Development of a field emitter-based extractor gauge for pressure measurement in cryogenic vacuum systems

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Motivation

In SIS100, stable beam operation with the planned high beam intensities and energies is ensured only if beam dynamic effects do not lead to pressure bumps exceeding the critical value of ~$5\cdot 10^{-12}$ mbar (hydrogen equivalent at 10 K) in the cryogenic beam vacuum sections. In order to monitor this vacuum condition the use of pressure measuring devices has to be taken into account. Such low vacuum pressures can be measured commonly only by ion gauges of extractor type. Commercially available extractor gauges, however, use hot filament cathodes whose operation would generate an immense and non-tolerable heat load to the cryogenic system. To avoid this problem we developed an extractor gauge whose thermionic cathode was replaced by a field emitter (FE) cathode. Although the idea of field emitter-based ion gauges is not a new one [1], according to our knowledge, no one before has ever used a FE-based ion gauge for pressure measurement in a cryogenic vacuum system.

Gauge structure and experimental results

For our studies we modified a conventional extractor gauge of IE 514 type (Leybold). A CNT (carbon nanotube) cathode was used as 'cold' electron emitter. One possible gauge structure is shown in Figure 1.

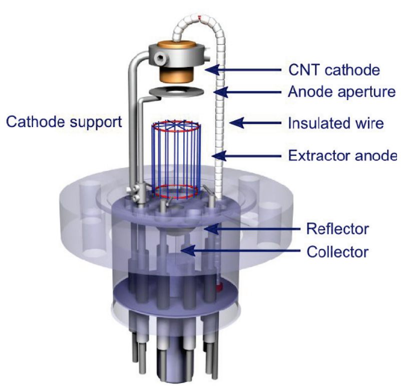

Figure 1: Possible layout of a CNT emitter-based extractor gauge

The gauge structure used in our experiments, however, deviated slightly from the one shown above. Instead of supporting wires, the CNT cathode and the deceleration electrode were mounted on a precision positioning manipulator with separate electrical feedthroughs in order to adjust an optimum distance between cathode and extractor anode.

First basic investigations have been carried out in order to study the long-term emission stability of the CNT cathode at cryogenic gas temperatures. Unfortunately, the long-term stability was only given for an anode current of 55 µA, which is a factor of ~30 lower than the anode current of an unmodified extractor gauge. At a higher value a sudden decrease in the emission current was observed, probably caused by a partial destruction of the CNT layer.

Following development work was focused on experimental studies for determination of an optimum working point of the gauge and measurement of basic gauge characteristics for different gas species. The experimental results at room temperature show, as expected, a perfect linear relationship between ion current and pressure in the vacuum range between $5\cdot 10^{-9}$ and 10^{-5} mbar. Finally, the operability of the modified gauge was tested in a LHe-cooled vacuum chamber. For that purpose we recorded the gauge response against the pressure reading of an extractor gauge with thermionic cathode while the cooled chamber was moderately heated-up from 9 to 25 K. The thermal-triggered pressure rise inside the chamber caused by hydrogen desorption was used for gauge calibration. In Figure 2 the pressure-dependent ion current is given, indicating the strongly linear measuring behavior.

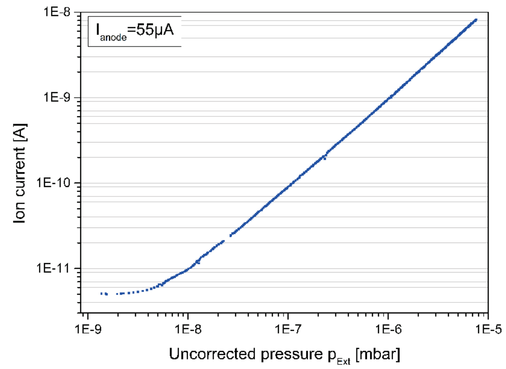

Figure 2: Ion current vs. pressure characteristic for H_2 at 9..25 K

Conclusion

We could clearly demonstrate that a FE-based extractor gauge works reliably under cryogenic vacuum conditions and provides meaningful pressure reading. However, the relative low emission current of the field cathode still restricts significantly the original measuring range of extractor gauge which is typically $1\cdot 10^{-12}$ mbar (at RT).

References

[1] Wilfert, St., Edelmann, Chr.; Vacuum 86 (2012), 556