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Flow Analysis of Gas Pressure Regulator by Numerical & Experimental Method

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Abstract - *Gas pressure regulators have become very familiar items over the years, and nearly everyone has grown accustomed to seeing them in factories, public buildings, by the roadside, and even in their own homes. Gas pressure regulators are widely used in both commercial and residential applications to control the operational pressure and flow of the gas. Gas regulators are devices that maintain constant output pressure regardless of the variations in the input pressure or the output flow. High pressure gas flows through an orifice in the valve and the pressure energy in the gas is converted to heat and flow at the lower, regulated, pressure. The orifice faces a movable disk that regulates the amount of gas flow. The regulator has a pressure sensing unit that has a conical poppet valve that regulates the gas flow. To analyze the regulator flow rate performance, the equation of motion for inner parts, the continuity equation for diverse chambers and the equation for mass flow rate were derived. Because of nonlinearity and coupling, these equations are solved using numerical methods. Natural gas pressure regulators are vital important in the role of transportation of natural gas to the consumer. To distribute natural gas to the flats, its pressure is reduced to 21 to 300 mbar by service pressure regulators, and it is brought into use of consumers. There are two types of service regulators one is Single stage and another is two stage. Operational function of both is same. The difference in two stage is that the pressure reduction takes place is in two stage and in single stage pressure reduction takes place in single stage. Advantage of two stage is getting more stable and sensitive outlet pressure and flow rate of gas. Here we are going to validate the expected result of flow rate of two stage regulator which is used in application of CNG gas pipe line by means of numerically and* experimentally.

Key Words: **Gas pressure regulator, Gas flow, CNG gas pipe line, Orifice, Poppet valve.**

1.INTRODUCTION

Gas Pressure Regulators are devices that maintain constant output pressure regardless of the variations in the input pressure or the output flow. They range from simple, single stage to more complex, multi stage, but the principle of operation is the same in all. High pressure gas flows through an orifice in the valve and the pressure energy in the gas is converted to heat and flow at the lower, regulated, pressure. The orifice faces a movable disk that regulates the amount of gas flow. A flexible diaphragm is attached to the disk by means of a mechanical linkage. The diaphragm covers a chamber such that one side of the diaphragm is exposed to atmospheric pressure and the other is exposed to the regulated pressure. When the regulated pressure is too high, the diaphragm and linkage move the disk to close the orifice. When the regulated pressure is too low, the disk is moved to open the orifice and allow more gas pressure and flow into the regulator. On the opposite side of the diaphragm, an upper chamber houses a wire coil spring and a calibration screw. The screw compresses the spring, which changes the steady state force on the diaphragm, allowing for the adjustment of the regulated pressure set point. If the regulated gas pressure rises above the safe operational pressure, an internal relief valve is opened to vent the excess gas through the upper chamber and into the atmosphere to prevent the danger of high pressure gas at the regulator outlet.

Fundamental design of pressure regulators is very simple. It works with a flexible diaphragm of that outlet pressure is exposed on one side and pressure of loading element is exposed on the other side, and closing element connected to this diaphragm. Pressure regulators are mechanical devices that control the motion of the machines or flow of fluids to meet specific standards.

Service pressure regulators, that provide the pressure range in which end user can use natural gas, have the capability of shut off gas in unexpected conditions without endangering operating medium. Two stage Service pressure regulators reduce 4 to 6 bar upstream pressure to generally 21 mbar downstream pressure. Optimum rate of orifice gaps of each stage in the regulator has been determined and taking account of basic flow characteristic.

2 LITERATURE SURVEY

Jianchun Gong et al. [3] have employed the experiment and numerical simulation method to study the pressure regulating valve of pressure characteristics, the spool opening different inlet temperature under different flow rates, respectively on the pressure within the valve flow field in different degrees by using the ANSYS.

Zhang Kai et al. [4] have developed experimental apparatus for further study of flow characteristics in micro channels. Compressible gas air is used as a work fluid. The experimental study were performed in micro tubes with the diameters 0.2mm, 0.3mm, 0.4mm,0.5mm and 1.0mm, and the roughness less than 3%. The conclusions have important significance for further revealing the characteristics of compressible flow in micro channels.

Longlong Gao et al. [5] have find general implication in the development of the design and analysis of the high pressure pneumatic system. They studied the mass flow rate and heat transfer characteristics are significant factors to the flow behavior of the high pressure air. it is obtained by analytical model and computational fluid dynamics (CFD) method during discharge and charge processes.

Xue-Song Wang et al. [6] shows Experimental results that the proposed self tuning pressure regulator can be adapted to parameters which vary with such factors as the volume of the chamber and the setting pressure and the better dynamic and static performances can be obtained.

Roger D. Shrouf et al. [7] shows by using A Restrictive Flow Orifice (RFO), enhance the safe design of a pressure system in several ways. Pressure systems frequently incorporate a regulator and relief valve to protect the downstream equipment from accidental overpressure caused by regulator failure. Flow through the RFO is equal for either forward or reverse directions; they minimize the potential for leakage by incorporating the highest quality threaded connections; and can enhance the safety of pressure systems.

Hamed Hossein Afshari et al. [8] have studied the dynamics of a direct pressure regulator valve through bond graph simulation technique. The governing equations of the system have been derived from the obtained model. While solving the system equations numerical, various pressure flow characteristics across the regulator ports and the orifices are taken into consideration and finally compare with experimental results.

Uss A.Yu. et al. [9] Follow the analysis and preliminary numerical calculation of the gas flow in the working cavity of the vortex pressure regulator its geometric parameters were defined and three-dimensional model was developed.

Mutlu Tekir et al. [10] defined Pressure regulators are as mechanisms that control or manage the flow of fluids or movements of machines in order to meet a specific standard. Primary function of pressure regulators is to meet the requirements of fluid pressure and flow. To meet this requirement, it makes necessary adjustments while measuring the outlet pressure.

Changjun Li et al. [11] equaling The flow velocity to local sonic velocity is called critical flow state, which means the local sonic velocity is the limited rate of gas reliving. However, the conservation laws mentioned above cannot express this velocity limit without specific constraints. In other words, if the critical state is not constrained by additional equations, the unreal supersonic gas velocity can be observed by using simulation methods for regular gas pipelines.

Edward Lisowski et al. [12] describes the primary function of a flow control valve is to maintain a constant flow rate, regardless of the pressures prevailing at the inlet and outlet of the valve

Dariusz Szpica [13] defines Fuel systems that use LPG as a replacement for conventional fuels are widely applied in traction spark ignition engines, motor vehicles in particular. They are gaining popularity across Europe and worldwide. The main reason for the application of this fuel is its price, which renders all other advantages and disadvantages less important. Currently, the process of downsizing initiated in the beginning of the XXI century and the increasingly stringent exhaust emission limits force the application of the LPG liquid phase injection systems. In modern solutions, original gasoline injectors are used to inject the liquid phase LPG. This type of LPG systems is still rare in the market and the adaptation of the engine requires a system dedicated to individual engine types and models.

Mikhail A. Ermilov et al. [14] studied An important problem connected with operation of gas-distributing stations and knots is increased noise levels and vibrations caused by a high-speed gas flow rate downstream of pressure regulators. Such intensive gas flow occurs due to a high pressure drop over gas pressure regulators. Significant values of sound pressure inside the pipe generate the vibration of the pipe walls. Such high-frequency vibration can lead to gradual destruction and damage of the pipes. This is the result of acoustic fatigue which is highly dangerous in the presence of asymmetric forms of natural oscillations of the pipe and in the case of the pipe branches and junctions in the construction.

Xinying Huang et al. [15] In an industrial production process, compressed air is an important transmission medium. Because air is a clean fluid that is available everywhere, pneumatic systems are widely used. A typical pneumatic system consists of air compressors, air modifying units (coolers, dehumidifiers, filters, etc.), pipeline systems, pressure regulating units, and terminal pneumatic loads

3. METHODOLOGY

3.1 Problem definition:

Natural gas pressure regulators are vital important in the role of transportation of natural gas to the consumer. To distribute natural gas to the flats, its pressure is reduced to 21 to 300 mbar by service pressure regulators, and it is brought into use of consumers. There are two types of service regulators one is Single stage and another is two stage. Operational function of both is same. The difference in two stage is that the pressure reduction takes place is in two stage and in single stage pressure reduction takes place in single stage. Advantage of two stage is getting more stable and sensitive outlet pressure and flow rate of gas.

3.2 Aim:

Here we are going to validate the expected result of flow rate of two stage regulator which is used in application of CNG gas pipe line by means of numerically and experimentally.

4. FUNDAMENTALS OF GAS PRESSURE REGULATOR

A schematic diagram of a typical gas pressure regulator is shown in Fig. 4.1. High pressure gas flows through an inlet orifice that is opened or closed by a disk and linkage attached to a diaphragm. The diaphragm moves in response to the balance between pressure inside the regulator body and the adjustment spring force. As the regulated pressure increases, the disk closes to restrict the incoming gas. When the regulated pressure is too low, the disk opens to allow more gas into the body cavity. The stability of the system depends on the amount of damping in the system, and much of the damping comes from flow restrictions within the regulator. In Gas Regulator model, we define three control volumes that are used in the dynamic analysis, identified in Fig. 4.2 the body chamber, the upper chamber and the lower chamber. Each control volume is characterized by pressure, volume, and the density as a function of time. For the purpose of this analysis, these control volumes are used to track the mass flow through the system.

The primary function of any gas regulator is to match the flow of gas through the regulator to the demand for gas placed upon the system. At the same time, the regulator must maintain the system pressure within certain acceptable limits A typical gas pressure system might be similar to that shown in Fig. 4.3, where the regulator is placed upstream of the valve or other device that is varying its demand for gas from the regulator If the load flow decreases, then the regulator flow must decrease. Otherwise, the regulator would put too much gas into the system and the pressure P2 would tend to increase. On the other hand, if the load flow increases, then the regulator flow must increase also in order to keep P2 from decreasing due to a shortage of gas in the pressure system. From this simple system it is easy to see that the prime job of the regulator is to put exactly as much gas into the piping system as the load device takes out.

4.1 Restricting Element

Since the regulator's job is to modulate the flow of the system, we can see that one of the essential elements of any regulator is a restricting element that will fit into the flow stream and provide a variable restriction that can module the flow of gas through the regulator. Figure 4.3 shows a schematic of a typical regulator restricting element. This restricting element is usually some type of valve arrangement.

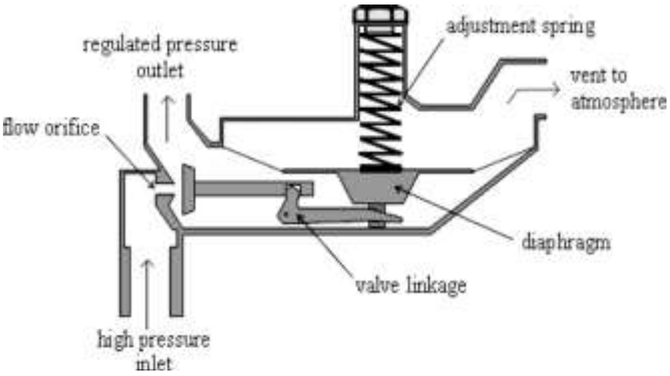

Fig. 4.1 Typical Gas Pressure Regulator

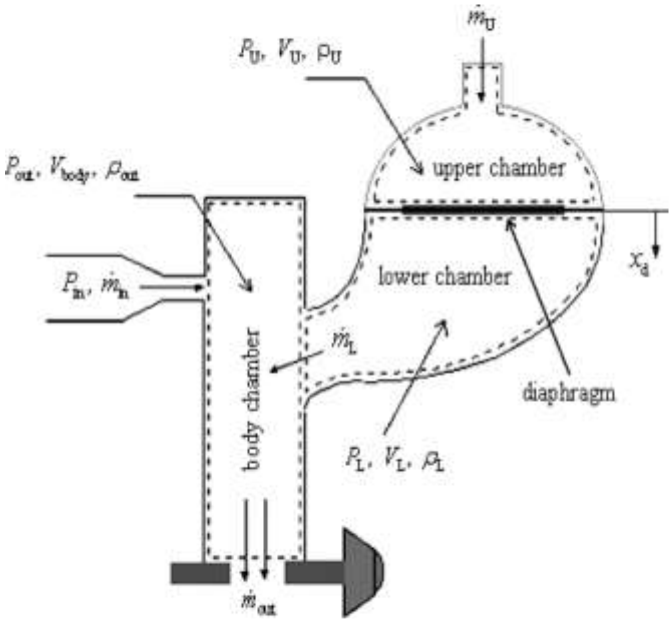

Fig. 4.2 Pressure Regulator Schematic

4.2 Loading Element

In order to cause this restricting element to vary, some type of loading force will have to be applied to it. Thus we see that the second essential element of a gas regulator is a loading element that can apply the needed force to the restricting element. The loading element can be one of any number of things such as a weight, a hand jack, a spring, a diaphragm actuator, or a piston actuator, to name a few of the more common ones. The spring will then overcome the reduced diaphragm force and open the valve to allow more gas into the system.

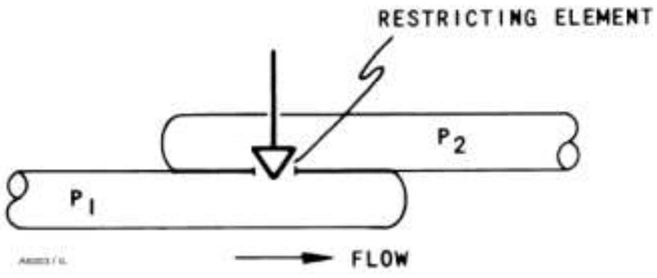

Fig. 4.3 Typical Restricting Element

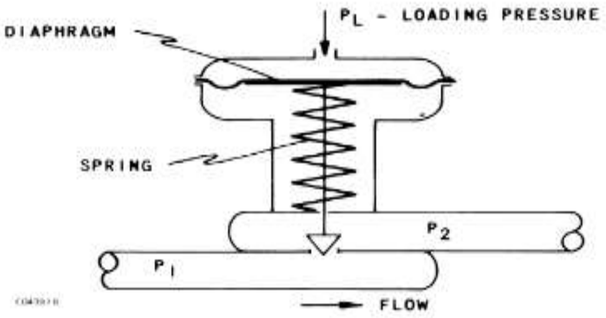

Fig. 4.4 Measuring Element Completes the Regulator

4.3 Measuring Element

A diaphragm actuator and a spring are frequently combined, as shown in Figure 4.4, to form the most common type of loading element. A loading pressure is applied to a diaphragm to produce a loading force that will act to close the restricting element. The spring provides a reverse loading force which acts to overcome the weight of the moving parts and to provide a failsafe operating action that is more positive than a pressure force. So far, we have a restricting element to modulate the flow through the regulator, and we have a loading element that can apply the necessary force to operate the restricting element. But, how do we know when we are modulating the gas flow correctly? How do we know when we have the regulator flow matched to the load flow? It is rather obvious that we need some type of measuring element which will tell us when these two flows have been perfectly matched. If we had some economical method of directly measuring these flows, we could use that approach. however, this is not really a very feasible method. We noticed earlier, in our discussion of Figure 4.3, that the system pressure P2 was directly related to the matching of the two flows. If the restricting element allows too much gas into the system, P2 will increase. If the restricting element allows too little gas into the system, P2 will decrease. We can use this convenient fact to provide a simple means of measuring whether or not the regulator is providing the proper flow. Manometers, Bourdon tubes, bellows, pressure gauges, and diaphragms are some of the possible measuring elements that we might use.

5 FLOW ANALYSIS USING CFD METHOD

In order to carry out the assumed CFD simulations, it was necessary to create discrete models of flow paths and adjust model parameters.

5.1 Geometric and discrete model of flow paths

In the first phase, a set of geometrical models of flow paths was created. The individual models correspond to different fixed positions of the throttle valve spool and the compensation valve spool. Geometrical models of the flow space were made using a parametric 3D model of the valve. The flow space models were created for each fixed position of the valve spools using the Boolean operation in UGNX. The created model of the inlet channel and the throttle valve with triangular gaps is presented in Fig.5.1, while an analogous model of the compensation valve gaps with the outlet channel is shown. Next, geometrical models of both flow paths were combined into a single flow space model. An exemplary cross section through the obtained model with a marked flow direction. The figure shows the axial cross-section through the flow space at the fixed positions of spools. Discrete flow space models were created in the ANSYS Fluent system using such advanced features as local grid refinement in Fig. 5.2.

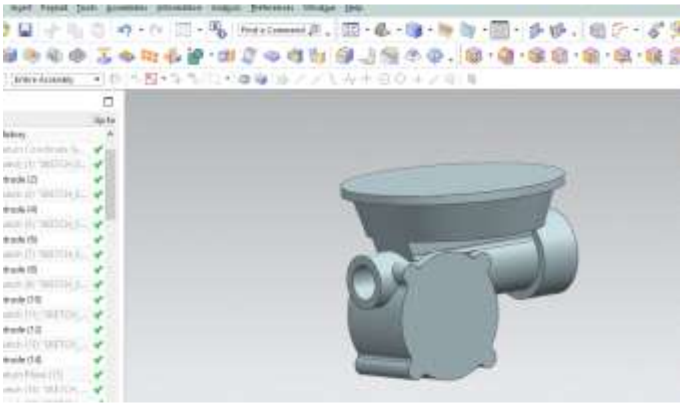

Fig. 5.1 Geometric model.

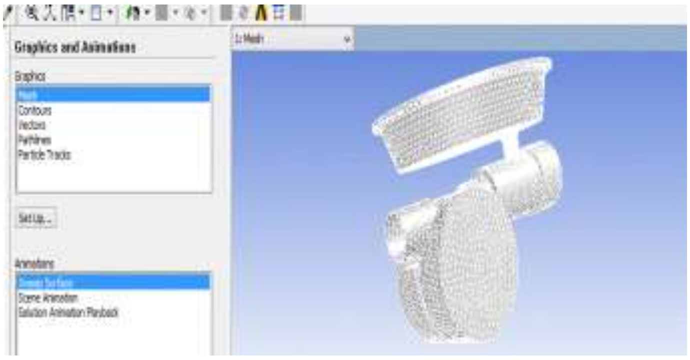

Fig. 5.2 Meshing of Geometric model.

5.2 CFD Model parameters

At first, the type of flow was determined on the basis of the calculated value of the Reynolds number. Considering the valve geometry, the provided flow rate range and working fluid viscosity, the obtained Reynolds number ranges from Re min ¼ 500 to Re max ¼ 4200. This results in transitional, partially turbulent flow. ANSYS Fluent system allows the turbulence to be chosen from the provided models. An analysis of flow through hydraulic control valves has been the subject of many articles. According to the assumed model the inlet velocity magnitude is defined as the boundary condition using the normal to the boundary option, while the outlet pressure is set as the Outlet condition. The turbulence intensity I is set on the basis of the Reynolds number, using an equation of internal flows The created model was meshed using mixed cells. According to the solving method, the Pressure based solver was used with segregated algorithm for pressure velocity coupling and the required criteria were achieved in Fig. 5.3.

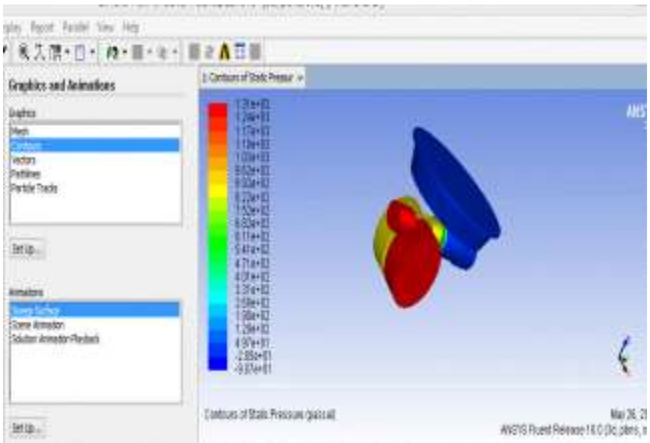

Fig. 5.3 Analysis Result of Geometric model.

6 EXPERIMENTAL METHOD

Experimental trials are performed at industry. The procedure of desired Pressure regulator is as follows:

Initially we required an Air compressor of sufficient capacity to achieve required flow. As we have volumetric ratio of CNG & Air, we perform trials with air as media. After completion of leak proof regulator fitment with desired inlet & outlet connection we can perform for trials. As we have install two pressure gauges of sufficient capacity in line with the regulator, one at inlet connection and another at outlet connection. Installed pressure gauges should be calibrated. Now we can start the air flow through the regulator with inlet pressure as per the capacity of regulator and we get outlet desired air pressure. We can measure the inlet pressure which is 5 bar and outlet pressure which is 250 mbar with the help of installed pressure gauges.

7 RESULTS AND COMMENT

As per our methodology we are going to validate analytical and experimental result of pressure regulator, so results of both the methods is tabulated as below.

Table -1: Result table

	Analytical method result	**Experimental method result**
Outlet pressure	260 mbar	250 mbar

As per our performance requirement of pressure regulator describe in introduction, our results for analytical and experimental method are within a limit.

So comparing the results in analytical and experimental methods we get 4% variation in results.

8 CONCLUSION

Computational fluid dynamics analyses are theoretical studies that are performed to remove uncertainty before tests, and to simulate real conditions in an effort to reduce test numbers. There are situations that these analyses can give faulty results, because these are theoretical studies. Reasons of these faulty results are numerical errors, coding errors, user errors, iterative converging errors, and discretization errors can be given in example to numerical errors. Lastly user errors point out human faults that are resulted by incorrect use of software, incorrect selection of solver methods, turbulence models, and constrain of computational time, incorrect mesh creation cause faulty results. For this reason in this study mesh number that provides good accuracy according to computational time was taken as a base, as a result of mesh study, likewise double precision in solver settings have been selected. However different capacities are achieved by adjusting spring preloading of each orifice. at small gaps of each orifices CFD software had difficulty in guessing the results right, at large gaps accurate results had been reached.

Considering the same we can conclude that under the similar working conditions for numerical analysis and experimental trials we are getting similar performance & results with minor deviation as described in introduction.

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