OXYGEN PRESSURE REGULATOR DESIGN AND ANALYSIS THROUGH FINITE ELEMENT MODELING

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Abstract: *Oxygen production centers produce oxygen in high pressure that needs to be defused. A regulator is designed and analyzed in the current paper for medical use in oxygen production centers. This study aims to design a new oxygen pressure regulator and perform an analysis using Finite Element Modeling in order to evaluate its working principle. In the design procedure,the main elements and the operating principles of a pressure regulator are taking into account. The regulator is designed and simulations take place in order to assessthe proposed design. Stress analysis results are presented for the main body of the regulator, as well as, flow analysis to determine some important flow characteristics in the inlet and outlet of the regulator.*

Keywords: Pressure Regulator, Finite Element Optimization, Stress Analysis, Flow Simulation

1. INTRODUCTION

Originally, a pressure regulator is principally a device that is used to reduce higher pressures of gasses or liquids to a more usable lower pressure. Its main function is to reduce a pressure and to keep this pressure as constant as possible while the inlet flow may differ. A regulator's exactitude and prowess in performing its function is determined by the combination of the four basic regulator components, designed into a specific regulator unit (Loading Mechanism, Sensing Element, Control Element, and Relief Valve). These components have to be designed according to mathematical guidelines, so that they work together harmoniously to give the desired results. Calculations are not only necessary for the good order of the regulator but also for the endurance in high pressures and the flow characteristics of the mean.

There is no much information published on pressure regulators due to the disquiet for leakage of proprietary knowledge. N.Zafera and G. R. Luecke(1)studied the stability of gas pressure regulators. Their research investigated the consolidation of a concrete implementation of pressure reducer system. Areas such as palpitation in regulatorsand possible design amendments are presented that expunge the not steady throb modes. T.i Kato *et.al*, (2)also investigated pressure regulators with high accuracy having quick response in pressure fluctuations. An effective adjustment of pneumatic palpitation isolation tables was presented. A regulator assembly was designed by the authors and the greatest characteristic of their design was the almost zero changes of pressure in the chamber that was detected by the transducer which changes the position of the servo valve, to preserve the initial pressure.

In another study Kakulka*et. al.*(3)studied a pressure regulator having a piston as a sensing mechanism. The sensingmechanism consisted of a conical poppet piston-valve that adjusted the flow of themean. The study dealt with the energetic results of limitative orifices and the upstream-downstream areas of the regulator.

However, the friction and pendulousnesseffects inside the areas of the body of the regulator, were not taken into accountin their research.B.G. Liptak(4)also reports on the changes in the exit pressure by creating fluctuates in the supplied flow. The author reports that any decrease in the fluctuations of the pressure abridges theconsistency of the output of the regulator. This had as result the regulator to make alot of noise when it worked with oscillatory pressure cycling. For stabilization, a larger downstream pipe is recommended. Also, the noise was eliminated by expunging the fluctuations of the flow routes and keeping theflow of the mean at speeds not exceeding supersonic speed.

In this study a new pressure regulator is developed and designed. The static behavior and the flow characteristics were determine through finite elements. More precisely calculations were made for the stress contribution in the main body of the regulator and additionally a flow analysis in order to determine some important flow characteristics in the inlet and outlet of the regulator.

2. PRESENTATION OF THE DEVELOPED CONCEPT

The pressure regulator that was developed was designed to be used in medical gas networks thus the primary flow mean is oxygen. The pressure regulator has been designed according to ISO: 9001 – ISO: 13485 for medical gas systems components. The developed model had to meet with some basic important requirements. The flow mean is oxygen in pressure of 200 bar, the outlet pressure has to be 10bar and the maximum flow at 200bar is $100m^3/h$.

Figure 1 presents the pressure regulator made of brass that was developed with explanation of the important features. The Loading Mechanism denoted with (1) is a spring-load mechanism. The spring is controlled by a plastic spigot on the top of the dome of the regulator. In the dome designed a small hole for extra safety, in case that high pressure goes accidentally to low pressure chamber and brakes the diaphragm. The sensing element denoted with (2) is a diaphragm from elastomer material (Ethylene Propylene) for sensitivity to pressure changes, simplicity and low cost. The control element denoted with (3) is an overpressure protection system developed to avoid the possibility of overpressure of the inlet pressure chamber. For this reason, a tiny hole was designed in the bottom of the pressure regulator. The working principle is based on the fact that for a certain amount of pressure the control element will cause the poppet to fracture the orifice. By this movement of the poppet the down exit is released and the compressed gas is getting out to avoid failure of the regulator. The safety valve denoted as (4) in Figure 1 was designed to protects the regulator from possible failure. In the case the high-pressure passes from the high pressure chamber to the low pressure chamber the spring of the valve is compressed in order to relief the extra pressure. Also certain slots for manometers and transducers were designed and denoted as (5) in Figure 1.

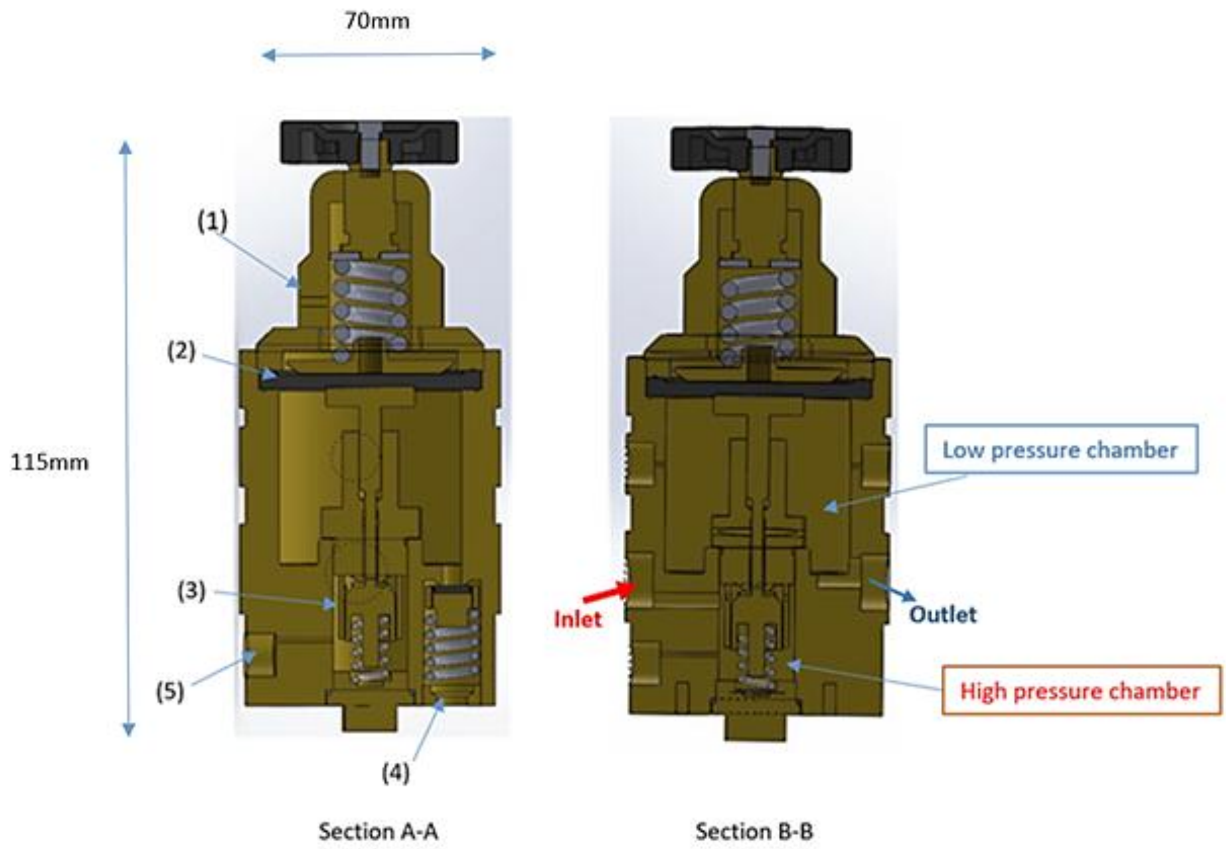

Fig. 1 *Intersections showing internaly the design of the pressure reducer*

3. DESIGN SIMULATION

3.1 Stress analysis

The stress analysis was performedusing finite element modeling. For the static analysis the internal chamber of the body of the regulator is set on high pressure. The purpose of the analysis was to show if the regulator can withstand ahigh gas pressure. The maximum pressure that is supposed to be applied in the regulator is 200 bar. For safety reasons the regulator was simulated under a pressure of 300 bar.The material that have been used for the analysis was brass having tensile strength of 0.478 N/m^2, yield strength 0.239N/m^2, elastic modulus 10^{10}N/m^2, shear modulus $34\cdot10^9$N/m^2 and Poisson's ratio 0.33.

The boundary conditions that have been used for the analysis are shown in Figure 2. For the analysis 21747 nodes and 13047 elements have been used. The results have shown that the maximum stress that is applied inside the regulator is 1.07N/m^2 which much lower than the yield strength of the material and the maximum displacement 0.012 mm. Figure 3 shown the stress and strain contours of the analysis. It should be noted that the applied pressure in the study was already higher than the pressure, thereby the results are somewhat conservative.

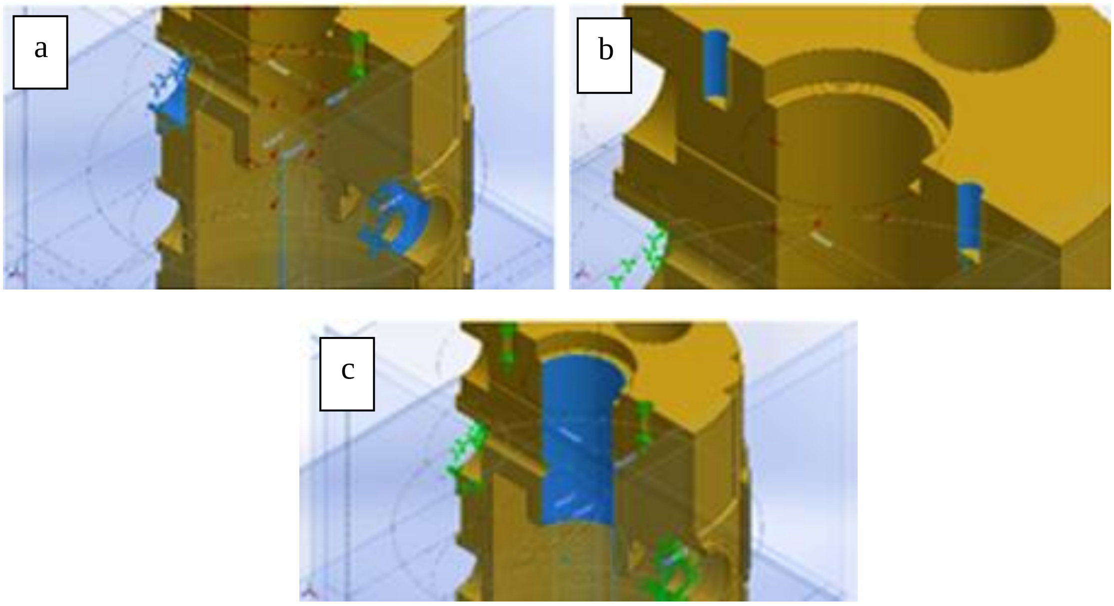

Fig. 2 *Boundary conditions used for the stress analysis of the pressure reducer with a)Fixes Inlet and outlet connectionsb) Botom is fixed with screws c) Chamber under high pressure (300 bar)*

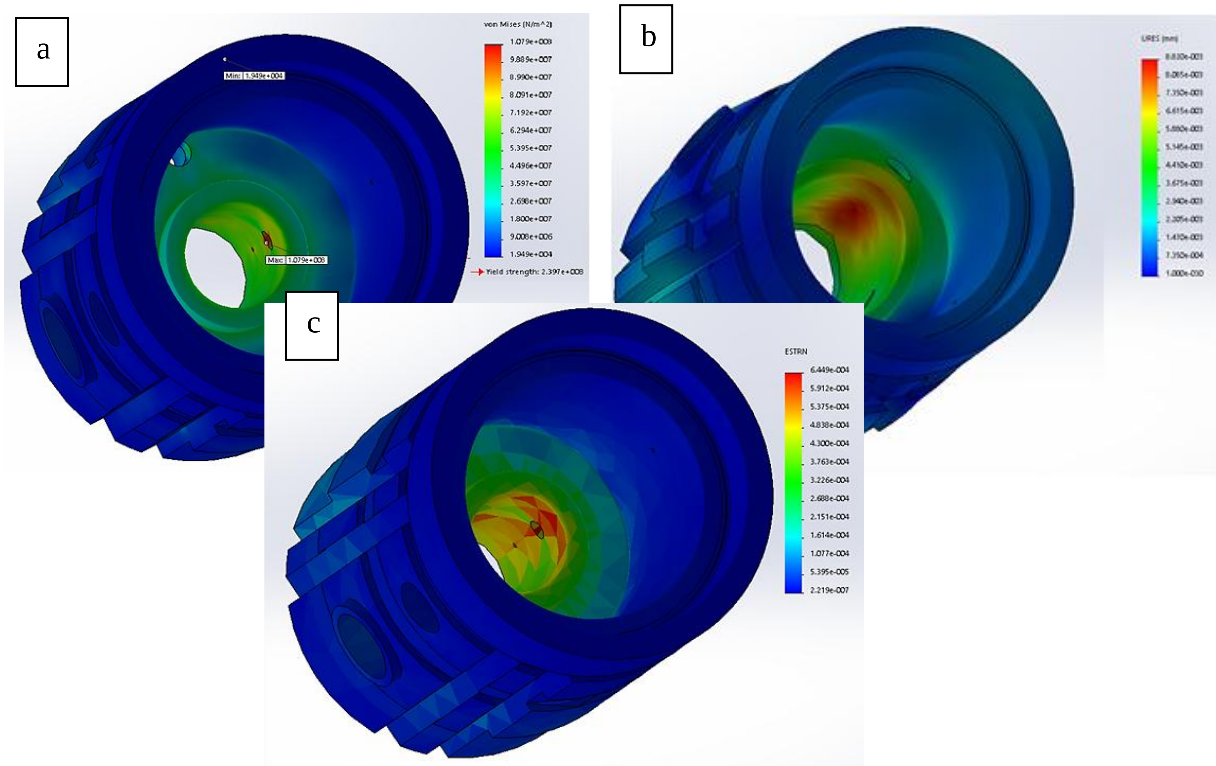

Fig. 3 *Stress contours of the pressure regulator showing:a) stress distribution, b) displacement distribution, c) strain distribution*

3.2 Flow Simulation

In this section the flow simulations are presented.For the flow simulation study, the pressure regulator simulated with the valve fullyopened in order to see the maximum outlet flow rate through the designed orifices. The properties measured, as depicted in Table I, were the average flowrate in the outlet, the average outlet total pressure and the average temperature in thedecompressionchamber.

Table I. *The properties measured in the flow simulation analysis.*

	Unit	Value	AvValue	MinValue	MaxValue
VolumeFlowRate	[m^3/s]	0,02	0,02	0,02	0,02
AvTotalPressure	[Pa]	1042610,71	1067482,10	958725,13	1155812,86
AvTemperature (Fluid)	[K]	239,15	236,77	231,99	240,43

The results show that the values obtained from the analysis were within the limits of the regulations. The flow trajectories are depicted in Figure 4(a). The pressure remains high in the high-pressure chamber and then passes through the control element that decreases the pressure with an adiabatic process. Then the oxygen expands in the low-pressure chamber that remains low until the gas exits the regulator. Figure 4(b) shows the temperature distribution inside the pressure regulator.

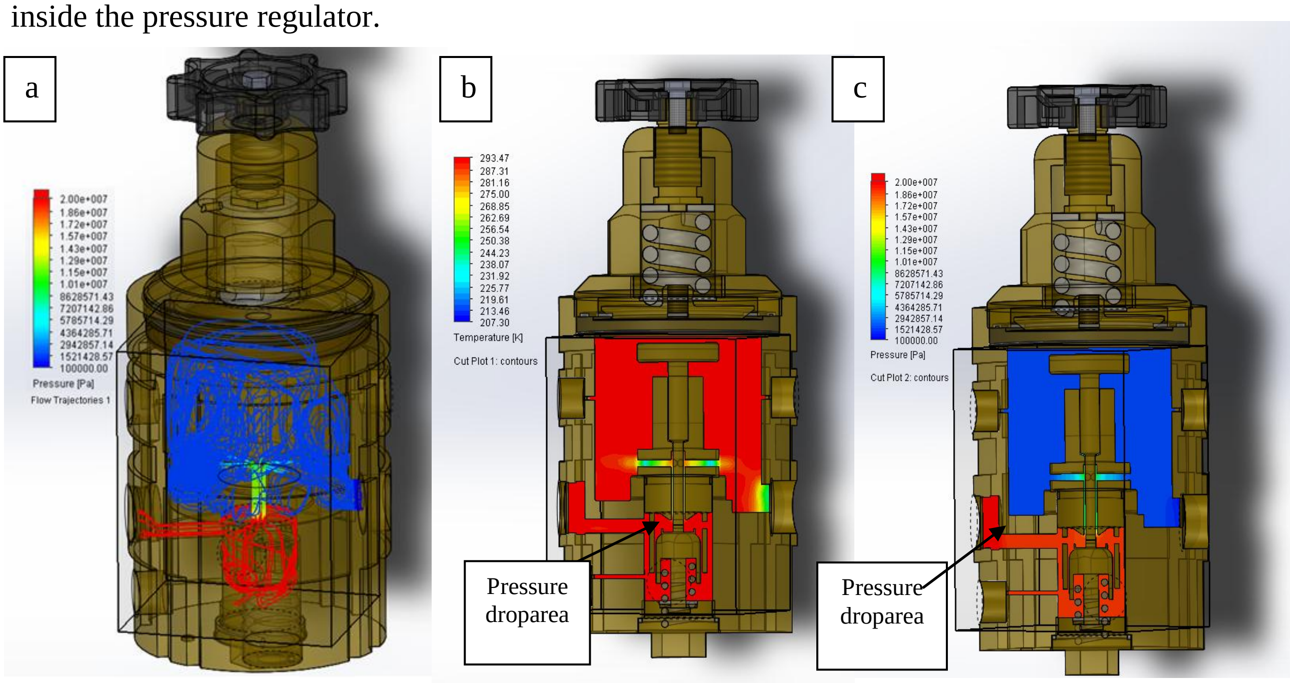

Fig. 4 *Stress contours of the pressure regulator showing: a)Flow trajectories b) Temperature distribution, c) Pressure distribution*

The temperature is about 293K when the oxygen inserts the regulator. Later the temperature decrease rapidly because of adiabatic expansion of the oxygen and then approaches again the room temperature. The lowest temperature is in the area that the pressure drop take place and it is about 217 K. Figure 4(c) presents the pressure distribution inside the regulator. The oxygen enters the pressure regulator in high pressure 200 bar. Pressure drop is occurred in the pressure reduction area. The oxygen exits the regulator having a 10 bar pressure.

4. CONCLUSIONS

The stress analysis have shown that the maximum stress that is applied in the chamber was $1.07 N/m^2$when the maximum yield strength of the material is almost 2 times higher. The displacement was also very small. Inflow simulation analysis of the pressure regulator have shown that the proposed design seems capable to feed the system after the regulator with about $100 m^3/h$ volumetric flow with the shutter fully opened, which is a very satisfying flow rate for medical uses. The lowest temperature is about 217 K which is a normal value because of the adiabatic expansion that take place inside the pressure drop area.

Furthermore, the flow diagrams show how the oxygen is diffused inside the regulator and this gives to the reader a more realistic and comprehensible view of how a pressure regulator works.The flow simulation analysis show a complicated flow distribution of the flow inside the pressure regulator. This distribution changes by alterationsof the shape of the internal orifices. Future work will investigate how the shape changes affect the important characteristics of the regulator such as the stability of the regulator in pressure changes and the external flowrate.

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