EXPERIMENTAL VALIDATION OF THE USE OF COLD CATHODE GAUGE INSIDE THE CRYOMODULE INSULATION VACUUM

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Abstract

The Proton Improvement Plan - II (PIP-II) project is underway at Fermilab with an international collaboration involving CEA in the development and testing of 650 MHz cryomodules. The risk analysis related to cryomodule operation proposed to add a vacuum gauge on the power coupler to prevent the untimely rupture of its ceramic. Due to the advanced design of the cryomodules, the gauge needs to be integrated inside the insulation vacuum to reduce the impact of this new modification. The lack of experience feedback on a similar operating condition requires an experimental validation before the implementation. This article details the experimental tests carried out before the approval of this solution.

MOTIVATION AND CONTEXT

Risk of Power Coupler ceramic fail:

- ❑ Risk analysis has raised the great impact of a PC ceramic failure, during operation.
- ❑ High number of PCs and an operation during several years increase the probability to have this incident.
- ❑ Experience has shown that many of these incidents are reported and are generally difficult to analyse without appropriate diagnostics.
- ❑ Ceramic degradation could be gradual due to some initially unseen weaknesses or instantaneous in case of a fail of one protection system, or of late detection of a strong event.

➔ Add a vacuum gauge on the power coupler window to reduce the risk.

Advantages of the solution:

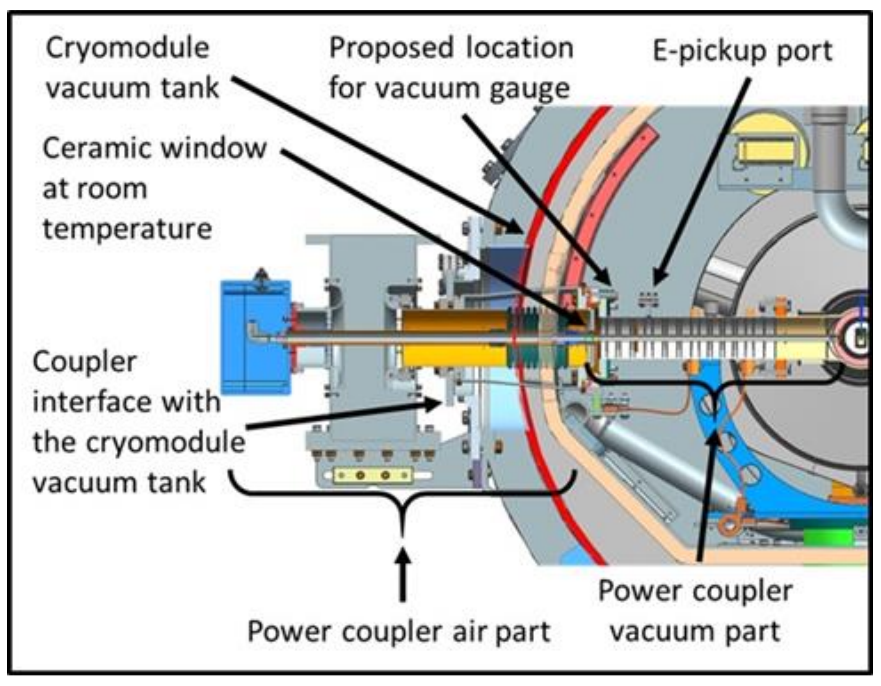
- ❑ Trigger of a protection interlock in case of strong vacuum event.
- ❑ Early detection of window tightness issues:
  - ➔ limit the degradation by adapting the operation conditions.
  - ➔ plan for a maintenance action.

Other arguments:

- ❑ Without vacuum gauge on PC, It is difficult to detect the leak in operation because of the cryo-pumping induced by cavities.
- ❑ Using the cavity performances degradation as a way to deduce of tightness problem is not an immediate way, does not give the possibility to have a precise estimation of the magnitude of the leak and may not allow to designate the leaky coupler.

Integration issue

- ❑ The advanced design of the HB650 cryomodule and the corresponding PC does not allow trivial use of the VG outside the vacuum tank .
- ❑ The use of the VG inside insulating vacuum seems to be the optimal option. Nevertheless, this configuration is not common for VGs generally used for these applications.
- ❑ Discussions with PC experts from DESY, KEK, CERN and Fermilab did not reveal any experience feedback on this practice.

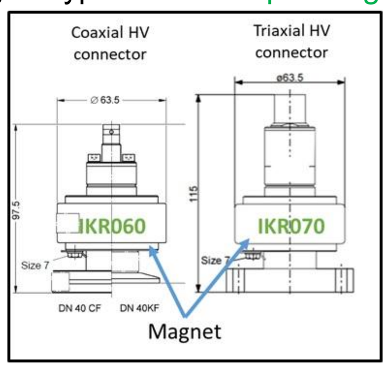


650 MHz Power Coupler assembled on the HB650 cryomodule. This design version have not a vacuum gauge.

CHOICE OF THE VACUUM GAUGE

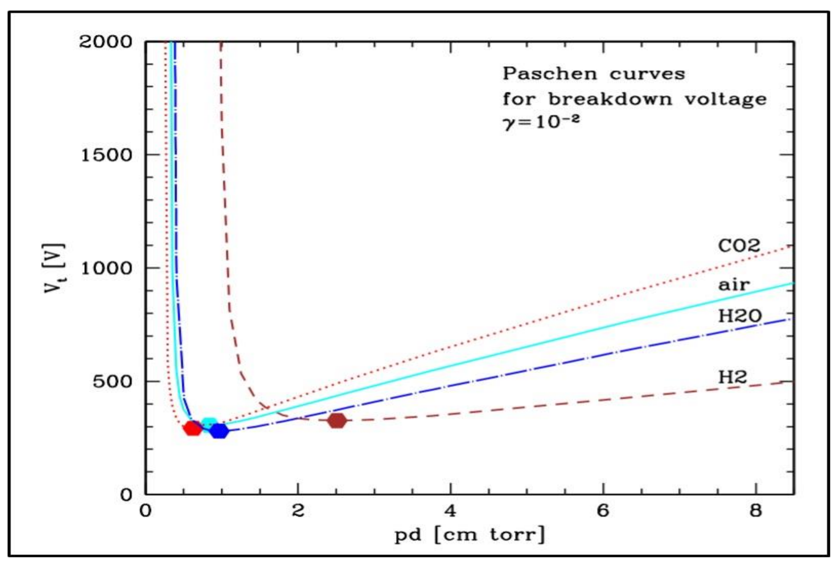
- ❑ The chosen gauge is a **Cold Cathode Ionization Measurement gauge** using the inverted magnetron principle, with high radiation sustainability, commonly used on accelerator applications.
- ❑ The baseline model is **IKR070**. The alternative model is the **IKR060**: They have almost the same design. The main difference is the use of a triaxial cable for IKR070 instead of coaxial one used for IKR060. Triaxial cable allows the measurement of lower currents and hence lower pressure levels.
- ❑ The same controller TPG300 is used for the 2 gauges types: same operating voltage 3.3kV.

Technical data	Cold cathode gauge head IKR 060, coaxial, metal seal	Cold cathode gauge head IKR 070, triaxial, metal seal
Bakeout temperature	250 °C	250 °C
Operating temperature: high temperature sensor cable	5-250 °C	
Operating temperature: standard sensor cable	5-80 °C	5-80 °C
Measurement range max.	$5 \cdot 10^{-3}$ hPa	$5 \cdot 10^{-3}$ hPa
Measurement range min.	$1 \cdot 10^{-10}$ hPa	$1 \cdot 10^{-11}$ hPa
Radiation resistance	$1 \cdot 10^{7}$ Gy	$1 \cdot 10^{7}$ Gy



Adapting the choice to the operating conditions

- ❑ First, the vacuum gauge (VG) need to be preserved from too low temperatures when the cryomodule is cold ➔ Proposed solution: RF window will operate at room temperature and will be equipped with heaters and copper straps to keep it warm during the cold operation. The same solution could be applied to the VG, if needed.
- ❑ Second, each VG is equipped with a permanent magnet ➔ Proposed solution: A magnetic shielding will be added to protect SC cavities from magnetic field and prevent the magnetization of the cryomodule components.
- ❑ Third, the activation of the cold cathode gauges requires a polarisation voltage of 3.3 kV. This represents a risk of creation of electron discharge during the vacuum pumping down, as predicted by Paschen's law ➔ Proposed solution: The operating procedure should automatically disable the VGs high voltage bias for a while during the cryomodule vacuum tank pumping. This operation has no consequence on the protection role fulfilled by the VG as the RF will be naturally switched off during that period.



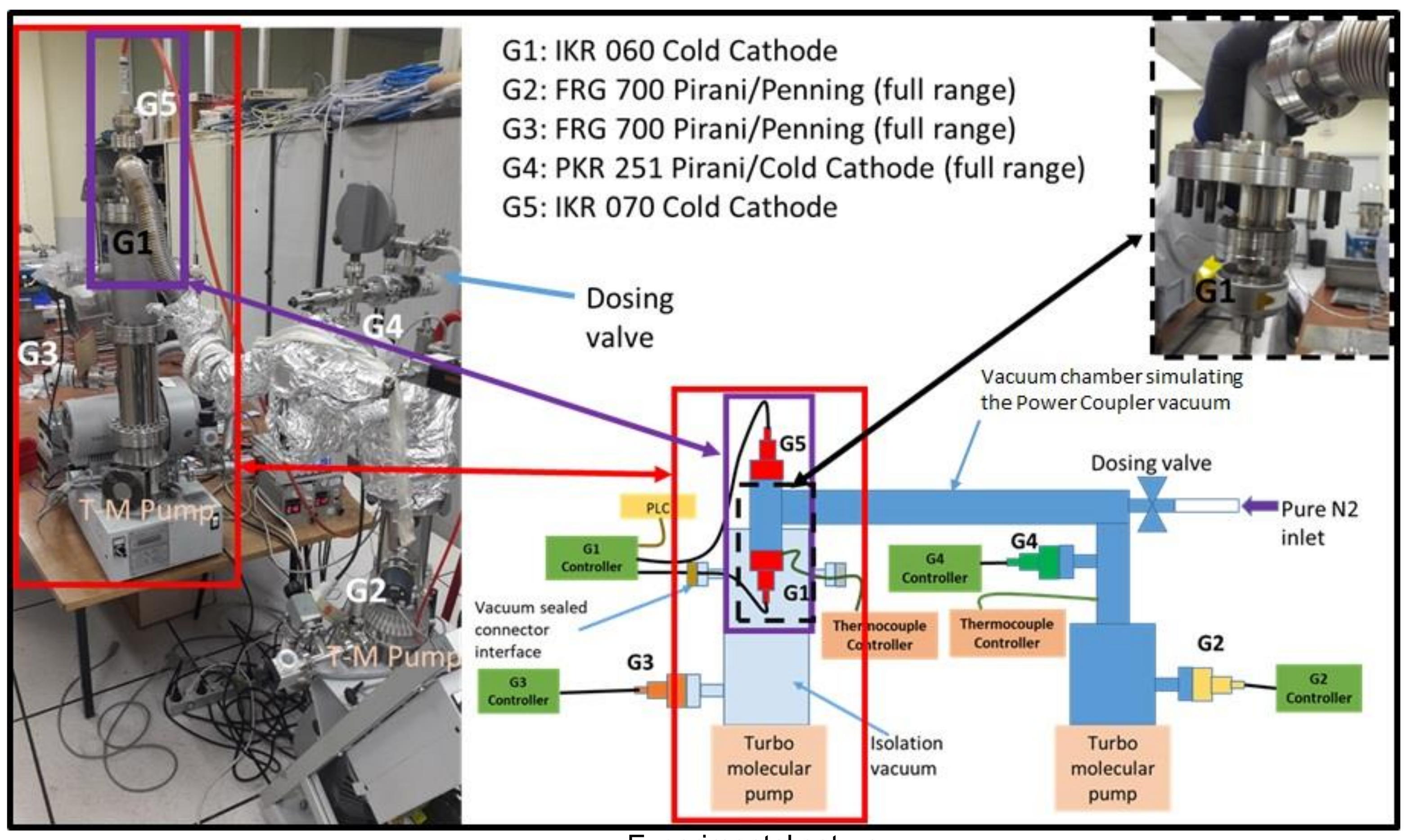
Paschen's law curve: Vt [V]is the breakdown voltage, p [torr] is the gas pressure, d [cm] is the distance between electrodes.

EXPERIMENTAL SET-UP

Objective of the experiment

Our objective is to check the following performances:

- ❑ The VG measurement consistency: comparing the IKR060 gauge measurement values atmospheric pressure vs under 'insulation' vacuum.
- ❑ The VG thermal stability: verifying that operation under vacuum does not increase the gauge temperature due to the lack of convective heat transfer.
- ❑ The VG operation reliability: observing the behavior consistency during relatively long continuous operation under vacuum.



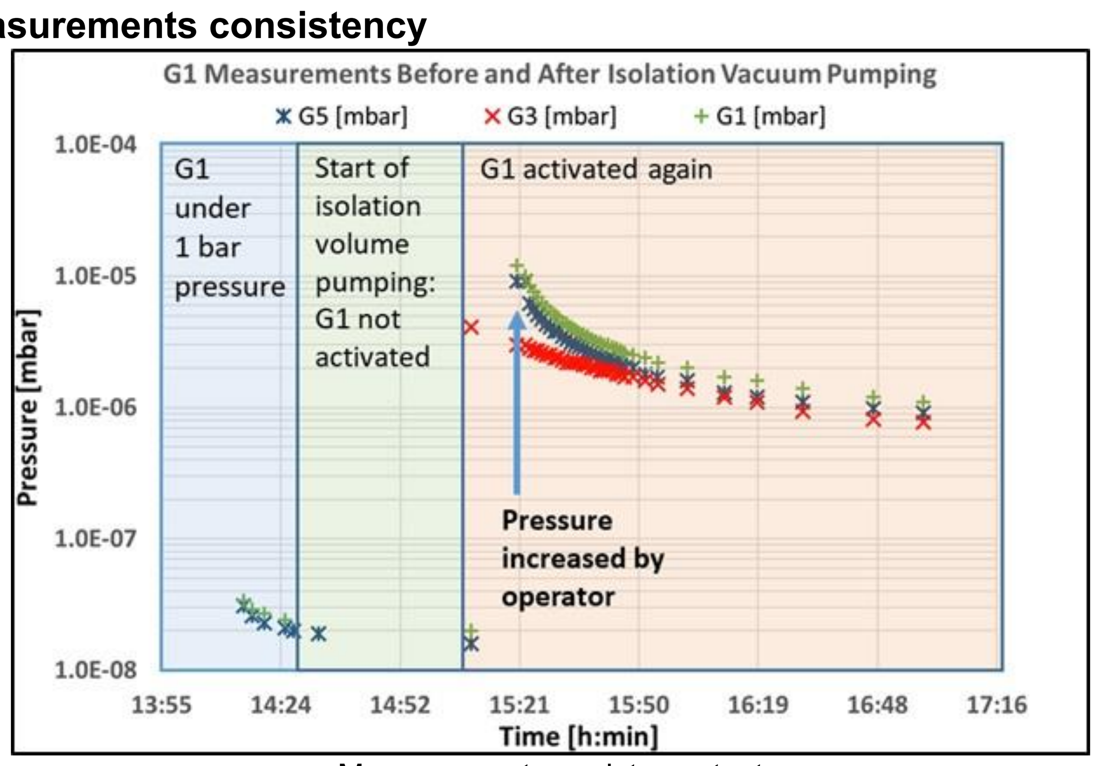
Experimental set-up

- ❑ to test the VG under configuration conditions similar to those of the cryomodule.
- ❑ All the tests are carried out at RT because we have proposed a solution to keep the gauge warm during cold operation of the cryomodule.
- ❑ G1 (IKR060) is the tested gauge. It is placed inside a vacuum chamber.
- ❑ G5 (IKR070) is the reference gauge (same technology). It is placed in the ambient air.
- ❑ 1 thermocouple is connected to the G1 gauge flange and 1 thermocouple is connected to the air side of the setup to measure the room temperature.
- ❑ A dosing valve allows to create a controlled leak in order to vary the pressure seen by G1 and G5.

NB:
We chose to test the IKR 060 only because feedthrough procurement difficulties for the triaxial connector of the IKR 070.

TEST RESULTS

Measurements consistency

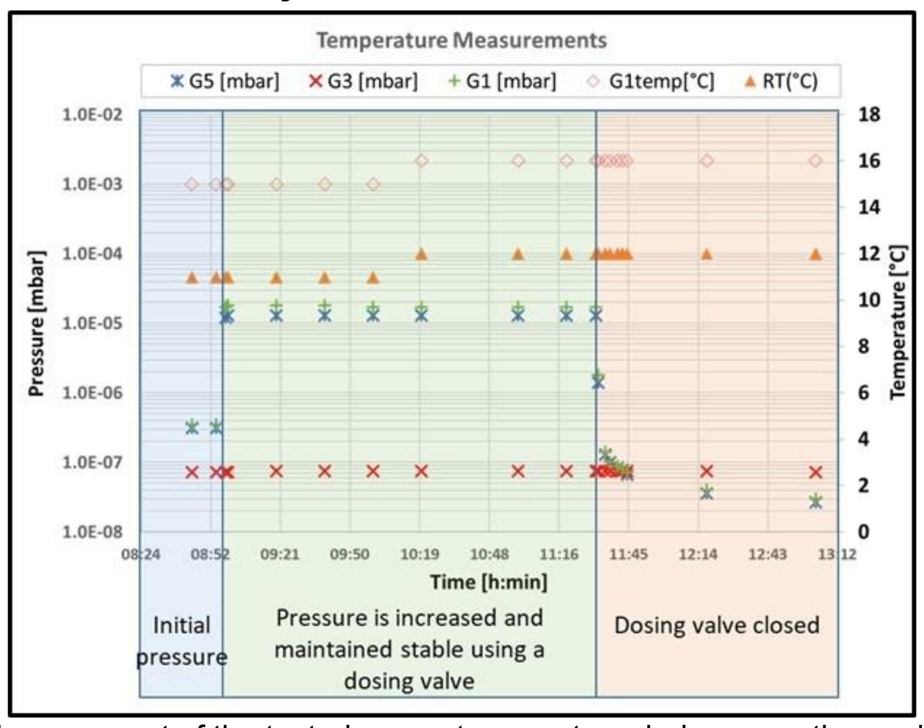


Measurement consistency test

- ❑ Consistency of G1 measurements performed under atmospheric pressure then under vacuum.
- ❑ Comparable behavior and measurements values for G1 and G5

NB: G1 activation have to be interrupted during the first stage of the isolation vacuum pumping to avoid electron discharges in the connector

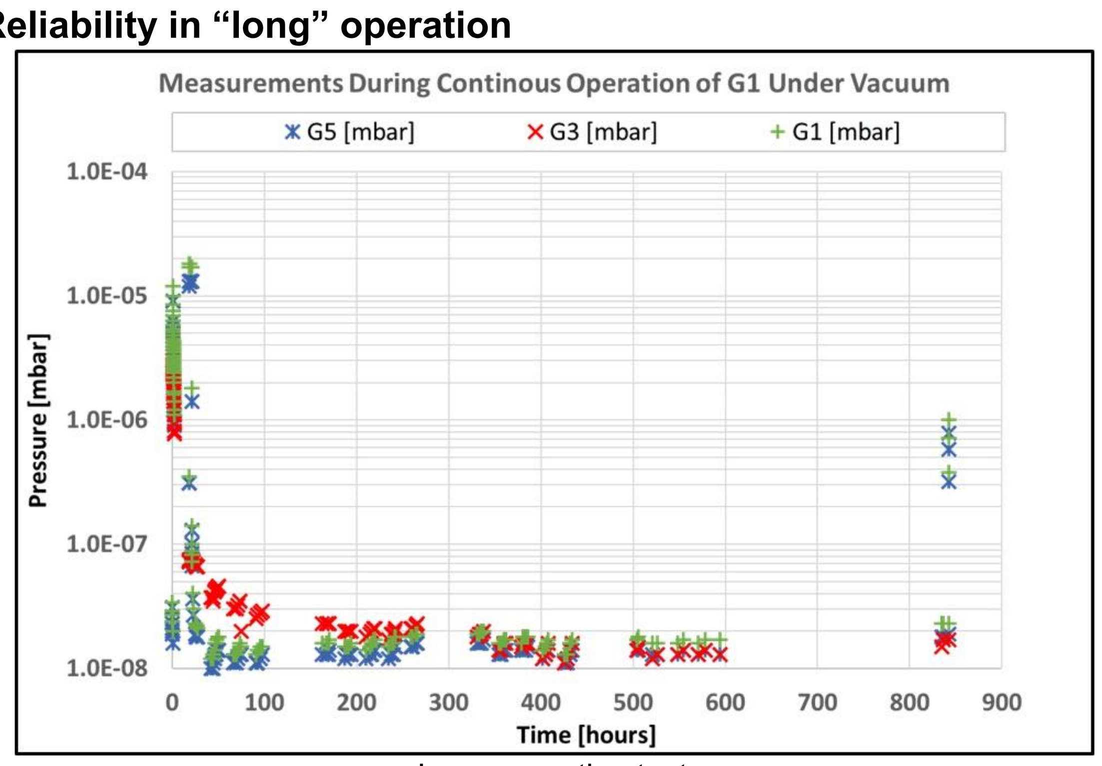
Thermal stability



Measurement of the tested gauge temperature during operation under vacuum

- ❑ We have a total correlation between G1 temperature and room temperature
- ❑ G1 temperature is stable even for relatively high measured pressures.

Reliability in "long" operation



Long operation test

- ❑ G1 (vacuum) and G5 (at atmospheric pressure) always have almost the same measurement values during about 35 days of testing.
- ❑ The relative measurement error of G1 considering that G5 gives the true pressure value was estimated during the long operation test for a stable pressure around 10^{-8} mbar. The error was between 15% and 30%.

Complementary tests

- ❑ Experimental determination of the pressure ranges corresponding to electron discharges in the vacuum gauge connector during pumping: from 10 mbar to 10^{-1} mbar
- ❑ The impact of the insertion of the feedthrough in the measurement chain was tested for a vacuum pressure of 1.9 10^{-7} mbar: the measured pressure is strictly the same wit and without the feedthrough.

Conclusion:

Using a vacuum gauge on the PIP-II 650MHz Power Coupler requires to integrate this diagnostic inside the insulation vacuum of the cryomodule. This uncommon configuration required several experimental validation tests. A test bench was built to perform the tests. Results obtained with IKR 060 cold cathode gauge were sufficiently conclusive to accept this solution for the PIP-II 650 MHz HB650 prototype cryomodule.

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