RECOMMISSIONING OF THE COLDEX EXPERIMENT AT CERN

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Abstract

COLDEX (COLD bore EXperiment), installed in the Super Proton Synchrotron (SPS) at CERN, is a test vacuum sector used in 2001-2004 to validate the Large Hadron Collider (LHC) cryogenic vacuum system with LHC type proton beams. In the framework of the R&D for the High Luminosity upgrade of the LHC (HL-LHC), COLDEX has been re-commissioned in 2014. The objective is the validation of the performance of amorphous carbon (a-C) coating at cryogenic temperature with LHC type beams. The existing COLDEX Cu beam screen has been therefore dismounted and carbon coated, while a complete overhaul of the vacuum, cryogenic and control systems has been carried out. This contribution describes the phases of re-commissioning, reviews the current experimental set-up and gives an overview of the possible measurements with COLDEX, in view of its HL-LHC experimental program.

INTRODUCTION

COLDEX is an experimental test vacuum sector that mimics the cold bore and beam screen cryogenic vacuum system adopted in the LHC cryomagnets. Originally designed to measure synchrotron radiation induced gas desorption [1], COLDEX was installed in SPS in 2001 to evaluate the impact of electron-cloud effects onto cryogenic vacuum systems [2].

During LHC Run 1, significant heal load due to beam induced electron cloud was observed on the beam screen of the Inner quadrupole Triplets. Extrapolation of these observations to the High Luminosity upgrade of the LHC (HL-LHC) predicts an intolerable increase of the dissipated heat load to the cryogenic system due to electron cloud build-up [3]. In order to reduce it, a-C coating is a potential candidate to mitigate the electron cloud effects due to its low Secondary Emission Yield (SEY) achieved at room temperature [4]. For HL-LHC purpose, this proposed base-line must be validated at cryogenic temperature with LHC type beams. For these reasons, COLDEX was re-commissioned and upgraded with a-C coated beam screen in 2014. A review of its scientific objectives is available in [5].

VACUUM SYSTEM

The COLDEX cryostat has been recovered from 2004. It houses a ~2.2 m long OFE copper beam screen (BS) inserted in a 316LN stainless steel cold bore (CB). The inner diameter (ID) of the CB is 113 mm. The BS is a circular, ID 67 mm, extruded pipe (Figure 1). It is perforated by two rows of 7.5x2 mm elongated holes (slots) which gives a transparency of 1% to the CB. The slots are shielded on their back with baffles capable to intercept straight electron paths to the CB. The BS is equipped with two 0.1 mm thin copper coated cold-to-warm transitions (CWTs) at its extremities. RF continuity is assured with RF fingers. The final adaptations to the upstream and downstream ID 100 mm chambers are tapered with conical apertures of 45°. Total pressure is measured at these two warm locations, *i.e.* upstream and downstream the BS, via calibrated Bayard-Alpert (VGI) hot cathode and Penning (VGHB) cold cathode ionization gauges.

Figure 1: Picture of the a-C coated beam screen during re-installation on February 2014.

A room temperature chimney faces a circular, ID 35 mm, vacuum port derived at the centre of the BS. At its top, a BA gauge is installed. This gauge allows monitoring the gas pressure in the BS which may be affected by electron stimulated desorption during electron cloud bombardment.

Two calibrated quadrupole mass spectrometers (RGA) are mounted on the BS chimney top and on the downstream chamber to perform analyses of the residual gas species in the cryogenic and room temperature parts, respectively. In the downstream warm chamber, a gas injection system, consisting in a bakeable 3.1 litres gas reservoir equipped with capacitance pressure gauges and connected to the vacuum system via variable leak valve, is fitted. This system is used to perform studies of gas transmission along the BS and pre-condensation of gas species onto the cold surface of the BS.

In order to give direct indication of electrons activity, two electrodes are employed. The chimney circular, Ø18 mm, electrode faces the BS aperture to the chimney

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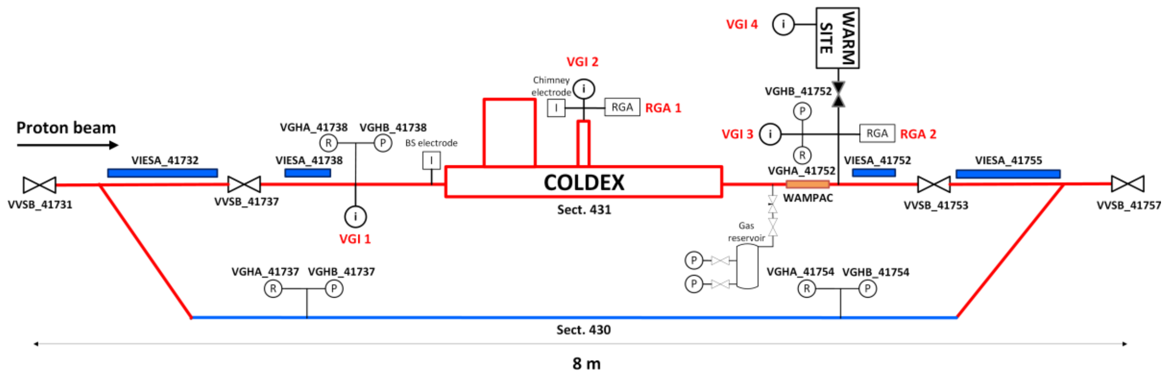

Figure 2: SPS/LSS4 vacuum sectors 430 and 431 during COLDEX operation.

port. It is shielded against beam image current by a grid. The BS electrode is obtained by electrically isolating one of 178.5 mm baffles facing the BS slots. During operation, the electrodes can be polarized up to ±1 kV, so to cover a large part of the energy spectrum typical of the electron cloud. Resulting electric current is shunted to ground through an electrometer. In 2014, the BS electrode was found shorted to ground, therefore not utilized.

Solenoid coils (VIESA in Fig. 2) have been wrapped on the transition chambers and the by-pass lines upstream and downstream to COLDEX. A longitudinal magnetic field up to 2 mT is obtainable, sufficiently large to clear out secondary electrons potentially produced by multipacting in these parts, thus isolating COLDEX from side effects. A TiZrV non-evaporable getter (NEG) coated WAMPAC [6] calorimeter, previously ex-situ activated and already electron cloud conditioned in the past, is installed downstream to COLDEX. A simplified schematics layout of the COLDEX experiment is shown in Figure 2.

CARBON COATING

In order to mitigate the electron cloud build up in modern high intensity particle accelerator, few methods have been recognized: surface conditioning (scrubbing), low SEY thin-film coatings, clearing electrodes, and beam pipe surfaces with grooves or slots. Amorphous carbon coating is a promising candidate due to its low SEY and convenient deposition on un-bakeable vacuum chambers [4, 7]. During re-commissioning, the inner walls of the COLDEX BS were coated with 400 nm thick a-C film using DC magnetron sputtering in cylindrical configuration. A graphite rod (ashes content below 400 ppm) was used as target. A magnetic flux of 180 Gauss was applied by a solenoid during the coating process. Krypton was adopted as discharge gas at a pressure of $5 \cdot 10^{-2}$ mbar. The power density was kept at 100 W/m and the discharge voltage ~700 V. The surface SEY was measured on witness samples after two months of air exposure, wrapped in aluminium foil. Details of the laboratory SEY measurement system can be found in [4]. The measurement results (Figure 3) show that the obtained δ_{max} after coating was < 1.1 at room temperature. The corresponding E_{max} is situated in the 280÷300 eV window. The surface SEY at cryogenic temperature (4.7 K) is expected to be similar [7].

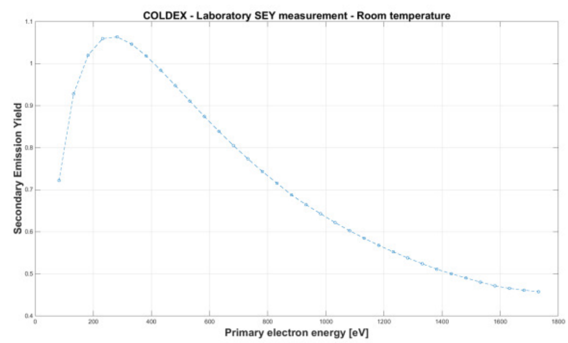

Figure 3: Laboratory measurement of SEY on one witness sample obtained during COLDEX BS a-C coating.

CRYOGENIC SYSTEM

The COLDEX cryogenic infrastructure is inherited from the 2001 installation in SPS/LSS4. During re-commissioning, no additional equipment was added to the installation: only logic and control system was refurbished/upgraded.

The required cryogenic capacity for COLDEX is delivered by a TCF20 Sulzer cold box. The process compressor, oil removal system and pressure management panel are installed in dedicated building on the surface, while the cold box itself is integrated underground, close to the client cryostat. The system runs in liquefaction mode and is able to deliver a maximum capacity of 0.8 g/s (without the optional LN_2 boost). The liquefied helium at 4.5 K and 1.3 bar is collected in an external 17 l phase separator dewar through a gas-return shielded transfer line, and then distributed to the COLDEX cryostat through a vacuum insulated transfer line. The maximum liquid helium inventory of the cryostat is estimated to be 15 l. On the inside, a small He buffer serves as phase separator. The gaseous flow due to He vaporization is used to cool down the BS. It is thermally controlled between 4.5 K and 100 K by means of an electric heater (P_{max} = 300 W). The flow rate is measured at room temperature after a warming-up heater at the outlet of the BS. Flow can be enhanced to reduce the BS temperature gradient by increasing the buffer vaporization rate. The He buffer is linked to the CB vessel via a Joule-Thompson valve. The CB can be cooled with liquid He at 4.5 K (1.3 bar), and eventually below 3 K by lowering the He bath pressure. The BS and CB temperatures are measured by calibrated CERNOX resistance sensors from 1.9 K to room temperature. The heat load per unit meter dissipated on the BS can be estimated by:

$$Q = \frac{G \cdot \left[h(T_{out}) - h(T_{in}) \right]}{L_{BS}} \text{ [W/m]} \quad (1)$$

G is the mass flow rate (g/s), h the gas enthalpy of the fluid at the BS outlet (T_{out}) and inlet (T_{in}) respectively and L_{BS}=2.232 m the length of the BS. In 2014, the typical static heat load measured on the BS was 1.9 W/m after facility cool-down. Dynamic heat load can be dissipated due electron cloud and is monitored during experimental runs. The contribution of power losses due to coupling impedance heating are negligible [8].

CONTROL SYSTEM

Installed in a by-pass line of the SPS ring, COLDEX is assembled on a moving stage so that beam can pass either through the experiment during experimental runs or through the standard SPS beam pipe during normal operation. A PLC-based architecture has been developed and implemented in order to control and monitor the stage movement, using a PLC Siemens S7-300 series and a HMI Siemens TP177BTM for on-site control. The stage movement is interlocked by the SPS LSS4 vacuum valve controller (VVS): both the sectors (430, 431) valves should be closed to enable it. In addition, an inhibition system, based in a human control interface through a safety key, has been implemented: COLDEX operation is allowed inhibiting the SPS beam East Extraction bump, not compatible due to aperture restriction.

The refurbishing of the cryogenic control system include the realization of a new electric infrastructure according to CERN standards, PLC (Schneider, Siemens) programming, implementation of a supervisory system and re-commissioning of the plant. The revamping strategy has been preceded by a requirement analysis and review of the previous logic developed in LabVIEW. Field process instrumentation has been partially upgraded; a brand new operator supervision interface has been deployed, taking particular care in developing automated control logics (*e.g.* PID regulation loops for CB/BS temperature adjustment, time controlled ramps for induced warm-up transients).

The experiment status is published on the CERN vacuum and cryogenic SCADA applications (Siemens WINCC-OA, UNICOS) and shared to the other control systems through the middleware interfaces as CMW. Data acquisition is performed during experimental runs to measure vacuum and cryogenic systems parameters. A LabVIEW console is adopted for this purpose, due to its flexibility. Total pressures along COLDEX, the BS temperatures and He cooling flow, and WAMPAC's temperature data are retrieved and stored. Live computation of the heat load dissipated on the BS is performed. Residual gas analyses are carried out continuously to monitor the residual gas composition and evolution in the cryogenic and warm parts. Some of this information (mainly system parameters) is in parallel retrieved by CERN SCADA applications and stored on the TIMBER logging service. In order to monitor the electron activity, electrodes are connected to Keithley sourcemeters and can be either DC polarized while electron current is read-out at 5Hz, or quick potential swept from -1kV to 1kV to acquire the energy spectrum of the impinging electrons. A Java API for Parameter Control (JAPC) is charged to retrieve data from the SPS DC Beam Current Transformer (BCTDC.31832) at 10 Hz and accurately monitor the beam intensity and supercycle circulating in COLDEX.

CONCLUSIONS AND PERSPECTIVES

Amorphous carbon coatings are proposed to mitigate electron cloud effects on the beam screens of the HL-LHC Inner Triplets. COLDEX, a system already installed in SPS in 2001, has been refurbished, upgraded and recommissioned to validate this baseline at cryogenic temperature with LHC type beams during a 2014-2016 experimental program. The current setup allows having experimental indication of the pressure rise, gas composition, dissipated heat load, and electron activity.

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