I'_S = required moment of inertia of the combined ring-shell cross section about its neutral axis parallel to the axis of the shell

CAUTION: Stiffening rings may be subject to lateral buckling. This should be considered in addition to the requirements for I_s and I'_s [see U-2(g)].

If the stiffeners should be so located that the maximum permissible effective shell sections overlap on either or both sides of a stiffener, the effective shell section for that stiffener shall be shortened by one-half of each overlap.

A = factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in the stiffening ring, corresponding to the factor B, below, and the design temperature for the shell under consideration

A_s = cross-sectional area of the stiffening ring

B = factor determined from the applicable chart or table in Section II, Part D, Subpart 3 for the material used for the stiffening ring [see UG-20(c)]

L_s = one-half of the distance from the centerline of the stiffening ring to the next line of support on one side, plus one-half of the centerline distance to the next line of support on the other side of the stiffening ring, both measured parallel to the axis of the cylinder. A line of support is:

  (a) a stiffening ring that meets the requirements of this paragraph;

  (b) a circumferential connection to a jacket for a jacketed section of a cylindrical shell;

  (c) a circumferential line on a head at one-third the depth of the head from the head tangent line as shown on Figure UG-28;

  (d) a cone-to-cylinder junction.

D_o, E, P, t, and t_s are as defined in UG-28(b).

The adequacy of the moment of inertia for a stiffening ring shall be determined by the following procedure.

Step 1. Assuming that the shell has been designed and D_o, L_s, and t are known, select a member to be used for the stiffening ring and determine its cross-sectional area A_s. Then calculate factor B using the following equation:

$$B = \frac{3}{4}\left(\frac{PD_o}{t + A_s/L_s}\right)$$

Step 2. See below.

(a) If tabular values in Section II, Part D, Subpart 3 are used, linear interpolation or any other rational interpolation method may be used to determine an A value that lies between two adjacent tabular values for a specific temperature. Linear interpolation may also be used to determine an A value at an intermediate temperature that lies between two sets of tabular values, after first determining A values for each set of tabular values. The value of A so determined is then applied in the equation for I_s or I'_S in Step 6(a) or Step 6(b).

(b) If material charts in Section II, Part D, Subpart 3 are used, enter the right-hand side of the applicable material chart for the material under consideration at the value of B determined by Step 1. If different materials are used for the shell and stiffening ring, use the material chart resulting in the larger value of A in Step 4, below.

Step 3. Move horizontally to the left to the material/temperature line for the design metal temperature. For values of B falling below the left end of the material/temperature line, see Step 5.

Step 4. Move vertically to the bottom of the chart and read the value of A.

Step 5. For values of B falling below the left end of the material/temperature line for the design temperature, the value of A can be calculated using the formula $A = 2B/E$.

Step 6. See below.

(a) In those cases where only the stiffening ring is considered, compute the required moment of inertia from the formula for I_s given above.

(b) In those cases where the combined ring-shell is considered, compute the required moment of inertia from the formula for I'_S given above.

Step 7. See below.

(a) In those cases where only the stiffening ring is considered, determine the available moment of inertia I as given in the definitions.

(b) In those cases where the combined ring-shell is considered, determine the available moment of inertia I' as given in the definitions.

NOTE: In those cases where the stiffening ring is not attached to the shell or where the stiffening ring is attached but the designer chooses to consider only the ring, Step 6(a) and Step 7(a) are considered. In those cases where the stiffening ring is attached to the shell and the combined moment of inertia is considered, 6(b) and (b) are considered.

[Highlighted should read: "Step 6(b) and Step 7(b)"]

Step 8. If the required moment of inertia is greater than the available moment of inertia for the section selected, for those cases where the stiffening ring is not attached or where the combined ring-shell stiffness was not considered, a new section with a larger moment of inertia must be selected; the ring must be attached to the shell and the combination shall be considered; or the ring-shell combination that was previously not considered together shall be considered together. If the required moment of inertia is greater than the available moment of inertia for those cases where the combined ring-shell was considered, a new ring section with a larger moment of inertia must be selected. In any case, when a new section is used, all of the calculations shall be repeated using the new section properties of the ring or ring-shell combination.

If the required moment of inertia is smaller than the actual moment of inertia of the ring or ring-shell combination, whichever is used, that ring section or combined section is satisfactory.

(a) In those cases where only the stiffening ring is considered, compute the required moment of inertia from the formula for I_s given above.

(b) In those cases where the combined ring-shell is considered, compute the required moment of inertia from the formula for I'_s given above.

Step 7. See below:

(a) In those cases where only the stiffening ring is considered, determine the available moment of inertia I as given in the definitions.

(b) In those cases where the combined ring-shell is considered, determine the available moment of inertia I' as given in the definitions.

NOTE: In those cases where the stiffening ring is not attached to the shell or where the stiffening ring is attached but the designer chooses to consider only the ring, Step 6(a) and Step 7(a) are considered. In those cases where the stiffening ring is attached to the shell and the combined moment of inertia is considered, Step 6(b) and Step 7(b) are considered.

Step 8. If the required moment of inertia is greater than the available moment of inertia for the section selected, for those cases where the stiffening ring is not attached or where the combined ring-shell stiffness was not considered, a new section with a larger moment of inertia must be selected; the ring must be attached to the shell and the combination shall be considered; or the ring-shell combination that was previously not considered together shall be considered together. If the required moment of inertia is greater than the available moment of inertia for those cases where the combined ring-shell was considered, a new ring section with a larger moment of inertia must be selected. In any case, when a new section is used, all of the calculations shall be repeated using the new section properties of the ring or ring-shell combination.

If the required moment of inertia is smaller than the actual moment of inertia of the ring or ring-shell combination, whichever is used, that ring section or combined section is satisfactory.

(b) Stiffening rings shall extend completely around the circumference of the cylinder except as permitted in (c) below. Any joints between the ends or sections of such rings, such as shown in Figure UG-29.1 (A) and (B), and any connection between adjacent portions of a stiffening ring lying inside or outside the shell as shown in Figure UG-29.1 (C) shall be made so that the required moment of inertia of the combined ring-shell section is maintained.

(c) Stiffening rings placed on the inside of a vessel may be arranged as shown in Figure UG-29.1 (E) and (F) provided that the required moment of inertia of the ring in (E) or of the combined ring-shell section in (F) is maintained within the sections indicated. Where the gap at (A) or (E) does not exceed eight times the thickness of the shell plate, the combined moment of inertia of the shell and stiffener may be used.

Any gap in that portion of a stiffening ring supporting the shell, such as shown in Figure UG-29.1 (D) and (E), shall not exceed the length of are given in Figure UG-29.2 unless additional reinforcement is provided as shown in Figure UG-29.1 (C) or unless the following conditions are met:

(1) only one unsupported shell arc is permitted per ring; and

(2) the length of the unsupported shell arc does not exceed 90 deg; and

(3) the unsupported arcs in adjacent stiffening rings are staggered 180 deg; and

(4) the dimension L defined in UG-28(b) is taken as the larger of the following: the distance between alternate stiffening rings, or the distance from the head tangent line to the second stiffening ring plus one-third of the head depth.

(d) When internal plane structures perpendicular to the longitudinal axis of the cylinder (such as bubble trays or baffle plates) are used in a vessel, they may also be considered to act as stiffening rings provided they are designed to function as such.

(e) Any internal stays or supports used as stiffeners of the shell shall bear against the shell of the vessel through the medium of a substantially continuous ring.

NOTE: Attention is called to the objection to supporting vessels through the medium of legs or brackets, the arrangement of which may cause concentrated loads to be imposed on the shell. Vertical vessels should be supported through a substantial ring secured to the shell (see G-3). Horizontal vessels, unless supported at or close to the ends (heads) or at stiffening rings, should be supported through the medium of substantial members extending over at least one-third of the circumference, as shown at (K) in Figure UG-29.1.

Attention is called also to the hazard of imposing highly concentrated loads by the improper support of one vessel on another or by the hanging or supporting of heavy weights directly on the shell of the vessel. (See Nonmandatory Appendix G.)

(f) When closure bars or other rings are attached to both the inner shell and outer jacket of a vessel, with pressure in the space between the jacket and inner shell, this construction has adequate inherent stiffness, and therefore the rules of this paragraph do not apply.

UG-30   ATTACHMENT OF STIFFENING RINGS

(a) Stiffening rings may be placed on the inside or outside of a vessel, and except for the configurations permitted by UG-29, shall be attached to the shell by welding or brazing. Brazing may be used if the vessel is not to be later stress relieved. The ring shall be essentially in contact with the shell and meet the rules in UG-29(b) and UG-29(c). Welding of stiffening rings shall comply with the requirements of this Division for the type of vessel under construction.

(b) Stiffening rings may be attached to the shell by continuous, intermittent, or a combination of continuous and intermittent welds or brazes. Some acceptable methods of attaching stiffening rings are illustrated in Figure UG-30.

Step 5. For value of B falling below the left end of the material/temperature line for the design temperature, the value of A can be calculated using the formula $A = 2B/E_x$. For value of B above the material/temperature line for the design temperature, the design shall be either per U-2(g) or by changing the cone or cylinder configuration, stiffening ring location on the shell, and/or reducing the axial compressive force to reduce the B value to below or at the material/temperature line for the design temperature. For values of B having multiple values of A, such as when B falls on a horizontal portion of the curve, the smallest value of A shall be used.

[Formula highlighted in yellow is incorrect and should be:
$A = 2B/E_X$]

Step 6. Compute the value of the required moment of inertia from the equations for I_s or I'_s. For the circumferential stiffening ring only,

$$I_s = \frac{AD_L{}^2 A_{TL}}{14.0}$$

For the shell-cone or ring-shell-cone section,

$$I'_s = \frac{AD_L{}^2 A_{TL}}{10.9}$$

Step 7. Determine the available moment of inertia of the ring only I or the shell-cone or ring-shell-cone I'.

Step 8. When the ring only is used,

$$I \geq I_s$$

and when the shell-cone or ring-shell-cone is used,

$$I' \geq I'_s$$

If the equation is not satisfied, a new section with a larger moment of inertia must be selected, and the calculation shall be done again until the equation is met.

The requirements of UG-29(b), UG-29(c), UG-29(d), UG-29(e), and UG-29(f) and UG-30 are to be met in attaching stiffening rings to the shell.

(c) Reinforcement shall be provided at the small end of the cone when required by (1) or (2). When the small end of the cone is considered a line of support, the moment of inertia for a stiffening ring shall be determined in accordance with (3).

(1) For cones attached to a cylinder having a minimum length of $1.4\sqrt{R_s t_s}$, reinforcement shall be provided at the junction of the conical shell of a reducer without a flare and the small cylinder. The required area of reinforcement shall be at least equal to that indicated by the following formula when Q_s is in compression:

$$A_{rs} = \frac{kQ_s R_s \tan\alpha}{S_s E_1} \tag{6}$$

At the small end of the cone-to-cylinder juncture, the $PR_s/2$ term is in compression. When f_2 is in tension and the quantity is larger than the $PR_s/2$ term, the design shall be in accordance with U-2(g). The calculated localized stresses [shall not] exceed the stress values specified in [...](2).

The [effective area of reinforceme]nt can be determined in [accordance with the following] formula:

$$A_{es} = \left[... \sqrt{...[\alpha]} \left(t_c - t_r \right) \right] \tag{7}$$

Any additional area of stiffener which is required shall be situated within a distance of $\sqrt{R_s t_s}$ from the junction, and the centroid of the added area shall be within a distance of $0.25\sqrt{R_s t_s}$ from the junction.

(2) For cones attached to flat covers, flanges, or other components where the length of cylinder, if present, is less than $1.4\sqrt{R_s t_s}$, the required reinforcement shall be at least equal to that indicated by the following formula:

$$A_{rS} = \frac{kQ_s D_s}{2S_c E_2} \tan\alpha \tag{8}$$

The effective area of reinforcement can be determined in accordance with the following formula:

$$A_{eS} = 0.55\sqrt{(D_s t_c / \cos[\alpha])}\left(t_c - t_r \right) \tag{9}$$

Any additional area of reinforcement that is required shall be added to the cone or the flange.

(3) When the cone-to-cylinder or knuckle-to-cylinder juncture is a line of support, the moment of inertia for a stiffening ring at the small end shall be determined by the procedure in Steps 1 through 8 below.

For cones attached to flat covers, flanges, or other components where the length of the cylinder, if present, is less than $1.4\sqrt{R_s t_s}$, length L_s in the formulas for A_{TS} and N shall be zero.

Step 1. Assuming that the shell has been designed and D_s, L_s, and t are known, select a member to be used for the stiffening ring and determine cross-sectional area A_{TS}. Then calculate factor B using the following formula. If F_s is a negative number, the design shall be in accordance with U-2(g):

$$B = \frac{3}{4}\left(\frac{F_s D_s}{A_{TS}} \right)$$

where

$$F_s = PN + f_2 \tan\alpha$$

$$N = \frac{R_s \tan\alpha}{2} + \frac{L_s}{2} + \frac{R_L{}^2 - R_s{}^2}{6R_s \tan\alpha}$$

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A_{TL}. Then calculate factor B using the following formula. If F_L is a negative number, the design shall be in accordance with U-2(g):

$$B = \tfrac{3}{4}\left(\frac{F_L D_L}{A_{TL}}\right)$$

where

$$F_L = PM + f_1 \tan \alpha$$

$$M = \frac{-R_L \tan \alpha}{2} + \frac{L_L}{2} + \frac{R_L^2 - R_s^2}{3R_L \tan \alpha}$$

Step 2. Enter the right-hand side of the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration at the value of B determined by Step 1. If different materials are used for the shell and stiffening ring, use the material chart resulting in the larger value of A in Step 4 below.

Step 3. Move horizontally to the left to the material/temperature line for the design metal temperature. For values of B falling below the left end of the material/temperature line, see Step 5 below.

Step 4. Move vertically to the bottom of the chart and read the value of A.

Step 5. For value of B falling below the left end of the material/temperature line for the design temperature, the value of A can be calculated using the formula $A = 2B/E_x$. For value of B above the material/ temperature line for the design temperature, the design shall be either per U-2(g) or by changing the cone or cylinder configuration, stiffening ring location on the shell, and/or reducing the axial compressive force to reduce the B value to below or at the material/temperature line for the design temperature. For values of B having multiple values of A, such as when B falls on a horizontal portion of the curve, the smallest value of A shall be used.

Step 6. Compute the value of the required moment of inertia from the equations for I_s or I'_s. For the circumferential stiffening ring only,

$$I_s = \frac{AD_L^2 A_{TL}}{14.0}$$

For the shell-cone or ring-shell-cone section,

$$I'_s = \frac{AD_L^2 A_{TL}}{10.9}$$

Step 7. Determine the available moment of inertia of the ring only I or the shell-cone or ring-shell-cone I'.

Step 8. When the ring only is used,

$$I \geq I_s$$

and when the shell-cone or ring-shell-cone is used,

$$I' \geq I'_s$$

If the equation is not satisfied, a new section with a larger moment of inertia must be selected, and the calculation shall be done again until the equation is met.

The requirements of UG-29(b), UG-29(c), UG-29(d), UG-29(e), and UG-29(f) and UG-30 are to be met in attaching stiffening rings to the shell.

(c) Reinforcement shall be provided at the small end of the cone when required by (1) or (2). When the small end of the cone is considered a line of support, the moment of inertia for a stiffening ring shall be determined in accordance with (3).

(1) For cones attached to a cylinder having a minimum length of $1.4\sqrt{R_s t_s}$, reinforcement shall be provided at the junction of the conical shell of a reducer without a flare and the small cylinder. The required area of reinforcement shall be at least equal to that indicated by the following formula when Q_s is in compression:

$$A_{rs} = \frac{kQ_s R_s \tan \alpha}{S_s E_1} \qquad (3)$$

At the small end of the cone-to-cylinder juncture, the $PR_s/2$ term is in compression. When f_2 is in tension and the quantity is larger than the $PR_s/2$ term, the design shall be in accordance with U-2(g). The calculated localized stresses at the discontinuity shall not exceed the stress values specified in 1-5(g)(1) and 1-5(g)(2).

The effective area of reinforcement can be determined in accordance with the following formula:

$$A_{es} = 0.55\sqrt{D_s t_s}\left[\left(t_s - t\right) + \left(t_c - t_r\right)/\cos \alpha\right] \qquad (4)$$

Any additional area of stiffener which is required shall be situated within a distance of $\sqrt{R_s t_s}$ from the junction, and the centroid of the added area shall be within a distance of $0.25\sqrt{R_s t_s}$ from the junction.

(2) For cones attached to flat covers, flanges, or other components where the length of cylinder, if present, is less than $1.4\sqrt{R_s t_s}$, the required reinforcement shall be at least equal to that indicated by the following formula:

$$A_{rS} = \frac{kQ_s D_s}{2S_c E_2}\tan \alpha$$

The effective area of reinforcement can be determined in accordance with the following formula:

$$A_{eS} = 0.55\sqrt{(D_s t_c)}\left(t_c - t_r\right)/\cos \alpha$$

Any additional area of reinforcement that is required shall be added to the cone or the flange.

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