Design, Development & Analysis of Vacuum Chamber of Potting Machine

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***Abstract*—This paper shows the Design and Finite Element analysis of vacuum chamber of potting machine designed for electronic ignition coil applications. There are two types of potting methods 1) With Vacuum 2) Without Vacuum.For ignition coil requires vacuum atmosphere to remove moisture and air bubble from the epoxy resin. Vacuum chamber having rectangular shape which operates at pressure of 20 Pa which is below the atmospheric pressure of 101325 Pa, which lead to the compressive forces acting inside the chamber.Analytical design, buckling failure analysis, modelingof vacuum chamber is done. But during trial of machine there is problem of deflection of structure and hence braking of inspection glass window of chamber. Hence added ribbing to the metallic chamber but still problem remains. To solve this problemwe Redesign, Development and FEA analysis of vacuum chamber.**

***Keywords*—Buckling failure analysis, Finite Element analysis, Ignition coil, Potting Machine, Vacuum chamber.**

I. INTRODUCTION

Potting Machines (PM) are widely used in industrial applications such as Automotive, Electrical and Electronics Ignition Coil, Transformer Potting, Isolator Switches, Sensors, PCB industries. Potting is process of filling a complete assembly with a solid or highly viscous compound (Resin) used for resistance to shock, vibration and exclusion of moisture and corrosive agents. There are two types of potting methods 1) With Vacuum 2) Without Vacuum. Vacuum potting method is more advantageous than the without vacuum. [2] We are designing the vacuum potting machine for ignition coil application. For ignition coil requires vacuum atmosphere to remove moisture and air bubble from the epoxy resin**.**Fig.1 shows the construction of Ignition Coil. It consists of group of copper coil which requires filling with resin and hardener mixture with the help of meter mix dispensing unit.

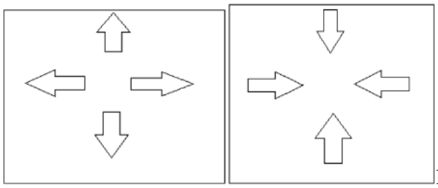
Fig. 1 Ignition coil

Potting machines consists of following main components,

1. Vacuum chamber - to supports 3 axis automated robot and object (ignition coil) which is to be potted inside the vacuum chamber. 2. Meter mix dispensing unit. 3. Resin and hardener tank. 4. Pressure gauges. 5. Vacuum pressure kill valve. 6. Vacuum pump with electric motor. 7. Material handling unit. [12]

Fig.2Actual Vacuum Potting Machine Set Up

M/s. Twin Engineers manufacturers of Potting Machines which consists of meter mix dispensing unit. Fig. 2 shows the construction and Actual Vacuum Potting Machine set up for ignition coil application. Vacuum chamber is very important and critical component in vacuum potting machine in which potting of object is completed inside the chamber.[12]



Positive

Pressure vessel Vacuum vessel

Fig 3: Direction of Internal Pressure. [5]

We are designing the vacuum potting machine chamber having rectangular shape made of mild steel (M.S.) plate structure which operates at pressure of 20 Pa which is below the atmospheric pressure of 101325 Pa, which lead to the compressive forces acting inside the chamber.

Fig 3 shows the direction of internal pressure and hence in vacuum chamber is subjected to external atmospheric pressure which leads to compressive stresses on vessel wall which causes buckling. [5]

II. LITERATURE SERVEY

Joel Nasheff, Henkel Inc, et al. [1] Studied and Give detail information on design related problem on adhesive potting and explosion proof motors. Adhesives play a critical role in the successful design of an explosion proof, UL 674 compliant motor, also studied other factors affecting explosion-proof motor design and potting adhesives.

Peter Caine, Heat Tek Incorporated, et al. [2] Studied the various types of resin used and machines used for potting application. Give the detail information on impregnation methods, resins and equipment. The savings in energy and cost for curing parts on average resulted in an immediate savings of approximately 25%. The effects on the equipment and machines processing parts were numerous. Exhaust emissions were reduced, heat losses were reduced, cure times became much shorter, and some new components were able to be used on the machines that were not previously used due to the lower operating temperatures.

U. Hahn, P.K. den Hartog, G. Schmidt, et al. [3] Examined 3 vacuum chambers for the VUV SASE FEL undulator sections at the TESLA Test Facility (TTF) were designed, tested and installed. Each chamber is 4.5m long and of 11.5mm thick. The inner diameter of the beam pipe is 9.5mm. Profile of the chamber is rectangular with a width of 128mm is used to integrate beam position monitorsand steerers. Aluminium material is selected for vacuum chamber for very ultra-vacuum with all special metal seals are used.

Mongol Phanak, SarunyuChaichuay, MetheeSophon and SupawanSrichan, et al. [4] Examined the design, construction and vacuum test of the ultra-high vacuum (UHV) chamber which is planned to be installed as a collimating mirror chamber for hard x-ray beam line at Synchrotron Light Research Institute (SLRI). Design, fabrication of S.S. vacuum chamber box shaped while an aluminium wire and OFHC copper gasket was chosen for the sealing of the UHV system and analysis is done by Ansys software.

Mr. Abdul Sayeed AW Sheikh, Prof. P.T.Nitnaware, et al. [5] Examined the Finite Element analysis of vacuum chamber. The analysis is done for electron microscopy applications, for scanning electron microscope it require vacuum atmosphere for viewing of the specimen. The specimen is to be viewed in vacuum. The vacuum level required for that is in the range of 93324 Pa, which lead to the compressive forces acting inside the chamber. The vacuum chamber is modeled in Catia and Simulation is done in Ansys. Also theoretical calculation is done for safety of vacuum chamber against buckling failure. Also, shell analysis is done for considering the thickness of the vacuum chamber which is done by using Hyper-mesh.

M.HommaMSakakiE.KanekoS.Yanabu, et al. [6] Studied the Vacuum circuit breakers(VCB) which brakes current in a vacuum and in its nature, a recycling of material and harmless to human body have been realized and also no global warming effect would be expected. A future trend of VCB must be discussed. Results of the recent development in Japan will be reviewed and the reflection of the results will be stated and the subjects of engineering in the 21st century will be discussed.

II. DESIGN, MODELING, FINITE ELEMENT ANALYSIS.

The first step in designing a vacuum chamber is to determine how the chamber will be used and to have a clear understanding of the processes that will be carried out inside the chamber wall. The designer must be aware of the risks for contamination to the vacuum chamber, and how will the inside of the vessel be checked for cleanliness prior to starting a process. Some additional design consideration includes what types of coatings are present inside thevessel during the test, at what temperature, and at what pressure will the test be carried out.

We are designing the Vacuum chamber which is subjected to vacuum pressure of 20 Pa which come under the category of medium vacuum. Vacuum chamber is made of mild steel plate structure and inspection glass window made of toughened glass. During testing of the vacuum potting machine it shows that there is vacuum chamber is deflected under the vacuum pressure of 20 Pa. Inspection glass window is also cracked due to the deflection in the chamber.

Due to failure of glass it causes damages to the machine component as well as operator. To increase the safety level and reduce the deflection of chamber structure added ribbing inside the plate but still problem remains hence Redesign, development and analysis of vacuum chamber subjected to vacuum pressure of 20 Pa.

A. Design of VacuumChamber

1. Working Pressure (Pi)= 0.2 mbar = 20 N/m^2
2. Design Pressure (P) = 1.01 bar =1.01 x 10^5 N/m^2
3. Vacuum Category – Medium Vacuum
4. Shape of vacuum chamber – Rectangular box type
5. Volume of vacuum chamber

Length (L) – 1146 mm

Breadth (B) – 1000 mm

Height (H) – 970 mm

Volume (V) = L×B×H =1146×1000×970 (1)

V = 1.11162×10^9 mm^3

V = 1.11162 m^3

6. Thickness of Glass (T min)

Glass selection – Toughened glass

Thickness of Glass (T min) is calculated as follows,

$$T_{min}=\sqrt{\frac{SPX2Y2}{M(X2+Y2)}} \qquad (2) \qquad [13]$$

Where,
Factor of safety (S) – 4

Pressure (P) – 15 psi

Unsupported length of the longer side of the part (X) – 20 inch

Unsupported length of the shorter side of the part (Y) – 14 inch

Rupture modulus of glass (M) – 24000 psi

$$T_{min}=\sqrt{\frac{4x15x202x142}{24000(202+142)}}$$

T_{min}= 0.573 inch = T_{min}=14.566 mm selecting 20 mm

7. Thickness of vacuum chamber plates (t_{min})

Thickness of vacuum chamber plate (t_{min})is calculated as follows,

$$t_{min}=\frac{C.Z.a.}{10}\sqrt{\frac{p}{f}} \qquad (3) \qquad [15]$$

Where,
a = short span of non-circular heads in mm = 1ooo mm ;

b = long span of non-circular heads or covers measured perpendicular to short span in mm= 1146 mm;

C = a factor depending upon the method of attachment to shell = 0.7;

p= design pressure in kgf/cm^2= 1.01 kgf/cm^2;

f= allowable stress value in kgf/mm^2=17.8kgf/mm^2;

t = minimum thickness of flat head or cover, exclusive of corrosion allowancein mm;

Z = a factor for non-circular heads depending upon the ratio of short span tolong span a/b = 1.15

For case 1 (Existing Design)

$\frac{a}{b}=\frac{1000}{1146}$ = 0.8726 hence from graph Z = 1.15 &t_{min} = 12 mm from existing design

$12=\frac{o.7x\ 1.15x\ 1000.}{10}\sqrt{\frac{1.01}{f}}$hence f = 45.45 kgf/mm^2= 445.88 N/mm^2

f = 445.88 N/mm^2

Above value of stress (f) is less than allowable stress value of 174.66 N/mm^2 (Failure of mild steel plate) hence redesign of thickness of plate.

For case 2 (Redesign)

$\frac{a}{b}=\frac{1000}{1146}$ = 0.8726 hence from graph Z = 1.15

$t_{min}=\frac{o.7x\ 1.15x\ 1000.}{10}\sqrt{\frac{1.01}{17.8}}$= 19.21 mm

t_{min}= 20 mm selected

8. Critical Buckling Pressure

Buckling is sudden failure of a structural member subjected to high compressive stress. Rectangular vacuum chamber subject to external atmospheric pressure. Consider a length L of the vessel,

The total force acting = Intensity of pressure × area

$= P \times B \times L$ [5]

The total resisting force acting on the vessel walls,

$= \sigma_h \times 2t \times L$

From above two equation's,

$\sigma_h \times 2t \times L = P \times B \times L$, hence $\sigma_h = \frac{P \times B}{2t}$

The compressive hoop force,

$W_h = \sigma_h \times L \times t$

$W_h = \frac{\nabla Pbuckle \times B \times L}{2}$ (4) [5]

Buckling will occur when compressive hoop force will equal to buckle force (W_b)

$W_b = \frac{\pi 2 EImin}{le2}$[19] $l_e = 2L$ (on end is fixed & other end is free) Since, $I_{min} = \frac{Lt3}{12}$

Hence, $W_b = \frac{\pi 2 Et3}{48\ L}$ (5)

Equating Eqn. (4) and (5)

$\frac{\nabla Pbuckle \times B \times L}{2} = \frac{\pi 2 Et3}{48\ L}$

$\nabla P_{buckle} = \frac{\pi 2 Et3}{24BL2} = \frac{\pi 2 \text{ x } 205\text{x } 109 \text{ x } (0.2)3}{24 \text{ x } 1.146 \text{ x } (1)2}$

∇P_{buckle}= 588.503 x10^3N/m^2=5.88 bar

∇P_{buckle}=5.88 bar

We have applied approximately p = 1.01x 10^5N/m^2 as per requirement and buckling pressure will be ∇P_{buckle}= 5.88 **x** x10^5N/m^2 hencethe impact will be very small. So it is safe from buckling failure.

B. Modeling of Vacuum Chamber

We are using Solid Edge CAD software for modeling of vacuum chamber. Bottom up assembly approach is used for modeling. Vacuum chamber is designed in rectangular box (L x B x H = 1146 x 1000 x 970) construction for easy to manufacture and low cost.

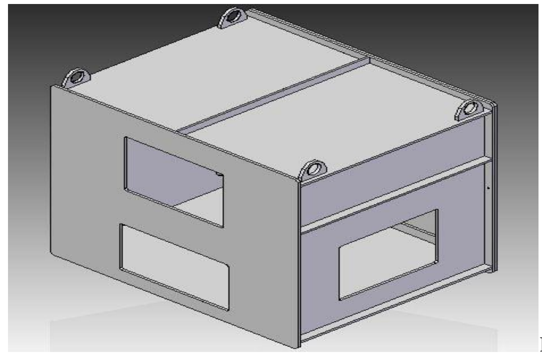


Fig. 4 vacuum chamber without ribbing (12 mm thickness)

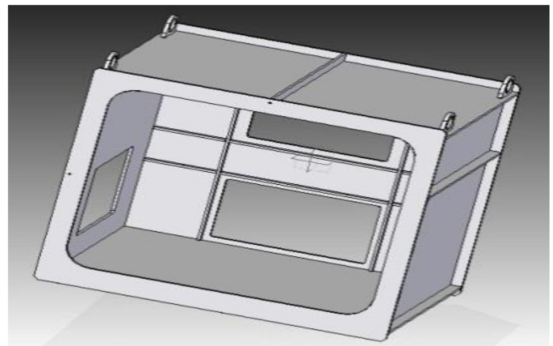


Fig. 5 vacuum chamber with ribbing (12 mm thickness)

There are two model of vacuum chamber of case 1 (initial existing design) vacuum chamber without ribbing as shown in fig (4) and vacuum chamber with ribbing as shown in fig (5) to reduce deflection of chamber.

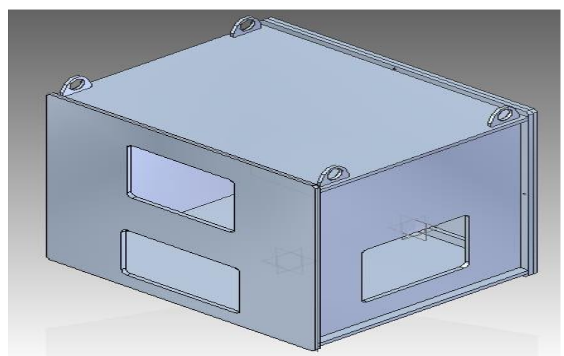


Fig. 6 vacuum chamber without ribbing (20 mm thickness)

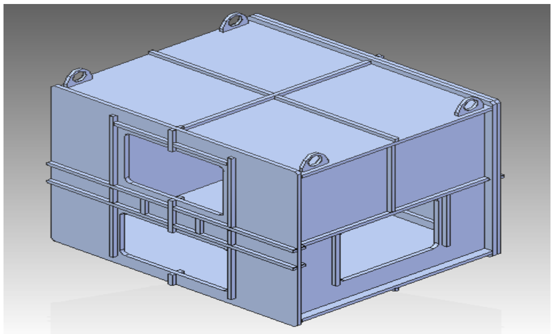


Fig. 7 vacuum chamber with ribbing (20 mm thickness)

There are two model of vacuum chamber of case 2 (Redesign) vacuum chambers without ribbing (20 mm thickness) as shown in fig (6) and vacuum chamber with ribbing (20 mm thickness) as shown in fig (7) to reduce deflection of chamber.

C. Finite Element Analysis

Finite element analysis (FEA) is a computational technique used to obtain approximate solutions of boundary value problems or complex engineering problems which is difficult to solve by analytically. In FEA a continuum or geometry is divided into number of finite number of elements, having finite dimensions and reducing to continuum having infinite degrees of freedom to finite degree of freedom is called as discretization or meshing.[17]

Tetrahedron Meshing has been used for FEA. In tetrahedron method the component is been divided into small triangle on its surface which gives no of nodes and elements of that component. The meshing has been done by changing the mesh size of the various component of the vacuum chamber. Due to change in the density of the meshing, it results in the variation of the no of nodes and elements of the meshed parts hence the variation in nodal displacement and stresses. [5]

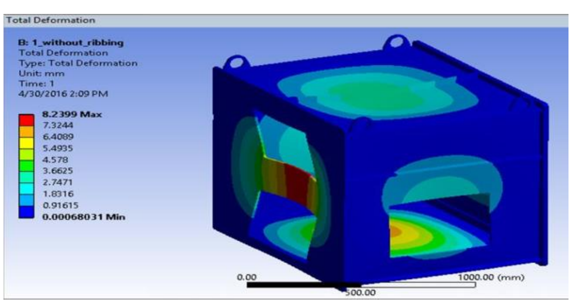


Fig. 8Deflection of vacuum chamber without ribbing (12 mm thickness)

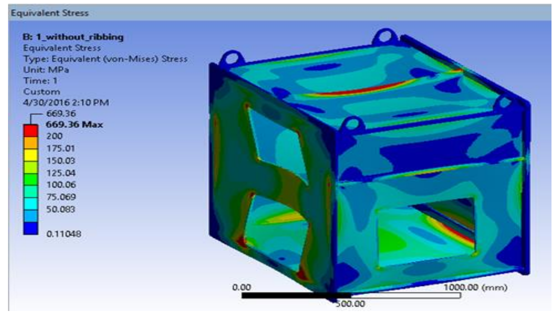


Fig. 9 stress of vacuum chamber without ribbing (12 mm thickness)

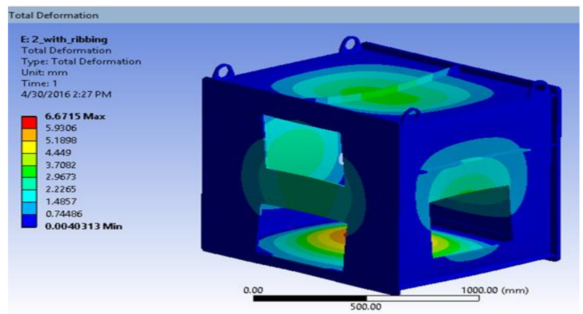


Fig. 10Deflection of vacuum chamber with ribbing (12 mm thickness)

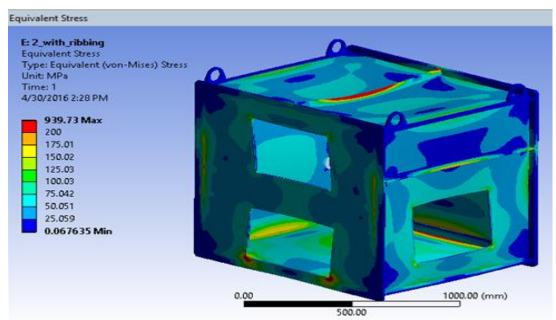


Fig. 11 stress of vacuum chamber with ribbing (12 mm thickness)

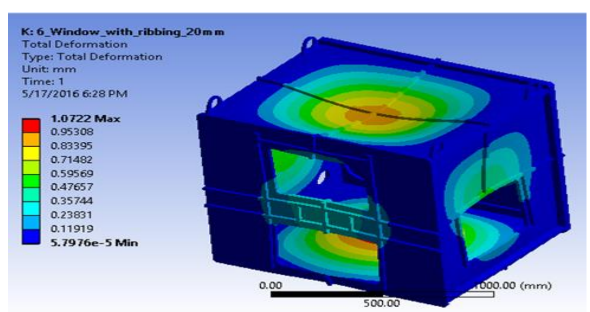


Fig. 12Deflection of vacuum chamber with ribbing (20 mm thickness)

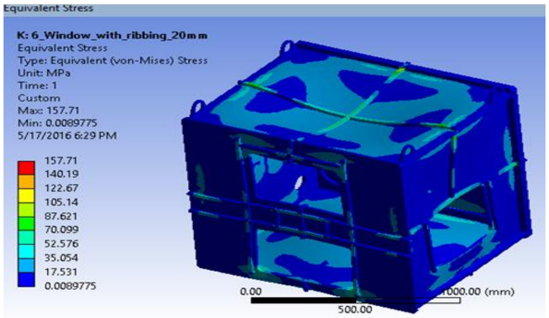


Fig. 13 stress of vacuum chamber with ribbing (20 mm thickness)

FEA is done with design pressure of 1.01 x 10^5 N/m2 (101 kPa) applying at the outer surface of the vacuum chamber plate structure and bottom plate of vacuum chamber is fixed used as boundary condition. A Static Structural Analysis is used to find the Deformation, Stresses and Factor of safety. We are using Ansys software for Finite element analysis (FEA) of vacuum chamber.

III. Results and Discussion

From above analytical solution of stresses and deflection comparing with Finite Element Analysis tool (Ansys) software solution is as follows.

TABLE 1
RESULT COMPARISION TABLE

Sr. No.	Description	Maximum Stress (Von mises stress) (Mpa)	Maximum Deflection (mm)
Analytical	12 mm without ribbing	445.88	-
	20 mm with ribbing	160.517	-
Software	12 mm without ribbing	669.79	8.239
	12 mm with ribbing	939.73	6.672
	20 mm with ribbing	**157.71**	**1.072**

From above table 1 it shows that stresses and deflection reduces due to increase in thickness from 12 mm to 20 mm of vacuum chamber plate structure. Software results of stress of 12 mm with ribbing is 939.73 Mpa shows more than the analytical results of 445.88 Mpa due to the stress concentration at the sharp corners and edges.A 20 mm with ribbing structures shows the maximum stress of 157.71 Mpa is less than the allowable stress limit of 174.66 Mpa of Mild steel so it is safe. Also glass window is designed based on modulus of rupture hence we get the 20 mm thickness of glass window.

IV.CONCLUSION

- From this paper it is concluded that for any engineering design problem solved by certain procedure.
- Hence in this paper we designed the vacuum chamber by analytically and comparing these analytical results with computer aided Finite Element Analysis tool (Ansys).
- Stress concentration is reduced by adding fillet radius to the sharp corner from 10mm to 25 mm.
- Also reduces stresses and deflection by increasing the thickness from 12mm to 20mm and adding ribbing to the weaker sections.
- From this it shows that avoiding failure of structure deflection and hence the failure of glass window.

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