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Structural Analysis and Optimization of Nozzle Attachment on Channel Shell Design

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ABSTRACT

In Channel shells, Nozzles are required for inlet and outlet purposes either to carry fluids or for providing multipurpose connections. If these nozzles present on peak of the dish end do not disturb the symmetry of the shell. However sometimes process requires that nozzles to be placed on the periphery of the shell. These nozzles disturb the symmetry of the shell. Geometrical parameters of nozzle connections may significantly vary even in one channel shell. These nozzles cause geometric discontinuity of the shell wall. So a stress concentration is created at the junction. Hence a detailed analysis is required. If nozzles are placed on the periphery of a channel shell, they disturb the axis symmetry of the system and cause eccentricity. Sometimes this cause generation of a couple & lead to a structural imbalance. So that it need to analysed in FEA to understand effects of nozzle on Stress attributes of the shell. This work also studies the effect of eccentricity of the nozzles under varying thickness of shell and reinforcement pad. The effect of material concession for nozzle and Shell on the stress induced is also studied. From the results obtained by ANSYS, optimum study was performed by response surface methodology to obtain optimum shell thickness and reinforcement pad thickness for different class of materials.

***Keywords*--** Channel shell, Nozzles, FEA, ANSYS, Optimization

I. INTRODUCTION

Geometrical parameters of nozzle connections may significantly vary even in one pressure vessel. These nozzles cause geometric discontinuity of the vessel wall. So a stress concentration is created around the opening [1-4]. The junction may fail due to these high stresses. Hence a detailed analysis is required. One of the parts of overall structural analysis for nozzle connections is the stress analysis of two intersecting shells.

Due to different loadings applied to these structures, a local stress state of nozzle connection characterized by high stress concentration occurs in intersection region. Internal pressure is primary loading used in the structure analysis for determination of main vessel-nozzle connections. However the effect of external forces and moments applied to nozzle should be taken into consideration in addition to the stresses caused by the internal pressure. External loading usually are imposed by a piping system attached to the nozzle [5-7]. Values of the loads & moments are calculated by an analysis of piping system.

Many works including analytical, experimental & numerical investigations have been devoted to the stress analysis of nozzle connections in pressure vessels, subjected to different external loadings. The codes suggest a procedure to design the junction, but do not provide any methodology to calculate the extended and magnitude of these high stresses. The available analytical solution WRC-107 is limited to simple geometries [8-10]. So, there is need to carry out a detailed finite element analysis of the junction to calculate stresses at the junction & both in the vessel & in the nozzle [11-14]. ANSYS package is used as a finite element tool.

II. DESIGN OF NOZZLES

2.1 Problem Statement

Pressure vessels are generally mounted with nozzles either to carry fluids or for providing multipurpose connections. The present work deals with evaluating and analysing the stress induced in the shell, nozzle with main focus on shell to nozzle junctions where the stress concentration effects are felt. This work

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also studies the effect of eccentricity of the nozzles under varying thickness of shell and reinforcement pad. The effect of material concession for nozzle and Shell on the stress induced is also studied. From the results obtained by ANSYS, optimum study was performed by response surface methodology to obtain optimum shell thickness and reinforcement pad thickness for different class of materials.

2.2 Shell thickness calculation for Carbon Steel material:

$$t_s = \frac{P*R}{S*E-0.6P} \text{ as per UG-27 (C)(1)}$$

Where P is internal design pressure

R is inside radius of the shell

S is maximum allowable stress

E is joint efficiency

t_s is minimum required thickness of shell

P = 12.3 kgf/cm^2

R = 228 mm

S = 1202.25 kgf/cm^2

E = 0.85

Therefore, by substituting the above values in the given formula we get

t_s = 2.7648 mm

Actual thickness t_s= 2.7648 + corrosion allowance = 2.7648 + 3 = 5.7648 mm

2.3 Shell thickness calculation for Stainless Steel material:

$$t_s = \frac{P*R}{S*E-0.6P} \text{ as per UG-27 (C)(1)}$$

S = 1264.44 kgf/cm^2

Therefore, by substituting the above values in the given formula we get

t_s = 2.627 mm (There is no corrosion allowance)

2.4 Shell thickness calculation for Alloy Steel material:

$$t_s = \frac{P*R}{S*E-0.6P} \text{ as per UG-27 (C)(1)}$$

S = 1070.70kgf/cm^2

Therefore, by substituting the above values in the given formula we get

t_s = 3.1066 mm

Actual thickness t_s= 3.1066 + corrosion allowance = 3.1066 + 3 = 6.1066 mm

Maximum allowable working pressure at given thickness t = 7 mm

As per TEMA minimum thickness of the shell t = 10 mm

t = actual thickness – corrosion allowance = 10 – 3 = 7 mm

2.5 Nozzle thickness calculation for D2 and V2:

ASME code, Section-VIII, Div. 1, 2015, UG-37 to UG-45

Actual outside diameter used in calculation = 60.325 mm

Actual thickness used in calculation = 8.738 mm

Required thickness per UG-37(a) of cylindrical shell,

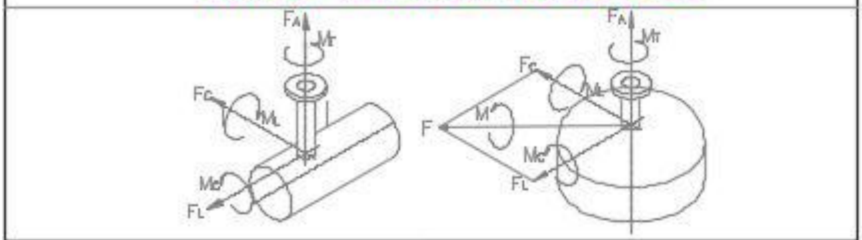
$$t_s = \frac{P*R}{S*E-0.6P} = 2.347 \text{ mm}$$

Required thickness per UG-37(a) of Nozzle wall,

$$t_n = \frac{P*R}{S*E+0.4P} = 0.3073 \text{ mm}$$

The maximum allowable Nozzle loads were shown in figure 1 below.

MAXIMUM ALLOWABLE NOZZLE LOADS



MAXIMUM ALLOWABLE NOZZLE LOADS

NOZZLES ON SHELL							
NOZZLE MARK	FORCES - Kgf			MOMENT - Kgf-m			
	±FA	FC	FL	MC	ML	MT	MR
N3,N4- 80NB	202	300	300	67	90	112	-

NOZZLES ON HEAD							
NOZZLE MARK	FORCES - Kgf			MOMENT - Kgf-m			
	±FA	FC	FL	MC	ML	MT	MR
	-	-	-	-	-	-	-

Figure 1 Nozzle Loads

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III. MODELING OF CHANNEL SHELL

The parts of Channel shell attached with Nozzles, vent and drain were modelled in the SOLIDWORKS software with the help of drawings provided. The parts were also assembled in SOLIDWORKS software.

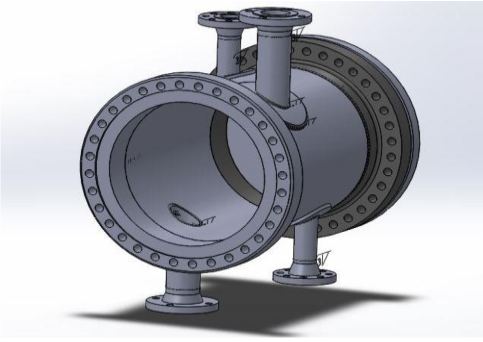

Figure 2 Isometric view of assembly

IV. ANALYSIS ON CHANNEL SHELL AND NOZZLES

A static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time-varying loads. A static analysis can, however, include steady inertia loads, and time-varying loads that can be approximated as static equivalent loads. Structural analysis is probably the most common application of the finite element method as it implies bridges and buildings, naval, aeronautical, and mechanical structures such as ship hulls, aircraft bodies, and machine housings, as well as mechanical components such as pistons, machine parts, and tools. Linear static analysis is concerned with the behavior of elastic continua under prescribed boundary conditions and statically applied loads. The applied loads in this case are maximum allowable Nozzle loads. The FE analysis is carried out using ANSYS.

Carbon steel material with Shell thickness of 10 mm and RF pad thickness of 10 mm is shown in figure 3 to figure 5.

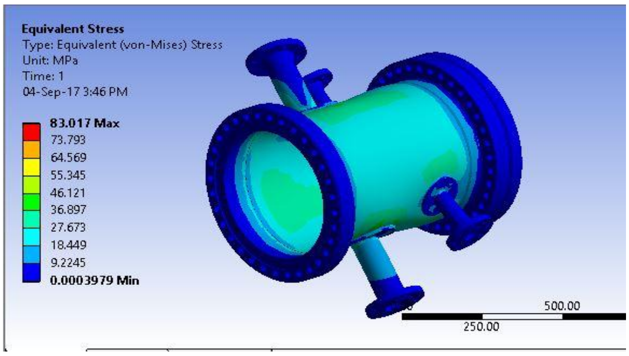

Figure 3 Stress for 80 mm and Carbon steel material

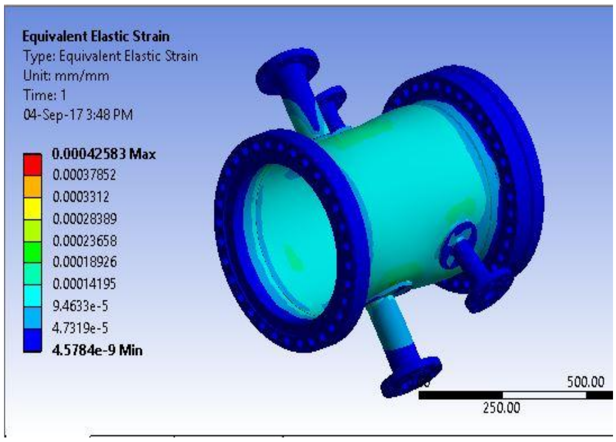

Figure 4 Strain for 80 mm and Carbon steel material

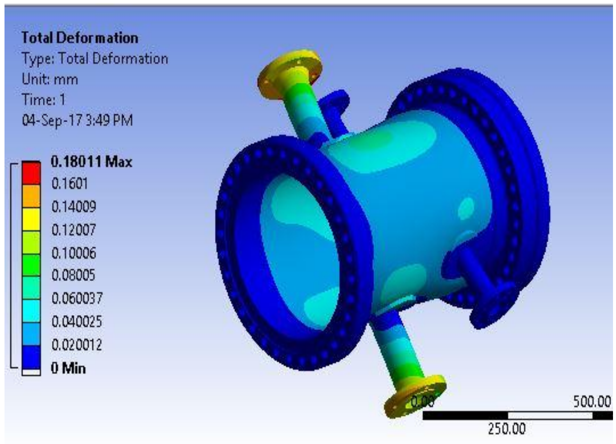

Figure 5 Deformation for 80 mm and Carbon steel material

Nozzle to channel shell centre distance of 80 mm and Carbon steel material shown in Table 1

Table 1: Nozzle to channel shell centre distance of 80 mm and Carbon steel material

SHELL THICKNESS (mm)	RF PAD THICKNESS (mm)	STRESS (MPa)	DEFORMATION (mm)	STRAIN
10	10	83.017	0.18011	0.00042583
10	12	82.99	0.16482	0.00042573
10	14	78.626	0.155880	0.00040033

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12	10	75.38	0.16514	0.00037588
12	12	73.651	0.16582	0.00037779
12	14	71.991	0.14566	0.00035123
14	10	72.851	0.21079	0.00038688
14	12	90.58	0.33264	0.00047315
14	14	73.652	0.212	0.00039113

Similarly the Stress, strain and deformation values were found on the model by varying the nozzle to channel shell centre distance and their materials.

Nozzle to channel shell centre distance of 80 mm and Stainless steel material is shown in Table 2

Table 2 Nozzle to channel shell centre distance of 80 mm and Stainless steel material

SHELL THICKNESS (mm)	RF PAD THICKNESS (mm)	STRESS (MPa)	DEFORMATION (mm)	STRAIN
10	10	85.515	0.00044312	0.18763
10	12	85.588	0.0004435	0.1722
10	14	87.405	0.00046238	0.16421
12	10	75.461	0.0003913	0.17077
12	12	75.551	0.00039149	0.17173
12	14	74.807	0.00039487	0.15308
14	10	74.453	0.00038678	0.21615
14	12	95.634	0.00054364	0.34898
14	14	74.826	0.00038774	0.21735

Nozzle to channel shell centre distance of 80 mm and Alloy steel material shown in Table 3

Table 3 Nozzle to channel shell centre distance of 80 mm and Alloy steel material

SHELL THICKNESS (mm)	RF PAD THICKNESS (mm)	STRESS (MPa)	DEFORMATION (mm)	STRAIN
10	10	96.243	0.00045297	0.17999
10	12	92.673	0.00043512	0.16408
10	14	91.173	0.00043714	0.15556
12	10	98.281	0.00046311	0.16168
12	12	81.996	0.00058499	0.16258
12	14	82.588	0.00038942	0.14452
14	10	80.521	0.00037891	0.20745
14	12	129.43	0.00062117	0.33833
14	14	80.841	0.00037957	0.20858

Nozzle to channel shell centre distance of 100 mm and Carbon steel material is shown in Table 4

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Table 4 Nozzle to channel shell centre distance of 100 mm and Carbon steel material

SHELL THICKNESS (mm)	RF PAD THICKNESS (mm)	STRESS (MPa)	DEFORMATION (mm)	STRAIN
10	10	80.058	0.0004198	0.19759
10	12	79.817	0.00040935	0.18666
10	14	76.017	0.00038984	0.17343
12	10	76.09	0.00034089	0.12728
12	12	69.033	0.00035405	0.17318
12	14	70.235	0.00034255	0.16119
14	10	71.051	0.00037085	0.23011
14	12	82.552	0.0004315	0.22819
14	14	78.149	0.00041338	0.22702

Nozzle to channel shell centre distance of 100 mm and Stainless steel material is shown in Table 5

Table 5 Nozzle to channel shell centre distance of 100 mm and Stainless steel material

SHELL THICKNESS (mm)	RF PAD THICKNESS (mm)	STRESS (MPa)	DEFORMATION (mm)	STRAIN
10	10	84.303	0.00047022	0.1905
10	12	82.814	0.00042916	0.1808
10	14	81.087	0.00042015	0.1752
12	10	70.187	0.00036378	0.12111
12	12	72.152	0.00038654	0.17236
12	14	73.629	0.00039947	0.16407
14	10	75.364	0.00039088	0.23063
14	12	75.323	0.00039039	0.22941
14	14	73.806	0.00003987	0.2282

Nozzle to channel shell centre distance of 100 mm and Alloy steel material is shown in Table 6.

Table 6 Nozzle to channel shell centre distance of 100 mm and Alloy steel material

SHELL THICKNESS (mm)	RF PAD THICKNESS (mm)	STRESS (MPa)	DEFORMATION (mm)	STRAIN
10	10	99.76	0.00047022	0.1905
10	12	98.339	0.00046276	0.17728
10	14	87.28	0.00041039	0.16645
12	10	70.8	0.00035733	0.11699
12	12	78.425	0.00036822	0.16356
12	14	78.013	0.00037583	0.1546
14	10	117.3	0.00055258	0.2212
14	12	81.483	0.00038265	0.21994
14	14	77.558	0.00036431	0.2187

Nozzle to channel shell centre distance of 120 mm and Carbon steel material is shown in Table 7

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Table 7 Nozzle to channel shell centre distance of 120 mm and Carbon steel material.

SHELL THICKNESS (mm)	RF PAD THICKNESS (mm)	STRESS (MPa)	DEFORMATION (mm)	STRAIN
10	10	79.651	0.00040848	0.21652
10	12	78.953	0.00040502	0.20464
10	14	75.772	0.00038864	0.18903
12	10	74.473	0.00036476	0.19748
12	12	81.802	0.00039231	0.1859
12	14	76.802	0.0003732	0.17558
14	10	84.304	0.0004403	0.2562
14	12	81.69	0.00043423	0.25271
14	14	87.025	0.00045948	0.25113

Nozzle to channel shell centre distance of 120 mm and Stainless steel material is shown in Table 8

Table 8 Nozzle to channel shell centre distance of 120 mm and Stainless steel material

SHELL THICKNESS (mm)	RF PAD THICKNESS (mm)	STRESS (MPa)	DEFORMATION (mm)	STRAIN
10	10	86.408	0.00047972	0.21671
10	12	85.744	0.0004779	0.20402
10	14	86.735	0.00048708	0.19193
12	10	74.948	0.00040321	0.20016
12	12	79.816	0.00041478	0.18768
12	14	76.653	0.00041231	0.17897
14	10	74.479	0.00038596	0.25
14	12	72.999	0.00039276	0.25137
14	14	90.112	0.00051513	0.25034

Nozzle to channel shell centre distance of 120 mm and Alloy steel material is shown in Table 9

Table 9 Nozzle to channel shell centre distance of 120 mm and Alloy steel material

SHELL THICKNESS (mm)	RF PAD THICKNESS (mm)	STRESS (MPa)	DEFORMATION (mm)	STRAIN
10	10	91.082	0.00045114	0.20761
10	12	93.266	0.00045307	0.19717
10	14	90.78	0.00042699	0.18245
12	10	80.144	0.00040299	0.19
12	12	78.869	0.00041635	0.17733
12	14	77.856	0.00040224	0.16901
14	10	78.287	0.00036758	0.23944
14	12	77.105	0.00036718	0.24048
14	14	90.552	0.00046894	0.23942

V. OPTIMIZATION BY RESPONSE SURFACE METHODOLOGY

RSM is an anthology of statistical and mathematical methods, helpful in generating improved methods and optimizing the process. RSM is more

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frequently used in analyzing the relationships and the influences of input parameters on the responses. The method was introduced by G. E. P. Box and K. B. Wilson in 1951. RSM uses a set of designed experiments to obtain an optimal response. Box and Wilson used first-degree polynomial model to obtain DOE through RSM and acknowledged that the model is only an approximation and is easy to estimate and apply, even when little information is known about the process.

RSM also improves the analyst's understanding of the sensitivity between independent and dependent variables. RSM is an experimental strategy and has been employed by research and development personnel in the industry, with considerable success in a wide variety of situations to obtain solutions for complicated problems.

In response optimization we will get the optimal values of the input parameters Shell thickness and RF Pad thickness, and the output parameters Stress, Strain and Deformation.

Goal of experiment

- To maximize the Stress
- To maximize the Strain
- To maximize the Deformation

Table 10 Defining Goal of experiment for Nozzle to channel shell centre distance of 80 mm and Carbon steel material

Parameters	Goal	Lower	Target	Upper
Stress (MPa)	Maximum	71.9910	90.5800	90.5800
Strain	Maximum	0.0004	0.0005	0.0005
Deformation	Maximum	0.1457	0.3326	0.3326

Similarly the goals are defined by varying the nozzle to channel shell centre distance and material of construction.

5.1 Optimization Results:

Result for Nozzle to channel shell centre distance of 80 mm and for Carbon steel material is shown in the figure 6.

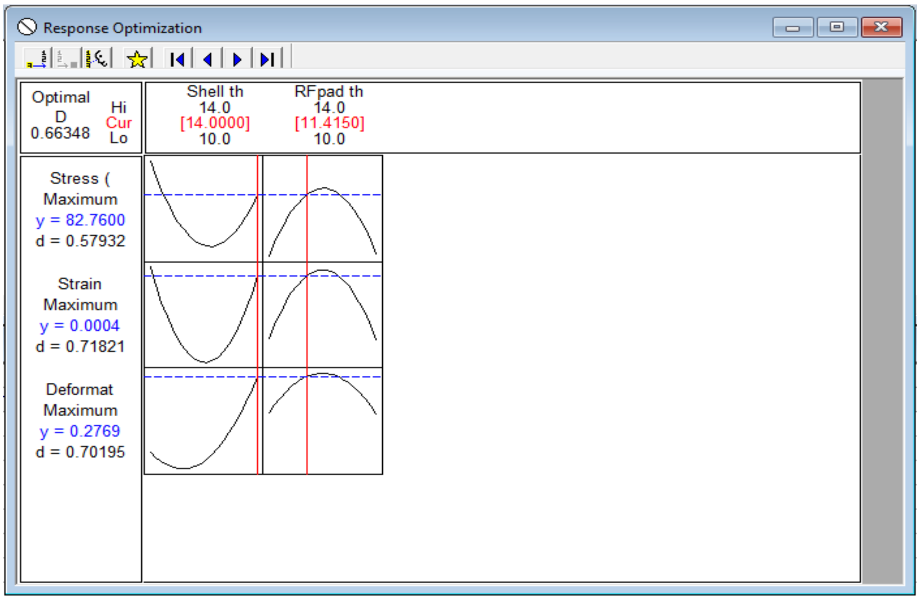

Figure 6 Response Optimization for Nozzle to channel shell centre distance of 80 mm and Carbon steel material

Response Optimization

Global Solution
Shell thickness (mm) = 14.0000
RF pad thickness (mm) = 11.4150

Predicted Responses

Stress (MPa) = 82.7600,
Strain = 0.0004,
Deformation (mm) = 0.2769

Table 11 Predicted responses using RSM

Shell thickness (mm)	RF Pad thickness (mm)	Stress (MPa)	Strain	Deformation (mm)
14	12	82.76	0.004	0.2769
14	12	86.2023	0.005	0.2016

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14	12	105.713	0.001	0.282
14	14	79.2150	0.0004	0.2352
10	14	82.1265	0.0005	0.1846
14	**10**	**107.221**	**0.001**	**0.2918**
14	14	85.8037	0.0005	0.2498
14	14	86.6461	0.0005	0.2494
14	14	87.3034	0.0004	0.2383

From the results obtained by RSM it is observed that shell thickness of 14 mm and RF Pad thickness of 10 mm take highest stress, strain and deformation values.

VI. CONCLUSIONS

1. The present thesis deals with Design and modelling of channel shell attached with Nozzles, vent and drain. The design based on allowable stresses on shell and nozzles, the shell thickness and RF Pad thickness were calculated for different material taken. The modelling of the channel shell and nozzles was done using SOLIDWORKS software.
2. The maximum stress values are obtained from the analysis for all the load cases. From the results of analysis, it can be observed that the maximum stress occurs at the junction of Pressure Vessel and the nozzle. High stress concentration is developed at this location due to abrupt change in the geometry and the consequent change in stress flow.
3. From the results obtained by ANSYS, optimum study was performed by response surface methodology to obtain optimum shell thickness and reinforcement pad thickness for different class of materials.
4. Based on the results obtained from Response surface methodology in MINITAB it is finally concluded that Alloy steel was the best material in the construction of channel shell and nozzles with nozzle to shell distance of 100 mm and Shell Thickness as 14 mm, RF PAD Thickness as 10 mm

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