(0.002)^{0.20} = 21{,}600 \text{ lb/in}^2$
$F = (8.5)(0.1875)(21{,}600) =$ **34,500 lb.**

(b) After stretching, the length of the piece is increased from 20.0 in to $2(10^2 + 5^2)^{0.5} = 22.361$ in
$\varepsilon = \ln(22.361/20) = \ln 1.118 =$ **0.1116**

(c) At the final length of 22.361 in, the thickness of the sheet metal has been reduced to maintain constant volume, assuming width $L = 8.5$ in remains the same during stretching.

t_f = 0.1875(20/22.361) = 0.168 in
Y_f = 75,000(0.1116)$^{0.20}$ = 48,400 lb/in^2
F = 8.5(0.168)(48,400) = **69,000 lb.**

(d) F_{die} = 2F sin A
A = tan^{-1}(5/10) = 26.57°
F_{die} = 2(69,000) sin 26.57 = **61,700 lb.**

20.32 Determine the starting disk diameter required to spin the part in Figure P20.32 using a conventional spinning operation. The starting thickness = 2.4 mm.

Solution: From part drawing, radius = 25 + (100 - 25)/sin 30 = 25 + 75/0.5 = 175 mm
Starting diameter D = 2(175) = **350 mm**

20.33 If the part illustrated in Figure P20.32 were made by shear spinning, determine (a) the wall thickness along the cone-shaped portion, and (b) the spinning reduction r.

Solution: (a) $t_f = t \sin \alpha$ = (2.4)sin 30 = 2.4(0.5) = **1.2 mm**

(b) $r = (t - t_f)/t$ = (2.4 – 1.2)/2.4 = **0.50 = 50%**

20.34 Determine the shear strain that is experienced by the material that is shear spun in Problem 20.33.

Solution: Based on sidewise displacement of metal through a shear angle of 30°,
Shear strain γ = cot 30 = **1.732.**

20.35 A 75 mm diameter tube is bent into a rather complex shape with a series of simple tube bending operations. The wall thickness on the tube = 4.75 mm. The tubes will be used to deliver fluids in a chemical plant. In one of the bends where the bend radius is 125 mm, the walls of the tube are flattening badly. What can be done to correct the condition?

Solution: Possible solutions: (1) Use a mandrel to prevent collapsing of tube wall. (2) Request the designer to increase the bend radius to 3D = 225 mm. (3) Pack sand into the tube. The sand will act as an internal flexible mandrel to support the tube wall.