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Flanges and their joints - Design rules for gasketed circular flange connections - Part 3: Calculation method for metal to metal contact type flanged joint

Flansche und ihre Verbindungen - Regeln für die Auslegung von Flanschverbindungen mit runden Flanschen und Dichtung - Teil 3: Berechnungsmethode für Flanschverbindungen mit Dichtungen im Kraft-Nebenschluss

Brides et leurs assemblages - Regles de calcul des assemblages a brides circulaires avec joint - Partie 3 : Méthode de calcul pour les assemblages a brides de type contact métal-métal

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Contents

Foreword

This document (CEN/TS 1591-3:2007) has been prepared by Technical Committee CEN/TC "Flanges and their joints", the secretariat of which is held by DIN.

EN 1591 *"Flanges and their joints — Design rules for gasketed flange connections"* consists of the following three parts:

— *Part 1: Calculation method*

— *Part 2: Gasket parameters*

— *Part 3: Calculation method for metal to metal contact type flanged joint (CEN/TS)*

— *Part 4: Qualification of personnel competency in the assembly of bolted joints fitted to equipment subject to the Pressure Equipment Directive*

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Introduction

Bolted Flange connections with metal to metal contact are frequently used in industrial plants for severe working conditions (thermal transients, pressure fluctuations). The use of metal to metal contact allows to avoid the damage of the sealing component by limiting the gasket loading stress and to limit the load variations on the gasket.

This Technical Specification describes a calculation method which enables to determine the internal forces of the BFC in all the load conditions. It ensures structural integrity and control of leak-tightness in BFC with MMC (BFC types which are outside the scope of EN 1591-1).

The calculation method may be divided into three steps:

Determination of the bolt tightening to reach the MMC.

Determination of the bolt tightening to maintain the MMC and to satisfy the leak-tightness criteria in all the load conditions.

Checking of the admissibility of the load ratio.

1 Scope

The aim of this Technical Specification is to describe a calculation method dedicated to Bolted Flange Connections (BFC) with metal to metal contact (MMC). It is dedicated to BFC where MMC occurs in a region between the outside diameter of the gasket and the inside diameter of the bolt hole region. For MMC inside the gasket and for MMC outside the bolt hole region, the present method is not appropriate.

The calculation method proposed in this Technical Specification is mainly based on the method described in EN 1591-1, dedicated to floating type BFC. The behaviour of the complete flanges-bolts-gasket system is considered. In assembly condition as well as for all the subsequent load conditions, the BFC components are maintained together by internal forces. This leads to deformations and forces balances (see Annex F) which gives the basic relations between the forces variations in the BFC.

The calculation of BFC with MMC leads to the consideration of an additional force compared to the EN 1591-1 calculation method: the reaction force in the MMC area. It explains why two compliance equations are required in this Technical Specification (in the EN 1591-1 calculation method just one compliance equation is needed to determine the internal forces in all the load conditions).

Unlike EN 1591-1 where the internal forces variations are determined with the compliance relation between the assembly and the considered load condition, here, the internal forces variations are determined by using the compliance relations between two consecutive load conditions.

This method does not treat non-gasketed pipe joints.

1.1 Requirement for use of the Method

Where permitted, the Method is an alternative to design validation by other means e.g.

— special testing;

— proven practice.

— Use of standard flanges within permitted conditions

1.2 Geometry

The Method is applicable to the configurations having:

— flanges whose section is given or may be assimilated to those given in Figures 4 to 12 of EN 1591-1:2001;

— four or more identical bolts uniformly distributed;

— gasket designed for MMC application;

— flange dimension which meet the following conditions:

a) $0{,}2 \leq b_\mathrm{F} / e_\mathrm{F} \leq 5{,}0$; $0{,}2 \leq b_\mathrm{L} / e_\mathrm{L} \leq 5{,}0$

b) $e_\mathrm{F} \geq \max\left\{e_2; d_{\mathrm{B}0}; p_\mathrm{B} \cdot \sqrt[3]{(0{,}01 \ldots 0{,}10) \cdot p_\mathrm{B} / b_\mathrm{F}}\right\}$

c) $\cos\varphi_\mathrm{S} \geq 1/(1 + 0{,}01 \cdot d_\mathrm{S} / e_\mathrm{S})$

NOTE 1 For explanations of symbols see Clause 3.

NOTE 2 The condition $b_\mathrm{F} / e_\mathrm{F} \leq 5{,}0$ needs not to be met for collar in combination with loose flange.

NOTE 3 The condition $e_F \geq p_B \cdot \sqrt[3]{(0{,}01...0{,}10)\, p_B / b_F}$ is for limitation of non-uniformity of gasket pressure due to spacing of bolts. The values 0,01 and 0,10 should be applied for soft (non-metallic) and hard (metallic) gaskets respectively. A more precise criterion is given in Annex A of EN 1591-1:2001.

NOTE 4 Attention may need to be given to the effects of tolerances and corrosion on dimensions; reference should be made to other codes under which the calculation is made, for example values are given in EN 13445 and EN 13480.

The following configurations are outside the scope of the Method:

— flanges of essentially non-axisymmetric geometry, e.g. split loose flanges, web reinforced flanges.

1.3 Materials

Values of nominal design stresses are not specified in this Calculation Method. They depend on other codes which are applied, for example these values are given in EN 13445 and EN 13480.

Design stresses for bolts should be determined as for flanges and shells. The model of the gaskets is modelled by elastic behaviour with a plastic correction.

For gaskets in incompressible materials which permit large deformations (for example: flat gaskets with rubber as the major component), the results given by the method can be excessively conservative (i.e. required bolting load too high, allowable pressure of the fluid too low, required flange thickness too large, etc.) because it does not take account of such properties.

1.4 Loads

This Method applies to the following load types:

— fluid pressure: internal or external;

— external loads: axial forces and bending moments;

— axial expansion of flanges, bolts and gasket, in particular due to thermal effects.

1.5 Mechanical model

The Method is based on the following mechanical model:

a) Geometry of both flanges and gasket is axisymmetric. Small deviations such as those due to a finite number of bolts, are permitted. Application to split loose flanges or oval flanges is not permitted.

b) The flange ring cross-section (radial cut) remains undeformed. Only circumferential stresses and strains in the ring are treated; radial and axial stresses and strains are neglected. This presupposition requires compliance with condition 1.2 a).

c) The flange ring is connected to a cylindrical shell. A tapered hub is treated as being an equivalent cylindrical shell of calculated wall thickness, which is different for elastic and plastic behaviour, but always between the actual minimum and maximum thickness. Conical and spherical shells are treated as being equivalent cylindrical shells with the same wall thickness; differences from cylindrical shell are explicitly taken into account in the calculation formula.

   This presupposition requires compliance with 1.2 c).

   At the connection of the flange ring and shell, the continuity of radial displacement and rotation is accounted for in the calculation.

d) The gasket contacts the flange faces over a (calculated) annular area. The effective gasket width (radial) b_{Ge} may be less than the true width of gasket. The calculation of b_{Ge} includes the elastic rotation of both flanges as well as the elastic and plastic deformations of the gasket (approximately) in assembly condition.

e) The unloading modulus of elasticity of the gasket may increase with the gasket surface pressure. The Method uses a linear model: $E_G = E_0 + K_1 \cdot Q$. This is the unloading elasto-plastic secant modulus measured between 100 % and 33 % of the highest surface pressure reached on the gasket.

f) Relaxation of the gasket under compression is approximated (see 4.9 and Annex C).

g) Thermal and mechanical axial deformations of flanges, bolts and gasket are taken into account.

h) Loading of the flange joint is axisymmetric. Any non-axisymmetric bending moment is replaced by an equivalent axial force, which is axisymmetric according to Equation (75).

i) Load changes between load conditions cause internal changes of bolt, gasket and MMC forces. These are calculated with account taken of elastic deformations of all components.

j) Load limit proofs are based on limit loads for each component. This approach prevents excessive deformations. The limits used for gaskets, which depend on Q_{max} are only rough approximations.

The model does not take account of the following:

k) Bolt bending stiffness and bending strength. This is a conservative simplification. However the tensile stiffness of the bolts includes (approximately) the deformation within the threaded part in contact with the nut or tapped hole (see Equation (37)).

l) Creep of flanges and bolts.

m) Different radial deformations at the gasket (this simplification has no effect for identical flanges).

n) Fatigue proofs (usually not taken into account by codes like this).

o) External torsion moments and external shear loads, e.g. those due to pipework.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1591-1:2001, *Flanges and their joints — Design rules for gasketed circular flange connections — Part 1: Calculation method*

prEN 1591-2:, *Flanges and their joints — Design rules for gasketed circular flange connections — Part 2: Gasket parameters*

3 Notation

3.1 Use of figures

Figure 1 illustrates the two configurations of metal to metal contact.

Figure 2 shows the variables used in the calculation of the inside diameter of the MMC area.

3.2 Subscripts and special marks

3.2.1 Subscripts

A Additional (F_A, M_A)

B Bolt

D Equivalent cylinder (tapered hub + connected shell) for load limit calculation

E Equivalent cylinder (tapered hub + connected shell) for flexibility calculation

F Flange

G Gasket

H Hub

I Load condition identifier (taken values 0, 1, 2 ...)

L Loose flange

M Metallic ring or metal to metal contact

P Pressure

Q Net axial force due to pressure

R Net axial force due to external force

S Shell, shear

T Shell, modified

X Weak cross-section

W Washer

Δ Symbol for change or difference

av average

c calculated

e effective

j identifier of reference dots (Q_{Gj}, e_{Gj}) used to described the gasket behaviour in compression

max maximum

min minimum

nom nominal

opt optimal

req required

s non-threaded part of bolt

t theoretical, torque, thread

0 initial bolt-up condition (I = 0, see subscript I)

3.2.2 Special marks

~ Accent placed above symbols of flange parameters that refers to the second flange of the connection, possibly different from the first

c exponent marking deformation terms due to creep relaxation

i Exponent marking terms related to the first compliance equation

ii Exponent marking terms related to the second compliance equation

3.3 Symbols

Where units are applicable, they are shown in brackets. Where units are not applicable, no indication is given.

A_B Effective total cross-section area of all bolts [mm²], Equation (36)

A_F, A_L Gross radial cross-section area (including bolt holes) of flange ring, loose flange [mm²], Equations (5), (7), (8)

A_{Ge}, A_{Gt} Gasket area, effective, theoretical [mm²], Equations (41), (39)

C Coefficient to account for twisting moment in bolt load ratio, Equation (121)

E_0 Unloading Compressive modulus of elasticity of the gasket [MPa] at zero compressive stress Q = 0 [MPa] (see prEN 1591-2)

E_B, E_F, E_G, E_L

E_M, E_W Modulus of elasticity of the part designated by the subscript, at the temperature of the part [MPa] (for E_G see prEN 1591-2)

F_A Additional external axial force [N], tensile force > 0, compressive force < 0, see Figure 1 of EN 1591-1:2001

F_B Bolt force (sum of all bolts) [N]

F_{BMMC} Bolt force (sum of bolts) required to reach MMC [N]

F_G Gasket force [N]

F_{GMMC} Gasket force required to reach the MMC [N]

F_M Metal to metal contact force [N]

F_Q Axial fluid-pressure force [N], Equation (74)

F_R Force resulting from F_A and M_A [N], Equation (75)

F_{RMMC} Force resulting from F_A and M_A corresponding to the tightening force F_{BMMC} [N]

$G(t)$ Relaxation function Equation (C.13)

I	Load condition identifier, for assembly condition I = 0, for subsequent conditions I = 1, 2, 3, ...
I_B	Plastic torsion modulus [mm³] of bolt shanks, Equation (121)
K_1	Rate of change of compressive modulus of elasticity of the gasket with compressive stress, prEN 1591-2
K_s	Systematic error due to the inaccuracy of the bolt tightening method
M_A	Additional external moment [N · mm], Figure 1 of EN 1591-1:2001
M_t	Bolt assembly torque [N · mm], Annex D of EN 1591-1:2001
$M_{t, B}$	twisting moment [N · mm] applied to bolt shanks as a result of application of the bolt assembly torque M_t, Equations (121) and (D.8) to (D.11) of EN 1591-1:2001
P	Pressure of the fluid [MPa], internal pressure > 0, external pressure < 0 (1 bar = 0,1 MPa)
Q	Mean effective gasket compressive stress [MPa], $Q = F_G/A_{Ge}$
$Q_{GMMCinf}$	Inferior boundary of the range of gasket compressive stress in which the MMC appears [MPa]
$Q_{GMMCsup}$	Superior boundary of the range of gasket compressive stress in which the MMC appears [MPa]
Q_I	Mean effective required gasket compressive stress at load condition I [MPa]
Q_{min}	Minimum necessary compressive stress in gasket for assembly condition (on the effective gasket area) [MPa], Equation (93), (see prEN 1591-2)
Q_{max}	Maximum allowable compressive stress in the gasket (depends on the gasket materials, construction, dimensions and the roughness of the flange facings) [MPa], Equation (120), see prEN 1591-2 (including safety margins, which are same for all load conditions)
$Q_{max, Y}$	Yield stress characteristic of the gasket materials and construction, see Table 1, and prEN 1591-2 [MPa]
T_B, T_F, T_G, T_L,	
T_M, T_W	Temperature (average) of the part designated by the subscript [°C] or [K], Equation (77), (78) and (80), (81)
T_O	Temperature of connection at assembly [°C] or [K] (usually + 20 °C)
U	Axial displacement [mm]; ΔU according to Equations (76), (77), (78) and Equations (79), (80) and (81).
W_F, W_L, W_X	Resistance of the part and/or cross-section designated by the subscript [N · mm], Equations (123), (135), (137), (139)
X_B, X_G, X_M, X_W	Axial flexibility modulus of bolts, gasket, metallic compression limiter ring, washer [1/mm], Equations (37), (44), (52), (46)
X_{FB}	Axial flexibility modulus corresponding to local compression of flange at contact area with nut [1/mm], Equation (73)

X_{FG}	Axial flexibility modulus corresponding to local compression of flange at contact area with gasket [1/mm], Equation (55)
X_{FL}	Axial flexibility modulus corresponding to local compression of collar at contact area with loose flange [1/mm], Equation (63)
X_{FM}	Axial flexibility modulus corresponding to local compression of flange at metal to metal contact area [1/mm], Equation (59)
X_{LB}	Axial flexibility modulus corresponding to local compression of loose flange at contact area with nut [1/mm], Equation (71)
X_{LF}	Axial flexibility modulus corresponding to local compression of loose flange at contact area with collar [1/mm], Equation (67)
Y_G, Y_M, Y_Q, Y_R	Axial compliance of the bolted connection, related to F_G, F_M, F_Q, F_R [mm/N], Equations (83) to (86) and (89) to (92)
Z_F, Z_L	Rotational flexibility modulus of flange, loose flange [mm^{-3}], Equations (30), (34), (35)
$a(T_I, T_0)$	Shift function Equation (C.17)
b_0	Width of chamfer (or radius) of a loose flange [mm] see Figure 10 of EN 1591-1:2001, Equation (17) such that: $d_{7min} = d_6 + 2 \cdot b_0$
b_F, b_L	Effective width of flange, loose flange [mm], Equations (5) to (8)
b_{Gi}, b_{Ge}, b_{Gt}	Gasket width (radial), interim, effective, theoretical [mm], Equations (38), (40), Table 1
b_{Mt}	Metal to metal contact area width [mm], Equation (48) and Figure 1
c_F, c_M, c_S	Correction factors, Equations (23), (127), (128)
d_0	Inside diameter of flange ring [mm] and also the outside diameter of central part of blank flange (with thickness e_0), in no case greater than inside diameter of gasket [mm], Figures 4 to 12 of EN 1591-1:2001
d_1	Average diameter of hub, thin end [mm], Figures 4, 5, 11 and 12 of EN 1591-1:2001
d_2	Average diameter of hub, thick end [mm], Figures 4, 5, 11 and 12 of EN 1591-1:2001
d_3, d_{3e}	Bolt circle diameter, real, effective [mm], Figures 4 to 12 of EN 1591-1:2001
d_4	Outside diameter of flange [mm], Figures 4 to 12 of EN 1591-1:2001
d_5, d_{5t}, d_{5e}	Diameter of bolt hole, pierced, blind, effective [mm], Figures 4 to 12 of EN 1591-1:2001
d_6	Inside diameter of loose flange [mm], Figures 10, 12 of EN 1591-1:2001
d_7	Diameter of position of reaction between loose flange and stub or collar [mm], Figure 1 of EN 1591-1:2001, Equations (17), (43)
d_8	Outside diameter of collar [mm], Figure 10 of EN 1591-1:2001
d_9	Diameter of a central hole in a blank flange [mm], Figure 9 of EN 1591-1:2001
d_{B0}, d_{Be}, d_{Bs}	Diameter of bolt: nominal diameter, effective diameter, shank diameter [mm], Figure 2 of EN 1591-1:2001, Table B.1 of EN 1591-1:2001

d_{B2}, d_{B3}	Basic pitch diameter, basic minor diameter of thread [mm], see Figure 2 of EN 1591-1:2001
d_{Ge}, d_{Gt}	Diameter of gasket, effective, theoretical [mm], Figure 3 of EN 1591-1:2001, Table 1
d_{G1}, d_{G2}	Inside, outside diameter of theoretical contact area of gasket [mm], Figure 3 of EN 1591-1:2001
d_{M1}, d_{M2}	Inside, outside diameter of theoretical metal to metal contact area [mm]
d_{M1e}	Effective inside diameter of metal to metal contact area [mm], Equation (49), (50)
d_{Me}, d_{Mt}	Diameter of metal to metal contact area, effective, theoretical [mm], Equation (51), (47)
d_E, d_F, d_L	Average diameter of part or section designated by the subscript [mm], Equations (5) to (8), (10)
d_S, d_X	to (12), Figures 4 to 12 of EN 1591-1:2001
d_{W1}, d_{W2}	Inside, outside diameter of washers Equation (46) [mm]
e_0	Wall thickness of central plate of blank flange within diameter d_0 [mm], Figure 9 of EN 1591-1:2001
e_1	Minimum wall thickness at thin end of hub [mm], Figures 4, 5,11, 12 of EN 1591-1:2001
e_2	Wall thickness at thick end of hub [mm], Figures 4, 5, 11, 12 of EN 1591-1:2001
e_D, e_E	Wall thickness of equivalent cylinder for load limit calculations, for flexibility calculations [mm], Equations (9), (11), (12), (124)
e_F, e_L	Effective axial thickness of flange, loose flange [mm], Equations (5) to (8)
e_{Fb}	Thickness of flange ring at diameter d_3 (bolt position) [mm] Equation (3)
e_{Ft}	Thickness of flange ring at diameter d_{Ge} (gasket force position), relevant for thermal expansion [mm], Equation (77), (78) and (80), (81)
e_{Fm}	Thickness of flange ring at diameter d_{Me} (metal to metal contact force position), relevant for thermal expansion and inside diameter of the metal to metal contact area [mm], Equation (77), (78) and (80), (81)
e_G	Thickness of gasket [mm], Figure 3 of EN 1591-1:2001
e_M	Thickness of metallic compression limiter ring [mm]
e_P, e_Q	Part of flange thickness with (e_P), without (e_Q) radial pressure loading [mm], Figures 4 to 12 of EN 1591-1:2001, such that $e_P + e_Q = e_F$
e_S	Thickness of connected shell [mm], Figures 4 to 8, 10 to 12 of EN 1591-1:2001
e_X	Flange thickness at weak section [mm], Figure 9 of EN 1591-1:2001
e_W	Washer thickness [mm]
f_B, f_E, f_F, f_L, f_S	Nominal design stress [MPa] of the part designated by the subscript, at design temperature [°C] or [K], as defined and used in pressure vessel codes

h_G, h_H, h_L, h_M	Lever arms [mm], Equations (15), (16), (18), (19)
h_D	Difference of lever arms h_G and h_M [mm], Figure 1, Equation (14)
h_P, h_Q, h_R,	
h_S, h_T	Lever arm corrections [mm], Equations (13), (24) to (27), (32), (33)
j_M, j_S	Sign number for moment, shear force (+ 1 or – 1), Equation (129)
k_Q, k_R, k_M, k_S	Correction factors, Equation (28), (29), (130)
l_{5t}	Depth of the blind holes, Figure 5 of EN 1591-1:2001, Equation (3)
l_B, l_s	Bolt axial dimensions [mm], Figure 2 of EN 1591-1:2001, Equation (37)
l_e	$l_e = l_B - l_s$
l_H	Length of hub [mm], Figures 4, 5, 11, 12 of EN 1591-1:2001, Equation (9), (124)
n_B	Number of bolts, Equations (1), (4), (36), (37), (46)
p_B	Pitch between bolts [mm], Equation (1)
p_t	Pitch of bolt thread [mm], Table B.1 of EN 1591-1:2001
r_0, r_1	Radii [mm], Figures 4, 10 of EN 1591-1:2001
r_2	Radius of curvature in gasket cross-section [mm], Figure 3 of EN 1591-1:2001
z_{1B}, z_{1F}, z_{1L}	thickness concerned by the local compression at the inner diameter of the component designated by the subscript [mm], Equation (55) to (73)
z_{2B}, z_{2F}, z_{2L}	thickness concerned by the local compression at the outer diameter of the component designated by the subscript [mm], Equation (55) to (73)
ΔU	Differential axial expansions [mm], Equation (76) to (81)
Θ_F, Θ_L	Rotation of flange, loose flange, due to applied moment [rad], Equation (97) to (100), (104), (105)
Ψ	Load ratio of flange ring due to radial force, Equation (131)
Ψ_Z	Particular value of Ψ, Equation (123), Table 2
Φ_B, Φ_F, Φ_G, Φ_L, Φ_X	Load ratio of part and/or cross-section designated by the subscript, to be calculated for all load conditions, Equation (120), (121), (122), (134), (136), (138)
Φ_{max}	Reduced maximum allowable load ratio, Equation (108)
α_B, α_F, α_G, α_L, α_W, α_M	Thermal expansion coefficient of the part designated by the subscript, averaged between T_0 and T_B, T_F, T_G, T_L, T_W, T_M [K^{-1}], Equation (77), (78) and (80), (81)
β, γ, δ, θ	Intermediate variables, Equations (9), (20), (21), (22), (43), (108), (124)
κ, λ, χ	