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The Geometry Optimisation of a Triple Branch Pipe Using Finite Element Method

The paper presents the geometrical optimization of a triple branch pipe submitted to an internal pressure. The goal of the optimization was to determine the optimum thickness of piping and branch pipe ribs, in the condition of reaching admissible values of the stress and displacement. The resistance calculus was realized with Cosmos DesignStar software and the geometry was modeled with Microstation Modeler software.

Key words: *branch pipe, optimisation, finite element*

1. Introduction

The branch pipe's geometry and terminology are presented in fig 1 and 2.

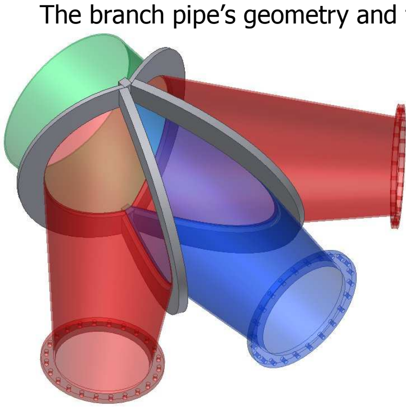

Figure 1. Branch pipe geometry

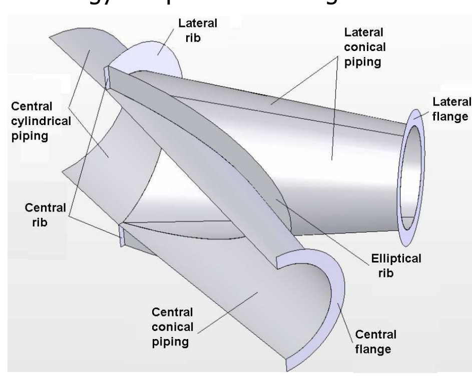

Figure 2. Branch pipe terminology

Resistance calculations were made using the finite element method and the Cosmos Design Star software [1]. They included the following steps:

- the 3D geometry of the branch pipe was generated as surfaces in the CAD Microstation Modeler software [2], [3], [4];

- the export of the geometry from the CAD Microstation Modeler software;
- the import of the geometry in the Cosmos Design Star;
- define the analysis study;
- the setting of the surfaces thickness;
- the assign the material to the surfaces from Cosmos library;
- constraints application;
- application of loads;
- meshing into finite elements;
- calculations;
- the visualization and analyze of the results.

2. The type of analyze

In theory, all the models can be designed and analyzed as solid models. In practice, a 3D problem can be simplified by approximation with the shell or 2D models, without major concessions regarding the calculation accuracy. Therefore, shell elements are recommended for thick models. The using of solid models leads, in these cases, to a big number of finite elements, which increases the calculation time and requires a strong hardware configuration. From the point of view of resistance, shell elements act similar to the membranes and can support bending loads. Shell finite elements, generated for shell studies, are classified in:

- linear shell elements – which correspond to a draft quality mesh; the element is a linear triangular type, defined through 3 corner junctions, connected by straight lines;
- parabolic shell elements – which correspond to a high quality mesh; the element is a parabolic triangular type, defined through 3 corner junctions, 3 middle junctions connected by parabolic edges.

For structural type application, every junction of a shell element has 6 degrees of liberty, which represents translations and rotations on the three orthogonal directions.

The geometry of the 3D branch pipe was modeled as surfaces (figure 2) and for the mesh of the geometry were used parabolic shell elements.

In order to obtain the optimum dimensions for the the branch pipe geometry (piping and ribs thickness), a couple of sets of analyses were applied. These analyses were made for two dimensions of piping thickness of the branch pipe (10 mm and 12 mm) and for parametrical (variable) thickness of the piping and ribs. The results materialized in the values of Von Mises stress and displacements for every case analyzed and in the colored diagrams corresponding to those values.

3. Constraints, charges and contact conditions

In order to prevent the movement of geometry, it must be submitted to constraints. The branch pipe will be connected to the neighboring elements by the central and lateral flange and by the diameter of the cylindrical part. In these areas *Fixed* type constraints will be applied, which impose the 0 value for the translations and rotations of the selected entities, figure 3.

To improve de calculation accuracy the symmetry of the branch pipe will be used, only half of branch pipe geometry being submitted to the analysis. For shell models, symmetry requires that faces coinciding with planes of symmetry should be prevented from moving in the normal direction (figure 4) and rotating about the other two orthogonal directions.

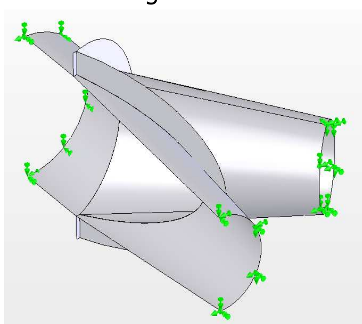

Figure 3. The *Fixed* constraints of the branch pipe

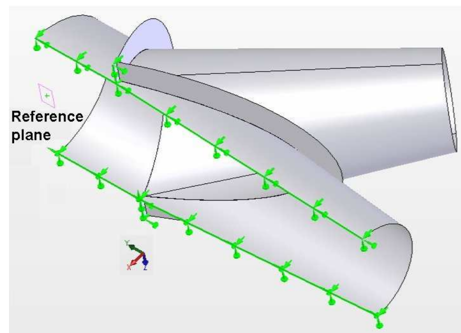

Figure 4. Symmetry constraints

The branch pipe works at the nominal pressure of p=10 bar and shall be checked at the pressure of 16 bar. The load taken into consideration for the stress calculation will be the internal pressure of the water for the two values previously specified [5]. The pressure shall be applied inside of the cylindrical, central conical and lateral conical piping (figure 5).

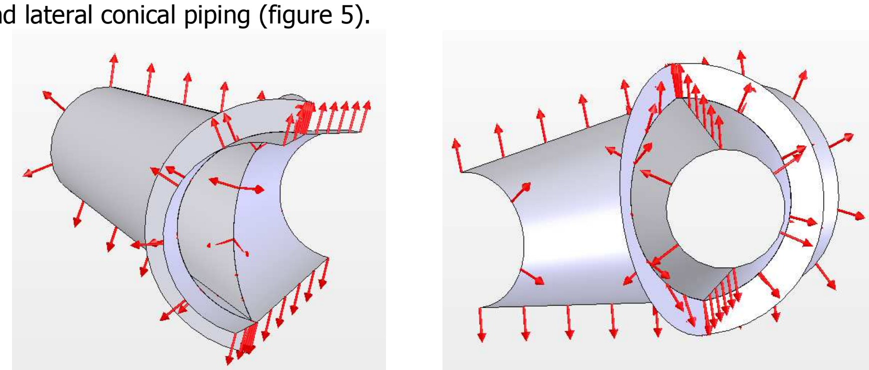

Figure 5. Internal pressure applied inside of the piping

From the geometrical point of view, the branch pipe is an assembly of surfaces linked by contact conditions. The contact condition imposed is *Bounded*, which ensure the continuity of the model and the transfer of the loads between the surfaces. The surfaces can be connected by a common edge or they can have small distanced between, resulted from geometrical modeling. The surfaces connected by the *Bounded* option works as if they were welded.

4. The branch pipe without ribs

The figure 6 show the mesh of geometry for the branch pipe without ribs. The high values resulted from the analysis (table 1 and figure 7), for both variants of piping thickness (10/12 mm), indicate the necessity of the branch pipe ribbing.

Table 1

Pressure	Piping thickness	Ribs thickness	Stress $\sigma_{VonMises}$	Maximum displacement
bar	mm	mm	MPa	mm
10	10	Without ribs	927.3	6.643
10	12		716	5.009

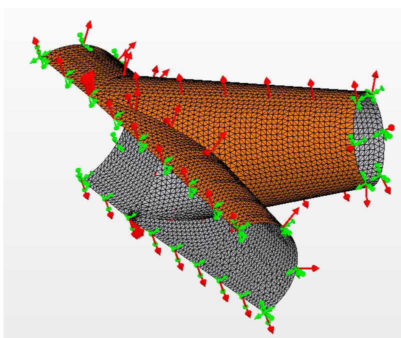

Figure 6. The mesh of the branch pipe without ribs

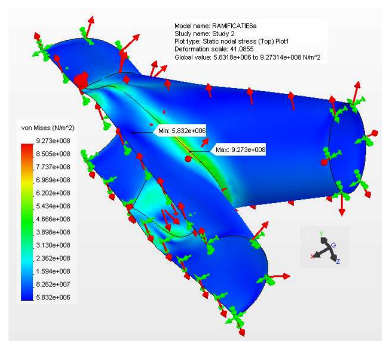

Figure 7. VonMises stress – Thickness of the pipe=10 mm; p=10 bar; $\sigma_{VonMises\ max}$= 927.3 MPa

5. Triple branch pipe with equal thickness on all the ribs

The results values are presented in table 2 and the graphical results in the figures 8 and 9. These results are for the cases of constant thickness (10 mm respectively 12 mm) for the cylindrical, central conical and lateral conical piping. The parametrical thickness for the central, elliptical and conical ribs, are varied from 10 mm to 70 mm, for constant pressure of 10 bar. As it can be observed in the figure 8, beginning with the thickness of 50 mm, the value of VonMises stress is constant. For this reason the increase of the ribs thickness above this value is unjustified.

Therefore a secure value of 70 mm will be adopted for the thickness of elliptical and central ribs of the triple branch pipe. The next step will be the study of the same parameters (stress and displacement) in the case of parametrical variation for the lateral rib thickness.

Table 2

Piping thickness: 10 mm			Piping thickness: 12 mm		
Ribs thickness	Stress $\sigma_{VonMises}$	Maximal displacement	Ribs thickness	Stress $\sigma_{VonMises}$	Maximal displacement
mm	MPa	mm	mm	MPa	mm
10	280.1	1.055	12	233.3	0.8734
20	188.9	0.7603	20	176.6	0.6829
30	145.2	0.6361	30	136.2	0.5705
40	120	0.5615	40	112.3	0.5022
50	118.7	0.5114	50	98.57	0.4556
60	117.6	0.4752	60	98.38	0.4216
70	115.9	0.4479	70	97.62	0.3958

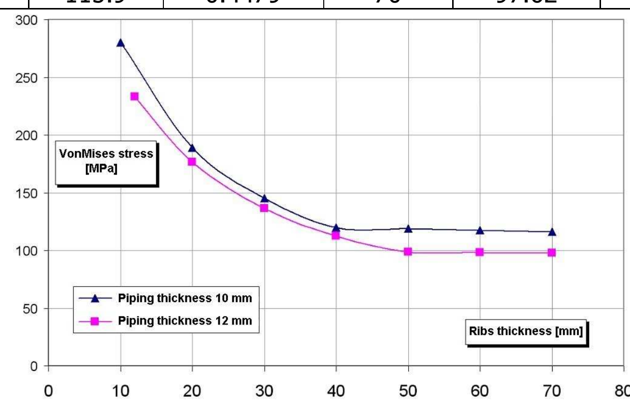

Figure 8. The VonMises stress for two values of piping thickness (10 mm / 12 mm) and equal thickness of the ribs (changed between 10 mm and 70 mm)

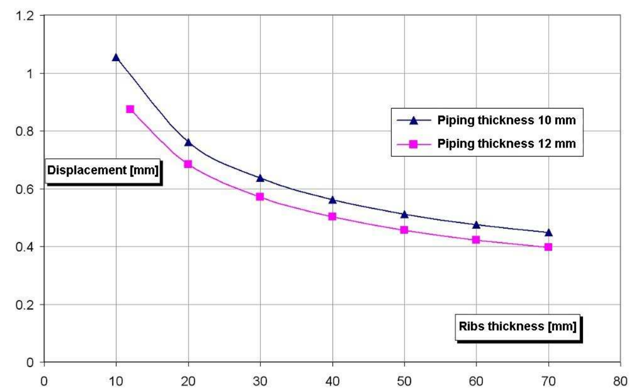

Figure 9. The displacement variation for two values of piping thickness (10 mm / 12 mm) and the equal thickness at all the ribs

6. The triple branch pipe with 70 mm thickness for the central and elliptical ribs and variable thickness for the lateral rib

Based on the previous calculus the 70 mm value of thickness was selected for the central and elliptical ribs. In this paragraph will be analyzed the stress and displacement evolution for the parametrical thickness value of the lateral rib, in the interval 10-70 mm. The results values are presented in table 3 and the graphical result is presented in the figures no. 10 and 11. These results correspond to the cases of constant thickness (10 mm respectively 12 mm) of the cylindrical, central conical and lateral conical piping and constant pressure of 10 bar.

Table 3

Central/elliptical ribs thickness = 70 mm					
Piping thickness = 10 mm			Piping thickness = 12 mm		
Lateral rib thick-ness	Stress $\sigma_{VonMises}$	Maximal displace-ment	Lateral rib thick-ness	Stress $\sigma_{VonMises}$	Maximal displace-ment
mm	MPa	mm	mm	MPa	mm
10	111.5	0.5349	10	107.8	0.4684
20	104.5	0.5121	20	87.03	0.4438
30	**102.5**	0.4918	30	86.5	0.4284
35	103.7	0.4841	35	**86.25**	0.4225
40	106.8	0.4769	40	87.15	0.4173
50	112.4	0.4645	50	91.72	0.4086
60	116.2	0.4544	60	95.18	0.4017
70	115.9	0.4479	70	97.62	0.3958

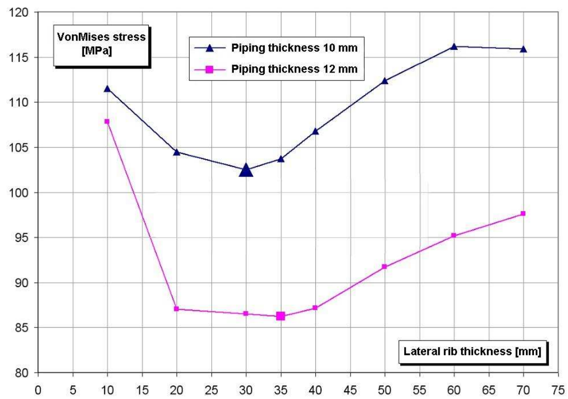

Figure 10. The VonMises stress variation for 70 mm thickness of central/elliptical ribs and variable thickness at the lateral rib.

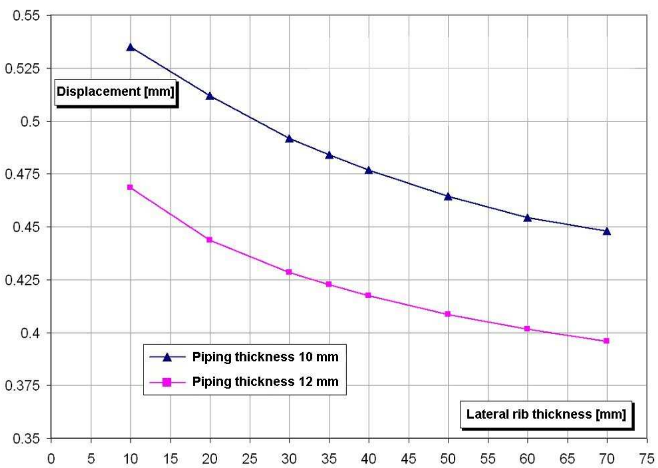

Figure 11. The displacement variation for 70 mm thickness of central/elliptical ribs and variable thickness of the lateral rib. The piping thickness -10/12 mm

From the figure 10 and table 3 it can be observed the minimum value of VonMises stress corresponding to the 30-35 mm thickness of the lateral rib.

7. Conclusions

From the figures 8 and 9 results a decrease of the stress and displacement linked to the increase of ribs thickness, for the same thickness at all the ribs and at the piping thicknesses of 10 and 12 mm. The values of stress and displacement are smaller for the piping thickness of 12 mm; the minimal value of the stress is

97.62 MPa for the ribs thickness of 70 mm, the corresponding minimal displacement being of 0.3985 mm. We can observe that the stress stabilizes around the value of 97-100 MPa, therefore a increase of ribs thickness is unjustified.

Setting the thickness of the pipe at 12 mm, the thickness value of central and elliptical rib at 70 mm and varying the lateral rib's thickness between 10 mm and 70 mm (figure 10), results a minimum stress of 86.25 MPa, the corresponding minimal displacement being of 0.4225 mm, for the thickness of lateral rib - 35 mm.

In conclusion, the optimum variant for the branch pipe has the following dimensional characteristics:

- piping thickness 12 mm
- central/elliptical rib's thickness 70 mm
- lateral rib thickness 35 mm.

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