Comparison between The Ring Flange and the new Quadra-Sector Flange- by modeling and analyzing of the mechanical stress qualification

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***Abstract*—IJOA Journal**

This article deals with the economic aspect and the mechanical reliability of two variants of a structure.
One variant is known and marketed (Ring Flange); the other is innovative and marketed without warranty specifications (Quadra-Sector Flange). The raw material benefit is the compromise between the two variants, and the warranty expected by the customers remains the concern. The manufacture of the two structures is carried out in two operating modes and based on the same raw material; they also both work in the same conditions. The rationale behind this study is reassuring the customers, showing them both patterns by means of a thorough structural stress study based on analyzing our input data (external effects) and comparing the results of the two patterns.

Keywords—IJOA, Journal, Optimozation

Flange, Stress, Black steel, Reliability

I. INTRODUCTION

The high production rate of galvanized steel pipes for drinking water supply and the construction of pumping stations require greater demand for black steel flanges [3,7] [3,8].The steel flange is essential connecting joints in industrial piping and remains very important for pipes assembly and disassembly.

It is a mechanical structure which is welded directly on the pipe or manufactured to be mounted on a more sophisticated mounting/dismounting equipment (simple dismounting joint, auto-stop dismantling joint, Gibault joint…) in order to ensure both coupling between two pipes and a dynamic sealing [7,6].
The high demand for these structures and the competitive price between suppliers pushed many of them to innovate a new structure (black steel flange), which functions under the same conditions as the other standard flange. This structure is made of four elements (Quadra-sectors), while the other is completely homogeneous (a single ring) [8, 63].
Many customers complain about the state of the finished product, others ask for a warranty of proper functioning. To better meet these demands we shall make a comparison between the two patterns (quadra-sector flange and ring flange) in order to distinguish the most robust flange structure, without stress.

II. MOTIVATION & METHODOLOGY

A. Motivation

In objective to give our client the justification of the reliable structure, and to assume that the quadra sector flange can make the same function, we have doing the present study.

B. Methodology

The flange is in direct contact with water, connected and mounted with another flange by bolts [2,10]
(As shown in fig 1). In our example, the contact is modeled by a fluid-structure coupling: the fluid is water with a density of 1000 Kg / m^3 at an ambient temperature of 35 ° C to 37 ° C, and the structural element is steel modeled by 210 MPa Young’s Modulus, with a density of 7.860 Kg / m^3.
Our operating environment is in most cases: underground pipes, pipe in conditioning workshops, drinking water supply for a terminal post, pipes in pumping station, or any water supply between two ends.

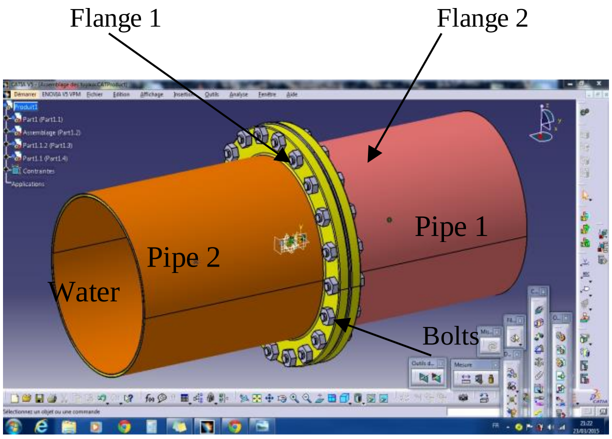

Fig 1: Flange mounting used for piping.

The fluid is water; it is incompressible (constant density): we are facing a Hydro-Elastic problem. Before starting the stress simulations we carried out a vibration analysis of the two patterns in order to observe the impact of the fluid on both structures. After that, we studied two structures using CATIA V5, and this showed us deterioration in the Quadra-sector structure, while the ring structure appeared without degradation. But this study remains limited because the input data are mechanical values and not consistent with CATIA V5 (because of the following: modeling water pressure as a load, the density is not included, and the large scale results). So we were pushed to focus on simulation, meshing and degradation analysis on ANSYS APDL, because its interfaces provide a better modeling and simulation of the fluid-structure coupling. In addition, the input parameters such as density, materials and environment are also included and do not require a large scale. The modeling on ANSYS APDL is justified by the importance of the structure and the final results.
We went through the modeling of structures on ANSYS APDL in order to make a geometric and a material definition to the structure and to represent the operating environment. (As shown in figs 2 and 3).

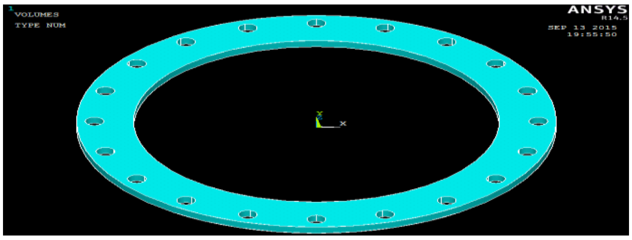

Fig 2: DN 500 PN 10 ring-flange.

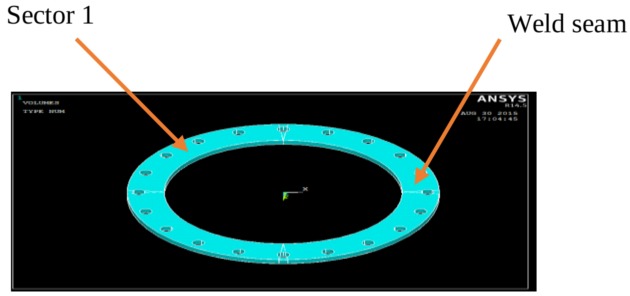

Fig 3: DN 500 PN 10 Quadra-sector flange.

We have a black steel structure, which is produced in manufacturing sites and by a specific preparation process, namely cutting, welding, and precision machining, drilling. Finally, to obtain the standard size and to ensure protection from moisture, a heat treatment is performed in galvanizing basins.
Since the steel ring flange structure has a material homogeneity and volume symmetry, we created the pattern by meshing to obtain a refined structure, represented in form of nodes. We used a tetrahedral meshing with 4 nodes 285 (As shown in fig 4), as this allows us to mesh the structure into more elements.

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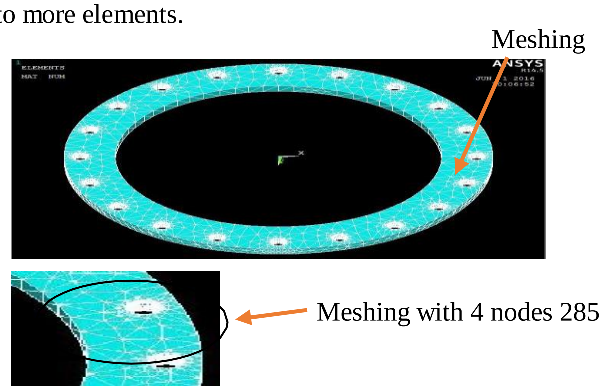


Fig 4: Meshing a DN 500 PN 10 ring-flange using ANSYS APDL

The quadra-sector flange has the same material features and functions under the same conditions as the ring flange, but its manufacture process is quite different.It has 4 elements(As shown in Fig 3) , ground and welded with each others to form a flange similar to the ring flange (As shown in Fig 5).We focused the modeling to one single element (sector) (As shown in figs 6, 7, 8), because the structure has a material symmetry, and it has also a uniform pressure distribution (a stable and uniform pressure of 2.5 Br on a single sector).That is why we used the same mesh modeling as in the first structure (ring flange).

After meshing the two types of flanges, we moved to modeling and analysing the results. The findings that interest us are: the displacement of the structure under the pressure (on the inner diameter), and the Von Mises stress. We used them to evaluate the stress of the structure. Results analysis isn't limited only to maximum and minimum values, but also to average extreme values of several nodes as we shall see in what follows.

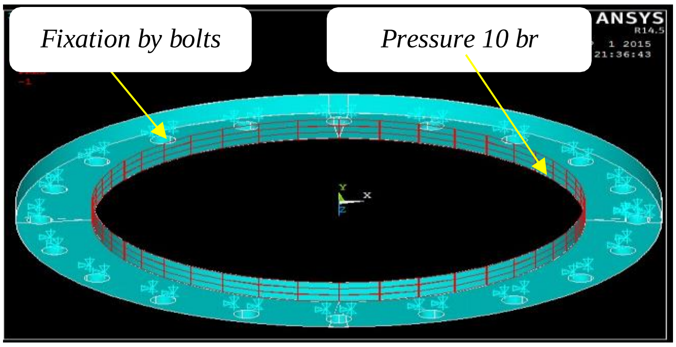


Fig 5: Boundary conditions for a DN 500 PN Quadra-sector flange.

Refining of a weld

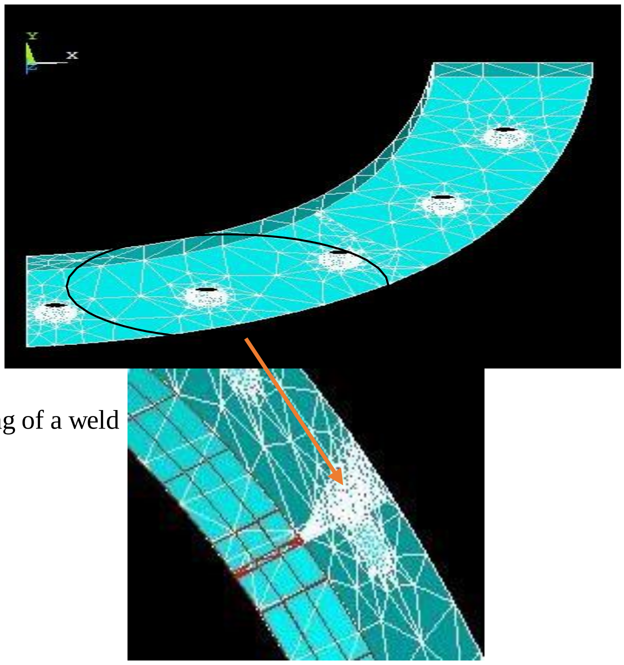


Fig 6 & 7: Meshing of one sector of a DN 500 PN 10 Quadra-sector flange **&** Refining of a weld seal.

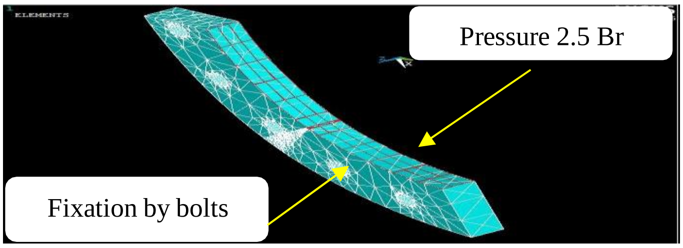


Fig 8: Boundary conditions for one flange sector.

III. RESULTS

Why a quadra-sector flange? For manufacturers the answer is related to the value of Quality/Cost: manufacturing a flange through more stages of production, but a cheaper cost of raw materials (a benefit of 78.29%). If we take a DN 500 PN10 flange (nominal diameter of 500 mm and an operating pressure of 10 br), the manufacture will require a sheet size of 720*720 mm² , with a thickness of 40 mm, and a weight of 165.89 Kg to produce a 36 Kg flange.So we use only 21.70% of the metal sheet to produce the structure.

It's too expensive for flange manufacturers! The production of flanges into sectors allows a significant benefit not only in raw materials, but also in product sales, in presence of a logical and motivating purchase-sale policy. Our concerns, however, are the claims and complaints of the customers about the heterogeneity of the structure and the appearance of welded surfaces on the flange.(As shown in fig 9).

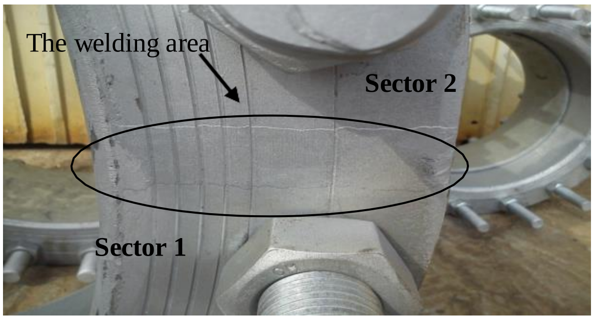


Fig 9: Appearance of the welded area after galvanizing

The following table gives the results of the vibration analysis of the hydro-elastic water-flange problem:

Points	water/ring-flange interaction	water/ Quadra-sector flange interaction
Point 1	43790.2	41051.2
Point 2	43857.3	45921.4
Point 3	43895.2	45933.5
Point 4	43988.2	45985.5
Point 5	44120.5	46133.6
Point 6	44132.7	46670.5

Table 1 : Natural vibration frequencies

Ring-flange pattern

After meshing and using boundary conditions, the flange was put under the conditions of the operating environment by coupling it to another flange (bolted with another flange), and applying a fluid (water) pressure of 10 Br to it. We got the following results in ANSYS APDL interface :

Displacement:

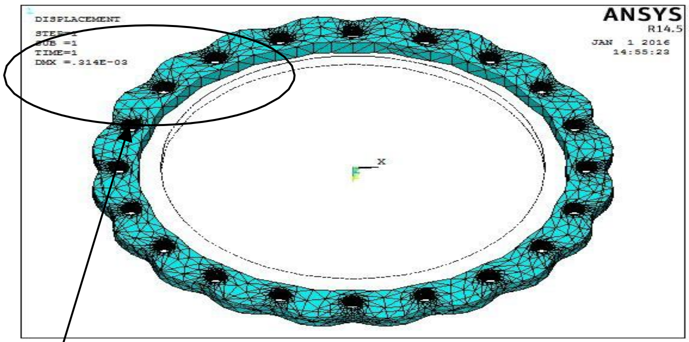


Fig 10: Displacement

The maximum value of displacement

We notice a slight displacement of the structure under the pressure applied, a displacement of $0.314*10^{-3}$ mm. This value is the maximum, and justifies the vibration of the structure when the fluid flows.

The maximum nodal displacement

Displacement (nodal solution)

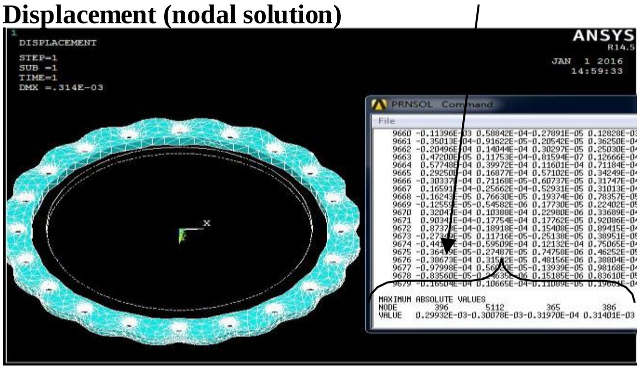


Fig 11: Displacement (nodal solution)

Node	Maximum value of displacement (mm)
396	$0.299*10^{-3}$
5112	$-0.3007*10^{-3}$
365	$-0.319*10^{-3}$
386	$0.314*10^{-3}$

Table 2 : maximum nodal displacements.

The advantage of this result is the nodal demonstration of the maximum displacement values. It helps us define the area having a maximum displacement, which causes no degradation of the structure (no critical area, no change in the structure shape, no cracking in our model).

Stress (Von Mises stress)

We illustrate in the following figure the stress of a DN 500 PN 10 ring-flange, by using the representation of Von Mises stress: the result of vibratory and cyclic stresses applied to the structure.

PLNSOL, S, EQV 0,1 ANSYS control allows to visualize the stress value in all nodes. The figure shows a minimum value of 0.016144 MPa and a maximum value of 2.49406 MPa, but both have no impact on the structure (no crack initiation, and no degradation)

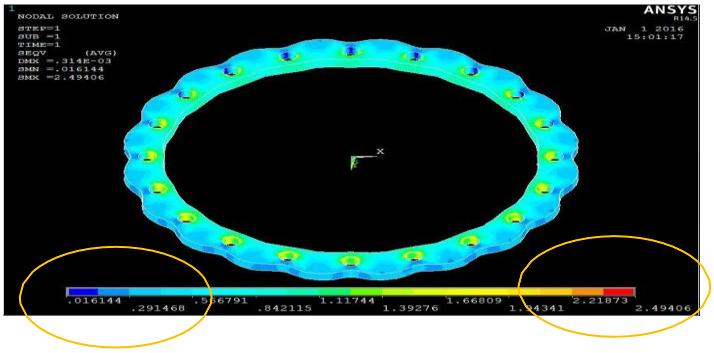


Fig 12: Stress (VON MISES stress)

Von Mises stress in nodal mode

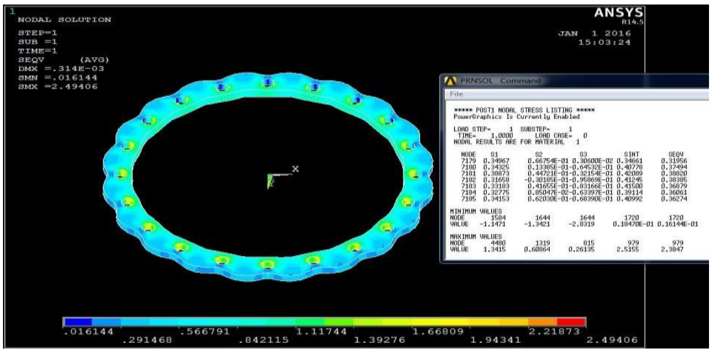


Fig 13: Stress (VON MISES stress)

By using the nodal solution, we got several maximum values of Von Mises stress:

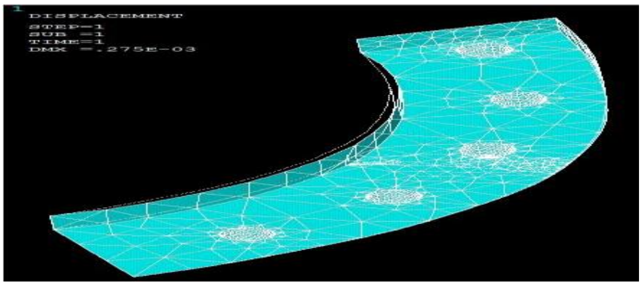
Node	Maximum values of Von Mises stress(MPa)
4480	1.3415
1319	0.6086
815	0.2613
979	2.5155
979	2.3847

Table 3 VON MISES stress (nodal solution)

On table 3 the nodal mode allowed us to read some maximum values of Von Mises stress, for example the value 2.3847 MPa at the node 979, which is close to the maximum value 2.49406 MPa.
The most stressed and critical areas of the flange are the holes. That's logical, because the internal surface of the holes undergoes a fixation exerted by the joining bolts, and a pressure at the internal surface of the ring.
A slight inward movement is generated; this movement of the structure (internal ring) causes deformation of the internal surface of the holes (without degradation), and that justifies the stress on holes (see the red color, see fig.6).

Quadra-sector flange pattern

After meshing and using boundary conditions, the quadra-sector flange was put under the conditions of the operating environment by coupling it to another similar flange, and applying a fluid pressure of 0.25 Br to it.We got the following results in the same interface ANSYS:



We have a maximum average movement of $0.275*10^{-3}$mm (0.275 micrometer) on the structure under the applied pressure. This value justifies the displacement of the structure when the fluid flows, and does not lead to any degradation under the effect of water pressure: there is no deformation or cracking on the structure [4, 31].

The maximum nodal displacement

Displacement(nodalsolution)

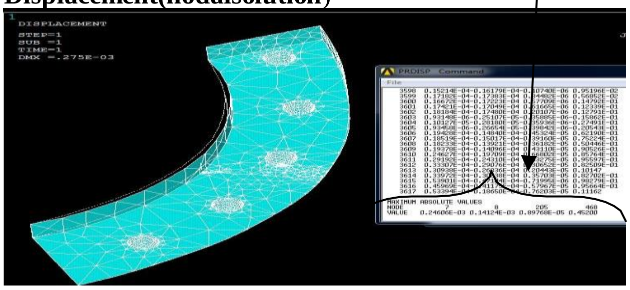


Fig 15: Displacement (nodal solution)

Node	Maximum value of displacement (mm)
07	$0.246*10^{-3}$
08	$0.141*10^{-3}$
205	$-0.897*10^{-5}$

Table 4 : maximum nodal displacements.

Now let's analyze the Von Mises stress in order to decide whether there is stress or not.

Stress (VON MISES stress)

We illustrate in this case the Von Mises stress of a sector of a DN 500 PN 10 flange. With the same PLNSOL, S, EQV 0.1 control, we can see clearly a minimum value of $0.381*10^{-4}$ MPa and a maximum value of 0.53980.2 MPa, (see figs 9 and 10).

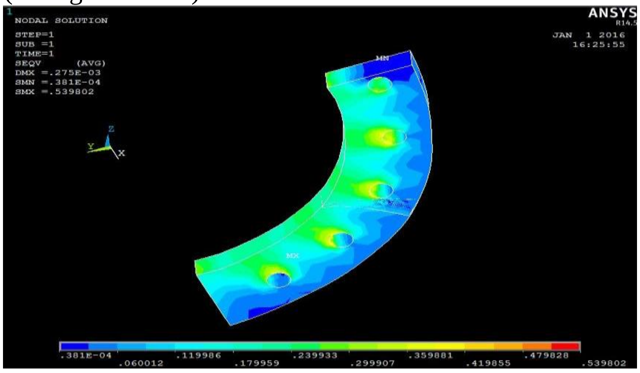


Fig 16: Stress (VON MISES stress)

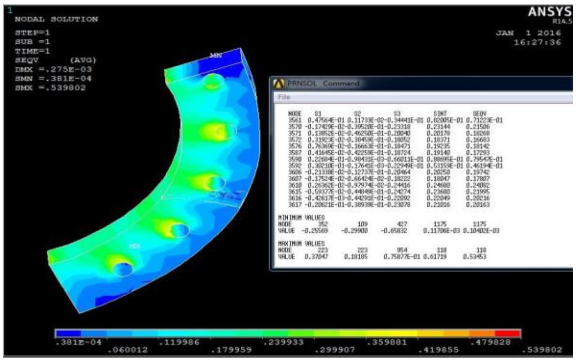


Fig 16: Stress (Maximum VON MISES stress)

As in the first case of the ring flange, the nodal solution gives us several maximum values of Von Mises stress:

Node	Maximum values of Von Mises stress (MPa)
223	0.3704
223	0.1818
954	$0.7587*10^{-1}$
118	0.6171
118	0.5345

Table 5: VON MISES stress (nodal solution)

We see on the table 5 above some maximum values of Von Mises stress. For example, the value 0.5345 Mpa at node 118, which is close to the average maximum value 0.5398 Mpa (see Fig 10).
The most stressed and critical areas of the sector are still the holes, but the degradation can be noticed on the weld seam,

which undergoes a deformation under the pressure of 0.25 Br. It's an internal deformation of the structure. See the figure below:

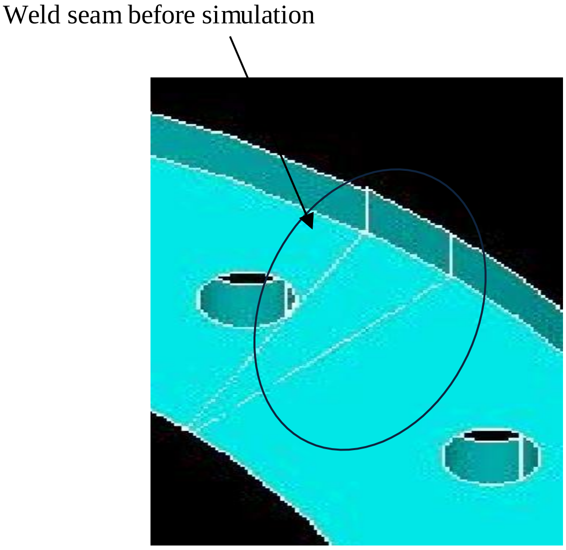


Fig 17: the weld seam before simulation

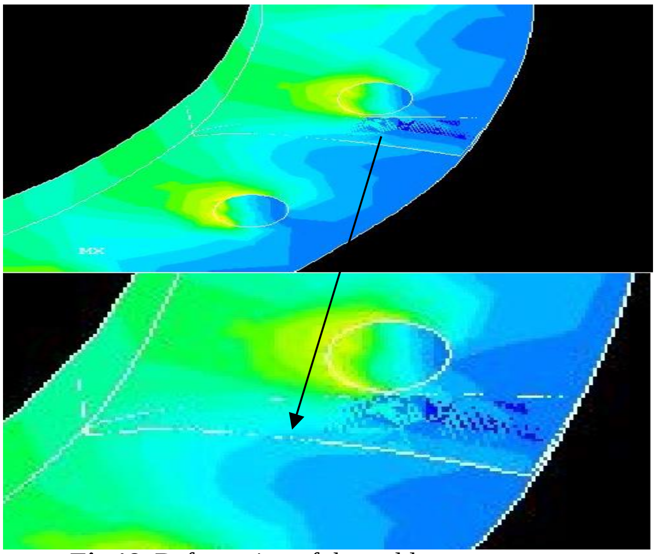


Fig 18: Deformation of the weld seam.

The simulation and analysis study of a sector (one element of the quadra-sector flange) helps us to detect a deformation of the weld seam, which is caused by pressure loads on the sector. Such a deformation causes crack propagation on the weld seam depending on the life time of the structure and the frequency of pressure.

We started our study with modeling and simulation on CATIA V5 interface. We considered the pressure as a mechanical load, and got automatically large scale results because of the transition from a pressure to a load(multiplying by surface unit), which is recommended by the simulation in CATIA V5.The stress analysis, based on the results we got, highlights the degradation of the second pattern (i.e. the quadra-sector flange). The lack of a good pressure modeling and the inadequacy of the parameters with the structure on CATIA V5 pushed us to work on ANSYS APDL interface, instead.

Firstly, we got a normal displacement, a maximum stress at the holes, without degradation or deformation of the ring flange structure. Based on this result, which is consistent with the result seen on CATIA V5, we can conclude that this structure isn't subject to degradation.

Secondly, we made use of the material and dynamic symmetry of the quadra-sector flange, in order to analyze just one element and then to draw conclusions about the quadra-sector flange type as a whole.

This study has shown significant deformation of the weld seam and a maximum stress in holes.

In a proper functioning under the conditions of the operating environment, a distorted weld joint, very close to a highly stressed area (fastening by bolting,) proved that the quadra-sector flange is indeed under stress and subject to degradation. Is this structure reliable or not? What are the qualitative and quantitative parameters that should be improved? The answers to these questions would be the subject of a reliability-based calculation in our next publication.

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