Study of Residual Gas Analyser (RGA) Response towards Known Leaks

Firozkhan S Pathan, Ziauddin Khan, Pratibha Semwal, Siju George, Dilip C Raval, Prashant L Thankey, Himabindu Manthena, Paravastu Yuvakiran and Kalpesh R Dhanani

Institute for Plasma Research, Near Indira Bridge, Bhat, Gandhinagar – 382428, Gujarat, India

E-mail: firose@ipr.res.in

Abstract. Helium leak testing is the most versatile form of weld qualification test for any vacuum application. Almost every ultra-high vacuum (UHV) system utilizes this technique for insuring leak tightness for the weld joints as well as demountable joints. During UHV system under operational condition with many other integrated components, in-situ developed leaks identification becomes one of the prime aspect for maintaining the health of such system and for continuing the experiments onwards. Since online utilization of leak detector (LD) has many practical limitations, residual gas analyser (RGA) can be used as a potential instrument for online leak detection. For this purpose, a co-relation for a given leak rate between Leak Detector and RGA is experimentally established. This paper describes the experimental aspect and the relationship between leak detector and RGA.

1. Introduction
A leak means an unintended crack, hole or porosity in an enveloping wall or joint. The basic function of the leak detection is to localize and to quantify the leak size in a sealed enclosure or system. In spite of modern technologies, it is practically impossible to seal any enclosure or system that can guarantee a complete leak proof system. What maximum can be practically feasible is to minimize it to the best possible extents. For such situations, the helium leak detection plays a major role.

Mass spectrometer based leak detectors (MSLD) are most commonly used detectors and are very sensitive instruments for identifying very small leaks presence in vacuum systems. Mainly there are two broad categories of MSLD based helium leak testing – (1) Spray method in which the object under scanning is evacuated and connected to the MSLD through the roughing line of the pumping system. Helium gas is spread throughout the system and if there is a leak the Helium gas will penetrate into the system due to pressure difference and will be detected by the MSLD. (2) Sniffer method in which the object under testing is pressurized with helium gas to a desired value and a helium-sensing probe connected to the MSLD is moved as close as possible to the weld joints, de-mountable joints and the surface of the object. Both the techniques are briefly represented in the figure 1.

SST-1 Tokamak [1, 2] is a steady state super-conducting tokamak for plasma discharge of 1000 sec duration. Mainly it comprises of two vacuum chambers. One is Vacuum vessel, which is ultra high vacuum chamber and other is Cryostat, which is a high vacuum chamber. Vacuum vessel will be
Figure 1. Different helium leak testing methods using MSLD.

Pumped to $< 1.0 \times 10^{-8}$ mbar and Cryostat will be pumped to $< 1.0 \times 10^{-5}$ mbar vacuum. Both this chambers are having pressurized subsystems inside, which if leaks will deteriorate the system vacuum. Figure 2 shows the schematic of SST-1 cryostat circuits.

Figure 2. High pressure circuits of SST-1 Cryostat

For baking of vacuum vessel at 150 °C during bake out, U-shaped SS 304L channels of 2 mm thickness have been welded on the inner surfaces of the vessel wall. Hot Nitrogen gas will be passed through this baking channels at pressure of 4.5 bar (g). Any leak on this baking channel will affect the vacuum inside vessel. Vacuum vessel is also equipped with first wall components which are having copper tubing for cooling and heating purposes. Any leakage in these Cu tubing will also disturb the vessel vacuum.
Cryostat is having 80 K shields, TF & PF coils and their supply and return headers. 80 K shields are cooled with liquid nitrogen at 6.0 bar (g) whereas TF & PF coils are cooled with supercritical liquid helium at 4.0 bar (a) 4.5 K. Considering such different pressurized circuits with different gases, the smooth operation of vacuum system requires a kind of online tool which keep watch on leak integrity of all these circuits and can give indication of a leak for various types of gases without disturbing the pumping process. Leak detector can not be utilized for this purpose, because (i) it cannot detect multiple gases as per system requirement, (ii) it cannot be kept online during operation and (iii) it will disturb the pumping process. These critical requirements foresee to find best alternative solution which could be online residual gas analyzer (RGA). Hence, efforts were made for characterization of the response of RGA towards known leaks.

Residual gas analyzer (RGA) is used to measure the partial pressures of gases present inside a vacuum system. There are various types of RGAs based on different working principles. MKS make RGA used in this experiment, is capable of scanning masses up to 200 amu with a minimum detectable pressure of $2.0 \times 10^{-11}$ torr [3]. If required, a particular mass can be selected to measure its partial pressure trend with time. Since a single mass is being scanned, the scanning rate and hence the response will be faster in this mode. This feature of RGA can be used for online leak detection in a large vacuum chamber like SST-1 Tokamak. With systematically pre-cleaned vacuum system, it is possible to detect the leaks smaller than $1.0 \times 10^{-12}$ torr l/s with a RGA [4].

2. Experimental set-up and procedure
The experiment is carried out in a stainless steel ultra-high vacuum (UHV) chamber. Chamber is pumped to an ultimate pressure $< 1.0 \times 10^{-7}$ mbar using a 520 l/s (Nitrogen) turbo-molecular pump (TMP). Leak integrity of the entire system is ensured at a background of $1.0 \times 10^{-9}$ mbar l/s. Vacuum measurement is carried out using B. A. gauge while the partial pressure is measured using MKS make RGA. Provisions are made to connect Standard leaks of different ranges to the system through a 25 KF right angle valves. Figure 3 shows the experimental set up used for the test.

![Figure 3. Experimental set-up for RGA characterization.](image-url)
Different standard leaks are used and also their locations are varied to see the response of RGA. Initially it is installed in such a way that almost all the helium gas coming out of standard calibrated leak gets fully exposed to RGA. Initially the standard leak is connected in such a way that RGA will be directly exposed to the gases coming from standard leak and then observations are noted. In the similar fashion, the standard leak is kept nearly 3.0 meters away using 25 KF bellow and again the observations are noted. Finally the standard leak is shifted in such a way that it is directly exposed to TMP and RGA is exposed partially. In this condition the observations are also noted. Finally observation for air leak is carried out. All these observations are only taken when the system is in very stable condition. Also the entire experiment is carried out for three (03) times to ensure the repeatability.

3. Results
The leak rates are calculated using RGA partial pressures with effective pumping speed of 275 l/s (Helium) which is as per system configuration. The observed partial pressures of the helium gas, base partial pressure of the system, the standard leak values and the calculated leak values are tabulated in the table 1.

| Location of Standard leak | Partial pressure of He (mbar) | Base Partial pressure of He (mbar) | ∆P (He) (mbar) | RGA based leak value (mbar l/s) | Standard leak value (mbar l/s) |
|---------------------------|-------------------------------|-----------------------------------|----------------|--------------------------------|-------------------------------|
| Directly exposed to RGA and very close to it | 1.27 × 10^{-09} | 3.00 × 10^{-11} | 1.24 × 10^{-09} | 2.45 × 10^{-06} | 3.70 × 10^{-06} |
| Directly exposed to RGA and 3.0 m away from it | 1.83 × 10^{-09} | 3.00 × 10^{-11} | 1.80 × 10^{-09} | 3.58 × 10^{-06} | 6.70 × 10^{-06} |
| Partial exposed to RGA | 3.09 × 10^{-09} | 3.00 × 10^{-11} | 3.06 × 10^{-09} | 6.15 × 10^{-06} | 1.04 × 10^{-05} |
|  | 4.40 × 10^{-09} | 3.00 × 10^{-11} | 4.10 × 10^{-10} | 8.24 × 10^{-07} | 3.70 × 10^{-06} |
|  | 6.30 × 10^{-09} | 3.00 × 10^{-11} | 6.00 × 10^{-10} | 1.21 × 10^{-06} | 6.70 × 10^{-06} |
|  | 1.00 × 10^{-09} | 3.00 × 10^{-11} | 9.70 × 10^{-10} | 1.95 × 10^{-06} | 1.04 × 10^{-06} |

While varying the standard leak values at given location, RGA snap shorts are taken in order to see the effects in the partial pressure variation which are shown in the figure 4 and figure 5.

![Figure 4. Screenshot of RGA scan with a single standard leak.](image-url)
Figure 5. Screenshot of RGA scan with different standard leaks.

Table 1 shows that in directly exposed conditions, response of RGA is in accordance to standard leak value at lower leak rate and it is within 10% variation. But as the leak value increases, difference between RGA and standard leak value differs more i.e. RGA shows less response. Even after varying standard leak distance, the same results are repeated. For partially exposed condition, the response of RGA is even more deteriorated.

Finally air leak is introduced and RGA scan is taken as shown in the figure 6. Data for air leak is tabulated in the table 2.

Figure 6. Screenshot of RGA scan with air leak.
Table 2. Experimental observation for air leak.

| Partial pressure of mass 14 (mbar) | Partial pressure of mass 16 (mbar) | Partial pressure of mass 28 (mbar) | Partial pressure of mass 32 (mbar) | Ratio (14+28)/(16+32) |
|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------|
| 6.13 × 10^{-09}                  | 3.15 × 10^{-09}                  | 8.50 × 10^{-08}                  | 1.97 × 10^{-08}                  | 3.99                  |

Table 2 shows a ratio of 3.99:1 for the partial pressure of Nitrogen to that of Oxygen which is same to the percentage composition of Nitrogen and Oxygen in air (4:1). Hence the air leak can be confirmed through RGA scan if this ratio appears.

4. Conclusion
RGA can be used as an online leak detector in a system like SST-1 tokamak with so many different high pressure components with different gases species. This will give an instant sense for a leak in a particular system.

References
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