MACHINE OPERATION ISSUES RELATED TO THE VACUUM SYSTEM OF THE ESRF

R. Kersevan*, M. Hahn, I. Parat, D. Schmied, ESRF, Grenoble, France

Abstract

This paper deals with various operational issues related to the vacuum system of the ESRF storage ring. The impact on the vacuum pressure, beam lifetime, beam losses and other machine parameters after installation of new chambers, RF cavities and insertion devices, and the appearance of vacuum leaks, is discussed in some detail. Particular emphasis is given to the behaviour of the prototype of a 2m-long cryogenic in-vacuum undulator, a spare RF cavity, and one NEG-coated chamber. Lessons learned from the operation of these vacuum components will be extended to the proposed machine upgrade, see also [1-8].

INTRODUCTION

The ESRF storage ring (SR) is in its 14th year of beam delivery to users. The 6 GeV, 200 mA beam (in multi-bunch filling mode), creates copious amounts of photons, which generate rather large outgassing loads. These, in turn, interact with the stored beam and generate bremsstrahlung radiation (BS) and beam losses on the walls of the vacuum chamber surronding the beam. The 79 insertion device (ID) segments installed on 28 5m-long straight sections contribute to create a harsh environment for many components and equipments installed inside the tunnel. A number of prototype chambers and vacuum equipment for the ambitious upgrade plan detailed in [1-8] is in the design and test phase now, as described below.

RECENT NEW INSTALLATIONS

Background

During the past 12 months, among many other components, the following vacuum installations have been performed on the SR. The impact of some of them on the operation of the machine is detailed in the following:

- Cryogenic in-vacuum undulator, on the ID6 straight section (SS).
- Prototype 5m-long “10mm”, NEG-coated extruded aluminium chamber, with middle-pump, on the ID30 SS.
- Un-baked in-vacuum undulator, on the ID15 SS.
- Spare 352 MHz RF cavity, cavity 5, on ID25 SS.

Cryogenic Permanent Magnet Undulator (CPMU)

A 2m-long CPMU has been installed during the 2007 Winter shutdown (SD) [4, 8]. From the vacuum point of view its preparation has been similar to that of non-cryogenic devices of the same length. We recall here that at the end of 2007 nine in-vacuum (IV) undulators were installed inside the SR (eight 2m-long ones, plus one 1.6m-long prototype). ***Lab set-up***: after assembly, the CPMU has been pre-baked for several days in the lab, prior to installation. The bake-out temperature was 120°C, constrained by the 100°C limit on the permanent magnet (PM) material. At the end of the bakeout (BO) cycle, the static pressure was 6.0E-10 mbar, with all pumps running. The pumping system of the CPMU consists of one 500 l/s double-ended ion-pump (IP), eight 75 l/s IPs, one GP500 lumped NEG pump (installed on the back flange of the 500 l/s IP), and two titanium sublimation pumps (TiSPs). Three inverted-magnetron gauges (IMGs) and one residual-gas analyzer (RGA) are installed on the device. Special care has been put into installing 20 type-T thermocouples inside the CPMU, in order to measure the temperature of sensitive parts, such as the RF contact fingers installed on the entrance and exit tapers, and some of the PM blocks and support aluminium beams. The last two are very important, since their temperature is linked to the magnetic beam intensity and spectral quality of the photon beam, because a temperature gradient along the PM is equivalent to a gap taper [8]. The RGA spectrum before the BO cycle has shown the presence of H_2, CO, CO_2, CH_4, strong H_2O peaks, and traces of higher masses corresponding to hydrocarbon contamination (C_xH_y). After BO, the C_xH_y peaks have considerably decreased, as well as the water peaks. ***Installation***: the CPMU has been installed on the ID6 BL, alongside with a ~2m-long, “10mm”, NEG-coated aluminium chamber (CV2093), hosting one standard ESRF ID segment. The SS, separated by gate valves from the two neighboring cells 5 and 6, has been mildly baked again for one week, while all the other vacuum components were being baked at temperatures between 150 and 200 °C, and the IPs fully baked using their internal heaters. After this in-situ BO cycle the pressures measured along the SS where as follows: PEN1= 1.6E-9 mbar; PEN3= 2.0E-9 mbar; PEN1-INVAC= 2.2E-9 mbar; PEN2-INVAC= 7.4E-10 mbar; PEN3-INVAC= 1.58E-9 mbar. PEN1 is the IMG installed upstream of the CPMU, while PEN3 is installed downstream of the 2m-long CV2093. The CPMU RGA spectrum showed that the C_xH_y peaks had almost disappeared, and the main gas specie was H_2, followed by CO, H_2O, and then CO_2 and CH_4. At this point the cryo-loop started feeding LN_2 via a dedicated transfer line [8], and the IV temperatures started to drop slowly, due to the rather large mass to cool down, and the relatively small cooling power of the cryo-coolers. After ~30 hours the temperatures of the PM Al bars had dropped to the 96-127 °K range, and the pressures had decreased considerably on 4 of the 5 IMG gauges, only PEN3 being insensitive to

---

*Corresponding author: kersevan@esrf.fr

the temperature and pressure drop inside the CPMU, due to the small vacuum conductance c and distributed pumping of the NEG-coated CV2093, c~1 l•m/s. This result was confirmed by the smaller change of the spectrum of the RGA installed in front of the PEN3 gauge, which was less sensitive to the outgassing of the CPMU during the cryo-loop warm-up. ***Dynamic vacuum***: once the machine has re-started, the CPMU conditioning has been rather smooth and uneventful. Its dynamic pressure rise, in mbar/mA, has decreased after an integrated beam dose D=100 A•hour from ~2.0E-9 down to ~2.0E-11 mbar/mA, with a power-law dependence on D with exponent ~ -2/3, similar to all other in-vacuum undulators installed on the SR since 1999. ***Warm-up cycle***: during the March 2008 SD, the Operation and ID Groups wanted to check what would have happened in case of a failure of the cryo-cooling loop, with a sudden temperature and pressure rise inside the CPMU. The cryo-loop was therefore stopped, and the temperatures on the CPMU went up to room temperature, in about 6 days. A pressure burst, measured on PEN1, the 3 IMGs on the CPMU and to a much smaller extent also PEN3, immediately followed this cryo-loop stop. The RGA spectrum at this point showed a sudden rise of the peaks corresponding to the following gas species: H_2, H_2O, CO, CH_4 and CO_2. The test lasted for ~4 days, and at the end all pumps along the SS were re-generated, and the NEG-coating of CV2093 re-activated at 180 °C for 2 hours. Static and dynamic pressures following cooling down of all pumps and chambers, were as good as those prior to the CPMU warm-up test.and showed only a very small initial rise followed by a steady decline, similarly to what is observed on all SSs after a SD.

Middle-Pump Narrow Gap Chamber Prototype

At the end of 2007, the ESRF SR was equipped with ~103 meters of NEG-coated chambers, mainly 5m-long ones (CV5073) [9]. One of the main changes foreseen for the machine upgrade is to increase the length of the SS available to IDs from ~5 to ~7 metres, by a careful re-design of the lattice and magnets [4, 6]. On the vacuum side, this will translate into the possibility of having either two 3m-long in-vacuum IDs or even a single 7m-long narrow-gap chamber hosting 4 undulator segments [4, 6]. In the last case the very small specific conductance of the chamber, very likely close to the 1 l•m/s value of the present CV5073s, could possibly be the source of high-BS radiation, in case of a reduced efficiency of the NEG coating. The decision was therefore taken to test the effectiveness of a small IP being installed in the middle of the CV5073, as a test bed for the longer ID chamber. The geometry of the pumping port and its effect on the pressure profile has been described elsewhere [9]. In order to have an additional point of measure of the pressures, we have added a "tee" to the CF38 flange on the chamber, and installed an additional IMG, called PEN2. By switching on and off the 20 l/s IP on the far end of the tee, and looking at the same time at the beam losses measured in the SR tunnel by a set of beam-loss monitors (BLMs) the effectiveness of the middle-IP concept has been checked. At the same time the Safety Group has looked at the data collected by a small ionization chamber accurately placed on-axis inside the experimental hutch of ID30, as done in [10]. The additional IMG has also given to us the opportunity to check the effectiveness of the NEG-coating along the CV5073, something we had not done since the first NEG-coated prototype had been installed for one full year in 1999-2000, a "15mm" profile [12]. When the middle-IP is stopped while a ~200 mA beam is stored, the pressure on PEN2 goes from 1.3E-9 mbar up to 2.0E-9 mbar, while the two neighboring IMGs PEN1 and PEN3 do not show any change at all. At the same time, the BLMs installed near crotch 1 and 2 of cell 30 show only a very modest increase, and the same is measured by the on-axis ionization chamber in the ID30 BL hutch. The installation and test of a ~6m-long ID chamber is foreseen for this year, by removing the existing and unused last quadrupole of cell 29 and first quadrupole of cell 30 [4-6], and the middle-IP concept will be maintained and its effectiveness checked again.

Unbaked In-Vacuum Undulator

In light of the promising results obtained by the CPMU discussed above, the ID group plans to change the material used for the PMs to one with higher coercivity [8]. The chosen material will not allow even a mild BO at 80-100 °C –which we would implement just to minimize the condensation of gas species during a BO of the remaining parts of the SS–, and therefore we have decided to test the installation of an unbaked IV ID, on the ID15 SS. As for ID6, the ID15 SS was composed of the 2m-long IV ID, plus a NEG-coated CV2093, with the same number of IMGs and RGAs as the ID6 SS (5 IMGs, 2 RGAs). The only precaution which was taken was to fully heat the nine IPs, activate the lumped NEG pump, degas and sublimate the two TiSPs, and degas the two RGA filaments, after installation and pump-down performed using dry boil-off N_2. The RGA spectrum taken in the lab at the end of the assembly of the IV ID was rather clean, showing only peaks corresponding to H_2, H_2O, CH_4, CO_2 and very small traces of C_xH_y, but this was not repeated, for reasons which have not yet been clarified, once the device was installed on the ID15 SS. At this time, the RGA showed a large contamination level, with peaks extending above the 100 a.m.u. limit of detection of our RGAs. We then simply heated all IPs, activated the lumped NEG pump, and degassed and sublimated the TiSPs. The obvious consequence of this contamination was that the pressure rise inside the device, when the first beam was injected at the re-start of the machine, was in the 10^{-6} mbar range with only 60 mA beam stored. On the other hand, the conditioning action of the photon beam was such that most RGA peaks corresponding to masses higher than ~70 a.m.u. disappeared within few tens of A•hour dose, and a steady reduction of all other peaks was measured again. Also, the beam lifetime after re-start was lower than that measured at comparable integrated beam doses after previous SDs.

In order to improve the situation, the only operation which could be carried out –unlikely all the other previous IV installations where pre- or in-situ BO cycles had been performed–, was to perfrormed repeated sublimations of the TiSPs. As a consequence, the dynamic pressure plots (dP/dI (mbar/mA) vs integrated beam dose D (A•hour)) produced the typical "sawtooth" profile, with sudden drops of dP/dI followed by a decreasing slope and saturation until another sublimation is performed. On the other hand, the experimental beamline ID15 has been able to take beam within few days after re-start, and the beam lifetime has risen to 47 hours at 200 mA and 11.3 A•hour dose (start of User Delivery Mode).

Installation of a Spare 352 MHz RF Cavity

At the end of RUN3 of 2007, a severe vacuum leak appeared on the RF cavity 5. This cavity had been installed together with cavity 6 on the ID25 SS during the summer SD of 1997. The leak was located on the Cu-to-Cu high-temperature braze on the port of one of the two cavity tuners, and was impossible to stop by applying the spray varnish which we had successfully used many times to seal vacuum leaks. Luckily, the leak would appear only when the cavity was in active mode, and disappear in passive mode. Therefore, cavity 5 and 6, which share the same waveguides and klystrons, were put off-line and left passive until the Winter 2007 SD, while a spare cavity was prepared and RF conditioned in a dedicated hutch. This spare cavity was installed during the 2007 Winter SD. At re-start, it became immediately clear that the vacuum inside this cavity was not as good as expected. The RGA installed on the cavity was showing peaks corresponding to severe C_xH_y contamination, and would condition extremely slowly. Also, and rather unexpectedly, it became evident that when 16-bunch mode filling was implemented on the machine, the lumped NEG pumps installed on the back flange of each of the two 500 l/s IPs pumping on the cavity were taken to very high temperatures, close to 300 °C. This in spite of the fact that the 500 l/s IPs have RF screens installed on the cavity flanges (namely seven 10mm-wide racetrack-shaped slots covering the CF150 flange opening, on a 2mm thick Cu disc, corresponding to a total conductance of ~ 910 l/s). Preliminary measurements carried out by the RF Group on the replaced and leaky cavity 5, using a spectrum analyser, have indeed given indications that the volume inside each 500 l/s IP body can act as a resonator for higher harmonics of the fundamental frequency [13], thus heating up the NEG pump inside the 500 l/s IP bottom flange. The concomitant pressure rise corresponding to the equilibrium pressure of the NEG material at 300°C [14], is close to the measured one of 4.0E-8 mbar. Cavity 6, on the other hand, has two TiSPs in place of the two GP500 NEG pumps, and better vacuum, and we are envisaging to replace the NEG pumps of cavity 5 with TiSPs soon.

CONCLUSIONS

The impact on the operation of the ESRF storage ring after installation of several vacuum components has been detailed. New cryo-cooled permanent magnet in-vacuum undulators seems to be a viable solution, even without bake-out. A new pumping concept for narrow-gap ID chambers has also been successfully tested. An unexpected problem on one spare RF cavity has led us to operate the machine under abnormal conditions, but still preserving all beam parameters for the users.

ACKNOWLEDGEMENTS

We wish to thank the collaboration and help from our colleagues in the Vacuum, Operation, RF, Front-End, ID, Safety, and Mechanical Engineering groups, and strong and encouraging support by the Machine Director Pascal Elleaume

REFERENCES

[1] V. Serriere, "Status of HOM Damped Room-Temperature Cavities for the ESRF Storage Ring", this conference MOPP108.

[2] D. Schmied et al., "Presentation of the ESRF Temperature Monitoring System From an Operational Point of View", this conference TUPP011.

[3] D. Schmied et al., "Presentation of the New ESRF Vacuum Control Applications From an Operational Point of View", this conference TUPP012.

[4] P. Elleaume et al., "Upgrade of the ESRF Accelerator Complex", this conference WEPC010.

[5] L. Hardy et al., "Operation and Recent Developments at the ESRF", this conference WEPC022.

[6] A. Ropert et al., "Upgrade Plans for the ESRF Storage Ring Lattice", this conference WEPC051.

[7] T. Perron et al., "New Preinjector for the ESRF Linac", this conference WEPC087.

[8] J. Chavanne et al., "Construction of a Cryogenic Permanent Magnet Undulator at ESRF", this conference WEPC105.

[9] R. Kersevan et al., "Upgrade Plans of the Vacuum System of the ESRF", Proc. PAC-07 Conf., MOPAN011.

[10] P. Berkvens, P. Colomp, R. Kersevan, "Calculation, Measurement and Analysis of Vacuum Pressure Data and Related Bremsstrahlung Levels on Straight Sections of the ESRF", Proc. EPAC-06 Conf., TUPCH171.

[11] M. Hahn et al., "Status of NEG Coating at ESRF", Proc. PAC-05 Conf., ROAD005

[12] R. Kersevan, "Performance of a Narrow-Gap, NEG-Coated, Extruded-Aluminium Chamber at the ESRF", Proc. EPAC-2000 Conf. , THP5B11.

[13] V. Serriere, ESRF RF Group, private communication.

[14] "SORB-AC Cartridge Pumps MK5 Series", SAES Getters Inc. document, http://www.saesgetters.com.