KAHVELab Proton Accelerator Vacuum System Tests

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I. Introduction

Kandilli Detector, Accelerator and instrumentation laboratory (KAHVELab) started the construction of a proton beamline funded by TUBITAK, Bogazici and Istanbul Universities. The project aims to build a Proton Testbeam At Kandilli (named as the PTAK project) campus in Istanbul, Turkey [1]. The proton accelerator at KAHVELab utilizes a 20 kV high voltage power supply units (PSU), two low voltage PSUs, one four-channel low voltage PSU, two turbomolecular pumps, two vacuum gauges, three pneumatic cylinders with PLC and PC control combined all in one LabVIEW GUI [2]. This document describes how the vacuum system of the proton accelerator works, as well as the tests currently being done on the vacuum system.

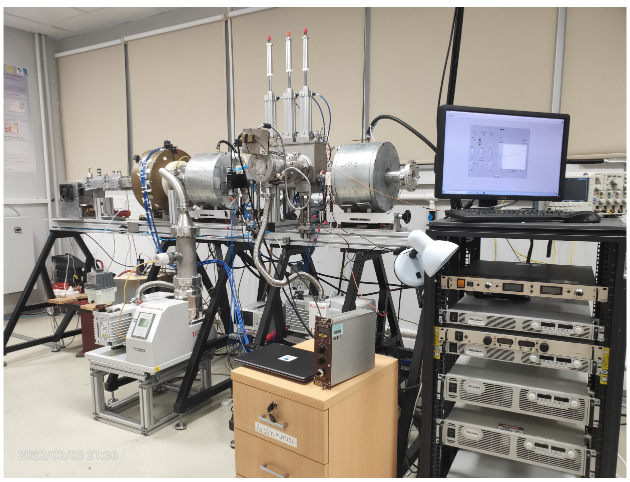

Fig. 1. The Proton Accelerator at KAHVELab [2]

II. The Vacuum System

The vacuum system comprises of mechanical pumps, turbomolecular pumps and vacuum gauges. Flanges and O-rings are used in conjunction to create leak-tight connections between the components of the system.

1) Mechanical Pump: The mechanical pump used is a rotary vane pump, model "Edwards RV12". Rotary vane pumps contain two or more chambers that compress, rotate, and discharge gases and liquids. These chambers create a vacuum that pressurizes the contents, allowing them to travel through the pump's outlet. The vanes slide in and out and turn against the inner wall of the rotor. As the vanes rotate, one chamber forms, and the outlet valve divides the chamber into suction and discharge sides. The fluid enters the suction side of the chamber, where it compresses with each rotation. Once the suction chamber reaches its maximum capacity, the contents are released into the discharge chamber and through the pump outlet. Finally, an exhaust valve prevents backflow by blocking contents that try to reenter the pump.

Fig. 2. Edwards RV12

For this model, the pump mechanism is driven directly by a single-phase or three-phase electric motor through a flexible motor-coupling. The motor is totally enclosed and is cooled by the motor cooling-fan which directs air along the motor fins. The pumps are cooled by an additional fan attached to the motor-cooling. The Edwards RV12 offers a peak pumping speed of 10 cfm at 60 Hz and an ultimate pressure of 2×10^{-3} mbar.

2) Turbo Molecular Pump (TMP): A Turbo Molecular Pump is a type of vacuum pump, used to obtain and maintain high vacuum. These pumps work on the principle that gas molecules can be given momentum in a desired direction by repeated collision with a moving solid surface. In a TMP, a rapidly spinning fan rotor 'hits' gas molecules from the inlet of the pump towards the exhaust in order to create or maintain a vacuum.

TMPs operate on the principle of momentum transfer, using rapidly rotating blades to propel gas molecules towards the exhaust, whereas RV Pumps function based on positive displacement, employing rotating vanes within a chamber to draw in and compress gas. The principle of TMPs leads to a more efficient evacuation of the chamber, which creates a vacuum of the order of 10^{-6} mbar.

The Turbo Molecular Pump used in the setup is Agilent TwisTorr 304 FS.

Fig. 3. Agilent TwisTorr 304 FS

The TwisTorr 304 FS pump uses a special bearing and dry lubrication, so it doesn't need oil or maintenance and can work in any orientation. It has an ISO 160 inlet flange and KF 16 foreline flange.

3) Vacuum Gauge: A vacuum gauge is a device used to measure the pressure in a vacuum system. The model used in the setup is "Pfeiffer Compact FullRange Gauge PKR 251 Active Pirani Cold Cathode Transmitter". The Pirani/Cold Cathode vacuum gauge is a type of vacuum gauge used to measure low to high vacuum pressures. It combines the principles of two different types of vacuum gauges: the Pirani gauge and the cold cathode gauge. The Pirani gauge operates on the principle of thermal conductivity. It consists of a filament that is heated electrically. The heat loss from the filament to the surrounding gas depends on the thermal conductivity of the gas, which varies with pressure. At low pressures, the gas density is low, and thus the thermal conductivity is lower, resulting in less heat loss. The change in temperature of the filament (and thus its resistance) can be measured and correlated to the pressure of the gas. The cold cathode gauge, also known as a Penning gauge, operates on the principle of ionization of gas molecules. In this gauge, a high voltage is applied between two electrodes, creating a strong electric field. Gas molecules in the vicinity are ionized, and the ions are collected by the electrodes. The current generated by these ions is proportional to the gas pressure. The cold cathode gauge is particularly useful for measuring very low pressures, typically in the high vacuum range.

   The combination of these two gauges into one device allows for a broader measurement range. The Pirani gauge covers the higher pressure range (from atmospheric pressure down to around 10^{-3} mbar), while the cold cathode gauge covers the lower pressure range (from 10^{-2} mbar to 10^{-9} mbar or even lower).

   Pfeiffer's Pirani/Cold Cathode model requires 15 to 30 VDC power input and produces a linear 0-10 VDC analog output signal. The output signal is converted to a pressure value using a PLC (Programmable Logic Controller). This vacuum gauge provides a vacuum pressure in the range 10^{-9} mbar to 10^{2} mbar. It also has a DN 25 ISO-KF 25 connection flange.

Fig. 4. Pfeiffer Compact FullRange Gauge PKR 251

III. The Tests

At present, the vacuum system fails to reach levels as low as 10^{-6} mbar. We are testing the components such as flanges and O-rings to find any potential leak.

We had a new blind flange made in the industry and we have started to test it. This was the setup in 17th of April:

Fig. 5. Setup 1

There's a plexiglass above the flange and we have tried to vaccuum only the steel component below. The minimum pressure stayed around 7×10^{-5} mbar.

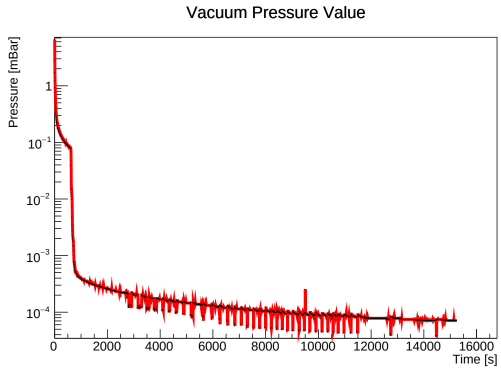

Fig. 6. 17/04/2024 Vacuum Pressure Levels

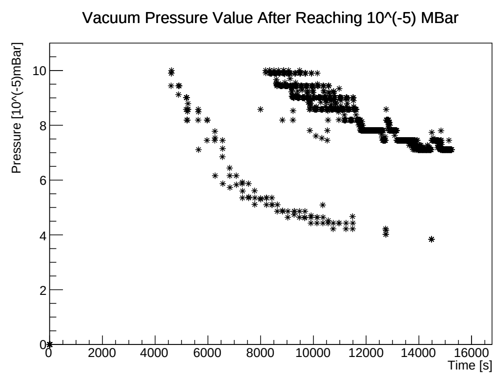

Fig. 7. 17/04/2024 Vacuum Pressure Levels After Reaching 10^{-5} mbar

From 19/04 to 07/05, we have tested the following setup:

Fig. 8. Setup 2

Both the Turbomolecular Pump and the mechanical pump are connected to the ion system with the new flange. In 19th of April, the minimum value we have reached is 2.17×10^{-5} mbar.

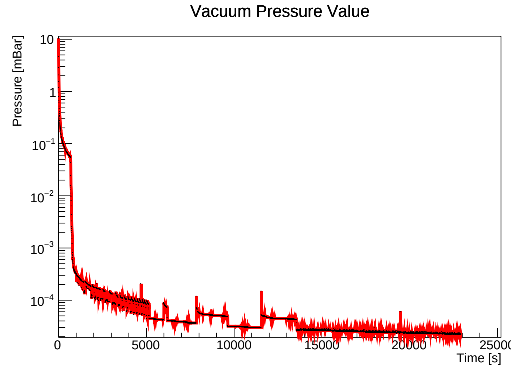

Fig. 9. 19/04/2024 Vacuum Pressure Levels

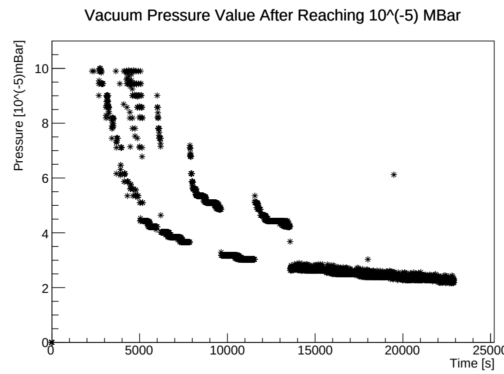

Fig. 10. 19/04/2024 Vacuum Pressure Levels After Reaching 10^{-5} mbar

In 29th of April, we have cleaned the setup with alcohol to find any leak, but we couldn't find any.

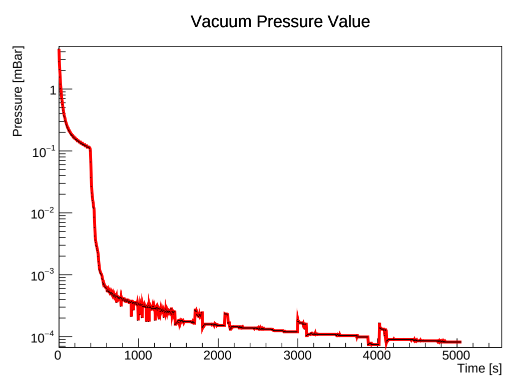

Fig. 11. 29/04/2024 Vacuum Pressure Levels

In 3rd of May, we have tested the same setup with a new o-ring inside the new flange. The minimum we could reach was 2.28×10^{-5} mbar.

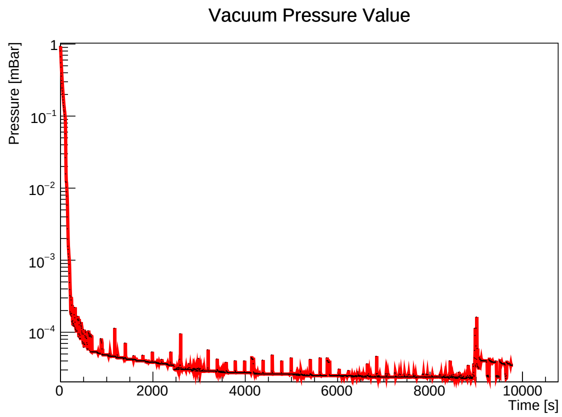

Fig. 12. 03/05/2024 Vacuum Pressure Levels

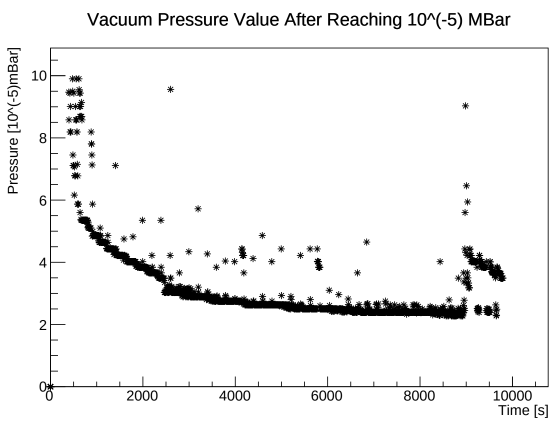

Fig. 13. 03/05/2024 Vacuum Pressure Levels After Reaching 10^{-5} mbar

We did not make any changes to the system on May 6 and May 7. After the vacuum test on May 3, instead of bringing the system back to atmospheric pressure, we put it back into vacuum, hoping to achieve 10^{-6} mbar levels through vacuum training. However, we were not able to reach this target.

In 6th of May, we have reached a minimum value of 1.88×10^{-5} mbar.

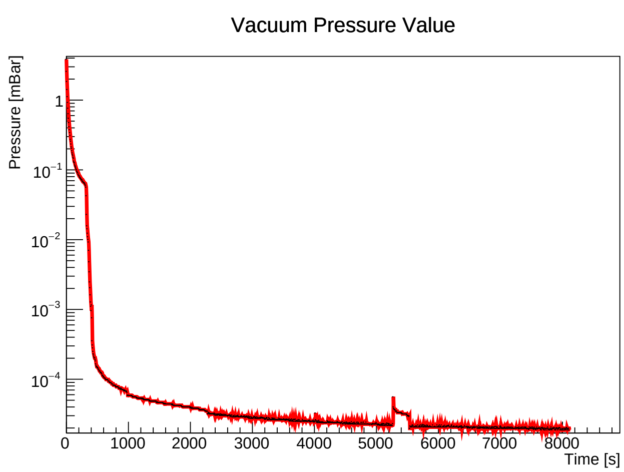

Fig. 14. 06/05/2024 Vacuum Pressure Levels

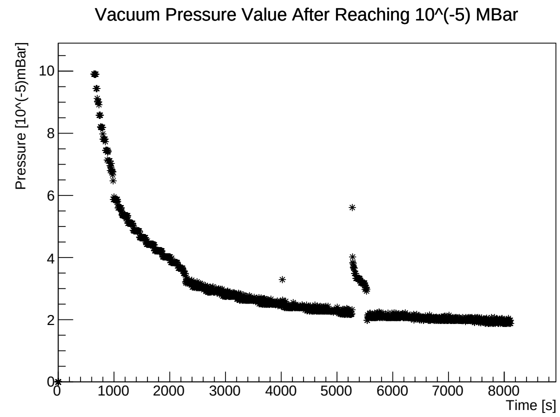

Fig. 15. 06/05/2024 Vacuum Pressure Levels After Reaching 10^{-5} mbar

In 7th of May, we have reached 1.71×10^{-5} mbar.

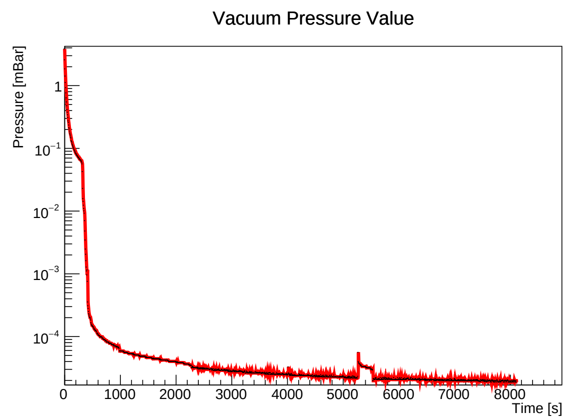

Fig. 16. 06/05/2024 Vacuum Pressure Levels

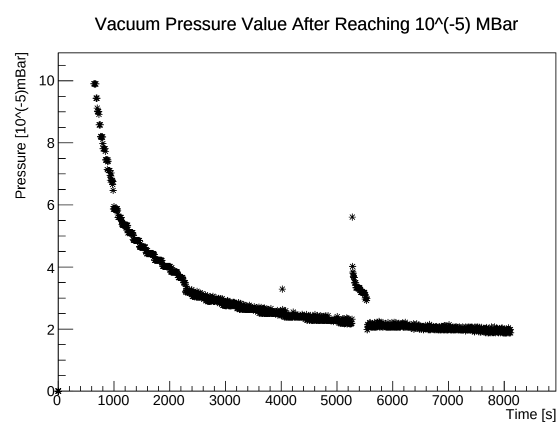

Fig. 17. 06/05/2024 Vacuum Pressure Levels After Reaching 10^{-5} mbar

References

[1] *Ion source and LEBT of KAHVELab proton beamline*. 2023. URL: https://iopscience.iop.org/article/10.1088/1748-0221/18/01/T01002.

[2] *Control Systems of DC Accelerators at KAHVELab*. 2022. URL: https://inspirehep.net/literature/2616842.

IV. Appendix

The operating instructions for the components by the providers:

- Edwards RV12
- Agilent TwisTorr 304 FS
- Pfeiffer Compact FullRange Gauge PKR 251