Title: Towards a documentary standard for an ionisation vacuum gauge

Abstract

The ionisation gauge is the only vacuum gauge type suitable for pressure measurements in both high and ultrahigh vacuum environments. Applications such as the manufacture of optoelectronics, semiconductor and coatings processing, high energy physics research and metrology all require accuracy, reproducibility and sensitivity data for many gas species, all properties which are generally lacking for current ionisation gauges. A standardised ionisation gauge would improve these properties and would reduce the risk that information on relative gas sensitivity factors ceases to be applicable when a commercial gauge design is changed or discontinued. Proposals should aim to determine the relevant parameters for an ionisation gauge which is accurate, robust and with long-term stability, together with known relative gas sensitivity factors, in order to support the standardisation work of ISO TC 112.

Keywords

Vacuum gauge, ionisation gauge, gas sensitivity, emissive cathode, long-term stability, transportation stability, high vacuum, ultra-high vacuum

Background to the Metrological Challenges

High and ultra-high vacuum environments are indispensable tools for industrial and scientific applications, as diverse as the semiconductor industry, coatings for tools and glass, the manufacture of optics, optoelectronics and solar cells, vacuum pump testing, outgassing rate measurements, high-energy accelerators, plasma and fusion science, surface science, thin film studies and metrology. Knowledge of the pressure in the vacuum environment is important to ensure the correct operation of processes and that reliable products and data are obtained.

The ionisation gauge is the only vacuum gauge suitable for measuring both high and ultra-high vacuum and is widely used in industry, in science and for calibrations. While some applications only require the ionisation gauge to provide an approximate indication of the pressure, e.g. to check the residual pressure in a vacuum system, other applications such as calibration, outgassing rate measurement or pump speed characterisation require the gauge to be both accurate and reproducible. For example, for pumping speed measurements ISO 21360-1 requires an accuracy of 3 % for pressure measurements using an ionisation gauge, and whilst this possible for nitrogen this is not currently the case for any other gas.

The physical principle of an ionisation gauge is based on the ionisation of neutral gas molecules by electronic impact and measurement of the resulting ion current. ISO 3529-3 classifies ionisation gauges under two categories - those with an electron emitting cathode which is usually a hot wire, and those that use strong crossed electrical and magnetic fields to obtain a continuous discharge of electrons confined in the crossed fields. In general ionisation gauges with an electron emitting cathode exhibit better linearity and short and long term stability than those with crossed fields. The non-linearity of crossed fields ionisation gauges can result in errors in the pressure indication of up to one order of magnitude which makes these gauges unsuitable for accurate measurements. The better performance of ionisation gauges with electron emitting cathodes is due to the fact that the electron current can be controlled by the emissive cathode, the space charge effect is greatly reduced and the trajectories of the electrons are better defined by the electrode geometry. The arrangement and design of the electrodes in an ionisation gauge with an electron emitting cathode determines its general operating range.

Despite the better characteristics of ionisation gauges with electron emitting cathodes, there are a number of factors limiting their performance. Ionisation gauges are relatively fragile due to the lack of rigidity of the structure of the electrodes and movement of the electrode structure, for example due to transportation or aging of the materials, and other factors such as insufficiently stable spatial emission from the cathode or materials exhibiting a high secondary electron yield all limit their long-term stability to about 5 % over one year. The response of any ionisation gauge is also dependent on the gas species. Manufacturers usually calibrate their products for nitrogen, however other gas species including oil vapours, gases with safety and environmental issues such as phosphine, bortrifluoride, tungsten-hexafluoride etc. or rare gases may be equally important to the end user. Relative sensitivity factors provide a ratio of the sensitivity of a selected gas species with respect to nitrogen and by applying the relevant factor the apparent pressure reading (for nitrogen) can theoretically be corrected to represent the pressure of the selected gas species. However, the many different designs of ionisation gauges each produce different relative sensitivity factors and it is uneconomic and impractical to measure all their sensitivities, particularly as manufacturers change the design of their gauges over time.

ISO TC 112 "Vacuum Technology", at its meeting in Liechtenstein on 12 November 2015, recognised the need (as identified in resolution 2015-09) for a stable, accurate and robust standardised ionisation gauge, and hence for standardisation of the key parameters of an ionisation gauge. In addition, research in this field would also support ISO TC 112's work in two other projects, namely ISO NP TS 20175 "Characterization of quadrupole mass spectrometers for partial pressure measurement" and ISO NP TS 20177 "Procedures to measure and report outgassing rates".

Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the protocol.

The JRP shall focus on metrology research necessary to support standardisation in vacuum technology and specifically ionisation gauges.

The specific objectives are

1. To determine and specify all relevant parameters that are required to elaborate an ISO standard for an accurate, robust and stable ionisation gauge in the measurement range from 10^{-6} Pa to 10^{-2} Pa in order to provide a substantial contribution to the standardisation work of ISO TC112 to support resolution 2015-09.
2. To determine and provide new data for a stable ionisation gauge including relative gas sensitivity factors of this ionisation vacuum gauge, in order to provide a substantial contribution to the two ISO TC112 projects ISO NP 20175 on the calibration of quadrupole mass spectrometers and ISO NP 20177 on outgassing rate measurement systems.
3. To work closely with ionisation gauge manufacturers in order to ensure that their experience is taken into account and that the standard for the ionisation gauge will result in a gauge that is easy to use and economical to produce.
4. To contribute to the standards development work of ISO TC112 and the technical committees of other standards developing organisations to ensure that the outputs of the project are aligned with their needs related to a standard for a reliable ionisation gauge, communicated quickly to those developing the standards and to those who will use them, and in a form that can be incorporated into the standards at the earliest opportunity

The proposed research shall be justified by clear reference to the measurement needs within strategic documents published by the relevant Standards Developing Organisation or by a letter signed by the convenor of the respective TC/WG. EURAMET encourages proposals that include representatives from industry, regulators and standardisation bodies actively participating in the projects.

Proposers should establish the current state of the art, and explain how their proposed research goes beyond this. In particular, proposers should outline the achievements of the EMRP project IND12 Vacuum and the EMPIR project 14SIP01 Vacuum ISO and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 0.6 M€, and has defined an upper limit of 0.8 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 30 % of the total EU Contribution to the project.

Any industrial partners that will receive significant benefit from the results of the proposed project are expected to be unfunded partners.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the "end user" community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the "end user" community (e.g. letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies, in particular ISO TC112,
- Transfer knowledge to vacuum gauge manufacturers, the semiconductor and manufacturing sector and the research community including high-energy physics, plasma and fusion science and surface science.

You should detail other impacts of your proposed JRP as specified in the document "Guide 4: Writing Joint Research Projects (JRPs)"

You should also detail how your approach to realising the objectives will further the aim of EMPIR to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work

Time-scale

The project should be of up to 3 years duration.