DESIGN, MODELING AND ANALYSIS OF A VACUUM CHAMBER FOR HIGH SPEED TURBINE

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Abstract - *High-speed balancing of bladed rotors is usually performed in a vacuum chamber to avoid high turbulence power loss. Vacuum chamber with integrated burst protection, makes it possible to high-speed balance and spin-test small to medium sized turbo-rotors right on the shop floor. The innovative system design provides a variety of unique features to absorb the energy released when a rotor burst occurs. Safety "crush zones" are engaged and easily restored in the event of a significant burst. In this projects a vacuum chamber used for high speed turbine will be designed and modeled in 3D modeling will be done in Pro/Engineer. The vacuum chamber designed will be easy setup for rotors up to 17,500 lbs., up to 67 inches in diameter, at speeds of up to 60,000 RPM. In this project structural, modal analysis and fatigue analysis will be done in Ansys. The present used material for vacuum chamber is steel. In this project it is replaced with aluminum alloy, brass and acrylic.*

Key Words: Vacuum chamber, High-speed balancing, modeling, designed.

1. INTRODUCTION

A vacuum chamber is a rigid enclosure from which air and other gases are removed by a vacuum pump. This result in a low pressure environment within the chamber commonly referred to as a vacuum. A vacuum environment allows researchers to conduct physical experiments or to test mechanical devices which must operate in outer space (for example) or for processes such as vacuum drying or vacuum coating. Chambers are typically made of metals which may or may not shield applied external magnetic fields depending on wall thickness, frequency, resistivity, and permeability of the material used. Only some materials are suitable for vacuum use.

Chambers often have multiple ports, covered with vacuum flanges, to allow instruments or windows to be installed in the walls of the chamber. In low to medium-vacuum applications, these are sealed with elastomero-rings. In higher vacuum applications, the flanges have hardened steel knives welded onto them, which cut into a copper gasket when the flange is bolted on. A type of vacuum chamber frequently used in the field of spacecraft engineering is a thermal vacuum chamber, which provides a thermal environment representing what a spacecraft would experience in space.

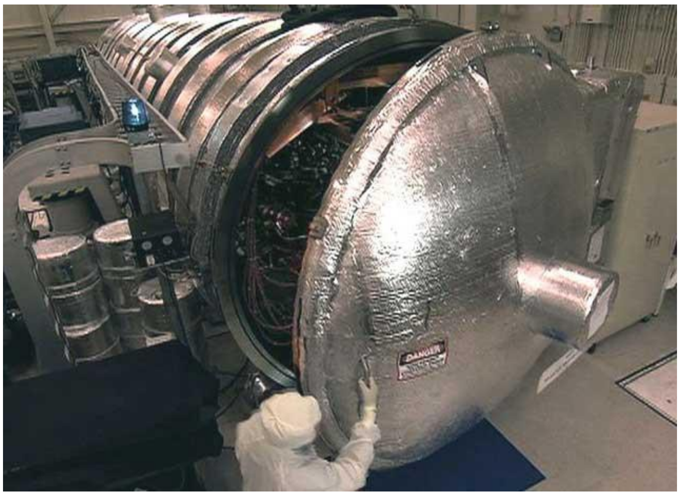

Fig no: 1 Vacuum Chamber

1.1 Design Rules for Vacuum Chambers

The first step in the mechanical design of a vacuum chamber is to clearly define what all the boundary conditions are and often this is not the easiest part of the job since most of the parameters are settled by the other systems making up the equipment, in the large sense, to be built. The vacuum chamber arrives late and should simply fit in what is left. The material is a subject of long debate, still alive, even for 'usual' types of equipment. The initial phase, the conceptual design, which usually does not need accurate studies, is followed by the detailed design, the latter strongly associated with the manufacturing, itself controlled by a quality assurance plan. This paper on mechanical design is intended to go through all the steps mentioned above. It is difficult to be exhaustive and we shall not be, since what we deal with will be related not only to accelerator equipment on the beam lines but also to other vacuum vessels for services such as cryogenics. However, the vacuum vessels we consider are static, the ones which move being subject to specific rules not presented here. Methodology, methods, and hints will be given, but consultation of some of the references is a must if you have to design such a system yourself. References on general mechanical design are not quoted here since there are many. It is also important to remember that a classical rule, valid for any type of equipment, is that more than 70% of the final cost is already defined at the end of the design phase. Investing more during the initial phase is always rewarding.

2. VACUUM CHAMBER FOR TESTING OF TURBINE BLADES

Ever increasing demands of high performance together with reliability of operation, long life and lightweight necessitate consistent development of almost every part of steam turbine blades from a vital part of a turbo machine. Apart from their shape and geometry, on which the performance characteristics of the machine largely depend, their dynamic strength is of considerable importance as far as the reliability operation and life of the engine are concerned. High cycle fatigue plays a significant role in many turbine blade failures. During operation, periodic fluctuations in the steam force occur at frequencies corresponding to the operating speed and harmonics and cause the bladed disk to vibrate. The amplitude of these vibrations depends in part of the natural frequencies of the bladed disk to the forcing frequency. Large amplitude vibration can occur when the forcing frequency approaches or becomes resonant with the natural frequency of the blades. Dynamic stresses associated with near resonant or resonant vibration produce high cycle fatigue damage and can initiate and propagate cracks very quickly. Steam turbine manufacturers typically design and manufacture blades with adequate margins between the forcing frequencies and the fundamental natural frequencies to avoid resonance.

The basic design consideration is to avoid or to minimize the dynamic stresses produced by the fluctuating forces. Since these forces are periodic we have to consider several numbers of these harmonics coincides with any of the natural frequencies of the blades. The turbo machinery components, specifically airfoils, are subjected to high variable loads that can cause failure, designing reliable components require in depth vibration and stress analysis. These machines are proving to be the backbones in important sectors such as power, industry (fertilizer, petrochemicals, cements, steels etc.) and defense sector (Naval applications). Further in the present environment of resource crunch and power shortages, where availability/reliability of the equipment is a matter of topmost priority, one can't afford breakdown in these machines. The breakdown and failures in turbo machinery in addition to their impact on factors mentioned above have far reaching influence such as consequential damages, hazard to public life and most importantly the cost of repairs.

2.1 Vacuum Chamber Materials

Vacuum chambers can be constructed of many materials. "Metals are arguably the most prevalent vacuum chamber materials. The strength, pressure, and permeability are considerations for selecting chamber material. Common materials are Stainless Steel, Aluminum, Mild Steel, Brass, High density ceramic, Glass, Acrylic.

2.1.1 3D Model

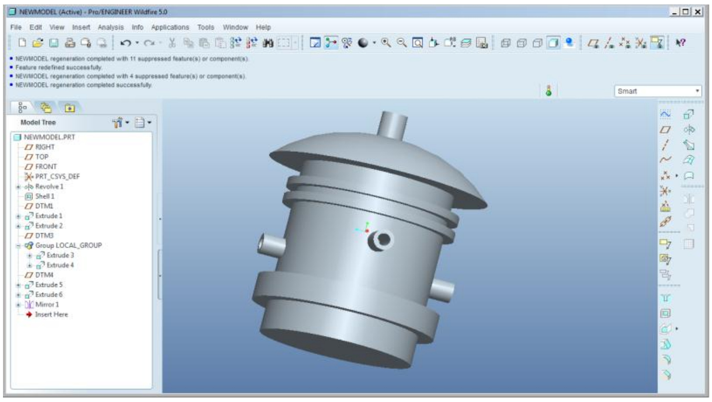

Fig no: 2 Final 3D Model Screenshot for Vacuum Chamber

2.1.2 2 Drawing

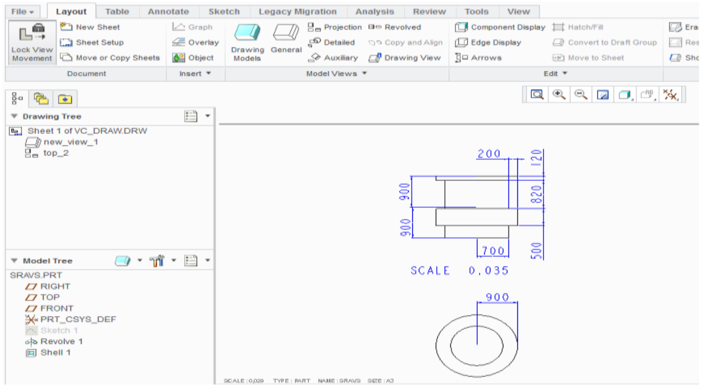

Fig no: 3 2D Drawing Screenshot for Vacuum Chamber

2.2 Boundary Conditions of Vacuum Chamber

Area of vacuum chamber (A)=3.14*(1930)2/4
A = 2924046.5 mm2

Force used in vacuum chamber =17500lbs

lbs converted to Newton's

17500 lbs = 77843.87 N

Pressure = Force / Area

Pressure (p) = 77843.87 / 2924046.5

P = 0.026621 N/mm2

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2.3 Structural Analysis of Vacuum Chamber

2.3.1 Material-Stainless Steel

Start→ Programs → ANSYS 10.0→ ANSYS

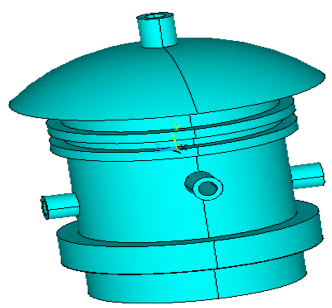
File→ Change directory → select required folder → Ok

File→ Clear and start new→ Ok

/UNITS, SI, MM, KG, SEC, K

File→ import→IGES→ Browse → select .igs files →Ok

2.3.2 Import IGES Model



Preprocessor → element type → add/edit/delete → add →solid, 20Node 186 → Ok → close

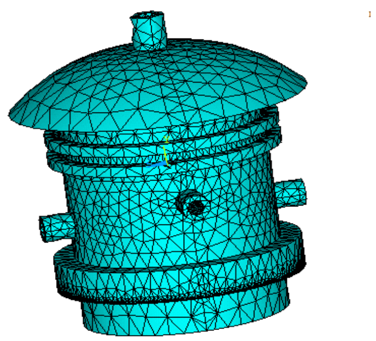
For Stainless Steel Material

Young's Modulus (EX) : 317000Mpa

Poisson Ratio (PRXY) : 0.346

Density : 0.00000901 kg/mm^3

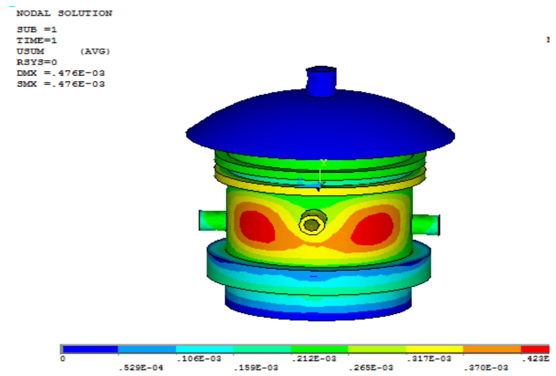
2.3.3 Meshed Model



Loads → define loads → apply → structural → displacement → on areas → select area → ok → select all DOF → ok

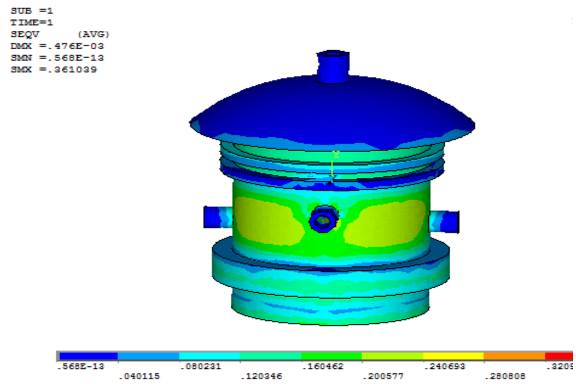
Loads → define loads → apply → structural → pressure → on areas → select area → ok → enter pressure value 0.00000134N/mm^2→ ok

2.3.4 Displacement Vector Sum



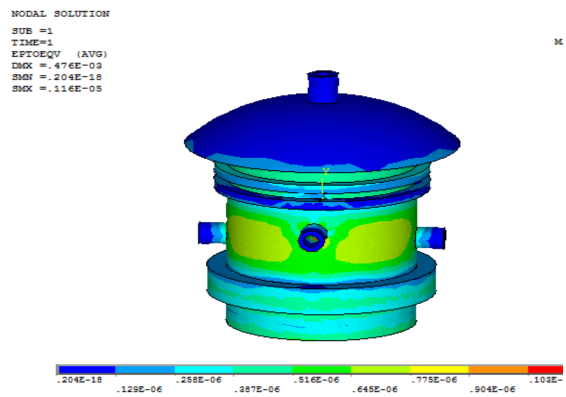
General post processor → plot results →counter plot →nodal solution → DOF solution → displacement vector sum → ok

2.3.5 Stress



General post processor → plot results →counter plot →nodal solution → stress → von mises stress

2.3.6 Strain



General post processor → plot results →counter plot →nodal solution → elastic strain → von mises strain

2.4 Thermal Analysis of a Vacuum Chamber

2.4.1 Material-Stainles Steel

Element Type: solid 20 node 90

Material Properties:

Thermal Conductivity – 34.3W/mK

Specific Heat – 0.620 J/kg K

Density - 0.00000901 kg/mm^3

Apply Loads

Loads – Define Loads – Apply – Thermal – Temperature

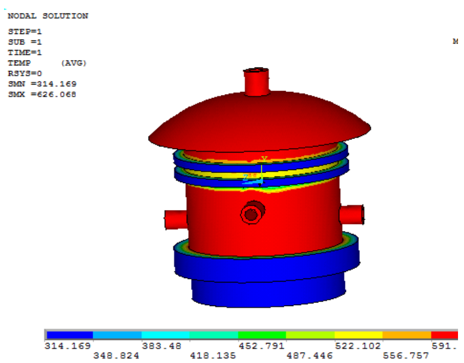
Temperature – 626K

Convection – On Areas

Bulk Temperature – 313K

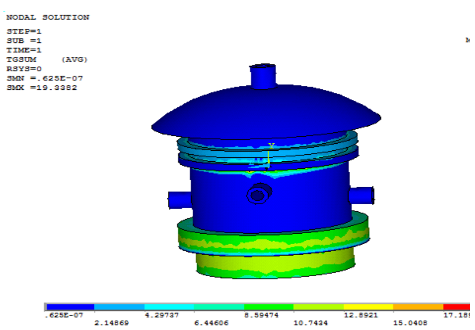
Film Coefficient – 25W/m^{2}K

2.4.2 Nodal Temperature Vector Sum



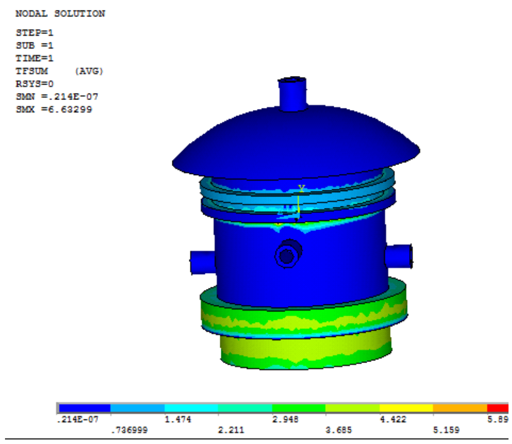
General Post Processor – Plot Results – Contour Plot - Nodal Solution – DOF Solution – Nodal Temperature Vector sum

2.4.3 Thermal Gradient Vector Sum



General Post Processor – Plot Results – Contour Plot - Nodal Solution – Thermal Gradient Vector sum

2.4.4 Thermal Flux Vector Sum



General Post Processor – Plot Results – Contour Plot - Nodal Solution – Thermal flux vector sum

3. RESULT TABLES

3.1 Structural Analysis

Material	Displacement (mm)	Stress (N/mm^2)	Strain
Stainless Steel	0.476E-3	0.361039	0.116E-03
Aluminum	0.00222	0.359678	0.540E-05
Brass	0.00129	0.358101	0.313E-05
Acrylic	0.045665	0.351496	0.110E-03

3.2 Thermal Analysis

Material	Nodel Temparature (K)	Thermal Gradient (k/mm)	Thermal Flux (W/mm^2)
Stainless Steel	626.068	19.3382	6.63299
Aluminum	626.073	20.6911	4.34513
Brass	626.072	20.4374	4.76191
Acrylic	626.082	23.2079	0.440949

4. CONCLUSIONS

In this project a vacuum chamber used for high speed turbine will be designed and modeled in 3D modeling will be done in Pro/Engineer. The vacuum chamber designed will be easy setup for rotors up to 17,500 lbs., up to 67 inches in diameter, at speeds of up to 60,000 RPM. In this project structural, and thermal analysis is done in Ansys. The present used material for vacuum chamber is steel. In this project it is replaced with aluminum alloy, brass and acrylic. By observing the structural analysis results, the stress values are less than the allowable stress values for all the four materials. Using Aluminum or acrylic will be advantageous since their densities less than steel and brass.

By observing thermal analysis results, using aluminum is better since the heat transfer rate is better. So it can be concluded that using aluminum is better than all other three materials.

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