NEW BEAM LOSS MONITOR IONISATION CHAMBERS ENGINEERING

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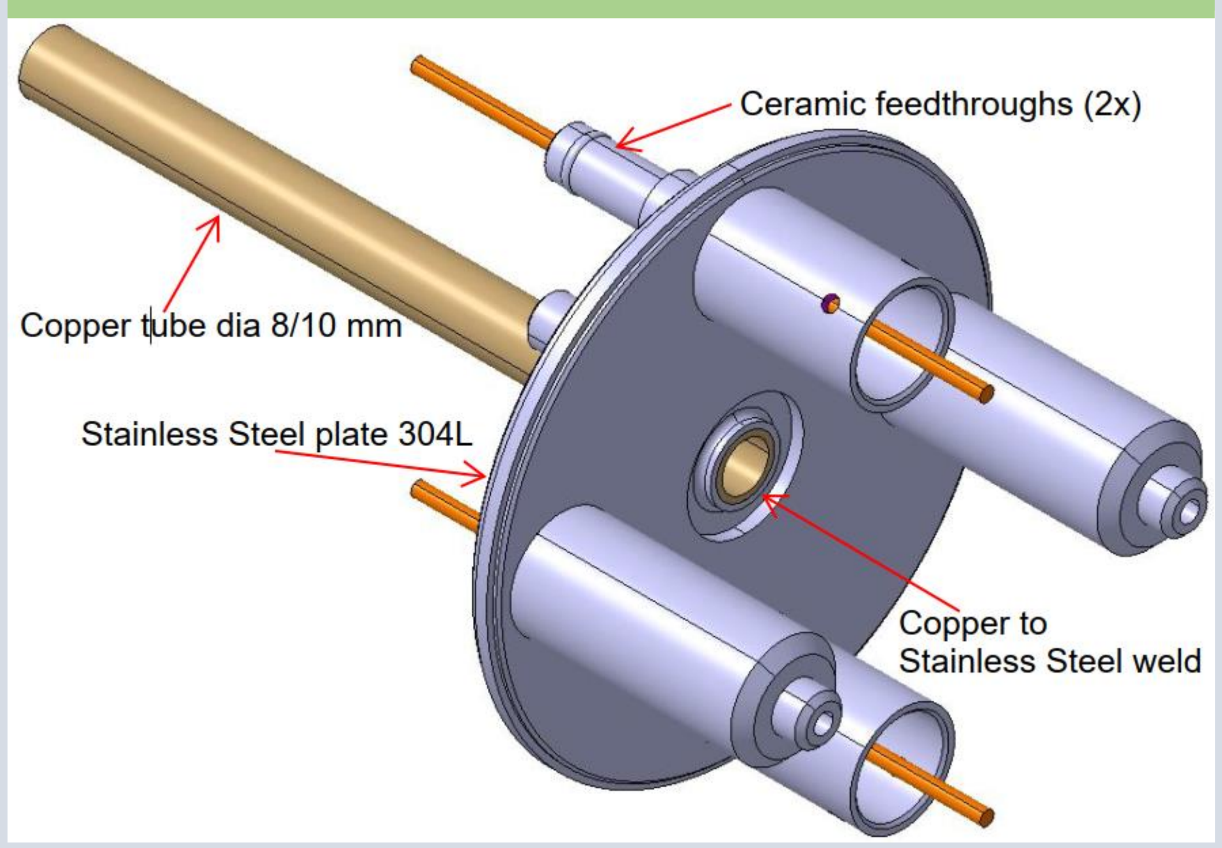
More than 4000 Beam Loss Monitor (BLM) systems are operating at CERN. About 93% of them are in-stalled in the LHC machine. The Ionisation Chambers (IC) are the part of the system where the lost beam particles ionise nitrogen gas in a chamber with electrodes at high voltage. The resulting current indicates the quantity of beam lost. In the last 20 years, all BLM ICs were produced in collaboration with external institutes.
Control of all details of the materials and processes are required to ensure instrument sensitivity and precision across the large series.
CERN took back this production process in 2022 and much of the specific knowledge of design details and production technology required re-engineering.
This paper presents production specifications, de-sign of tooling and test facilities for the first proto-types of a new series to be produced including their test at CERN facilities with beam. The future ramp-up to an industrial process to allow for a production of 1000 units in the years to come is discussed.

Beam Loss Monitor Ionisation Chamber (BLM IC)

The BLM ICs are the signal pick-up element of the beam loss monitoring system. The signal is measured by acquisition modules in the LHC tunnel, followed by processing and decision modules on the surface as part of the beam protection and interlock system. The BLM system latency to trigger a beam abort needs to remain below 3 beam revolutions around the LHC, corresponding to 267 µs. CERN has long experience with the production of BLM ICs in collaboration with external institutions. The objective of the present manufacturing campaign of 1000 BLM ICs is to prepare for the CERN High-Luminosity LHC (HL-LHC) upgrade and to complete the BLM renovation in the LHC injector complex.
The design criteria is to make BLM ICs resistant to radiation in the CERN environment for to up to 30 years of operation. To achieve this objective, only metals (aluminium, copper and stainless steel) and ceramic such as Al_2O_3 can be used. Experience has shown that very strict control of all components, pro-cesses and assembly is essential in keeping the re-quired precision.

End Plate Manufacture require a multitude of competencies:

- Precision Mechanics
- Ultra high vacuum (UHV) compatible cleaning
- Leak tight welds of stainless steel and copper
- Helium leak check to 10^{-9} mbar.l/s
- Documentation



The technically admissible leak rate for the BLM ICs, with a pressure difference of 100 mbar over a 30-year span, is $1*10^{-6}$ mbar.l/s. Assuming possible leak degradation, allowing for contingencies and adhering to standard leak test practices in industry, a maximum leak rate of $1*10^{-9}$ mbar.l/s is calculated as the engineering criterion for the delivery of the ICs.

Finished BLM (left) and electrode stack of the ionisation chamber with ceramic insulators on either side (right).

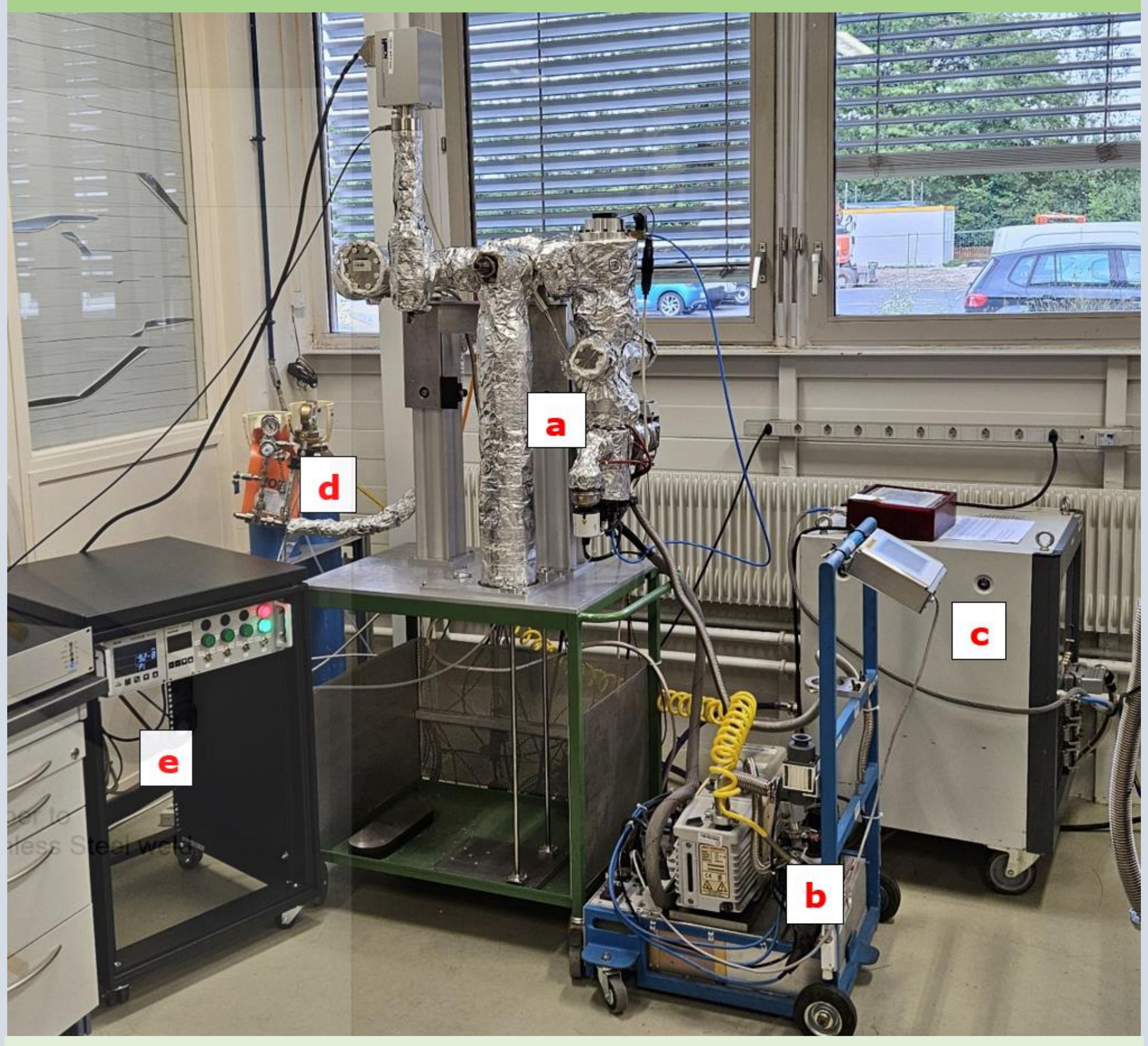
The standard BLM IC monitor is about 50 cm long with a diameter of 9 cm. The internal volume is about 1.5 l. There are 61 parallel aluminium plates separated by 0.5 cm, filling most of the vacuum container. Between each of the plates, there is a voltage of 1.5 kV. They are equipped with a low-pass filter out-side the vacuum envelope. A key element of the BLM IC is a very high impedance ceramic supporting the rods to which the parallel electrodes are fixed. The maximum current permissible across the ceramics of the assembled electrode stack is 1 pA when a voltage of 1.5 kV is applied.

Electrical Qualification

The proper functionality of the BLM IC is evaluated through the electrical qualification process. Its primary phase examines critical IC components prior to assembly, while its secondary phase validates the detector at the end of its production cycle. The primary phase is directed towards the rigorous testing of the ceramic insulators and feedthroughs guaranteeing that the procured elements comply with the specification. A custom-made test bench was built to identify electrically defective insulators. The instrument simulates the operational electrical conditions of the detector and classifies any ceramic as faulty after measuring a leakage current above 10^{-12} A. The delicate measurements of the test bench are susceptible to environmental conditions such as electromagnetic noise, temperature, humidity, and the chemical or biological contamination of the ceramic. The enclosure of the ceramic inside a Faraday cage, as well as the recording of environmental data assure the proper functionality of the device and evaluation of the ceramic.

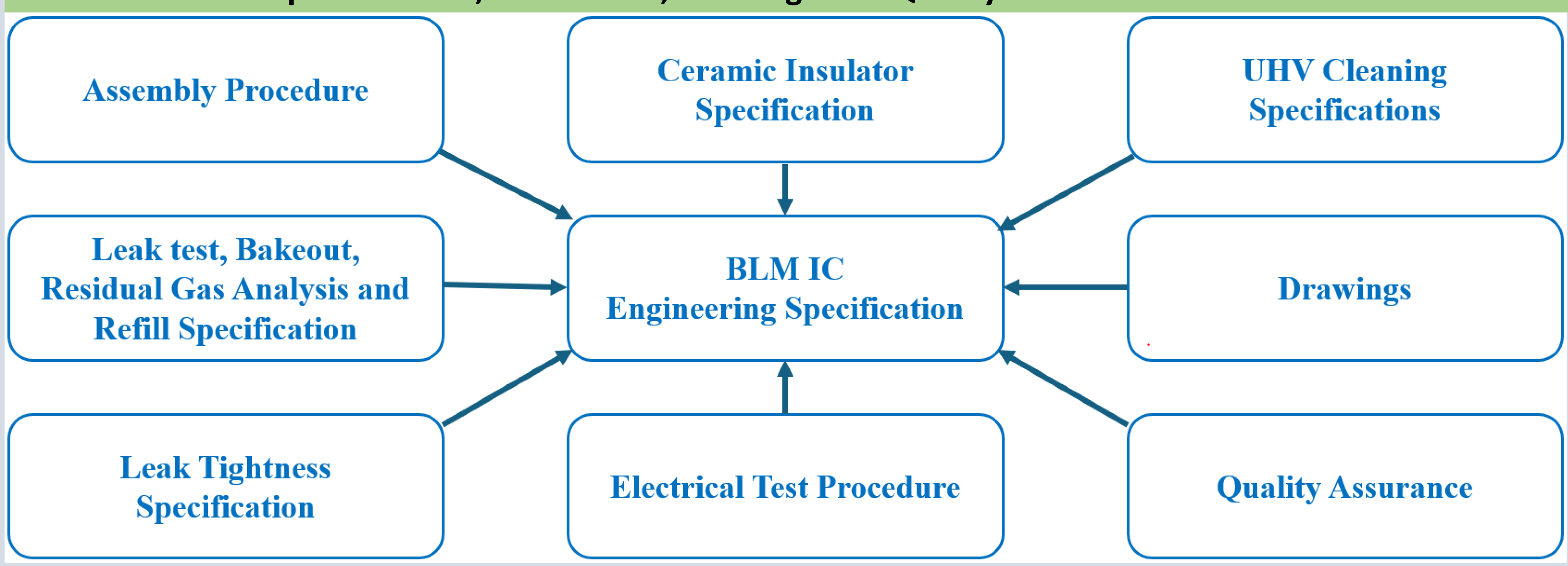
BLM IC Test Stand including:

a) bakeout and injection device with vacuum gauges and Residual Gas Analyser (RGA);
b) pumping group
c) bakeout controller
d) nitrogen and helium bottle
e) control rack for the gauges and valves.



The BLM IC is mounted on the Test Stand and a leak check to a minimum sensitivity of 10^{-9} mbar.l/s is performed. If no leak is detected, the bakeout cycle can start once the electronics of the RGA are removed.
The chambers are baked at 220 °C while being pumped. The ramp rate to heat up and cool down is 50 °C/h with a minimum plateau time of 12 h. The RGA is degassed once the system is stable at 150 °C towards the end of the bakeout, followed by a cool-down to room temperature. After over-night pumping of the system, an RGA scan is performed. If the absence of leaks and hydrocarbon levels of atomic masses above 40 relative to hydrogen can be demonstrated to be a factor of 100 lower, the scan is registered. At the end of the bakeout cycle, nitrogen class 50 is used to re-fill the BLM to the absolute final pressure of 1100 mbar, i.e., 100 mbar overpressure and the so-called "pinch-off" is performed. The pinch-off is the cut of the soft copper tube using a special plyer tool allowing for a leak tight cut of the tube from the test stand. If the remaining part of the tube on the test stand is leak tight, the opposite side on the BLM IC is considered leak tight from experience.
Currently the BLM test stand allows only one BLM IC at a time. However, an extension is planned to enable the simultaneous testing of up to 20 units during series production.

Schematic of the Specifications, Procedures, Drawings and Quality Assurance:



To reduce dependency on a small number of suppliers and ensure that the know-how is well documented, a series of technical specifications have been developed. The structure of these specifications and documents is shown on the left. This enables CERN to choose from several options for BLM IC chamber production: in-house, in collaboration with partner institutes, through industry or a combination of these options.
The ramp-up of CERN in-house production is ongoing to achieve a production of 400 BLM ICs by the end of 2025. CERN is looking forward to identifying industrial partners from CERN member states or to set up collaborations with institutes to produce a total of 600 BLM ICs starting in 2026.