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Design and Analysis of Impregnation Chamber Used In Vacuum Pressure Impregnation Process

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Abstract: *The simple explanation is that in nature and in manufacturing, things leak. Vacuum impregnation stops leak. The ultimate goal of vacuum impregnation is to seal leak/migration paths without impacting the functional, assembly or appearance characteristics of a part. The impregnation chamber which is used in VPI process operates maximum up to 80 to 150 psi.it is important to analyse and design the pressure vessel that will provide safety, durability and serviceability to the company. Accomplishing this task will require a very good understanding of behaviour and a good knowledge of parameters that affecting the pressure vessel due to varying loads, pressure and thickness of shell element. The most important one is that the given geometry of pressure vessel must be analysed to assure it should meet the design standards.*
Keywords: *analytical solution,FEA,impregnation chamber,Vacuum impregnation process.*

I. Introduction

Vacuum impregnation as an industrial process has been in commercial use for more than 60 years. For the world's largest manufacturers, it continues to be the preferred process through which to guarantee the pressure-proof, leak-proof, and corrosion-proof requirements of parts and components in critical operations. The ultimate goal of vacuum impregnation is to seal leak / migration paths without impacting the functional, assembly or appearance characteristics of a part. Functional characteristics include the ability for fluids or gasses to flow only where needed in order to enhance in-service performance of the components' design. Assembly characteristics, which must be maintained, include performance of tapped holes; the integrity of mating and sealing surfaces, the elimination of residual internal contamination in water jackets, sockets, surfaces and dimensional areas. Appearance characteristics include oxidation and discoloration. Vacuum impregnation is governed by military standard MIL-STD-276A as well as numerous proprietary and customer specifications.
The vacuum component of the process removes the air that occupies the migration path commonly known as porosity in cast or pressed metals. The impregnation component of the process fills the void with a durable and stable material suitable for field of use. These materials can be silicate or epoxies. [7]

During normal operation, transformers are subjected to the failure of the insulation system. How long an insulation system will be serviceable depends on the materials chosen and the service environment. Thermal, mechanical, voltage and environmental stresses all combine to reduce the service life of the transformer. Solid-state Controls, Inc. (SCI) manufactures all of its transformers using the Vacuum Pressure Impregnation (VPI) process. This system strengthens the insulation system and extends the service life of the transformer. The VPI process is the most advanced system in use today. The VPI process is the most effective way known to eliminate the dead air spaces that cause hot spots within the transformer coils. These hot spots can be 20^0 higher than the average coil temperature. The VPI process, along with a good resin, provides a low thermal resistance path that lowers the average operating temperature of the transformer.The resin seals the transformer against environmental conditions and bonds all components of the insulation system together for good mechanical strength. This is very effective in reducing mechanical vibrations. This greatly reduces the audible noise level of the transformer. The VPI process and resin also enhances the dielectric capability between windings and between the windings and ground. This allows the transformer to survive higher voltage stress levels without failure.

The general VPI process contain following parts

In the impregnation chamber (also known as an autoclave, pressure vessel or vacuum vessel) air is evacuated from the leak path in the part by using a deep vacuum. The evacuated leak path is filled with sealant by covering the part with the sealant and applying pressure. More energy is required to penetrate the porosity with sealant than to evacuate the air. In the recovery station (also known as drain station, centrifuge) excess sealant is recovered for reuse. In the wash/rinse station (also known as surge station, rolling rinse or pump over station) residual sealant is washed from the part's internal passages, taps, pockets and features where sealant is undesirable. In the cure station (also known as standing, rolling cure or pump over station) the sealant, impregnated into the walls of the part, is polymerized in the leak path.

In general, vacuum impregnation includes four steps.

1. Transformers are placed in the impregnation chamber and a vacuum pulled to a minimum of 29mm of mercury and held for 20 minutes.
2. The resin is then allowed to flow into the chamber until the transformers are completely covered.
3. The vacuum is maintained at two tor for a minimum of 20 minutes.
4. The vacuum is then released and the chamber is allowed to pressurize to 80 to 150 psi (0.55 mpa to 1.03 mpa) for a minimum of 20 minutes. [6]

For more than two decades, the finite element method has been the most effective numerical tool for the analysis of solids and structures. The method however can only provide approximate solutions to a given mathematical model of a physical problem. The magnitude and distribution of the solution errors depend on the finite element discretization used.

The VPI system contain cylindrical pressure vessel as a impregnation chamber, this vessel operates at a specific pressure and vacuum in its operation But previously no work has been done on design and optimization of impregnation chamber used in VPI system hence, It is important to analyse and design the impregnation chamber that will provide safety, durability and serviceability to the company. Accomplishing this task will require a very good understanding of behaviour and a good knowledge of parameters that affecting the pressure vessel due to varying loads, pressure and thickness of shell element. The most important one is that the given geometry of pressure vessel must be analysed to assure it should meet the design standards.

II. Literature

Pressure vessels are a commonly used device in marine engineering. Until recently the primary analysis method had been hand calculations and empirical curves. New computer advances have made finite element analysis (FEA) a practical tool in the study of pressure vessels, especially in determining stresses in local areas such as penetrations, O-ring grooves and other areas difficult to analyse by hand. This project set out to explore applicable methods using finite element analysis in pressure vessel analysis. David Heckman [9]**.**The design of pressure vessels is an important and practical topic which has been explored for decades. Even though optimization techniques have been extensively applied to design structures in general few pieces of work can be found which are directly related to optimal pressure vessel design. These few references are mainly related to the design optimization of homogeneous and composite pressure vessels.

The detail study done on vacuum pressure impregnation unit by Marvin M. Fromm [10] which gives the working of VPI process and operating condition of pressure vessel used in it,the apparatus is placed inside a pressure-tight vessel which is then evacuated to an absolute pressure below 20 mm. mercury, and preferably below 10 mm mercury. This high vacuum adequately removes any air entrapped within the apparatus after that the surface of the mixture is then subjected to an air pressure of 80-150psi for several hours. A work on optimization techniques for designing pressure vessels was presented by Middletown and Owen [1],who used parametric optimization techniques to minimize the maximum shear stress in the design of a pressure vessel dished end (head) modelled with axisymmetric finite elements. Middletown [2] applied these parametric optimization techniques to design a pressure vessel nozzle considering the minimization of the maximum shear stress. Mechanical and thermal loads were taken into account by specifying different temperatures in the internal and external walls of the nozzle and dished end (head). The work of Malinowski and Magnuki [3] employed parametric discrete optimization techniques to design internal reinforcements of pressure vessels by minimizing the reinforcement mass considering stress constraints. Following an analytical approach Jaroslav Mackerle [4] gives review of finite element methods (FEM) applied for the analysis of pressure vessel structures/components from the theoretical as well as practical points of view. You-Hong Liu [5] explained about Limit pressures and corresponding maximum local membrane Stress Concentration Factors (SCF) are assessed for two orthogonally intersecting thin-walled cylindrical shells subjected to internal pressure. The limit pressures of 81 models with parameters $\rho=d/D\leq0.8, D/d\geq10, d/t\geq10, \lambda=d/\sqrt{DT}$ are calculated using inelastic analyses by the 3D finite element method. The scope of ASME section VII, division 1 is presented by Urey R. Miller [8], any pressure retaining vessel, whether the pressure is internal or external to the container, can be designed to meet the requirements of the division.

III. Analysis By Analytical Solution

3.1 Industrial Geometry

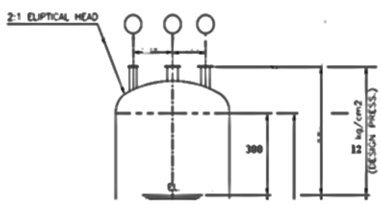

Fig.1 Schematic Diagram of pressure vessel

The fig.3.1 represents schematic diagram of pressure vessel used as an impregnation chamber, this model of pressure vessel having internal pressure of 0.98 mpaand having 500 mm internal diameter while shell length is of 600mm.upper dome have 150mm height and lower have 100mm.

3.2 Evaluation of Joint Efficiency (Butt Welds) (uw-12):

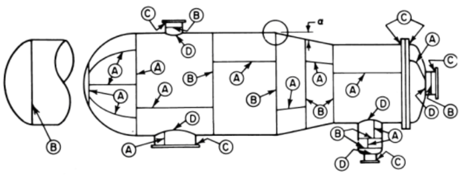

Fig.2 UW-3: Illustration of welded joint locations typical of categories A, B, C &D

3.3 Thickness of the Shell under Internal Pressure (Ug-27)

The minimum thickness of shells and heads used in compressed air service, steam service, oil service& water service made from materials listed in table ucs-23 shell is 3/32 in. (2.4mm) exclusive of any corrosion allowance. For components made from ductile materials like steel, yield strength is considered to be criterion of failure. When such components are over loaded and the stress due to external force exceeds yield strength of the material, there is small amount of plastic deformation, which is usually does not put the component out of service. Ductile components have a homogenous structure and residual stresses can be relieved by proper heat treatment the stress analysis is more precise in case of static forces. Due to these reasons, the factor of safety is usually small in such cases. The recommended factor of safety is 1.5 to 2, based on yield strength of material. Hence According to table ucs-23 the maximum allowable stress can be taken as 138 mpa. [11].

3.4 Design Data

Inside diameter		: 500.000mm
Total height		: 850.000mm
Type of vessel		: vertical
Material used		: mild steel
Provided positive tolerance		= 6.00mm
Possible inside diameter (corroded)		= 512.00mm
Inside radius (corroded)	R	=256.000mm
Corrosion allowance	C.A	= 3.000mm
Working pressure	P	= 0.980 Mpa
Internal design pressure at bottom	P	=1.1775 Mpa
Max. Allowable stress	S	= 138 Mpa
Longitudinal joint efficiency	E_L	= 0.85
Circumferential joint efficiency	E_c	=0.85
Factor of safety		=1.812
Thinning allowance		=1

Table 3.1 Joint Efficiency Table UW-12

Description of joints	**Joint category**	**Proposed Type No.**	**Proposed NDE**	**Joint Efficiency table UW-12**
1.longitudinal joints	A	(1)	Spot	E_l = 0.85
2. ellipsoidal joints	B	(2)	Spot	Ec = 0.85

1. Circumferential stress
   $0.385SE_L = 45.161$ Mpa
   Design pressure P=1.1775 mpa
   Since $P<0.385SE_L$
   FromASME Code Section VIII, Division 2Minimum thickness of shell
   $$t = \frac{PR}{[(SE-0.6P)]} + C.A. \quad (1)$$
   $$t = \frac{1.1775 \times 256}{[(138\times 0.85)-(0.6\times 1.1775)]} + 3 = 5.58\text{mm}$$
   $$t = 5.58 + 1 = 6.58$$
2. Longitudinal stress
   $1.25SE_C$=143.625 Mpa
   Design pressure P=1.1775 mpa

Since

D/2h	3.0	2.8	2.6	2.4	2.2	2.0	1.8	1.6	1.4	1.2	1.0
K_1	1.36	1.27	1.18	1.08	0.99	0.90	0.81	0.73	0.65	0.57	0.50

$P<1.25SE_C$

$$t = \frac{PR}{[(2SE+0.4P)]} + C.A. \quad (2)$$

$$t = \frac{1.1775\times256}{[(2\times138\times0.85)+(0.4\times1.1775)]} + 3 = 4.282\text{mm}$$

$$t = 4.282 + 1 = 5.282$$

Minimum required thickness maximum of 1 and 2

t=6.58=7mm

3.5 Formed Heads Pressure on Concave Side: (Ug - 32)

Type of head =2:1Ellipsoidal
Inside depth =150mm
Ratio of major axis to minor axis D/2h =2.56
From table 3.2 For D/2h=2.56
Radius Factor K =1.18

Table 3.2 radius factor UG-37

3. Minimum design thickness

$$t = \frac{PDK}{[2SE-0.2P]} + C.A. \quad (3)$$

$$t = \frac{1.1775\times512\times1.18}{[(2\times138\times0.85)-(0.2\times1.1775)]} + 3 = 6.035\approx7$$

From equation (1) and (3) we get minimum thickness required for impregnation chamber. In order to validate the thickness obtained by analytical equation, a simulation using ansys workbench is undertaken in detail in section following.

IV. Analysis By Simulation

Numerical simulations are carried out using ANSYS and the procedure incorporated in this section.

The 3D modelling of this model was done in CATIA modelling software and this 3D geometry is imported in ANSYS software for further analysis. In ANSYS, with the help of import the modelling has been saved for meshing and further analysis, the whole model and taking 1.18 mpa internal pressure by specifying boundary condition. After the solution obtained by solution process is general solution. The figure 4 is show the von misses stress developed

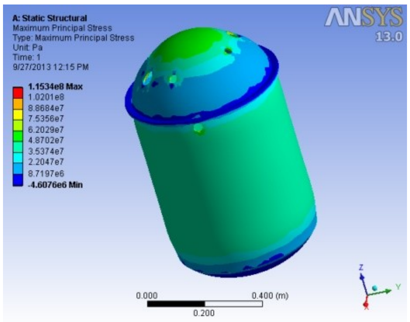

Figure 4 von misses stress

V. Conclusion

From figure4 we can find that at pressure 1.18 mpa the stress produced on the pressure vessel which is 115 mpa less than allowable or safe stress that is 138 mpa and this pressure vessel can sustain pressure. Hence the design is found to be satisfactory since result obtained from analytical is validated by ansys.

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