ÍNDICE

NEXT100: DESIGN AND FABRICATION OF FLANGES

The designed product must be feasible, functional, reliable, feasible within the stipulated period and competitively saleable (Quality Handbook, COINTRA, 1972).

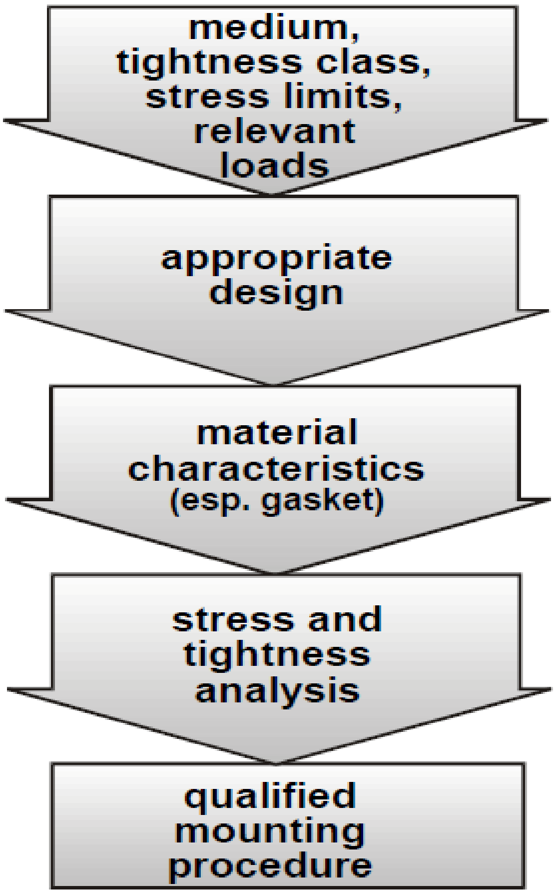
ABSTRACT

This paper proposes an integral flange without a hub which will allow the fabrication with a plate. For a given geometry, materials (titanium and Inconel) and gasket (Hellicoflex from Garlock) this paper applies the rules of design specified by ASME VIII, Division 1, Appendix 2, Appendix Y (nonmandatory) and Division 2, Part 4.16 for a fixed thickness.

The assumed flange satisfied the requirements of the Appendix Y. The best solution may be an integral face-to-face flange without hub (or with a welding hub) according with Appendix Y.

1 BACKGROUND

On the whole, the steps for design a flange are:

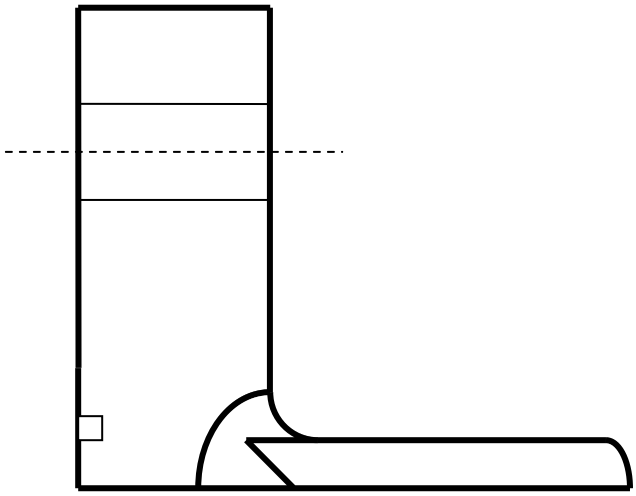


With the vessel for the NEXT 100´s project there is another stage, a previous phase: **feasibility**. We can follow the five steps and to find a design no feasible, or feasible with a huge cost.

The pressure vessel flanges had been constructed with steel, cooper and aluminium, but not with titanium, the titanium has been used in pressure vessels as cladding material.
The more common flanges are hubbed flanges made by forging, steel, aluminium and cooper flanges are standardised. It is possible to find a titanium flange with hub with a reasonable cost? From ASM Handbook, Volume 14, Forming and Forging:

> TITANIUM ALLOYS are forged into a variety of shapes and types of forgings, with a broad range of final part forging design criteria based on the intended application. As a class of materials, titanium alloys are among the most difficult metal alloys to forge, ranking behind only refractory metals and nickel/cobalt-base superalloys. Therefore, titanium alloy forgings, particularly closed-die forgings, are typically produced to less highly refined final forging configurations than are typical of aluminum alloys (although precision forgings in titanium alloys are produced to the same design and tolerance criteria as aluminum alloys; see the section "Titanium Alloy Precision Forgings" in this article) and to equivalent or more refined forging design sophistication than carbon or low-alloy steel forgings, because of reduced oxidation or scaling tendencies in heating. Because of the high cost of titanium alloys in comparison to other commonly forged materials, such as aluminum and alloy steels, final forging design criteria in titanium closed-die forgings are typically balanced between producibility demands and cost considerations (particularly machining costs and overall metal recovery).

We propose, bearing in mind the feasibility, an **integral narrow flange without hub** jointed with the cylindrical shell with a welded joint (full penetration).



This flange can be fabricated with plate (cutting, welding and machining). Another solution is constructing the flange with a hot rolled billet bended and welded. The first process is easier, although produces more scrap.

Fabrication of flange's ring

Process	Billet	Plate	
Cutting	--	+	Abrasive water-jet cutting. Garnet and silica, the most common abrasive materials used. The central circle shall be scraped.
Heating	+	---	Perhaps 815ºC, minimum forging temperature for C.P. titanium.
Hot forming	+	---	
Welding ring	+	---	End to end of billet, after forming. High risk of lack of fusion, difficulties for radiographic inspection (high thickness).
Welding flange-shell	+	+	
Machining	+++	+	

Note: +++ more difficult than +.

The use of plate for a flange without hub must be justified:

ASME Code treats the use of plate for flanges:

(d) Fabricated hubbed flanges shall be in accordance with the following:

(1) Hubbed flanges may be machined from a hot rolled or forged billet or forged bar. The axis of the finished flange shall be parallel to the long axis of the original billet or bar. (This is not intended to imply that the axis of the finished flange and the original billet must be concentric.)

(2) Hubbed flanges [except as permitted in (1) above] shall not be machined from plate or bar stock material unless the material has been formed into a ring, and further provided that:

(a) in a ring formed from plate, the original plate surfaces are parallel to the axis of the finished flange. (This is not intended to imply that the original plate surface be present in the finished flange.)

(b) the joints in the ring are welded butt joints that conform to the requirements of this Division. Thickness to be used to determine postweld heat treatment and radiography requirements shall be the lesser of

$$t \text{ or } \frac{(A-B)}{2}$$

2010 ASME VIII, Div. 1, Mandatory Appendix 2

4.16.4 Flange Materials

4.16.4.1 Materials used in the construction of bolted flange connections, excluding gasket materials, shall comply with the requirements given in Part 3.

4.16.4.2 Flanges made from ferritic steel shall be given a normalizing or full-annealing heat treatment when the thickness of the flange section exceeds 75 mm (3 in.).

4.16.4.3 Fabricated flanges with hub shall be in accordance with the following:

a) Flanges with hubs may be machined from a hot rolled or forged billet or forged bar. The axis of the finished flange shall be parallel to the long axis of the original billet or bar, but these axes need not be concentric.

b) Flanges with hubs, except as permitted in paragraph 4.16.4.3.a, shall not be machined from plate or bar stock material unless the material has been formed into a ring, and further provided that:

1) In a ring formed from plate, the original plate surfaces are parallel to the axis of the finished flange;

2) The joints in the ring are welded butt joints that conform to the requirements of Part 6. The thickness to be used to determine postweld heat treatment and radiographic requirements shall be $\min\left[t, (A-B)/2\right]$.

2010 ASME VIII, Div. 2, Part 4.16

The use of plate for flanges with hubs is forbidden by ASME, but nothing about flanges without hubs.

The European Standard EN 13445-3: 2010, Unfired pressure vessels. Part 3, Design, as ASME, forbids (but not in the strict sense of the word) the use of plate for flanges with hubs (see 11.4.4).

On the other hand, ASME allows the use of plate in the fabrication of hubs for flat heads (not for flanges) from plate.

3.9 Supplemental Requirements for Hubs Machined From Plate

3.9.1 General

The supplemental requirements of paragraph 3.9 are required for plate materials that are used in the fabrication of hubs for tubesheets, lap joint stub ends, and flat heads machined from plate when the hub length is in the through thickness direction of the plate.

3.9.2 Material Requirements

3.9.2.1 Plate shall be manufactured by a process that produces material having through thickness properties which are at least equal to those specified in the material specification. Such plate can be but is not limited to that produced by methods such as electroslag (ESR) and vacuum arc re-melt (VAR). The plate must be tested and examined in accordance with the requirements of the material specification and the additional requirements specified in the following paragraphs.

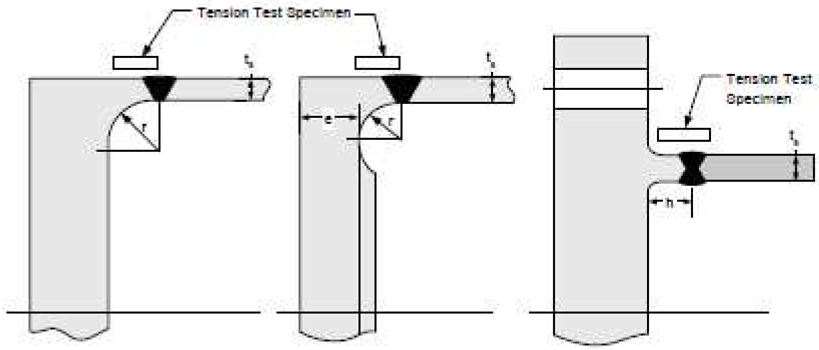
3.9.2.2 Test specimens, in addition to those required by the material specifications, shall be taken in a direction parallel to the axis of the hub and as close to the hub as practical, as shown in Figure 3.2. At least two tensile test specimens shall be taken from the plate in the proximity of the hub, with one specimen taken from the center third of the plate width as rolled, and the second specimen taken at 90° around the circumference from the other specimen. Both specimens shall meet the mechanical property requirements of the material specification. For carbon and low alloy steels, the reduction of area shall not be less than 30%; for those materials for which the material specification requires a reduction of area value greater than 30%, the higher value shall be met.

3.9.2.3 Subsize test specimens conforming to the requirements of SA-370, Figure 5 may be used if necessary, in which case the value for percent elongation in 50 mm (2 in.), required by the material specification, shall apply to the gage length specified in SA-370, Figure 5.

3.9.2.4 Tension test specimen locations are shown in Figure 3.2.

2010 ASME VIII, Div. 2, Part 3

2010 SECTION VIII, DIVISION 2



Note: These details are not permissible if machined from plate unless the requirements of paragraph 3.9 are satisfied.

Figure 3.2 – Typical Locations for Tensile Specimens

The use of plate in the fabrication of the flange come up a problem: due to the fibrous structure of wrought products, the mechanical properties may be different for different orientations of the test specimen with respect to the fiber (working) direction. These phenomena (planar anisotropy) can be controlled breaking three specimens of the plate in the tension test, with 0º respect to rolling direction, 45º and 90º respectively.

Another question is to choose the appropriate design. We have three alternatives:

1 ASME VIII, Division 1: Mandatory Appendix 2: Rules for bolted flange connections with ring type gaskets;

2 ASME VIII, Division 1: Nonmandatory Appendix Y: Flat flanges with metal-to-metal contact outside the bolt circle; and

3 ASME VIII, Division 2: Part 4.16: Design Rules for Flanged Joints.

The rules of Appendix 2 and Part 4.16 apply specifically to the design of bolted flange connections with gaskets that are entirely within the circle enclosed by the bolt holes and whit no contact outside this circle (floating gasket).

The Nonmandatory Appendix Y applies to bolted flanged connections where the flanges are flat faced and are in uniform metal-to-metal contact across their entire face during assembly before the bolts are tightened or after a small amount of preload is applied to compress the gasket. **This Appendix assume that the gasket seating loads are small and may be in most cases be neglected**.

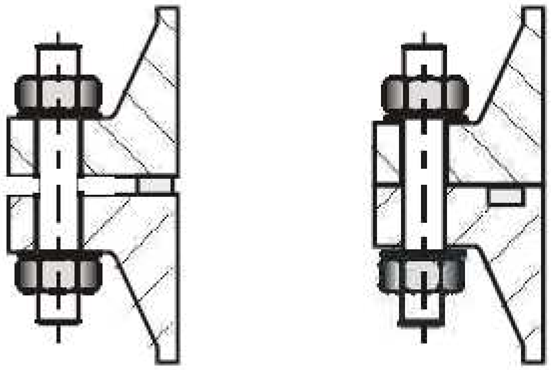


Fig. 3 : flange type with floating gasket (left) and flange type with metal-to-metal contact (right)

We also have the other side the European Standards:

The paragraph 11.10.3 Design of EN 13445-3 applies to flange type with metal-to-metal contact and assumes as negligible the gasket load.

EN-1591-1:2001+A1, March, 2010, Flanges and their joints. Design rules for gasket circular flange connections. Part 1: Calculation method, apply only to flanges with the gasket floating between the flange plates.

From the document “Critical review of European Standards for flanged joints”, J. Batonicek and others:

> “In general the European standardization projects cover the entire chain that is necessary to prove function of a flanged joint with the floating between the flange plates.
> There are no European Standards (and no projects) regarding flanged joints with metal-to-metal contact of the flange plates”.

Tab. 1: standards (EN) for dimensions 2001/03

Flanges and their Joints - **circular flanges** for pipes, valves, fittings and accessoires **PN-designated**	prEN 1092-1	part 1: Steel flanges
	EN 1092-2	part 2: Cast iron flanges
	cancelled	part 3: Copper alloy flanges
	prEN 1092-4	part 4: Aluminum alloy flanges
Flanges and their Joints - **circular flanges** for pipes, valves, fittings and accessoires **CLASS-designated**	prEN 1759-1	part 1: Steel flanges - NPS 1/2 to 24
	prEN 1759-2	part 2: Steel flanges with bore sizes DN 650 bis DN 1500
	cancelled	part 3: Copper alloy flanges
	prEN 1759-4	part 4: Aluminum alloy flanges
Flanges and their Joints - **bolts and nuts**	EN 1515-1	part 1: selection of bolting
	prEN 1515-2	part 2: Bolting, classification
Flanges and their Joints - **dimensions of gaskets** for PN-designated flanges	EN1514-1	part 1: Non-metallic flat gaskets with or without inserts
	EN 1514-2	part 2: Spiral wound gaskets with steel flanges
	EN 1514-3	part 3: Non-metallic PTFE envelope gaskets
	EN 1514-4	part 4: Corrugated, flat or grooved metallic and filled metallic gaskets for use with steel flanges
	prEN 1514-5	part 5: Metallic ring-joint gaskets for use with steel flanges
	prEN 1514-6	part 6: Kammprofile gaskets for use with steel flanges
	prEN 1514-7	part 7: Covered metal jacketed gaskets for use with steel flanges
Flanges and their Joints - **dimensions of gaskets** for Class-designated flanges	prEN 12560-1	part 1: Non-metallic flat gaskets with or without inserts
	prEN 12560-2	part 2: Spiral wound gaskets with steel flanges
	prEN 12560-3	part 3: Non-metallic PTFE envelope gaskets
	prEN 12560-4	part 4: Corrugated, flat or grooved metallic and filled metallic gaskets for use with steel flanges
	prEN 12560-5	part 5: Metallic ring-joint gaskets for use with steel flanges
	prEN 12560-6	part 6: Kammprofile gaskets for use with steel flanges
	prEN 12560-7	part 7: Covered metal jacketed gaskets for use with steel flanges

Tab. 2: standards (EN) for gasket characteristics

Flanges and their Joints - **Gasket parameters and test procedures** relevant to the design rules for gasketed circular flange connections	prEN 13555	
Flanges and their Joints - **quality assurance standards for gaskets**	WI 0074031	

Tab. 3: standards (EN) regarding flange calculation

Flanges and their Joints - **design rules** for gasketed circular flange connections	EN 1591	part 1: Calculation method (part 2: gasket factors)
unfired pressure vessels part 3: design	prEN 13445-3	Calculation according ASME Calculation according EN 1591

Tab. 4: other standards (EN) for flanged joints

Flanges and their Joints - p/T rating method	WI 0074018	

2 DATA DESIGN

Material: Titanium grade 2, R50400 (shell and flange)
Inconel 718, N07718 (bolts).

From ASME II:

Table Y 1:

Material	Specification	Denomination	YS(MPa)	TS(MPa)
Ti, grade 2	SB 265	R50400	275,6	344,5

Titanium:

Material	Table	Section	Division	Maximum allowable stress value, (MPa)
Ti, grade 2, plate	1B	ASME VIII	1	S=98,5
Ti, grade 2, plate	5B	ASME VIII	2	Sm=143,3

Inconel 750 (N07750): 70Ni-16Cr-7Fe-Ti-Al:

Material	Table	Section	Division	Min Y.S (MPa)	Min. T.S (MPa)	Max. all. Stress, MPa
N07750	3	VIII	1 and 2	1033,5	1274,6	255

Module of elasticity E, MPa.:

Material	Table	E, (MPa)
Ti, R50400	TM-4	106795
Inconel N07718	TM-5	199121

Gaskets:

Gasket, Helicoflex	
Al jacket, CS	5mm
Y1=Ym1	30N/mm
Y2	220N/mm
e2	0,9mm
Pu	63
Ym	30
Gg,groove depth	6,78mm
Fg, groove widt	4,1mm

Geometric values:

Inside diameter (mandatory)	B=1140mm
Diameter at location of gasket load reaction	G=1147,5mm
Bolt-circle diameter	C=1235mm
Outside diameter of flange	A=1370mm

3 CALCULATIONS OF FLANGE

3.1 Floating gasket, Division 1, Appendix 2

Thickness of shell, (no hub) depending of design rules, g0=g1=10mm

VESSEL THICKNESS	
Division 1	
t	8,996064606
g0	10
P (with g0)	1,710069444

With the rules of Division 1, with **P=MAWP=1,54MPa**, a joint efficiency, E=1, the thickness of shell works out 8,99mm, we choose 10mm because 9mm is an odd commercial thickness.

Bolt loads

The first step is to calculate the bolt loads for each of the two design conditions of operating and gasket seating.

The required bolt load for the operating condition (OC) Wm1 shall be sufficient to resist the hydrostatic end force H exerted by the maximum allowable working pressure on the area bounded by the diameter of gasket reaction, G, and, in addition, to maintain on the gasket a compression load Hp which experience has shown to be sufficient to assure a tight joint.

$H=0.785\ G^2P= 1591827\ N$
Hp==2bx3,14GmP=3,14GYm=108095 N

$W_{m1}=H+Hp=1699922\ N$

Before a tight joint can be obtained, it is necessary to seat the gasket properly by applying a minimum initial load, W_{m2}, under atmospheric temperature conditions without the presence of internal pressure.

$W_{m2}=3,14GY_2=792693\ N$

The total cross-sectional area of bolts Am required for both the operating conditions and gasket seating is the greater of the values for Am1 and Am2, where

$Am_1=W_{m1}/Sb=6895mm^2$, and
$Am_2=W_{m2}/Sb=3109\ mm^2$,

$Am=6895\ mm^2$

A selection of bolts to be used shall be made such that the actual total cross-sectional area of bolts Ab will not be less than Am.

Selecting bolts (nonmandatory):

For the area of bolts we shall use the root diameter of bolt dr.

dr=db-1,2268p, where *db* is the nominal diameter and *p* the pitch.

The number of bolts (bolt spacing) is important for tightening. We choose N bolts of size (M dbXp) such that the following relationship will be accomplished:

$\pi C/Ndb = 3.$