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Design and Analysis of Vacuum Chamber Cover

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***Abstract* — This paper shows the design and analysis of vacuum chamber cover. The analysis is done for degassing application which is less than atmospheric pressure which lead to the compressive forces acting on the chamber cover, the vacuum chamber and is modeled in Solidworks and Simulation also done in Solidworks simulator. In this study we mainly concentrated on design and optimizing the vacuum chamber cover with respect to the engineering requirements and ergonomic requirements. Finally the paper summarizes the comprehensive design to meet operational and functional requirements, based on the structural strength and Lifting index for the larger size vacuum chamber cover.**

Keywords— Vacuum Chamber Cover; Design, Analysis; Ergonomics.

I. INTRODUCTION

This paper shows the design and analysis of vacuum chamber cover. The analysis is done for degassing application which is less than atmospheric pressure which lead to the compressive forces acting on the chamber cover, the vacuum chamber and is modeled in Solidworks and simulation also done in Solidworks simulator. In this study we mainly concentrated on design and optimizing the vacuum chamber cover with respect to the engineering requirements and ergonomic requirements. Finally the paper summarizes the comprehensive design to meet operational and functional requirements, based on the structural strength and lifting index for the larger size vacuum chamber cover.

A majority of micro or nano-fabrication processes are conducted under partial vacuum conditions, i.e., at pressures orders of magnitude below ambient atmospheric pressure. This is done, among other, to avoid a contamination of films during their deposition.

A majority of processes for fabricating micro-electromechanical systems (MEMS) and nano-electromechanical systems (NEMS) are conducted under partial vacuum conditions, i.e., at pressures orders of magnitude below ambient atmospheric pressure.

II. DESIGN OF CHAMBER AND CHAMBER COVER

A. Vacuum chamber design

Design of vacuum chamber includes the identifying the boundary conditions (inner and outer dimensions of the chamber), choosing the right material for the application, designing and selecting the each and individual parts, manufacturing and assembling these parts. This process will be elaborated in this following section.

B. Chamber material selection

Metal	Coefficient of thermal expansion $\times 10^{-6} K^{-1}$	Melting point °C	Boiling point °C	Density in lbs/in^3
Aluminum	23.5 @ 0-100°C	660	2467	2.7
Copper	17.0 @ 0-100°C	1083	2870	8.96
Iron	12.1 @ 0-100°C	1535	2750	2.87
Titanium	8.9 @ 0-100°C	1660	3287	4.5

Table-1: Thermal and physical properties of some of the materials.

The commonly used and suggested material for high-vacuum chamber applications are listed in the table-1. Fast surface outgassing and fight to surface oxidation are most valuable characteristics of using stainless steel and aluminum, but, stainless steel is to be difficult to machine and might need common tool and cutting tool additional changes. Stainless steel chambers also spreads its vibration to all involved components. These vibration and pumping systems vibrations are transferred to the shop floor. Those may destruct precision vacuum devices in addition to confuse the vibration measurements in the chamber.

From the table-1, compared to stainless steel Aluminum gives significant advantages in vacuum technology, so we considered aluminum for our chamber cover design.

C. Conceptual design of the chamber cover

The conceptual design of the model is shown in the below Fig. 1 and Table-2, describes its dimensions of the model.

We know that material reduction is one of the method for the weight reducing techniques without affecting the process and application of the same. So we tried to implement the material removal techniques here without affecting the strength and ergonomics conditions.

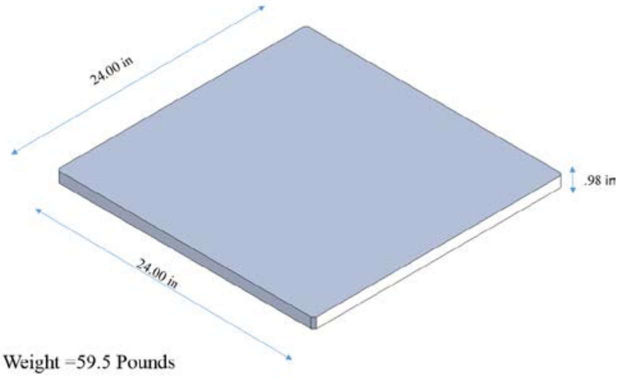

Fig-1: CAD model of the conceptual Chamber Cover

Description	Value in Inches
Width of the chamber cover	24
Length of the chamber cover	24
Thickness of the chamber cover	0.98

Table-2: Dimensions of vacuum chamber cover

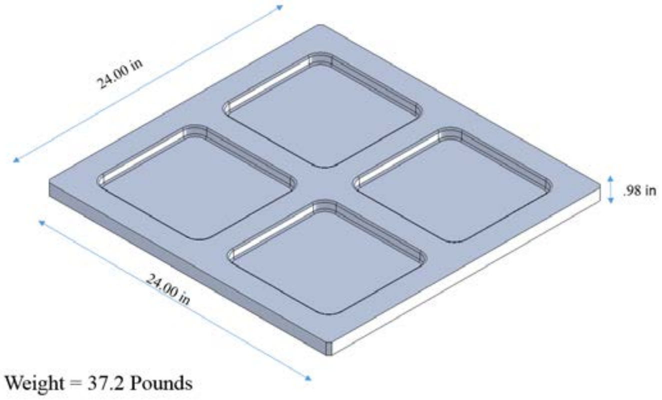

Fig-2: Weight reduction Design

III. FINITE ELEMENT ANALYSIS OF VACUUM CHAMBER COVER.

The finite element method (FEM), sometimes referred to as finite element analysis (FEA), is a computational technique used to obtain approximate solutions of boundary value problems in engineering. In this method all the complexities of the problems, like varying shape, boundary conditions and loads are solved. The fast improvement in computer hardware technology and slicing of cost of computers have boosted this method. There are different types of packages are available for FEA such as STAAD-PRO, NISA, Solid work simulation, ANSYS and NASTRAN. By using these packages we can analyses several complex structures and geometry problems associated with mechanical field. It is used for solving different and complex engineering problems like, fluid flow analysis, structural analysis, vibrational analysis, heat transfer analysis and etc.

A. Modelling

Vacuum chamber cover comprises of square plate with 24in x 24in x .98in. The same weight reduction model developed in the design phase in the Solidworks is used for the analysis workbench. The model is split by XY and YZ planes as it is symmetric about both symmetric planes, and giving fixed constrains in X-Axis. A face to face contact is defined between the chamber and cover.

B. Units

Material: Aluminum 6061-T6
Young's modulus of elasticity, $E=9.98\times10^{6}$ psi.
Poisson's ratio, $\mu = 0.33$
Mass density, $\rho = 0.097$ lbs /in^{3}
Yield strength = 0.39×10^{6} psi.

C. Meshing

Meshing is the method of dividing the model into the number of elements to obtain good accuracy in the analysis. It has been done by using the method of tetrahedron. In tetrahedron method the component is been divided into small triangle on its surface which gives number 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 number of nodes and elements of the meshed parts.

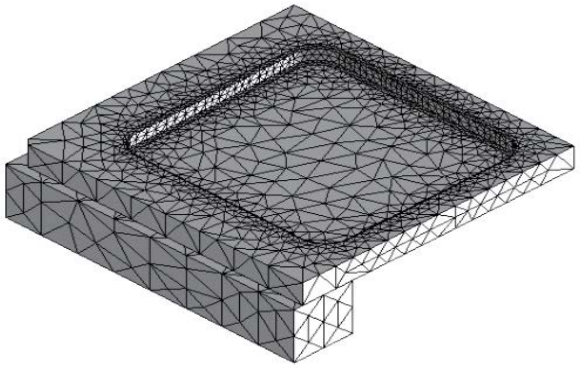

Fig-3: Meshing Model

D. Boundary Conditions

The simulation is done for atmospheric pressure 14.7psi is applied on the chamber cover which leads to compressive pressure on the chamber cover. Thus 14.7psi pressure applied on the all walls of the chamber cover, the direction of the pressure is inwards.

E. Structural Analysis

A static structural analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions assumed: i.e. the loads and the structure's response are assumed to vary slowly with respect to the time.

F. Solver

9944 tetrahedron elements are used for meshing which are connected at 17877 nodes. As there is three degrees of freedom in solid structural analysis. So number of equations to be solved for the displacement are 17877. The maximum deformation calculated from the analysis is 0.024in in the chamber cover.

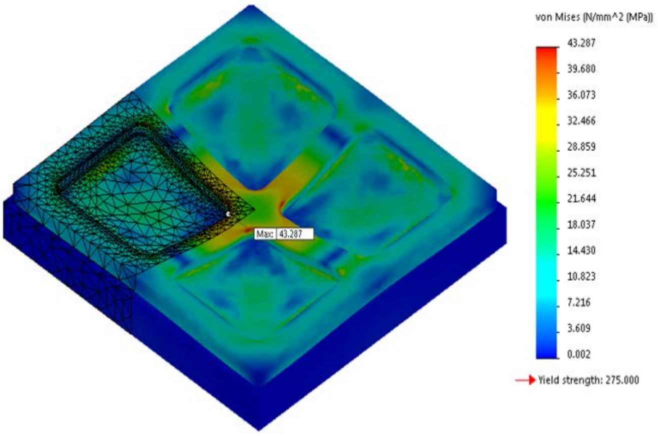

Fig-4: Stress analysis results

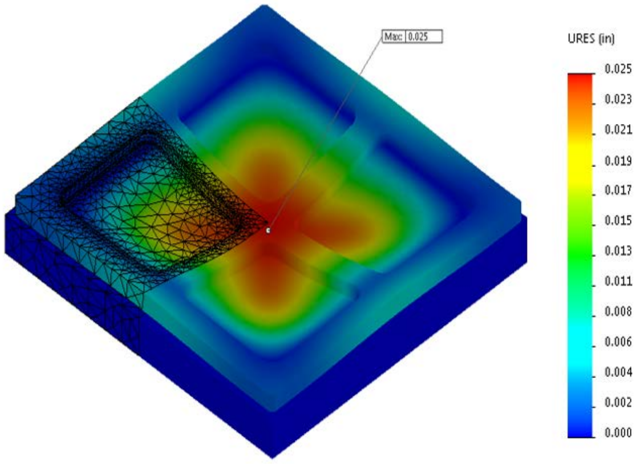

Fig-5: Displacement analysis results

Maximum deflection = 0.025in

Maximum design stress = 43.2Mpa = 6236.6psi

Factor of safety (FOS) = Yield stress / Design stress

= 39885.4 / 6236.6

= 6.3

G. Structural results

Deformation and Von Mises Stress at different regions has been calculated using post processor. Von Mises criterion also known as the maximum distortion energy criterion, is often used to estimate the yield of ductile materials. The Von Mises criterion states that failure occurs when the energy of distortion reaches the same energy for yield/failure in uniaxial compression/tension. Max Von Mises stress calculated from the analysis is 6236.6psi on the chamber, which is very less than compressive yield strength 39885.4psi, so it is safe from this criterion

IV. ERGONOMIC DESIGN OF CHAMBER COVER

The goal of ergonomics is to prevent soft tissue injuries and musculoskeletal disorders (MSDs) caused by sudden or sustained exposure to force, vibration, repetitive motion, and awkward posture. To create an ergonomically sound work environment, National Institute for Occupational Safety and Health (NIOSH) ergonomists and industrial hygienists recommend designing tasks, work spaces, controls, displays, tools, lighting, and equipment to fit employee's physical capabilities and limitations. The NIOSH lifting equation is a tool used by occupational health and safety professionals to assess the manual material handling risks associated with lifting and lowering tasks in the workplace. This equation considers job task variables to determine safe lifting practices and guidelines.

The primary product of the NIOSH lifting equation is the Recommended Weight Limit (RWL), which defines the maximum acceptable weight (load) that nearly all healthy employees could lift over the course of an 8 hour shift without increasing the risk of musculoskeletal disorders (MSD) to the lower back. In addition, a Lifting Index (LI) is calculated to provide a relative estimate of the level of physical stress and MSD risk associated with the manual lifting tasks evaluated.

Lifting Index (LI): Answers the question… "How significant is the risk consists?"

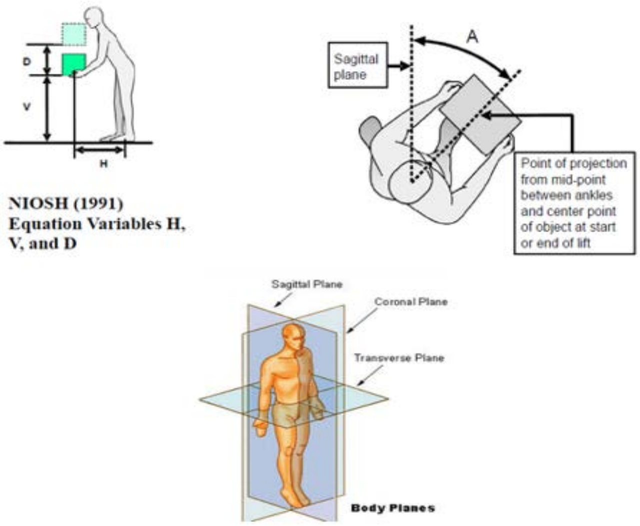

Fig-6: NOISH equation variables

A Lifting Index value of less than 1.0 indicates a nominal risk to healthy employees. A Lifting Index of 1.0 or more denotes that the task is high risk for some fraction of the population. As the LI increases, the level of low back injury risk increases correspondingly. Therefore, the goal is to design all lifting jobs to accomplish a LI of less than 1.0.

The NIOSH lifting equation always uses a load constant (LC) of 51 pounds, which represents the maximum recommended load weight to be lifted under ideal conditions. From that starting point, the equation uses several task variables expressed as coefficients or multipliers (In the equation, M = multiplier) that serve to decrease the load constant and calculate the RWL for that particular lifting task.

NIOSH Lifting Equation:
$LC(51) \times HM \times VM \times DM \times AM \times FM \times CM = RWL$ (1)

- H = Horizontal location of the object relative to the body
- V = Vertical location of the object relative to the floor
- D = Distance the object is moved vertically
- A = Asymmetry angle or twisting requirement
- F = Frequency and duration of lifting activity
- C = Coupling or quality of workers grip on the object

Horizontal Multiplier (HM) $= 10/H$ (3)

Vertical Multiplier (VM) $= 1 – (.0075\,(V-30))$ (4)

Distance Multiplier (DM) $= (0.82 + (1.8/D))$ (5)

Asymmetric Multiplier (AM) $= (1 – (.0032 \times A))$ (6)

Frequency Multiplier (FM) =From NOISH frequency multiplier Table

Coupling Multiplier (CM) = From NOISH frequency multiplier Table

Lifting Index (LI) = Weight / RWL (2)
(For single person 2 hand lifting)

Here

W = width of the object in the sagittal plane = 22.00 inches

V = Vertical distance in inches =50 inches (From ergonomics standards necessary vertical)

D = Vertical travel distance = 1.00 inches

A = Angle of asymmetry (Angular displacement of the load from the sagittal plane = 90 °

H = Estimated horizontal distance in inches.
From NOISH standard
V< 10 inches, then $H = 10 + W/2$ (7)
V>10 inches, then $H = 8 + W/2$ (8)

Here, V = 50 inches
by (8),
$H = 8 + 22/2$
H = 19 inches.
by (3),
$HM = 10/19$
$HM = 0.53$
by (4),
$VM = 1 – (.0075\,(50-30))$
$VM = 0.85$

by (5),
$DM = (0.82 + (1.8/1))$
$DM = 2.62$

by (6),
$AM = (1 – (.0032 \times 90))$
$AM = 0.71$
$FM = 1$
$CM = 1$
by (1),
$RWL = 51 \times 0.53 \times 0.85 \times 2.62 \times 0.71 \times 1 \times 1$
$RWL = 42.56$
by (2)
$LI = 42.56/42.56$
$LI = 0.87$

Lifting index is 0.87 signifies it can be lifted by single person with two hands.

CONCLUSION

The greatest value of the stress developed in the design chamber cover is 6236.6psi, with deflection 0.025in.

By considering the SN curve for the Aluminum 6061 - T6 material. The material can with stand infinite times under the stress of 6236.6psi.

The highest value of the deflections in the chamber cover is 0.63in, which is very small, so that deflection is allowable.

So the vacuum cover designed is safer for the buckling failure under cyclic loading conditions.

The yield strength of the aluminum material is much greater than the Von Mises stresses calculated by structural finite elemental analysis, so it is safe for this applications.

So Lifting Index for the chamber cover is 0.87 so it is safer to lift by one person with two hands. This design of the cover is ergonomically accepted for the employees working on the floor.

The presented analysis of the vacuum chamber cover made of Aluminum 6061-T6 which meets the structural and ergonomic design requirements under high vacuum and cyclic loading condition

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