An Overview of Low Vacuum System for the Pressure Range from 1 Pa to 133 Pa*

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Low vacuum has numerous applications especially in the industrial processes where different gases are mixed under controlled environment. In such cases, the system must have the capability to provide controlled atmosphere which can enhance the quality of the end product. A low vacuum system has been developed by Vacuum Laboratory at Korea Research Institute of Standards and Science (KRISS) that can be used for the generation for stable pressure points in the pressure range from 1 Pa–133 Pa during continuous flow mode. The system’s chamber is made of SS 304 and equipped with latest vacuum measuring/regulating instruments like CDGs, MFCs, RGA, RVC etc. This paper describes some established features of the system.

1. Introduction

Initially, vacuum was considered as a laboratory tool but with the passage of time advancements in the field of vacuum science and technology often contributed to advances of other areas of studies such as metallurgy, surface physics, nuclear physics, electronics, etc. For the generation of a vacuum environment, the system’s design, vacuum generating and measuring instruments and similar other features like chamber’s shape and its orientation (if not spherical), use of baffle plates and traps, etc. are important. In this regard, new instruments are introduced gradually that has largely affected the vacuum generation, measuring and control processes.

KRISS, besides its primary vacuum systems in the range from low to ultra-high vacuum ranges1–3), has assembled a new dynamic flow-control system (FCS–705). This is a multipurpose system and can be used for the study of advanced scientific applications as well as calibration of different types of vacuum gauges by direct comparison method with reference gauge. In this review paper, various characteristics of the system are briefly discussed.

2. System design and instruments

The main chamber of this system is made of SS 304, inside of which was, before installation, electro-polished and ultrasonically cleaned. Its volume is about 0.03650 m³ and evacuated by a high vacuum pumping system consisting of a turbomolecular pump (TMP) (pumping speed for N₂: 0.56 m³/s) backed by a 300 l/min scroll pump. A pneumatically controlled gate valve with 8 inch CF flange is installed between process chamber and TMP. A flange is inserted at the top inside the main chamber to achieve homogeneous pressure. The chamber was wrapped with a heating jacket that enables to achieve a constant bake-out temperature up to 200°C. The temperature was regulated by an automatic temperature controller with an accuracy of ± 1°C. The chamber contains several conflate flange (CFF) ports, which are necessary for gas inlet, vacuum gauges and connections to other equipment.

The mass flow controllers, MFC–1 and MFC–2 (Type–Tylan 2900 Series with time constant of 500 ms), have 1 slm and 3 sccm full scale, respectively. A schematic diagram of the flow-control system is shown in Fig. 1. The system has the facility of automatic control of gas flow through MFCs’ and regulated valve controller (RVC) with five inlet manifolds. All the equipment including pumps, gauges, mass flow controllers, valves, RGA, etc. are fully controlled with LabView program. RVC operates in a constant pressure mode or a constant flow mode. A needle valve was installed in the roughing line of the main chamber. The system has the facility to regulate a constant flow of different gases and to achieve a constant pressure inside the chamber covering a whole range from 1 Pa to 133 Pa.

3. System characteristics

3.1 Outgassing rate

The outgassing rate of a main chamber was measured by using the pressure rise method4). Figure 2 shows the time dependence of the pressure change in main vacuum chamber after closing the gate valve. The pressure was raised up to about 3 × 10⁻³ Pa in 25 min. A rapid pressure rise was observed at the beginning because the valve plate released a burst of gases by mechanical stress. A nearly linear rise can be observed after about 10 minutes; that shows a small outgassing quantity corresponding to a low equilibrium pressure in a shorter time.

The outgassing rate calculated for the chamber of this system was approximately 2 × 10⁻⁵ Pa m³/s/m². The influence of outgassing and/or pumping effect of IG are ignored in this measurement.

3.2 Generation of constant pressure points

For generation of constant pressure points in the vacuum chamber of the system, MFCs 1, 2 were used with high purity N₂ as test gas with following scheme as shown in Table 1. The data were recorded in a sequence of increasing pressure throughout the entire range of
Fig. 1 Schematic and LabView diagram of the FCS–705: TMP; Turbomolecular pump, GV; Gate valve, CR; Conductance reducer, CG; Convectron gauge, CFF; Conflat flange, RVC; Regulating valve controller, NV; Needle valve, MFC; Mass flow controller, GR; Gas regulator.

Fig. 2 Pressure rise in main process chamber as a function of time, after the gate valve was closed.

Table 1 Scheme of pressure control.

| Vacuum region | Status of pump | Valve used | MFC used |
|---------------|----------------|------------|----------|
|               | TMP            | SP         | GV       | TV       | 1 | 2 |
| TMP           | ✓              | ✓          | ✓        | x        | ✓ | ✓ |
| SP            | x              | ✓          | x        | ✓        | ✓ | ✓ |

TMP: Turbomolecular pump, SP: Scroll pump, GV: Gate valve, TV: Throttle valve, MFC: Mass flow controller, ✓: On, x: Off

In case of TMP region, MFC–1 and MFC–2 were used to generate a constant pressure in the range from \(6.5 \times 10^{-4}\) to \(4 \times 10^{-1}\) Pa. The effective gas flow (sccm) was calculated by subtracting outgassing rate from the actual value of gas flow into the vacuum chamber. Various pressure points were generated within the prescribed pressure range and each set was repeated 5 times. The standard deviations and the relative deviations from the average of each data point were measured. It was observed that the errors in generated pressure (for each data point) were less than 4.2\% in our case.

In order to extend the upstream pressure limit of the system up to 133 Pa, a conductance reducer (CR) of dimensions \(3.5 \times 2\) mm was installed in the bypass line which worked well as shown in Fig. 15.

3.3 Measurement of pressure differences

Since the pressure in the main chamber had been never uniform in the dynamic flow condition, we measured the pressure differences at various points of the chamber by using five capacitance diaphragm gauges (CDGs). The maximum deviation in pressure is observed at point C which is about 1.5\%. The differences in pressure at point A, B, and D are 0.3\%, 1.2\% and 0.6\%, respectively as shown in Fig. 36. While at position E, the CDG’s reading was taken as reference (Fig. 1).

The difference of the results between 133 Pa and 1 Pa was less than 0.0021\%. Low pressures at point C could be attributed to the directional motion of the gas molecules\(^7\) so that when entering the chamber, they are directly attracted smoothly towards the gas sink (vacuum pump).

3.4 Time constant of the chamber

Time constant \(\tau = V/C\) (with \(V\) volume and \(C\) as conductance of the system at the pump side which is CR in our case) and equilibrium time are important characteristics of a dynamic flow system. The values of \(C\) in Table 2 were calculated by dividing the flow rate \(Q\) of MFC by the pressure difference \(\Delta P\) across the CR in the pumping line. Since the downstream pressure was negligible, due to high pumping speed of the turbomolecular pump, \(\Delta P\) was equal to the upstream pressure (pressure inside the chamber).

The values of time constant \(\tau\), for different pressure
Table 2  The values of conductance and equilibrium time for the three gases.

| Number of measurement | Flow (sccm) | Ar  |  | N2  |  | He  |  |
|-----------------------|------------|-----|---|-----|---|-----|---|
|                       |            | C  | 3τ | C   | 3τ | C   | 3τ |
|                       | m³/s       | Time (min) | m³/s | Time (min) | m³/s | Time (min) |
| 1                     | 0.03       | 6.50E-05 | 28.07 | 7.60E-05 | 24.01 | 1.94E-04 | 9.41 |
| 2                     | 0.08       | 6.70E-05 | 27.23 | 7.50E-05 | 24.33 | 1.89E-04 | 9.66 |
| 3                     | 0.50       | 7.70E-05 | 23.70 | 8.40E-05 | 21.73 | 1.94E-04 | 9.41 |
| 4                     | 1.00       | 8.90E-05 | 20.50 | 9.20E-05 | 19.84 | 1.97E-04 | 9.26 |
| 5                     | 1.50       | 9.80E-05 | 18.62 | 9.90E-05 | 18.43 | 1.89E-04 | 9.66 |
| 6                     | 3.00       | 1.17E-04 | 15.59 | 1.18E-04 | 15.47 | 1.88E-04 | 9.71 |
| 7                     | 5.00       | 1.36E-04 | 13.41 | 1.37E-04 | 13.32 | 2.04E-04 | 8.95 |
| 8                     | 8.00       | 1.55E-04 | 11.77 | 7.60E-05 | 11.62 | 2.29E-04 | 7.97 |
| 9                     | 11.00      | —   | —   | 1.57E-04 | 10.49 | 2.58E-04 | 7.07 |
| 10                    | 13.00      | —   | —   | 1.74E-04 | 9.92  | 2.81E-04 | 6.49 |
| 11                    | 15.00      | —   | —   | —   | —   | 3.03E-04 | 6.02 |

Fig. 3  Relative deviations in pressure from the average values at four different locations on the vacuum chamber. (■) and (●) were measured at 1 Pa and 133 Pa, respectively.

Fig. 4  LabView graph of gas flow versus pressure in the chamber for He gas.

points in the chamber, were calculated from the ratio of volume \( V \) of the chamber to conductance \( C \) of the pumping path. For the chamber of this system, the time constant and equilibrium time were calculated using different gases including; \( \text{N}_2, \text{Ar}, \text{He} \) shown in Table 2 for He gas only. For the three gases, the equilibrium times were from 28.07 min to 11.77 min, 24.01 min to 9.92 min, and 9.41 min to 6.02 min respectively, as given in Table 2.

4. Conclusions

A dynamic flow system has been assembled by Vacuum Lab. at KRISS in the low vacuum range. This system is compact and equipped with latest vacuum related equipment and instruments including scroll & turbomolecular pumps CDGs, RGA, RVC, MFCs, etc. Precise and stable pressure points can be generated in the vacuum chamber of this system in the pressure range from 1 Pa to 133 Pa. Various characteristics of this system were analyzed and compared. This is a multi-pur-
pose system and contributes to the semiconductor industry for various purposes such as calibration of vacuum gauges by direct comparison method with reference gauge, measurement of outgassing rates of various materials, and the other general purposes.

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