$$l'_b = r_c - r_c \cdot \sin(\alpha_b) + \max\left(l_b - r_c \cdot \frac{\pi}{4}, 0\right) = 73{,}21\,\text{mm}$$

$$T_{sc,min} = \frac{45° - \alpha_s}{45°} \cdot T_{min} + \frac{\alpha_s}{45°} \cdot T_{c,min} = 7{,}650\,\text{mm}$$

$$T_{bc,min} = \frac{45° - \alpha_b}{45°} \cdot T_{1,min} + \frac{\alpha_b}{45°} \cdot T_{c,min} = 5{,}827\,\text{mm}$$

$$A_{fs} = \max\left(l'_b - r_c, 0\right) \cdot T_{min} = 29{,}7\,\text{mm}^2$$

$$A_{fsc} = \left(\left(r_c + \frac{T_{sc,min} + T_{c,min}}{2}\right) - r_c^2\right) \cdot \pi \cdot \frac{45° - \alpha_s}{360°} + T_{sc,min}^2 \cdot \frac{\tan(\alpha_s)}{2} = 550{,}8\,\text{mm}^2$$

$$A_{fbc} = \left(\left(r_c + \frac{T_{bc,min} + T_{c,min}}{2}\right) - r_c^2\right) \cdot \pi \cdot \frac{45° - \alpha_b}{360°} + T_{bc,min}^2 \cdot \frac{\tan(\alpha_b)}{2} = 341{,}2\,\text{mm}^2$$

$$A_{fb} = \max\left(l'_b - r_c, 0\right) \cdot T_{1,min} = 0{,}0\,\text{mm}^2$$

$$A_f = A_{fs} + A_{fsc} + A_{Fbc} + A_{fb} = 921{,}7\,\text{mm}^2$$

$$A_{psc} = r_c^2 \cdot \left(\frac{1}{2} \cdot \left(1 - \sin(\alpha_s)\right)^2 - \pi \cdot \frac{45° - \alpha_s}{360°} + \frac{1}{2} \cdot \sin(\alpha_s) \cdot \left(\cos(\alpha_s) - \sin(\alpha_s)\right)\right) = 968\,\text{mm}^2$$

$$A_{pbc} = r_c^2 \cdot \left(\frac{1}{2} \cdot \left(1 - \sin(\alpha_b)\right)^2 - \pi \cdot \frac{45° - \alpha_b}{360°} + \frac{1}{2} \cdot \sin(\alpha_b) \cdot \left(\cos(\alpha_b) - \sin(\alpha_b)\right)\right) = 950\,\text{mm}^2$$

$$A_p = \left(\frac{D_1}{2} + l'_s\right) \cdot \left(\frac{D}{2} + l'_b\right) - l'_s \cdot l'_b + A_{psc} + A_{psb} - A_f = 163\,038\,\text{mm}^2$$

$$\frac{A_p}{A_f} = 176{,}89$$

(B.7): $T_X = 2{,}285$ mm

(B.5): $X = 29{,}7$ %

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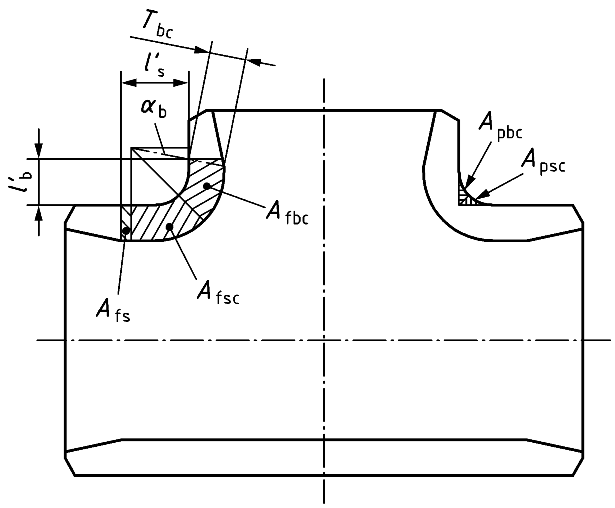

Figure B.2 — Additional dimensions and areas used in the calculation A_p and A_f of a tee

B.4.5 Reducers

For the determination of the pressure resistance of reducers several aspects have to be taken into consideration. The calculations are based on the following preconditions:

— wall thickness in the conical section is at least the wall thickness at the major end of the reducer;

— a reducer has cylindrical sections on both ends. In some cases minimal lengths of these sections are required;

— at the transition of cylindrical sections and conical sections the inside and outside surfaces shall merge smoothly;

— transition between the cylindrical sections and the conical section at the major end may be curved. In this case the distance between the knuckle and the end of the reducer shall be at least:

$$L'_{2,\min} = 0,5 \cdot \sqrt{\left(D - T_{L2}\right) \cdot T_{L2}} \tag{B.10}$$

— transition between the cylindrical sections and the conical section at the minor end may be curved too. The wall thickness of the knuckle shall be the same as of the conical section.

Figure B.3 shows wall thicknesses, minimal lengths at the ends and the semi angle for both concentric and eccentric reducers.

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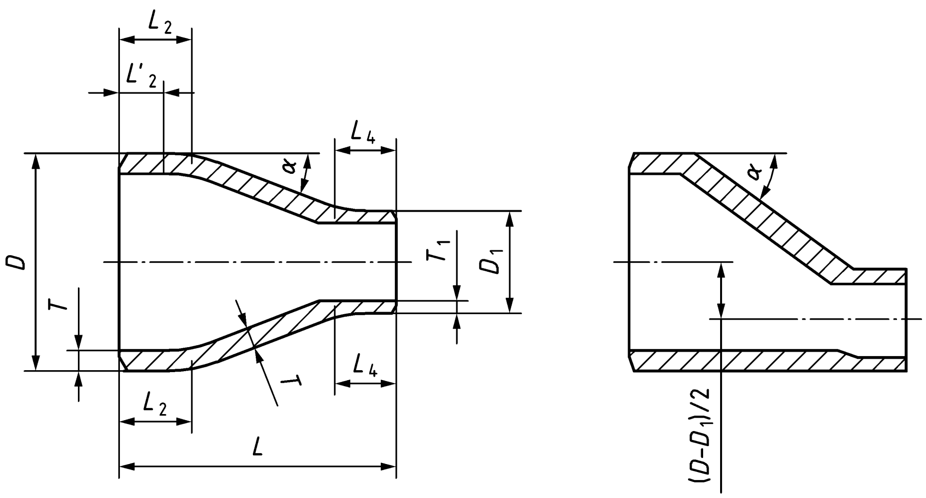

Figure B.3 — Concentric and eccentric reducer type A

The design of a reducer comprises the determination of the wall thickness at the cylindrical sections, the wall thickness at the conical section and the wall thicknesses at the transitions between cylindrical and conical sections. Therefore, first the equivalent wall thickness at different sections of the reducer has to be calculated. In the next step the overall equivalent wall thickness of the reducer is determined.

$$T_{X,23} = T_{min} \cdot \frac{D}{\beta \cdot (D - T_{min}) + T_{min}} \tag{B.11}$$

$$T_{X,3} = T_{min} \cdot \cos(\alpha) \cdot \frac{D}{D - 2 \cdot T_{min} - \sqrt{\frac{(D - T_{min}) \cdot T_{min}}{\cos(\alpha)}} \cdot \sin(\alpha) + T_{min} \cdot \cos(\alpha)} \tag{B.12}$$

$$T_{X,34} = T_{min} \cdot \frac{D}{\beta_H \cdot (D_1 - T_{1,min}) \cdot \frac{T_{min}}{T_{1,min}} + T_{min}} \tag{B.13}$$

$$T_{X,4} = T_{1,min} \cdot \frac{D}{D_1} \tag{B.14}$$

$$T_X = \min(T_{X,23}, T_{X,3}, T_{X,34}, T_{X,4}) \tag{B.15}$$

$$T_{1,X} = T_X \cdot \frac{D_1}{D} \tag{B.16}$$

with the factors β and β_H:

$$\beta = \max\left(\frac{1}{3} \cdot \sqrt{\frac{D - T_{min}}{T_{min}}} \cdot \frac{\tan(\alpha)}{1 + \frac{1}{\sqrt{\cos(\alpha)}}} - 0{,}15, 1\right) \tag{B.17}$$

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$$s = \frac{T_{min}}{T_{1,min}} \tag{B.18}$$

$$\tau = \begin{cases} s \cdot \sqrt{\dfrac{s}{\cos(\alpha)}} + \sqrt{\dfrac{1+s^2}{2}} & \text{if } s < 1 \\ 1 + \sqrt{s \cdot \dfrac{1+s^2}{2 \cdot \cos(\alpha)}} & \text{if } s \geq 1 \end{cases} \tag{B.19}$$

$$\beta_H = 0{,}4 \cdot \sqrt{\frac{D_1 - T_{1,min}}{T_{1,min}}} \cdot \frac{\tan(\alpha)}{\tau} + 0.5 \tag{B.20}$$

Afterwards, the minimal lengths at the ends have to be calculated. In a first step, the wall thicknesses T_{L2} and T_{L4} are determined. These wall thicknesses are required at the cylindrical sections so that the reducer is able to resist the pressure expressed by the pressure factor *X*. The following formulae have to be solved by iteration:

$$T'_{L2} = \beta \cdot T_X \cdot \frac{D}{D + (\beta - 1) \cdot T_X} \tag{B.21}$$

$$T_{L2} = \max\left(T_X, T'_{L2}\right) \tag{B.22}$$

$$T'_{L4} = \beta_H \cdot T_{1,X} \cdot \frac{D}{D + (\beta_H - 1) \cdot T_X} \tag{B.23}$$

$$T_{L4} = \max\left(T_{1,X}, T'_{L4}\right) \tag{B.24}$$

with the factors β and β_H:

$$\beta = \frac{1}{3} \cdot \sqrt{\frac{D - T'_{L2}}{T'_{L2}}} \cdot \frac{\tan(\alpha)}{1 + \dfrac{1}{\sqrt{\cos(\alpha)}}} - 0{,}15 \tag{B.25}$$

$$s = \frac{T_{min}}{T'_{L4}} \tag{B.26}$$

$$\tau = \begin{cases} s \cdot \sqrt{\dfrac{s}{\cos(\alpha)}} + \sqrt{\dfrac{1+s^2}{2}} & \text{if } s < 1 \\ 1 + \sqrt{s \cdot \dfrac{1+s^2}{2 \cdot \cos(\alpha)}} & \text{if } s \geq 1 \end{cases} \tag{B.27}$$

$$\beta_H = 0{,}4 \cdot \sqrt{\frac{D_1 - T'_{L4}}{T'_{L4}}} \cdot \frac{\tan(\alpha)}{\tau} + 0{,}5 \tag{B.28}$$

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With these wall thicknesses the minimal lengths are calculated:

$$L_{2,min} = \frac{T_{L2} - T_X}{T_{min} - T_X} \cdot 1{,}4 \cdot \sqrt{(D - T_{L2}) \cdot T_{L2}} \quad \text{(B.29)}$$

$$L_{4,min} = \frac{T_{L4} - T_{1,X}}{T_{1,min} - T_{1,X}} \cdot \sqrt{(D_1 - T_{L4}) \cdot T_{L4}} \quad \text{(B.30)}$$

The length $L_{2,min}$ is applicable only if T_X is less than T_{min}, $L_{4,min}$ is applicable if $T_{1,X}$ is less than $T_{1,min}$. If the reducer is located between pipes with minimal wall thicknesses larger than T_{L2} and T_{L4}, respectively, the minimal lengths do not apply, too.

NOTE 1 Formulae (B.12) to (B.28) are applicable only for semi angle α less than or equal to 60° and ratios of $T_{min}\cos(\alpha)$ to D not smaller than 0,001.

NOTE 2 The calculation of reducers is based on the following sections/formulae in EN 13480-3:2017:

Formula (B.10) is based on the stipulations in 6.4.7.2;

Formula (B.11) takes into account 6.4.6.3 a) and 6.4.6.3 g);

Formula (B.12) takes into account 6.4.6.3 b) and 6.4.6.3e);

Formula (B.13) takes into account 6.4.8.3;

Formula (B.14) takes into account the pressure resistance of the cylindrical part at the minor end;

Formulae (B.17) and (B.25) are based on (6.4.6-1);

Formulae (B.18) and (B.26) are given as (6.4.8-1);

Formulae (B.19) and (B.27) are based on (6.4.8-2) and (6.4.8-3);

Formulae (B.20) and (B.28) are given as (6.4.8-4);

Formula (B.21) is derived from (6.4.6-2) and (6.1-1);

Formula (B.23) is derived from (6.4.8-6) and (6.1-1).

The calculation of the minimal length at the ends of the reducers Formulae (B.29) and (B.30) takes into account that the wall thickness near the junction may be increased and the wall thickness further away may be reduced provided that the cross-sectional area remains constant (see last paragraph of 6.4.6.2 and last paragraph of 6.4.8.2 in EN 13480-3:2017) and that the reducer will be located between pipes with minimal wall thicknesses of at least T_X and $T_{1,X}$.

No additional calculation of the wall thickness of the knuckle at the major end is required. The formulae in EN 13480-3:2017, (6.4.7-1) to (6.4.7-4) give wall thicknesses which are not larger than for junctions without a knuckle.

The rules for a knuckle at the minor end differs from the stipulations in EN 13480-3:2017.

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EXAMPLE Pressure factor of a concentric reducer 323,9 × 7,1 − 168,3 × 4,5, c_0 = 0 mm, semi angle α = 35°:

Table A.3: L = 203 mm

(B.1): T_{min} = 7,1 mm (100 – 12,5)/100 – 0 mm = 6,213 mm

$T_{1,min}$ = 4,5 mm (100 – 12,5)/100 – 0 mm = 3,938 mm

(B.17): β = 1,000

(B.18): s = 1,578

(B.19): τ = 2,833

(B.20): β_H = 1,139

(B.11): $T_{X,23}$ = 6,213 mm

(B.12): $T_{X,3}$ = 5,715 mm

(B.13): $T_{X,34}$ = 6,674 mm

(B.14): $T_{X,4}$ = 7,578 mm

(B.15): T_X = 5,715 mm

(B.16): $T_{1,X}$ = 2,970 mm

(B.5): X = 91,9 %

The calculation of the minimal lengths at the ends of the cylinders:

Result of solving (B.21) and (B.25) by iteration: $T"_{L2}$ = 4,499 mm, β = 0,784

Result of solving (B.23) with (B.26), (B.27) and (B.28) by iteration: $T"_{L4}$ = 3,261 mm, s = 1,905, τ = 3,320, β_H = 1,100

(B.22): T_{L2} = 5,715 mm

(B.24): T_{L4} = 3,261 mm

(B.29): $L_{2,min}$ = 0,00 mm (no specific length required)

(B.10): $L'_{2,min}$ = 21,32 mm

(B.30): $L_{4,min}$ = 6,99 mm

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B.4.6 Caps

The design of a cap comprises the determination of the wall thickness of the spherical part, the wall thickness of the knuckle and the wall thickness of the cylindrical part. Therefore, first the equivalent wall thickness at different sections of the cap has to be calculated. In the next step the overall equivalent wall thickness of the cap is determined:

$$T_{X,s} = T_{\min} \cdot \frac{D}{R_1 + 1.5 \cdot T_{\min}} \tag{B.31}$$

$$T_{X,kny} = T_{\min} \cdot \frac{D}{2 \cdot \beta \cdot \left(0.75 \cdot R_1 + 0.2 \cdot \left(D - 2 \cdot T_{\min}\right)\right) + T_{\min}} \tag{B.32}$$

$$T_{X,knb} = \frac{D}{\frac{2}{111} \cdot \left(\frac{0.75 \cdot R_1 + 0.2 \cdot \left(D - 2 \cdot T_{\min}\right)}{T_{\min}}\right)^{1.5} \cdot \left(\frac{D - 2 \cdot T_{\min}}{R_2}\right)^{0.825} + 1} \tag{B.33}$$

$$T_X = \min\left(T_{X,s}, T_{X,kny}\ T_{X,knb}, T_{\min}\right) \tag{B.34}$$

The factor β is calculated:

$$Y = \min\left(\frac{T_{\min}}{R_1}; 0.04\right) \tag{B.35}$$

$$Z = \log\left(\frac{1}{Y}\right) \tag{B.36}$$

$$X = \frac{R_2}{D - 2 \cdot T_{\min}} \tag{B.37}$$

$$N = 1.006 - \frac{1}{6.2 + \left(90 \cdot Y\right)^4} \tag{B.38}$$

$$\beta_{0.06} = N \cdot \left(-0.3635 \cdot Z^3 + 2.2124 \cdot Z^2 - 3.2937 \cdot Z + 1.8873\right) \tag{B.39}$$

$$\beta_{0.1} = N \cdot \left(-0.1833 \cdot Z^3 + 1.0383 \cdot Z^2 - 1.2943 \cdot Z + 0.837\right) \tag{B.40}$$

$$\beta_{0.2} = \max((0.532 - 1.843 \cdot Y - 78.375 \cdot Y^2); 0.5) \tag{B.41}$$

$$\beta = \begin{cases} 25 \cdot \left(\left(0.1 - X\right) \cdot \beta_{0.06} + \left(X - 0.06\right) \cdot \beta_{0.1}\right) & if\ 0.06 \le X \le 0.1 \\ 10 \cdot \left(\left(0.2 - X\right) \cdot \beta_{0.1} + \left(X - 0.1\right) \cdot \beta_{0.2}\right) & if\ 0.1 < X \le 0.2 \end{cases} \tag{B.42}$$

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NOTE 1 Formulae (B.31) to (B.42) are applicable provided that the following conditions are simultaneously fulfilled:

$R_2 \leq 0,2\ (D - 2\ T_{min})$

$R_2 \geq 0,06\ (D - 2\ T_{min})$

$R_2 \geq 2\ T_{min}$

$0,001\ (D - 2\ T_{min}) < T_{min} \leq 0,08\ (D - 2\ T_{min})$

$R_1 \leq D$

NOTE 2 Where $T_{min} > 0,005\ (D - 2\ T_{min})$, it is not necessary to calculate (B-33) $T_{X,kn\ b}$.

NOTE 3 The calculation of caps is based on the following formulae in EN 13480-3:2017:

Formula (B.31) is derived from (7.1.3-1) and (6.1-1),

Formula (B.32) is derived from (7.1.3-2) and (6.1-1),

Formula (B.33) is derived from (7.1.3-3) and (6.1-1),

Formula (B.35) is given as (7.1.5-1)

Formula (B.36) is given as (7.1.5-2)

Formula (B.37) is given as (7.1.5-3)

Formula (B.38) is given as (7.1.5-4)

Formula (B.39) is given as (7.1.5-5)

Formula (B.40) is given as (7.1.5-7)

Formula (B.41)) is given as (7.1.5-9),

Formula (B.42) is given as (7.1.5-6) and (7.1.5-8).

EXAMPLE

Pressure factor of a seamless cap 1219x10,

c_0 = 0 mm, $R_2 = 0,15 \cdot D$, $R_1 = 0,8 \cdot D$

$R_2 = 0,15 \cdot 1219 = 183$ mm

$R_1 = 0,8 \cdot 1219 = 975$ mm

(B-1) : T_{min} = 10 mm · (100 – 12,5) / 100 – 0 mm = 8,75 mm

(B-31) : $T_{X,s}$ = 10,792 mm

(B-35) : $Y = 0,00897$

(B-36) : $Z = 2,047$

(B-37) : $X = 0,152$

(B-38) : $N = 0,855$

(B-39) : $\beta_{0,06} = 1,110$

(B-40) : $\beta_{0,1} = 0,826$

(B-42) : $\beta = 0,661$

(B-32) : $T_{X,kn\ y}$ = 8,251 mm

(B-34) : T_X = 8,251 mm

(B-4) : X = 94,3 %

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B.5 Wall thicknesses of fittings of type B

B.5.1 General

The formulae hereafter are applicable for fittings designated by their outside diameter having the reinforcement to the internal. In general, they are not applicable for fittings designated by their inside diameter having the reinforcement to the external. The calculation for tees explicitly takes into account the diameters at the body of the tee D_s and D_b and may therefore be used for fittings designated by their inside diameter, too.

B.5.2 Elbows

Wall thicknesses and other dimension of an elbow type B are illustrated in Figure B.4.

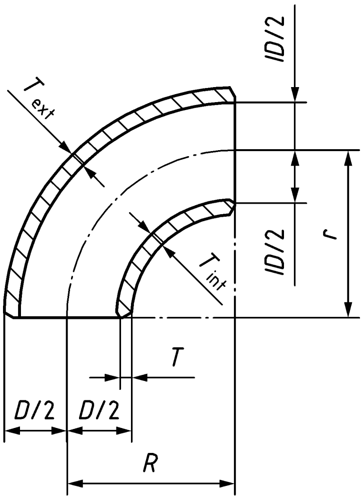

Figure B.4 — Elbow type B

The wall thickness on the intrados of the elbow shall be calculated:

$$T_{int,min} = T_{min} \cdot \left(\frac{D}{2 \cdot T_{min}} + \frac{r}{T_{min}} - \left(\frac{D}{2 \cdot T_{min}} + \frac{r}{T_{min}} - 1 \right) \cdot \sqrt{ \frac{ \left(\frac{r}{T_{min}} \right)^2 - \left(\frac{D}{2 \cdot T_{min}} \right)^2 }{ \left(\frac{r}{T_{min}} \right)^2 - \frac{D}{2 \cdot T_{min}} \cdot \left(\frac{D}{2 \cdot T_{min}} - 1 \right) } } \right) \tag{B.43}$$

where

$$\frac{r}{T_{min}} = \sqrt{ \frac{1}{2} \cdot \left\{ \left(\frac{D}{2 \cdot T_{min}} \right)^2 + \left(\frac{R}{T_{min}} \right)^2 \right\} + \sqrt{ \frac{1}{4} \cdot \left(\left(\frac{D}{2 \cdot T_{min}} \right)^2 + \left(\frac{R}{T_{min}} \right)^2 \right)^2 - \frac{D}{2 \cdot T_{min}} \cdot \left(\frac{D}{2 \cdot T_{min}} - 1 \right) \cdot \left(\frac{R}{T_{min}} \right)^2 } } \tag{B.44}$$

The wall thickness on the extrados of an elbow shall be equal to the wall thickness of the corresponding straight pipe:

$$T_{ext,min} = T_{min} \tag{B.45}$$

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Between intrados (α = 0°) and crown (α = 90°) of the elbow the wall thickness shall be:

$$T_{\alpha,\min} = T_{\min} + \left(T_{\text{int},\min} - T_{\min}\right) \cdot \cos(\alpha) \tag{B.46}$$

Between the crown of the elbow (α = 90°) and extrados (α = 180°) the wall thickness shall be $T_{\min}$.

NOTE 1 Setting $T_{\text{ext,min}} = T_{\min}$ ensures that the design requirements of EN 13480-3:2017 are met for all corrosion or erosion allowances.

NOTE 2 Formulae (B.43) and (B.44) are given in EN 13480-3:2017 as (B.4.1-3) and (B.4.1-4).

EXAMPLE Wall thicknesses of an elbow (welded) model 2D – 711 × 7,1 (R = 711 mm).

(B.1): $T_{\min}$ = 7,1 mm – 0,35 mm = 6,75 mm

(B.44): $r/T_{\min}$ = 105,66

(B.43): $T_{\text{int,min}}$ = 10,067 mm

(B.45): $T_{\text{ext,min}}$ = 6,75 mm

Wall thicknesses including tolerances are:

(B.2): T_{int} = 10,07 mm + 0,5 mm = 10,57 mm,

T_{ext} = 6,75 + 0,35 mm = 7,1 mm

B.5.3 Tees

The wall thickness of tees cannot be calculated directly, but shall be assumed in a first step. This assumption shall then be verified by means of the described method. This method leads to a relation between the pressure loaded area A_p and the stress loaded cross section area A_f shown in Figure B.5. Under certain circumstances, the calculation may need to be repeated using an improved assumption of the wall thickness.

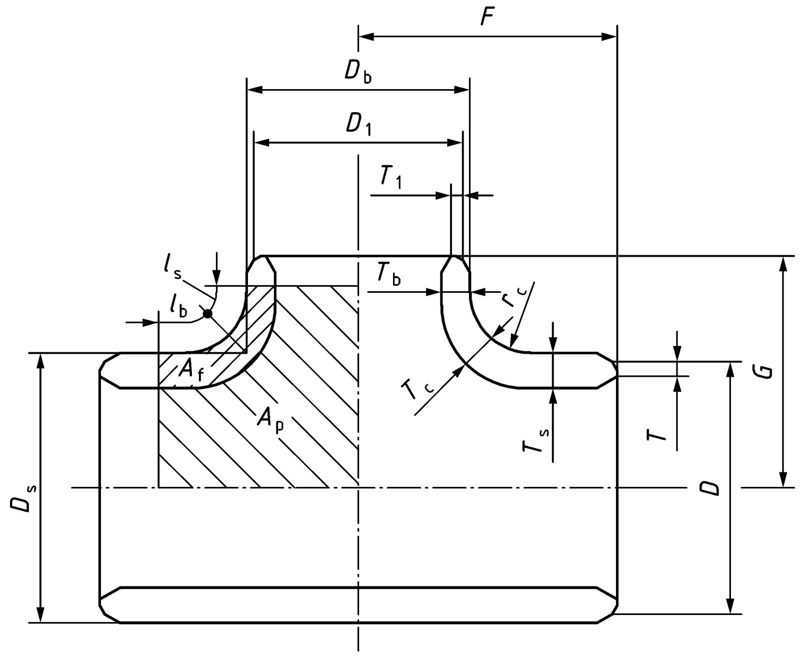

Figure B.5 — Dimensions and areas A_p and A_f of a tee

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For the tee the following condition shall apply:

$$\frac{A_p}{A_f} \leq \max\left(\frac{D - 2 \cdot T_{min}}{2 \cdot T_{min}}, \frac{D_1 - 2 \cdot T_{1,min}}{2 \cdot T_{1,min}}\right) \qquad (B.47)$$

The reinforcing lengths are calculated:

$$l_s = \min\left(\sqrt{\left(D_s - T_{s,min}\right) \cdot T_{s,min}}, F - \frac{D_b}{2} - \left(1 - \frac{\pi}{4}\right) \cdot r_c - T_{min}\right) \qquad (B.48)$$

$$l_b = \min\left(\sqrt{\left(D_b - T_{b,min}\right) \cdot T_{b,min}}, G - \frac{D_s}{2} - \left(1 - \frac{\pi}{4}\right) \cdot r_c - T_{1,min}\right) \qquad (B.49)$$

The wall thickness $T_{s,min}$ and $T_{b,min}$ apply to the whole perimeter of the run and the branch, respectively. At the transitions between the run and the branch (crotch zone) the inside and outside surfaces shall merge smoothly.

The minimum wall thickness at the branch $T_{b,min}$ shall not be larger than the minimum wall thickness at the run $T_{s,min}$.

NOTE 1 Formula (B.47) is derived from (8.4.3-3) and (6.1-1) from EN 13480-3:2017, Formulae (B.48) and (B.49) are based on (8.4.1-2) and (8.4.3-1) from EN 13480-3:2017. The requirement $T_{b,min} \leq T_{s,min}$ is more restrictive than the stipulations in EN 13480-3:2017, Figure 8.3.1. In 8.3.8 and 8.4.4 of EN 13480-3:2017 some restrictions for the applicability of the referenced design formulae are given.

NOTE 2 The subtraction of T_{min} and $T_{1,min}$ in (B.48) and (B.49), respectively, approximately considers the taper borings at the ends.

EXAMPLE Wall thicknesses of a reducing tee (welded) 813 × 8,0 − 508 × 6,3 with the geometry F = 597 mm, G = 533 mm, $D_s = D$, $D_b = D_1$, r_c = 95 mm and $T_{c,min} = (T_{s,min} + T_{b,min})/2$.

Assumed wall thicknesses to be checked: T_s = 19,0 mm, T_b = 15,5 mm

(B.1): T_{min} = 8 mm − 0,35 mm − 0 mm = 7,650 mm

$T_{1,min}$ = 6,3 mm (100 − 12,5)/100 − 0 mm = 5,513 mm

$T_{s,min}$ = 19,0 mm − 0,5 mm = 18,5 mm

$T_{b,min}$ = 15,5 mm (100 − 12,5)/100 = 13,563 mm

$T_{c,min}$ = (18,5 mm + 13,563 mm)/2 = 16,031 mm

(B.48): l_s = 121,24 mm

(B.49): l_b = 81,89 mm

For the calculation of areas A_f and A_p see Figure B.2.

$$\alpha_s = 45° \cdot \max\left(1 - \frac{l_s}{\frac{\pi}{4} \cdot r_c}, 0\right) = 0{,}00°$$

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