Development of High Pressure-High Vacuum-High Conductance Piston Valve for Gas-filled Radiation Detectors

D N Prasad1, R Ayyappan, Lata P Kamble, J P Singh, L V Muralikrishna, Mary Alex, V Balagi and P K Mukhopadhyay
Electronics Division, Bhabha Atomic Research Centre, Mumbai, India
dnprasad@barc.gov.in, dnprasadbarc@yahoo.co.in, jpsingh@barc.gov.in, maryalex@barc.gov.in, balagiv@barc.gov.in

Abstract. Gas-filled radiation detectors need gas filling at pressures that range from few cms of mercury to as high as 25kg/cm² at room temperature. Before gas-filling these detectors require evacuation to a vacuum of the order of ~1 x 10⁻⁵ mbar. For these operations of evacuation and gas filling a system consisting of a vacuum pump with a high vacuum gauge, gas cylinder with a pressure gauge and a valve is used. The valve has to meet the three requirements of compatibility with high-pressure and high vacuum and high conductance. A piston valve suitable for the evacuation and gas filling of radiation detectors has been designed and fabricated to meet the above requirements. The stainless steel body (80mmx160mm overall dimensions) valve with a piston arrangement has a ½ inch inlet/outlet opening, neoprene/viton O-ring at piston face & diameter for sealing and a knob for opening and closing the valve. The piston movement mechanism is designed to have minimum wear of sealing O-rings. The valve has been hydrostatic pressure tested up to 75bars and has Helium leak rate of less than 9.6x10⁻⁹ m bar ltr/sec in vacuum mode and 2x10⁻⁷ mbar ltr/sec in pressure mode. As compared to a commercial diaphragm valve, which needed 3 hours to evacuate a 7litre chamber to 2.5x 10⁻⁵ mbar, the new valve achieved vacuum 7.4x10⁻⁶mbar in the same time under the same conditions.

1. Introduction
Gas-filled radiation detectors ¹ (such as ionisation chambers and proportional counters for reactor control instrumentation and area monitoring applications) typically consist of two or more coaxial metallic electrodes mounted on high purity alumina spacers and housed in an enclosure (Fig.1).

¹Corresponding Author
One or more of these electrodes serve as the HT electrode while the remaining is used as signal electrode. The volume between these electrodes forms the “sensitive volume” of the chamber and is filled with a suitable gas at adequate pressure. Radiation falling on this volume generates ion pairs. The drift of these charges in opposite direction under the influence of an applied electric field constitutes the signal output from the chamber. The assembly is welded to a pair of end plates at the ends of the enclosure and the chambers are filled with a gas or a gas mixture. Prior to gas filling at pressures that range from few cm of mercury to as high as 25kg/cm$^2$ at room temperature, these detectors require evacuation to a vacuum of the order of $\sim 1 \times 10^{-5}$ mbar. For these operations of evacuation and gas filling, a system consisting of a vacuum pump with a high vacuum gauge, gas cylinder with a pressure regulator gauge, gas manifold and a high vacuum-high pressure-high conductance valve is used (Fig. 2). Since the volume of the detectors can be as high as a few litres, the valves used in these operations need to have high conductance as well.

Disadvantages of existing valves and need for indigenous development of a special valve:
Conventional valves like bellow sealed valves; diaphragm valves, gate valve and butterfly valves are compatible with high vacuum but cannot withstand high pressures. These valves cannot be used in applications where the pressure exceeds few bars. Certain high-pressure cylinder gas regulators and needle valves for precious rare gases are compatible with both high pressure and high vacuum but have a low conductance. Hence the detectors need to be evacuated for longer periods of time to ensure complete evacuation of occluded gases. Moreover since the three requirements such as high pressure-high vacuum and high conductance are rarely encountered in industry; commercial suppliers do not commonly manufacture such valves. On account of the difficulties encountered in the existing valves, there is a need to develop valves having high vacuum, high pressure and high conductance. Electronics Division, BARC has indigenously developed a piston valve suitable for the evacuation and gas filling of radiation detectors.
1.1 Design of the valve

Figure 3 shows the construction details of the valve. Fig. 4&5 show the photographs of the valve and its components. The valve consists of a stainless steel body with a cylindrical hole for piston. A ½ inch inlet/outlet opening is provided for connecting the valve to the gas-filling system. Neoprene/viton O-rings are used at the piston face & diameter for sealing. A circular knob is provided for opening and closing the valve. The valve has an overall diameter of 80mm and an overall length of 160mm. One important feature of the valve is that the piston movement mechanism is designed to have minimum wear and tear of sealing O-rings. This has been achieved by the use of a screw mechanism, which facilitates the axial movement of the piston and prevents the rotational movement thereby minimizing the wear and tear of the O-rings. In addition to this, replacement of O-ring is facilitated by the easily demountable flange design. O-rings are well supported in grooves and have about 20 % compression between cylinder and piston. On account of the narrow surface of O-ring, the sealing material encounters least force to cause deformation/deflection when exposed to high pressure and ensures leak tightness at high pressure and high vacuum. The inlet / outlet opening has been designed to be ½ inch, compatible with a ½” vacuum angle valve and also since the gas filling tube in the filling assembly for any detector has a diameter of less than 10 mm. The valve body and components which need to withstand high pressure of 50 bar (750 psi) have been designed as per ASME pressure vessel code.
1.2 Two types of piston design were tested:
In the first design, a facial-sealing method for closing & opening of the valve was adopted by providing an O-Ring on piston face (Fig. 3). This design is suitable only in uses where the flow is unidirectional. If the flow direction is reversed and valve is in the closed position there are possibilities of the O-Ring getting displaced from the groove during opening of the valve. This is an undesirable situation. This phenomenon is more pronounced at pressures in excess of a few bars.
In the second design, dynamic gland method for closing & opening of the valve was employed. In this design the O-Ring is mounted on the step diameter grooves provided in the piston (Fig. 3). Here, flow in both directions is possible since the O-ring is held in such a manner as to prevent it from getting displaced due to high pressures. This design therefore permits interchanging inlet and outlet.

Fig. 4. Photograph of the piston valve

Fig. 5. Photograph of the components of the Piston valve
2.0 Tests and results

2.1 Pressure and Leak Tests
The valve was leak and pressure tested at CDM, BARC as per ASME pressure vessel code Section V and VIII. The hydrostatic pressure testing was carried out at 75 kg/cm². The valve did not show any pressure drop for half-hour period. Also the test ensured the mechanical ruggedness of the design. In the vacuum mode the valve had helium leak rate $9.6 \times 10^{-9}$ m bar ltr/sec and in the pressure mode the Helium leak rate was $2 \times 10^{-7}$ mbar ltr/sec.

2.2 Comparison of performance of valves
To compare the performance of the indigenously developed valve with the conventional valves, an experiment was conducted to determine the vacuum achieved, the time taken to achieve the vacuum and the maximum pressure that the valves could withstand. Three valves which included a diaphragm valve (1/2”) and a needle valve (1/2”) obtained from commercial suppliers and the in-house developed piston valve were tested. Each of the valves was connected to an evacuation and gas filling system (Fig. 6), which consisted of a turbo molecular pump, high vacuum gauge, pressure gauge, and a 7ltr spherical ionisation chamber.

With the diaphragm valve in the circuit the system was able to evacuate the chamber to a vacuum of $3.0 \times 10^{-4}$ mbar in 30 minutes. The ultimate vacuum achieved after 6 hours was $1.2 \times 10^{-5}$ mbar. It was also observed that the diaphragm valve started leaking at pressure above 3 bars.

With the needle valve in the circuit the system was able to evacuate the same chamber to a vacuum of $2.2 \times 10^{-4}$ mbar in 30 minutes. The ultimate vacuum achieved after 6 hours was $8.6 \times 10^{-6}$ mbar.
Although needle valves can withstand high pressures of the order of few tens of bars, the flow rate is low as seen from the above result. On the other hand the present piston valve provided 8.6x 10^{-5} mbar vacuum in 30 minutes. The ultimate vacuum achieved in 6 hours was 4.6 x 10^{-6} mbar. Fig. 7 shows the comparison of the performance of the three valves.

![Graph showing performance comparison of different valves.](image)

**Fig. 7.** Comparison of Performance of Different Valves

### 3.0 Conclusion
The present design of the valve is capable of meeting the three-fold requirement of ability to withstand high-pressure, compatibility with high vacuum and high conductance. The valve is compatible with vacuums of the order of 2.5x10^{-6}mbar.

### 4.0 Acknowledgement
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### References
- G F. Knoll, “Radiation Detection and Measurement”
- ASME B&P Vessel Code Section V&VIII
- V.V. Rao, T.B. Ghose and K.L. Chopra “Vacuum Science and Technology”, Allied Publishers Ltd., New Delhi (2001)