Simulation Based Design Analysis of Pressure Chamber for Metrological Application up to 200 MPa

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Abstract

In the high pressure applications, safety and handling of the design parts are crucial and essentially required. If the design parameters are not properly optimized, sometimes it leads to fatal accidents or huge money loss. With the advent of modern computational tools, the simulation based design analysis is now a day's address above issues amicably to ultimately helping to improve development process and final product. The paper describes the step by step design process and simulation analysis of the pressure chamber. The theoretical FEA studies carried out on the designed pressure cell show that the chamber is working smoothly within the desired pressure range from atmospherics pressure to 200 MPa based on safety factor of the material used. Such devices are mostly imported and not available indigenously. Thus, the fabrication of simulated device is one step forward to develop an import substitute item and promote 'Make in India' product. Simulated results are found to quite encouraging. The actual experiments on the fabricated pressure cell would be performed in due course of time.

Keywords: *Design; Finite element analysis; Pressure Chamber; Pressure metrology*

1. Introduction

Pressure is one of the most important variables to be measured in scientific and industrial application. It is generally the result of molecules, within a gas or liquid, interacting each other and on their surroundings usually the walls of the containing vessel. Its magnitude depends on the force of impacts over a defined area. It is a quantity which cannot be measured directly but is derived from base unit through definitions (i.e. force acting upon an area or the displacement of a liquid column of known density under a known local acceleration of gravity).

Scientific community has continuously been making focused efforts to measure pressure in a simple, cost-effective and precise way. During the last few decades, the rapid and ever-increasing use of using high-pressure technology in science and engineering has invited the attention of the researchers for better instrumentation and technologies with improved measurement uncertainties over a wide range of applications. This finally results into the development of new and advanced measurement techniques and standards to address the challenge of calibration and traceability for instruments used [1-5].

Various types of sensors have been commonly used as a secondary standard for measurement of pressure with different principles and design. But in case of the high pressure measurements, the leak proof design of transducer plays an important role [6-8]. The simplest design of the sensor is based on diaphragm based closed thick walled chamber. These pressure chamber subjected to internal pressure has several applications such as pressure vessels, Arms barrel, high pressure transducers, pressure cleaner pipes etc. Along with metrological characterizations, the safety also plays a crucial role. Therefore, to prevent any accident or failure of components, it needs thorough design analysis related to material selection, geometry optimization and other stress based simulations [9-15].

In the present paper, a pressure chamber is designed and optimized using modern computational tools such as SolidWorks and Ansys. The maximum bearing capacity of the pressure cell with the variation of different materials has been analyzed. The Von misses yield criterion has been used in the theoretical FEA studies. The paper also discusses the stress, strain and deformation distribution in the cell the cell under the pressure condition.

2. Material selection and CAD modeling

The first stage of the design of pressure chamber is material selection; which is an always a crucial process because of risk overlooking possibilities in the commercially available materials. It becomes even more important in designing of high pressure equipment because of elastic limitation, cost and pressure bearing limit. Out of several commercially available materials, the present study is carried out on Aermet-100 material for chamber design. Selection of this material is based on its yield strength and material cost. The typical yield strength of the different alterative materials is included in table 1 [16-17].

Table1. Yield strength of different type of steel

Material	Yield strength (MPa)
SS304	205
SS316	280
SS410	290
SS440C	1750
AISI17-4PH	1000
Aermet 100	1800
Maragin Steel	2400

The next stage was to design the CAD model of the pressure chamber. Making the design of leak proof system is always a challenge and one of the prime considerations along with tolerance in surface finish, parallelism etc. The connector assembly is used to connect pressure chamber to the high pressurized fluid line by using external pump. After taking care of all the measures of leak proof system, a model of pressure chamber was created with the help of CAD tool (SoildWorks). Pressure chamber includes modeling of two components, first is main body where pressure is applied and another is cap of the pressure chamber. The typical model of the pressure chamber is shown in Figure1.

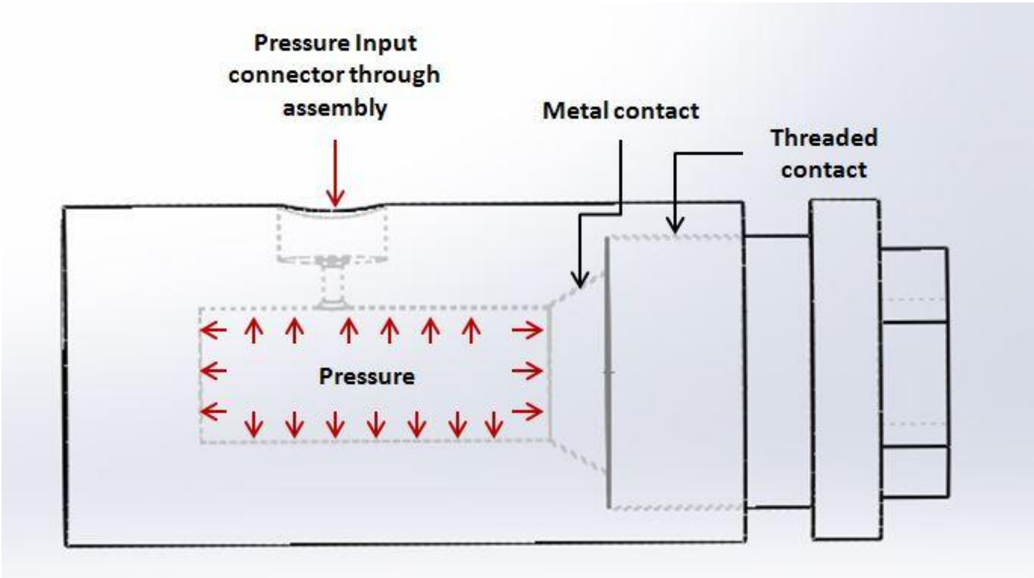

Figure 1. CAD model of pressure chamber

3. Finite Element Analysis

The simulation part has been carried out in Ansys (Version R15) with as a function of applied pressure from atmospheric to 200 MPa. As mentioned earlier, the designing material used for pressure chamber is Aermet-100 steel round bar. Aermet is an alloy of an ultra-high strength steel and its typical mechanical properties are summarized in the table 2. [16].

Table 2. Mechanical properties of Aermet-100

Properties	**Value**
Density	7890 (kg/m^3)
Modulus of Elasticity	195×10^3 MPa
Poisson's Ratio	0.3
Yield Strength	1800 MPa

The dimensional optimization with size different size iterations has been carried out in the design stage of the pressure cell taking into consideration various factors like factor of safety, permissible stress, strain and deformation etc. for the maximum pressure conditions. The element type used is tetrahedron. The total nodes and elements used were 5538 and 2979, respectively. The automated meshing has been performed using Ansys workbench (Figure 2).

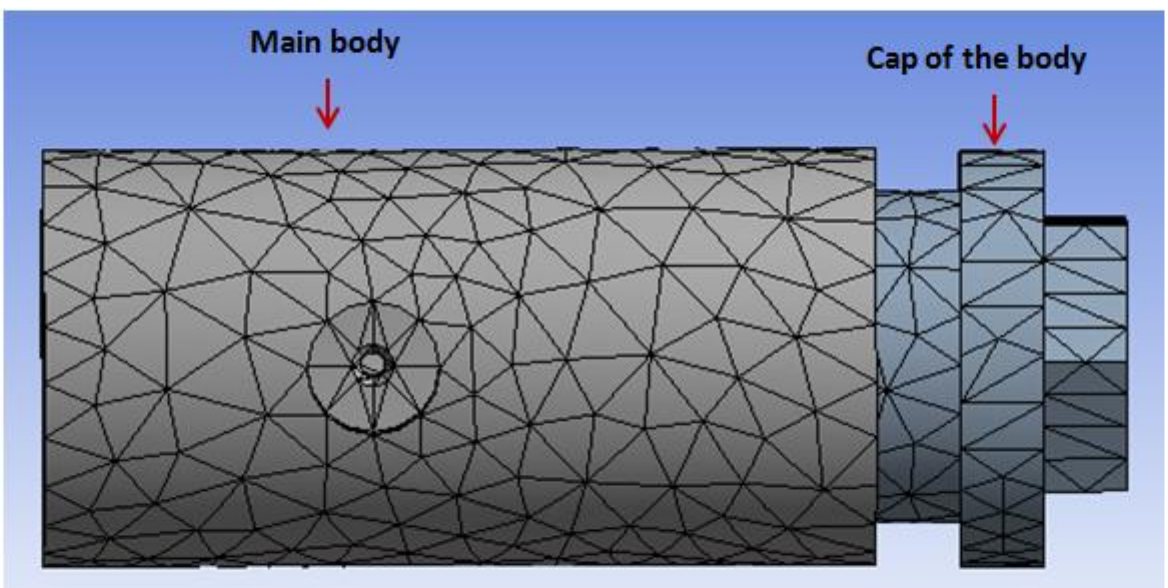

Figure 2. Meshing of pressure chamber

After meshing of the pressure chamber, suitable boundary conditions were applied to the geometry in design modeler (Figure 3). The finite element analysis is assumed to be linear with isotropic material properties. The results thus obtained on maximum Von-mises stress, maximum Von-mises strain and deformation in the pressure cell at a maximum pressure of 200 MPa are found within the permissible limits and are shown in figure 4. There are some small points or regions where maximum stresses (red zone area) are observed in the simulation results. These small regions may be due to the abrupt change of the geometrical dimensions. The design will adjust itself during the testing phase due to the phenomena called autofrettage. In autofrettage of the material, the yield strength of the material gets increased because of dislocation movements within the crystal structure of the material (our refs).

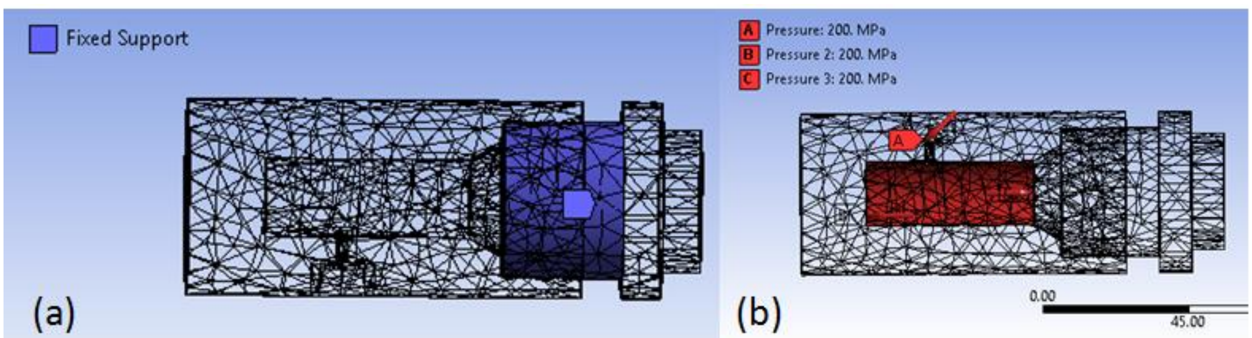

Figure 3. Boundary conditions, (a) fixed support (b) Pressure application

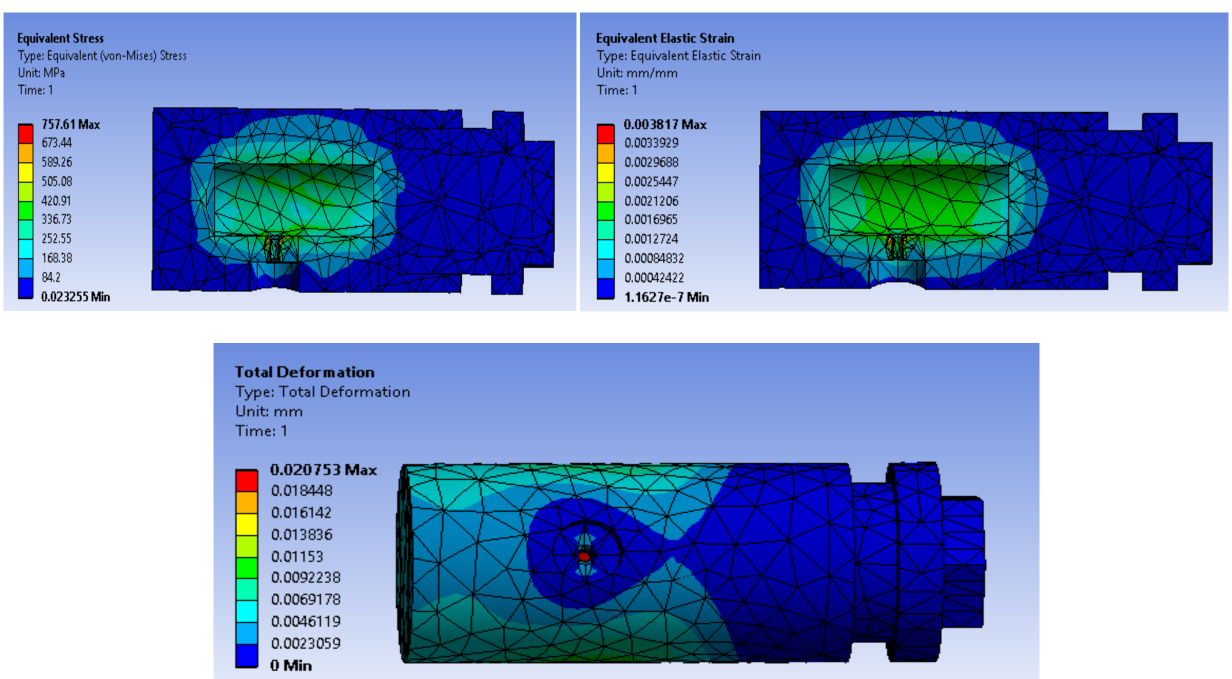

Figure 4. (a) Maximum equivalent stress (b) Maximum equivalent strain and (c) Total deformation in pressure chamber

4. Result and discussion

After appropriate CAD modeling and material consideration, the FEA is used for the simulation analysis. Figure 4 clearly show that the maximum stress value is 757.61 MPa, which is less than the yield strength of Aermet material under the maximum pressure (200 MPa). The value of maximum equivalent strain and total deformation is found 0.0038 mm/mm and 0.020 mm respectively. In the computational study, nowhere any alarming regions of stress and strain are noticed. Although, it will be experimentally tested for actual leak proof design and to check any over burst pressure mechanisms due to material nonlinearity, practical constrained and various assumption made in the design stages.

The factor of safety is found to be 2.3 (Figure 5) which is quite encouraging. The table 1 depicts the possible alternative combination of material of the design analysis. Out of the different combinations materials (SS440C, Aermet-100, AISI17-4PH and Maragin steel) was found well within the expected yield limits under the maximum pressure conditions. However, Aermet-100, were used in the final form due to the availability and less cost as compare to Maragin steel.

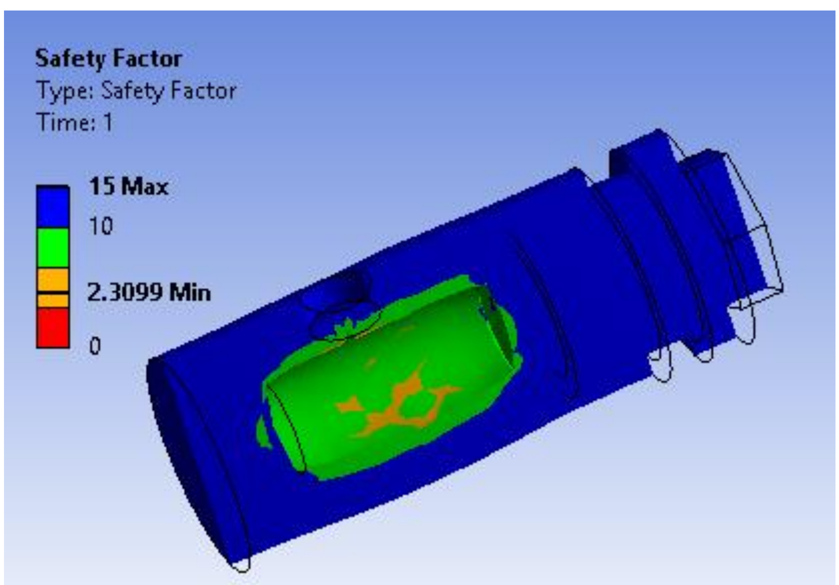

Figure 5. Design of pressure chamber with Factor of safety

In the high pressure equipment design, one technique names Autofrettage is generally used to increase the pressure bearing capacity of pressure chamber without any change in dimension or material. In this process, the pressure chamber loaded autofrettage pressure so that the part of the inside chamber becomes plastic. When the applied internal pressure is released, the plastic deformation in the wall remains, while the elastic external region springs back and the yielded region is set into a so called residual stress condition. The elastic forces act as an external pressure on the plastically deformed region; the developing residual stresses are compressive in nature and used as a prevention measure in the design of high pressure instruments.

5. Conclusion

The pressure chamber is made with Aermet-100 material. The modeling and design analysis has been carried out by modern CAD and simulation tools. The leak proof design is found to work perfectly within the desired pressure range from atmospherics pressure to 200 MPa with 2.3 factor of safety. The simulation results obtained on maximum stress, strain and deformation in the chamber are found within the permissible limits in pressure range of (0-200) MPa. The pressure chambers thus designed can be used as pressure transducers for various sensing domain such as piezo-resistive, capacitive, ultrasonic etc.

Presently, several industries and accredited laboratories are importing the high pressure measuring equipments at high cost. Even though international suppliers and companies are identified but they work within import restrictions, therefore the import of items becomes time consuming and complex. Such problems would be solved and the Indian manufacturers can use these pressure chambers as import substitute for producing indigenous high pressure measuring instruments which ultimately results into reduced imports and even for export i.e. enhancing Indian trade fulfilling the goals of AtmaNirbhar Bharat (self- reliant India) initiated by Government of India.

Future work

The design analysis is carried out only for hydraulic pressure range from atmosphere to 200 MPa. The range of the pressure can be further extended by using some other high strength materials or design modification. At present, material selection, modeling and design analysis part is carried out and its fabrication, testing and calibration would be carried out in near future.

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