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INSTALLATION AND COMMISSIONING OF THE SIRIUS VACUUM SYSTEM

R. M. Seraphim†, R. O. Ferraz, H. G. Filho, G. R. Gomes, P.H. Lima, R. F. Oliveira, B. M. Ramos, T. M. Rocha, D.R. Silva, M. B. Silva, CNPEM, Campinas, Brazil

Abstract

The installation of the Sirius accelerators was completed in 2019. The vacuum installation of the booster took place in October 2018. The booster vacuum chambers were baked-out *ex-situ* and the vacuum pumps, gauges and valves were assembled prior to the installation in the tunnel. The vacuum installation of the storage ring took place from May to August 2019. The vacuum system of the storage ring is based on fully NEG-coated chambers and each sector was baked-out *in-situ* for NEG activation. The average static pressure in the booster is in the range of low 10^{-9} mbar. In the storage ring, 95% of the pressures are in 10^{-11} mbar range and 5% are in 10^{-10} mbar range. The first beam was stored in the storage ring in December 2019. The vacuum system has been performing well, and an effective beam cleaning effect has been observed for the NEG-coated chambers. At a beam dose of 70 A·h, the storage ring already achieved the design normalized average dynamic pressure of $3x10^{-12}$ mbar/mA.

A summary of the installation and the commissioning status of the vacuum system will be presented.

INTRODUCTION

Sirius is a 4th generation light source with a sub-nm.rad horizontal emittance. The booster has a circumference of 497 m and its lattice is based on 50 modified FODO cells [1]. The storage ring is based on a 5-bend achromat (5BA) lattice [2], with a circumference of 518 m comprising 20 achromat cells, 10 straight sections of 7 m and 10 straight sections of 6 m.

The vacuum chambers of the booster and transfer lines were made of AISI 316L stainless steel and their pumping is based on discrete small ion pumps. In the storage ring, which is based on a compact lattice, narrow vacuum chambers made of OFS copper were used, and the vacuum pumping is based mainly on NEG coating. Unused synchrotron radiation is distributed along the vacuum chambers' cooled walls.

The booster and transfer lines target pressures are in 10^{-8} mbar range with a beam dose of 1 A.h. The storage ring has a target pressure of $1\cdot10^{-9}$ mbar considering a stored current of 350 mA when a beam dose of 100 A·h is achieved.

The vacuum system of the storage ring was designed for using an in-situ bake-out concept, which uses thin heaters permanently installed on the chambers. The vacuum chambers and heaters were designed for a maximum bake-out temperature of 230 °C. More details about the bake-out and used heaters can be found in [3].

† rafael.seraphim@cnpem.br

INSTALLATION

The installation of the Sirius accelerators started with the Linac in March 2018. In October 2018, the booster and Linac-to-booster transfer line (LTB) vacuum systems were installed in 11 days. The storage ring and booster-to-storage ring transfer line (BTS) were installed from May 2019 to August 2019. A strategy of using two installation teams working in parallel was adopted. The process flow chart showing the main installation steps can be seen in Fig. 1.

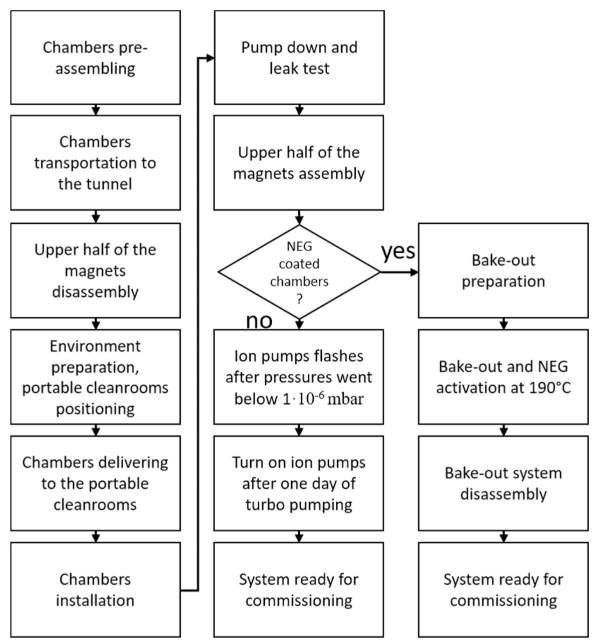

Figure 1: Vacuum installation process flow chart.

Booster and Transfer Lines

The LTB and BTS have 21.3 m and 27 m, respectively. The vacuum system of the LTB and BTS are divided by all-metal gate valves in 3 and 4 sectors, respectively.

The booster is installed in the same tunnel of the storage ring. The vacuum system of booster is divided in 14 sectors. Excluding some sectors (e.g., injection, extraction, and RF cavity), each booster sector has about 50 m and is sectorized by all-metal gate valves.

The vacuum chambers of the booster and transfer lines were baked-out *ex-situ*. The vacuum pumps, gauges and valves were assembled prior to the installation in the tunnel. In this way, only the electron beam path connections were done during the installation, which allowed a quick assembly and therefore the chambers were exposed to atmosphere for a short time.

The installation of the chambers was carried out by two teams working in parallel in two separated ISO 7 portable

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cleanrooms (Fig. 2). There was a third team preparing the chambers by venting, disassembling blank flanges and unused right-angle valves, and delivering the chambers ready to be installed.

The sectors were pumped down by in-house designed pumping carts. Each pumping cart is comprised of a turbo-molecular pump, a dry mechanical pump, a vacuum gauge integrated to an 835 VQM mass spectrometer and a gas venting system with a purifier.

Right after the chambers were connected, a helium leak check was performed to certify a leak tightness equal or better than $1 \cdot 10^{-9}$ mbar·l/s.

The ion pumps (individually controlled) started to be flashed when the pressures were below $1 \cdot 10^{-6}$ mbar and were turned on after about 24 hours of pumping down with the pumping carts.

Figure 2: Vacuum teams assembling the booster sectors.

Storage Ring

All the storage ring vacuum chambers were manufactured and NEG-coated in-house. After the NEG coating process, the chambers were sealed and stored in batches according to their assembling sectors in the storage ring. The developed bake-out thin heaters [3] were installed on the chambers prior to the installation in the tunnel (Fig. 3).

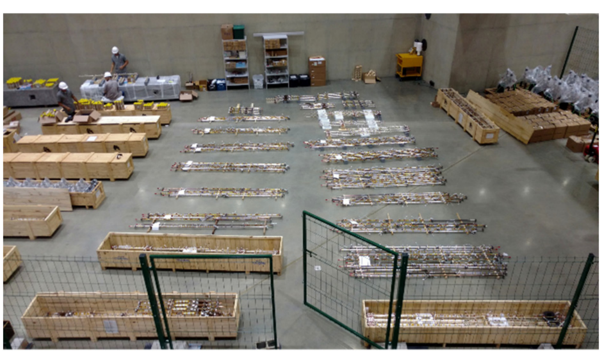

Figure 3: Chambers' preparation area - bake-out heaters' installation phase.

The installation started by assembling all the 20 arcs and then assembling the straight sections. The injection section was the last installed. The installation was carried out by two teams working in parallel in the same arc. Inside of each portable cleanrooms the teams were divided in two pairs, one pair of people was responsible for preparing the chambers by venting and disassembling the cap flanges, and the other pair of people was responsible for installing the chambers and components. Two people outside of the portable cleanrooms were responsible for unboxing and delivering the chambers to the installation teams in the portable cleanrooms.

Each sector was pumped down by 3 pumping carts. A careful helium leak check was performed to certify a leak tightness equal or better than $2 \cdot 10^{-10}$ mbar·l/s. After certifying the leak tightness of the sectors, the bake-out system was prepared by installing heating jackets and tapes on valves, bellows, BPMs and masks. Figure 4 shows an arc ready for the bake-out process. The bake-out of each sector took about 60 hours, with 20 hours of NEG activation. During the bake-out process, two leak checks were performed: one at the non-NEG coated chambers plateau temperature, and one at the NEG activation temperature. A final leak check was performed right after the chambers cooled down and then the sector was considered ready.

Figure 4: A storage ring arc ready for the bake-out process.

Main Problems

During the installation period, few problems were faced. A booster dipole chamber was damaged during the alignment of the girders. Fourteen convection enhanced Pirani gauges were leaking. Few RF shielded bellows stuck in closed position after bake-out and had to be reopened by using a special developed expanding device. One right angle valve was leaking after pumping cart ventilation. One arc was vented by a human mistake right after the NEG activation.

VACUUM PERFORMANCE

The commissioning of the Sirius accelerators started in 2018. In the first semester of 2018, the commissioning started with the Linac right after its installation. The first beam turns (still with 150 MeV) in the booster were achieved in March 2019, but the commissioning was interrupted during the storage ring installation and restarted in October 2019. In 2019, the storage ring was installed and in December the first beam was stored.

Booster and Transfer Lines

The vacuum in the booster and transfer lines is monitored by 23 and 8 inverted magnetron gauges (IMGs), respectively. The pressures measured by the ion pumps are also used to monitor the vacuum. The average static pressure measured by the IMGs in the transfer lines and booster are in low 10^{-9} mbar range. The vacuum commissioning of

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the transfer lines has evolved well. The dynamic pressure decreased as expected and quickly achieved the target of staying below $5 \cdot 10^{-8}$ mbar.

In the booster, the dynamic pressure has been slowly decreasing with the beam dose and have not achieved the target of staying in low 10^{-8} mbar range yet. The dynamic pressure is still a factor of 5 higher than the design value. The current beam dose is 0.4 A·h and there is a tendency to get closer to the target pressure when the design beam dose of 1 A·h is achieved.

Storage Ring

The storage ring is based on fully NEG-coated vacuum chambers. The vacuum is monitored by 60 IMGs, 2 IMGs in each arc and 1 IMG in each straight section. As in the booster and transfer lines, the pressures measured by the ion pumps are also used to monitor the vacuum. After the installation, 95% of the pressures measured by the IMGs were in 10^{-11} mbar range and 5% were in 10^{-10} mbar range.

The pressures stayed in 10^{-10} mbar range with the first stored beam current of 30 µA.

Figure 5 shows the normalized average dynamic pressure rise (ΔP/I) as a function of the beam dose. The average dynamic pressure decreased well as the beam dose increased. Also, an effective beam cleaning effect is verified by the slope of the curve, -0.78, which is close to the values reported in other machines [4, 5]. The target normalized average dynamic pressure of $3 \cdot 10^{-12}$ mbar/mA was already achieved with a beam dose of about 70 A·h.

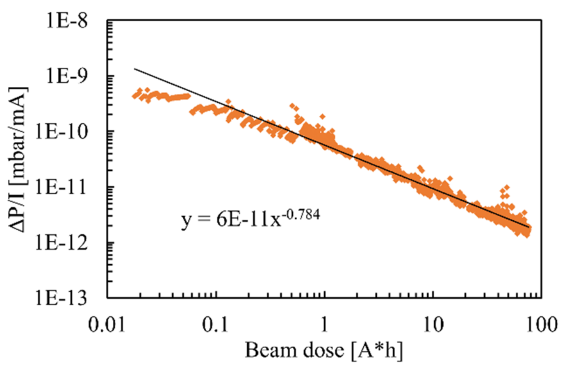

Figure 5: Normalized average dynamic pressure rise (ΔP/I) as function of the beam dose.

Figure 6 shows the lifetime evolution with the beam dose, which can also be used as an indication of the vacuum conditioning. The discontinuity observed in the dose range between 0.5 to 4 A·h is explained by a problem in the vertical scraper (described in the next section). After removing the scraper from the machine, the lifetime continued to increase with the same tendency as before, reflecting the good vacuum conditioning. At the dose of about 30 A·h, the lifetime started to be dominated by Touschek scattering and the increase observed from about 60 A·h is related to an increase in the betatron coupling value, which increased the Touschek lifetime.

During 2020, there were 5 shutdowns for installing 5 planar undulators with in-house built NEG-coated aluminum vacuum chambers of 6 mm gap [6].

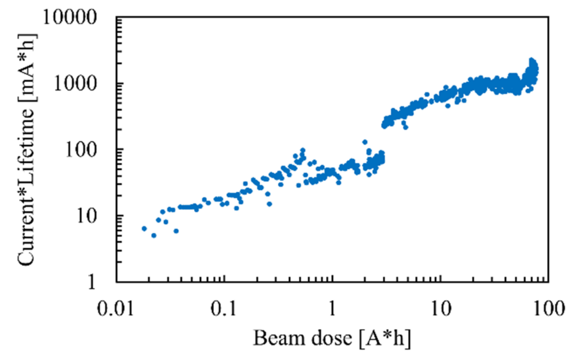

Figure 6: Lifetime evolution.

VACUUM RELATED PROBLEMS DURING COMMISSIONING

During commissioning, few problems related to vacuum have been faced. Leaks were identified in the thin-walled injection septum vacuum chambers of the booster and storage ring. The leaks were caused by high voltage arcs on the chambers due to a lack of insulation. Some ion pumps induced pressure spikes when operated in voltages higher than 3 kV, probably due to a field emission effect. So, all the ion pumps were set to operate in 3 kV fix mode. One ion pump went into short-circuit after some time of machine operation and was successfully replaced by Neon venting [7] the sector in a scheduled machine shutdown. A hot spot was detected in an uncooled chamber in one of the photon exit ports due to a wrongly assembled support that wrongly positioned the chamber. Finally, the horizontal and vertical scrapers were removed due to problems. The horizontal had one of its blades stuck in an intermediate position. In the vertical, one of the blade's electrical contact coil springs popped up in front of the beam path (Fig. 7) affecting the beam lifetime and injection.

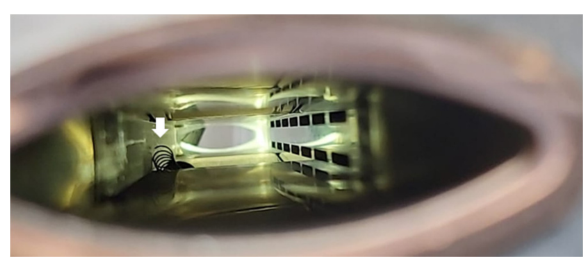

Figure 7: Vertical scraper with the coil spring that popped up in front of the beam path.

CONCLUSION

Considering the complexity of the Sirius vacuum system, the installation went well and was done in a short time. The expected static pressures were achieved right after the vacuum installation, and the machine was delivered for starting the commissioning without delays. Despite the few problems that have been faced during the commissioning, the vacuum has been performing well, and pressures have decreased as expected with beam conditioning. A fast conditioning has been observed for the NEG-coated chambers, and the design pressure was achieved with a beam dose of about 70 A·h.

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REFERENCES

[1] L. Liu, X. R. Resende, A. R. D. Rodrigues, and F. H. de Sá, "A New Booster Synchrotron for the Sirius Project", *in Proc. 5th Int. Particle Accelerator Conf. (IPAC'14)*, Dresden, Germany, Jun. 2014, pp. 1959-1961. doi:10.18429/JACoW-IPAC2014-WEPRO009

[2] L. Liu, N. Milas, A. H. C. Mukai, X. R. Resende, A. R. D. Rodrigues, and F. H. de Sá, "A New 5BA Low Emittance Lattice for Sirius", in *Proc. 4th Int. Particle Accelerator Conf. (IPAC'13)*, Shanghai, China, May 2013, paper TUPWO001, pp. 1874-1876.

[3] P. H. Nallin *et al.*, "The Sirius Heating System for the In-situ NEG Activation", in *Proc. 10th Int. Particle Accelerator Conf. (IPAC'19)*, Melbourne, Australia, May 2019, pp. 4109-4111. doi:10.18429/JACoW-IPAC2019-THPTS004

[4] C. Herbeaux, N. Béchu, and J.-M. Filhol, "Vacuum Conditioning of the SOLEIL Storage Ring with Extensive Use of NEG Coating", in *Proc. 11th European Particle Accelerator Conf. (EPAC'08)*, Genoa, Italy, Jun. 2008, paper THPP142, pp. 3696-3698.

[5] E. Al-Dmour and M. J. Grabski, "The Vacuum System of MAX IV Storage Rings: Installation and Conditioning", in *Proc. 8th Int. Particle Accelerator Conf. (IPAC'17)*, Copenhagen, Denmark, May 2017, pp. 3468-3470. doi:10.18429/JACoW-IPAC2017-WEPVA090

[6] B. M. Ramos *et al.*, "Aluminum Vacuum Chamber for the Sirius Commissioning Undulators", presented at the 12th Int. Particle Accelerator Conf. (IPAC'21), Campinas, Brazil, May 2021, paper WEPAB336.

[7] G. Bregliozzi, "Neon Venting of Activated NEG Beam Pipes in the CERN LHC Long Straight Sections without Losing Vacuum Performance", in *Proc. 23rd Particle Accelerator Conf. (PAC'09)*, Vancouver, Canada, May 2009, paper MO6RFP006, pp. 360-362.