ANALYSIS OF STRESS CONCENTRATION AT OPENING IN PRESSURE VESSEL USING ANOVA

Avinash R.Kharat[1], V. V. Kulkarni[2]

[1]Assistant professor, Bharati Vidyapeeth College of Engineering, Kolhapur
[2]Dr. Principal, Sanjay Ghodawat College of Engineering, Kolhapur, India

Abstract

Pressure vessels are used for storage, transportation and application of energy and fluids and also for carrying out reactions and many other purposes. Openings in tanks and pressure vessels are necessary to carry on normal operations. Openings are generally made in both vessel shells as well as heads. Unfortunately, these openings also result in penetrations of the pressure restraining boundaries and are seen as discontinuities. Nozzles represent one of the most common causes for stress concentration in pressure vessels and stress concentration factors can be very useful in pressure vessel design. Finite Element Analysis is very efficient method for determination of stress concentration factors; however reliability of Finite Element Analysis should always be assessed.

In this paper The analysis of variance method is used to serve the relation between nozzle size and stress produce in the nozzle area. To reduce the errors in the experimental result the randomize sequence method is used. To test the influence of the both parameters that is opening diameter and internal pressure on each other the randomized test sequencing is generated and experimental test is conducted to investigate the stress distribution near opening area.

Keywords: *Pressure, Opening, Stress Concentration Factor, FEA, Stress Distribution*

---***---

1. INTRODUCTION

Pressure vessels find wide applications in thermal and nuclear power plants, process and chemical industries, in space and ocean depths, and fluid supply systems in industries. The failure of pressure vessel may result in loss of life, health hazards and damage of property. Discontinuities like opening in cylindrical part weaken the containment strength of a pressure vessel because stress intensification is created by the existence of a void in an otherwise symmetrical section [1]. Openings in tanks and pressure vessels are necessary to carry on normal operations. They allow for the mounting of equipment, the insertion of instrumentation, and the connection of piping facilitating the introduction and extraction of content but they also leads to the high stress concentration which get to the failure of pressure vessel [2]. In recent years, researchers have put enormous amount of effort in investigating techniques for analysis stress concentration near openings. The failure of structures due to stress concentration at any discontinuity/opening has been baffling engineers for long. It has been found that structure failures in ships, offshore structures, boilers or high rise buildings subjected to natural calamities is due to stress concentration. Stress concentration mainly occurs due to discontinuities in continuum [3]. Due to stress concentration the magnitude of the maximum stress occurring in any discontinuity is comparatively higher than the nominal stress. Stress concentration cause strength degradation and premature failure of structures because of fatigue cracking and plastic deformation frequently occurring at these points. To avoid such type of pressure vessel failure the design engineer must have positive assurance that stresses generated will never exceed the strength. Stress analysis of a pressure vessel is a very sophisticated area [4].

This study presents a systematic approach to determine the effect of stress concentration factor at openings in pressure vessels using ANVOA.

2. ANALYSIS OF VARIANCES (ANOVA)

The Analysis of Variances (ANOVA) is one of the most commonly used methods of analyzing experiments. It is flexible and powerful tool of analysis. The mathematics involved required diligence in calculation, yet the way ANOVA works is relatively simple. In any experiment several factors are followed are allowed to vary, a situation called experimental error exits. Experimental error is the random errors created in the experiment from the chance variations in uncontrollable factors such quality of material, environmental conditions, and operators involved. Taken together this experimental error creates a background “noise” in the data. ANOVA is extremely useful technique concerning researchers in the field of economics, biology, education, psychology, and business industries and in researches of several other disciplines. In many industrial cases, we will have to compare three or more averages. [5]

3. EXPERIMENTAL SETUP

A pressure vessel with the external diameter 305 mm and wall thickness 3 mm is used for preparing the experimental model. Four plugged pipes are welded on the vessel to produce four nozzles, designated D1, D2, D3 and D4, which is shown in Figure 1. The dimensions of the vessel and the nozzles with the geometric are shown in Table 1. The pipes are left with enough length so that length does not influence the stress distribution. There is also enough distance between the pipes to not influence the stress distribution. In the longitudinal and circumferential direction of the nozzle area, four strain gauges of 120 ohm are installed on the vessel on enough distance from the nozzle which is shown in Fig 2. So there are four measuring points and twin cylinder, two stage reciprocating type compressor of 12 bar capacity is used to produce the internal pressure and the test pressure are 2, 4, 6 and 7 bar respectively. For measurement of strain, multi-channel strain gauge indicator is used.

Table 1 Dimensions of the vessel and the nozzles

Parameters	Values
Pressure	0.2, 0.4, 0.6, 0.7Mpa
Vessel Diameter (O.D)	305mm
Thickness	3mm
Length of vessel	900mm
Opening/nozzle Diameter	32mm, 40mm, 65mm, 80mm

Fig 1: Experimental setup

Fig 2: Strain gauge setup at 80mm nozzle Diameter

4.1 Strain Measurement

The strain gage is a transducer which converts force, pressure, tension, etc. to an electrical signal and is used for electrical measurement of these mechanical quantities. The wire strain gages depend upon the fact that when the wire is stretched elastically, its length and diameter are altered. The underlying principle of the strain gage is that a stressed metallic conductor undergoes a change in electrical resistance directly proportional to a change in length. The quarter arm bridge which is shown in Fig 3 is excited with the help of fixed 5 volts supply using regulator I.C. 7805. A 10 Kilo ohm helical pot and 100 kilo ohms carbon pot form the course and fine balancing controls respectively.

The bonded electrical resistance strain gage is a simple device, in fact deceptively so. The gage functions on the principle that when it undergoes strain, its electrical resistance changes. And if the relationship between the relative change in resistance (ΔR/R) and the strain (ΔL/L), (which is defined as the Gage Factor), is known, then the strain can be determined. All that is necessary therefore is to measure ΔR/R. But this is more easily said than done because the values of ΔR are very small (and ΔR/R, even smaller). The Gage Factor (GF) is approximately 2.0 for gages made of the metal alloys most commonly used in their manufacture. A typical gage resistance is 120 ohms. In order to use such a gage for detecting a strain of 1 με, a change of resistance ΔR of 0.00024 ohm must be measured. [6][7]

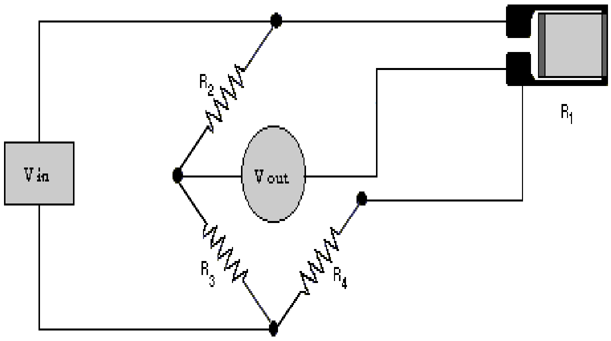

Fig 3: Quarter Arm Bridge of strain indicator

4.2 Randomized Sequence Selected

From previous study it is seen that the stress distribution in opening area is depends on the openings geometry and the internal pressure applied. So to test the influence of the both parameters that is opening diameter and internal pressure on each other the randomized test sequencing is generated using the Microsoft Excel sheet shown in Table 2. This randomized test sequence is necessary to prevent the effect of unknown nuisance variables, perhaps varying out of control during the experimentation, from contaminating the results. This test sequencing is related with internal pressure from 0.2 to 0.7 Mpa. Each set is selected with common start of pressure then end with random pressure. [8]

Table 2 Sequence of experimental testing

P1	P2	P3	P4
1	4	3	2
1	3	2	4
1	2	3	4
2	4	3	1
2	3	1	4
2	1	3	4

3	2	1	4
3	4	1	2
3	1	2	4
4	3	2	1
4	2	1	3
4	1	3	2

3.3 Experimental Testing Results

Experiment performs on pressure vessel by using the strain gage measurement device. The test results are presented in Table 3 and Table 4

Where, P1 = 0.2Mpa, P2 = 0.4 Mpa, P3 = 0.6Mpa, P4 = 0.7Mpa.

Table 3 Experimental testing results 1

Nozzle diameter mm	Micro-strain Readings			
32 mm	P1	P2	P3	P4
	0.000022	0.000037	0.00006	0.000073
	0.000021	0.000036	0.000061	0.000074
	0.000023	0.000037	0.000059	0.000075
	0.000023	0.000036	0.000062	0.000076
	0.000021	0.000035	0.000063	0.000074
	0.000024	0.000037	0.000062	0.000075
40mm	P1	P2	P3	P4
	0.000032	0.000046	0.000065	0.000078
	0.000029	0.000045	0.000066	0.00008
	0.000031	0.000049	0.00007	0.000083
	0.000032	0.000045	0.00007	0.000085
	0.00003	0.000044	0.000068	0.000082
	0.000029	0.000046	0.000066	0.000085

Table 4 Experimental testing results 2

Nozzle Dia.	P1	P2	P3	P4
65mm	0.000035	0.000052	0.000075	0.000092
	0.000036	0.000055	0.00008	0.000094
	0.000034	0.000054	0.000075	0.000092
	0.000035	0.000055	0.000076	0.000093
	0.000036	0.000055	0.00008	0.000091
	0.000035	0.000062	0.000079	0.000095
70mm	P1	P2	P3	P4
	0.000039	0.000064	0.00009	0.0000102
	0.00004	0.000065	0.000085	0.0000104
	0.000042	0.000063	0.000088	0.0000105
	0.000044	0.000062	0.000089	0.0000106
	0.00004	0.000064	0.000087	0.0000102
	0.000042	0.000065	0.000091	0.0000104

3.4 ANOVA Analysis by Two Factorial Factor Designs

For factorial design two factor or sets of treatments is selected. The pressure change has no effect on nozzle diameter change is considered null hypothesis and pressure change has some effect on the nozzle diameter is considered alternative hypothesis. A factorial design involves two factors, in this case pressure and Nozzle diameter is taken which is the only choice. From experiment it is known that the pressure increase will affect the nozzle diameter. So decided to test all the pressure at all four nozzles diameters with n=6 readings for each combinations of pressure and nozzle diameter. The experimental and resulting observation data are given in Table 5 and Table 6. The ANOVA results interaction are shown in Fig 4. [8]

Table 5 Input results of nozzle and pressures for two factorial analyses.

group	d1	d2	d3	d4
p1	0.000022	0.000037	0.00006	0.000073
	0.000021	0.000036	0.000061	0.000074
	0.000023	0.000037	0.000059	0.000075
	0.000023	0.000036	0.000062	0.000076
	0.000021	0.000035	0.000063	0.000074
	0.000024	0.000037	0.000062	0.000075
p2	0.000032	0.000046	0.000065	0.000078
	0.000029	0.000045	0.000066	0.00008
	0.000031	0.000049	0.00007	0.000083
	0.000032	0.000045	0.00007	0.000085
	0.00003	0.000044	0.000068	0.000082
	0.000029	0.000046	0.000066	0.000085

Table 6 Input results of nozzle and pressures for two factorial analyses.

group	d1	d2	d3	d4
p3	0.000035	0.000052	0.000075	0.000092
	0.000036	0.000055	0.00008	0.000094
	0.000034	0.000054	0.000075	0.000092
	0.000035	0.000055	0.000076	0.000093
	0.000036	0.000055	0.00008	0.000091
	0.000035	0.000062	0.000079	0.000095
p4	0.000039	0.000064	0.00009	1.02E-05
	0.00004	0.000065	0.000085	1.04E-05
	0.000042	0.000063	0.000088	1.05E-05
	0.000044	0.000062	0.000089	1.06E-05
	0.00004	0.000064	0.000087	1.02E-05
	0.000042	0.000065	0.000091	1.04E-05

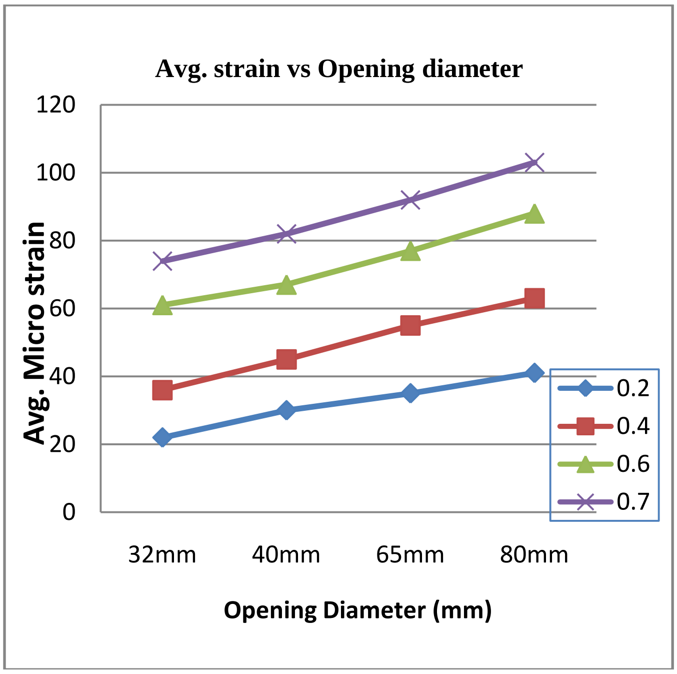

Fig 4 Avg. Micro strain Vs opening diameter

4. DISCUSSION

From the graph shown in Fig 4 and the analysis of variance for it is seen that the F critical value is less than F value. So from this it is seen that the null hypothesis in which it is considered that the pressure change has no effect on nozzle diameter is rejected. The alternating hypothesis is accepted in which it is considered that the pressure and nozzle diameter change has interaction and influence on each other. To assist in interpreting the results of this experiment; it is helpful to construct a average responses at each treatment combination. The low strain is attended at the small size opening at 32mm. changing from 32mm opening to 80mm the strain reading attended the higher level with increasing pressure from 0.2Mpa to 0.7Mpa. Strain attended the minimum level at 0.2Mpa and get higher with increasing pressure from 0.2 to 0.7Mpa for each opening. From lower opening size to higher size the strain is increases for 0.6Mpa and 0.7Mpa and it is lowered for the 0.2Mpa and 0.4Mpa.0.2 Mpa and 0.4Mpa gives the significant results if lower strain is required.

5. CONCLUSIONS

It is observed that sudden change in strain flow lines causes the strain and stress to rise abruptly. Through gradual change in gradient of flow lines mitigation of strain is observed. The rise in the strain reaches to its maximum value. There is significant interaction between the pressure and strain readings. The computed strain increases with increasing the opening size in the geometry.

REFERENCES

[1] A. J. Durelii & V. J. Parks, "Stresses in a pressurized ribbed cylindrical shell with a reinforced hole", The Journal of Strain Analysis for Engineering Design, Vol. 8, PP 140-150, 1973.

[2] P Makulsawatudom, D Mackenzie and R Hamilton, "Stress concentration at crossholes in thick cylindrical vessels", The Journal of Strain Analysis for Engineering Design, Vol. 39, PP 471-481, 2004.

[3] You-Hong Liu, "Limit pressure and design criterion of cylindrical pressure vessels with nozzles", International Journal of Pressure Vessels and Piping, Vol. 81, PP 619–624, 2004.

[4] Les M. Bildy, "A Proposed Method for Finding Stress and Allowable Pressure in Cylinders with Radial Nozzles", Codeware ,2000

[5] D.C.Montgomery, "Design of Experiments", Arizona State University, John and Wiley, Fifth edition, 2005.

[6] T. H. Baek, "Hybrid Stress Analysis of Perforated Composites Using Strain Gages", Journal of Experimental Mechanics Springer link Journals, Vol. 41, No. 2, June2001, PP 195-203.

[7] Josip Kacmarcik, "Comparison Of Numerically And Experimentally Determined SCF For Nozzle In Cylindrical Pressure Vessel", 14th International Research/Expert Conference Trends in the Development of Machinery and Associated Technology TMT 2010, Mediterranean Cruise, 11-18 September 2010.

[8] Jiju Antony, "Design of Experiments for Engineers and Scientists", The University of Strathclyde. First edition, 2003.

BIOGRAPHIES

Avinash Kharat is Assistant Professor at Bharati Vidyapeeth, Has completed M.E in CAD/CAM/CAE from Kit's college of Engg., Kolhapur. The topic of his dissertation is effect of opening pattern on stress distribution of pressure vessel.

Dr. V. V. Kulkarni completed his PhD in Mechanical Engineering and presently working as Principal and Head, at Sanjay Ghodawat College of Engineering, Kolhapur. His research interest includes, Computer Aided Fixture Design, FEA, and Pressure Vessel Design.