THE ELETTRA 3.5 T SUPERCONDUCTING WIGGLER REFURBISHMENT

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Abstract

A 3.5 Tesla 64 mm period superconducting wiggler (SCW) was constructed by the Russian Budker Institute of Novosibirsk (BINP) and installed in the Elettra storage ring as a photon source for the second X-ray diffraction beamline in November 2002, but never used due to the lack of the funding required for the beamline construction. About three years ago, the beamline construction was finally funded together with the refurbishment of the SCW. This upgrade, that was necessary in order to make the SCW operations compatible with the top up mode of Elettra storage ring aimed in a drastic reduction of the liquid helium consumption by means of replacing the cryostat with a new version. At the same time the upgrade aimed to improve as well the reliability of the cryostat, to update the control system and to verify the magnetic field performance after a very long time of inactivity. In this paper we present the upgrade and the performances of the SCW following its refurbishment carried out by BINP team and its re-commissioning in the Elettra storage ring.

INTRODUCTION

After the signature of the collaboration agreement with the Indian government for the construction of two new beam lines (XRD2, XPRESS) and with the still open possibility of a third line for pharmaceutical research, powered by the same insertion device, funds were allocated for the construction of the second X-ray diffraction beamline. Consequently, additional funds were also devoted to the refurbishment of the SCW, consisting in the upgrade of the cryostat, of the control system and the check of the magnetic performance. The order was placed to BINP in November 2011. The wiggler was then removed from the storage ring in January 2012 and sent to Novosibirsk. After about one year, in April 2013, it was successfully tested (FAT - Factory Acceptance Tests), and sent to Elettra. In July of the same year, after successfully completing the site acceptance tests, with only two quenches both occurring at a field higher than the nominal maximum value of 3.5 T, it was installed in the storage ring (fig.1).

The Elettra superconducting wiggler consists of 45 full poles with a maximum field of 3.5 T and a period of 64 mm [1]. It was designed to power hard x-rays beamlines mainly for crystallography. Its critical energy at 2.0 (2.4) GeV is 9.3 (13.4) keV while its brilliance stays almost constant, in the order of 10^{15} ph/sec/mm^2/rad^2/0.1%bw up to 30 keV at 2.4 GeV.

SCW UPGRADE

The main objective of the refurbishment was to improve the reliability of the cryostat and decrease liquid helium consumption by means of replacing the whole cryostat with the new version. In order to improve the reliability of the cryostat and – at the same time – reduce the liquid helium consumption, the refurbishing activities comprised the replacement of the whole cryostat with a new design. It was also decided to keep and use whenever possible the existing standard components.

The design specifications – agreed with BINP – for the new cryostat included a maximum of two liquid Helium (LHe) refilling per year, during normal user mode of operation with accumulated electron beam of 330 mA at 2 GeV and the magnetic field of SCW set to 3.5 T. The old cryostat made use of 4 Leybold cryo-coolers: two Coolpower 4.2GM, 45 W @ 50 K (first stage) and 1 W @ 4.2 K (second stage) and two Coolpower 10 MD, 25 W @ 40 K, 15 W @ 17 K. They will operate also in the refurbished system. The “old” conception of the cryostat design (based on cold gas cooling current leads, cryo-coolers for re-liquefaction of gas helium and stainless steel spacers between vacuum chamber and copper liner) provided a liquid helium consumption of about 0.6-0.9 litre/hour [2,3] and consequently a frequent LHe refilling (once every 10-15 days).

Magnet tests carried at BINP also revealed that one superconducting coil was defective. One spare coil was still available and used to successfully repair the magnet.

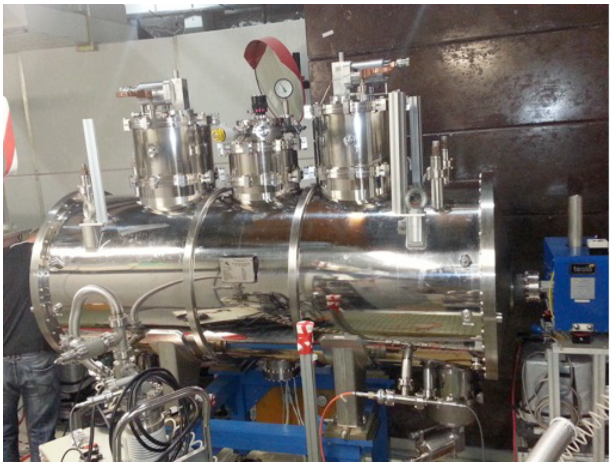

Figure 1: The refurbished superconducting wiggler installed in the Elettra storage ring.

ISBN 978-3-95450-132-8

The explanation of this failure is not well known and could be related to some mechanical stress during cooling down and warming up in presence of water in LHe vessel, since the SCW was left cold for a long time without LHe inside.

Cryostat Upgrade

The new BINP concept of the cryostat (see fig.2) is based on the idea of intercepting all possible heat in-leak into LHe vessel using heat sinks connected to Coolpower 4.2GM cold heads. The new design of current leads block assembled together with Coolpower 4.2GM cold heads is also used to prevent heat conduction and joule heat in-leak through current leads. In addition, BINP used new material with very low heat conduction as spacers between vacuum chamber and copper liner that decreases heat load to LHe vessel and practically excludes influence of electron beam on LHe consumption. This type of cryostat, that does not make use of liquid nitrogen, has already been working successfully round-the-clock at CLS, Diamond, LNLS, CAMD LSU, ALBA CELLS.

The heat load on shield screens and LHe vessel was designed by BINP to have a good margin with respect to the cooling capacity. The result is as follows: on the first (second) 60 K (20 K) screen 132 W (11 W) with a cooling capacity of 210 (25) W. For the 4.2 K LHe vessel the cooling capacity is 2 W against a load of 1.1 W.

The magnet is then inserted into the new custom-build cryostat with working temperature at 3.7–4.5 K. The total capacity of the helium vessel (~300 litres, with ~200 litres working volume between the min-max level) has not changed. The LHe vessel is now detached from the external atmospheric pressure and should operate with a pressure slightly lower than 1 bar.

The SCW coils are now connected permanently with the current leads. Current leads are composed of two parts – HTSC ceramics current leads in lower part and ordinary brass current leads at the upper part. The HTSC current leads are located between SCW and ordinary current leads. The temperature at contact terminal is measured by a semiconductor probe. Brass current leads have a length of 250 mm and a cross section of about 80 mm2 with resistance in working state (cool down) of 0.3 mOhm. The bottom HTSC current leads parts have thermal contact to the second stage of the cryo-cooler for interception of heat in-leak through the current leads. The temperature of the bottom part of the current leads is kept below 4.2 K with the help of the cryo-coolers. The bottom parts of the HTSC current leads are connected electrically to Nb-Ti/Cu SC cable, which enters the liquid helium vessel from vacuum volume through special vacuum feedthrough. A temperature probe with interlock function is installed at the bottom of cryo-cooler stage for quench protection of Nb-Ti cable if the temperature at the bottom stage of the cryo-cooler becomes higher than 7 K.

The small vertical size of the wiggler magnetic gap does not allow for the room temperature beam vacuum chamber (beam duct) design. So the vacuum chamber of liquid helium volume with the temperature of 4.2 K is used simultaneously as beam vacuum chamber. A new version of the special copper liner (see fig. 3) inside the 4K Helium chamber is connected with 20 K radiation shield, spaced with use of ULTEM plastic pins. The liner reduces the heat flux to the helium chamber from the room temperature walls of the wiggler cryostat and from storage ring parts. It prevents the helium chamber from being hit by electron beam, synchrotron radiation and wake fields. Between the room temperature external flange and the copper liner there is an RF stainless steel screen whose internal surface is copper-plated. Aperture for electron beam has remained unchanged [1].

The common insulating vacuum (for operation it is requested to be around 10^{-9}-10^{-10} bar) that occupies a volume between the internal part of the SCW housing and the external part of the liquid helium tank joined together does not require an ion pump any more.

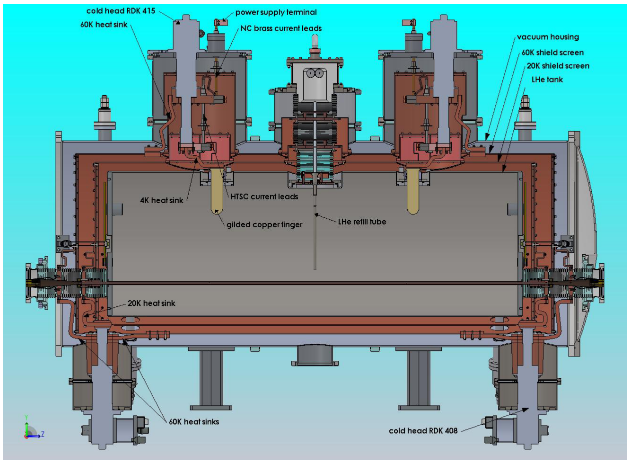

Figure 2: Superconducting wiggler cross section.

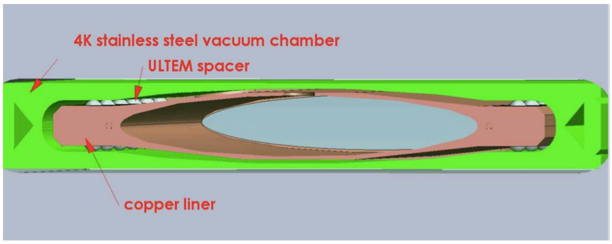

Figure 3: Cross section of the wiggler vacuum chamber and the copper liner.

Control System Upgrade

In conjunction with the refurbishment of the cryostat, to take advantage of the new available technologies, the SCW control system has also been updated. The TANGO control system framework (see e.g. [4]) has been adopted and deployed on renewed hardware. A dedicated front-end machine, based on Emerson MVME5110 VME single board computer, has been installed and supplemented with interface boards for serial lines and AD conversion. Three TANGO device servers have been developed to control the Junction Box, the Danfysik MPS883 power supplies and the four cryo-coolers. An additional TANGO device server is in charge of monitoring all the device logics and executing the field ramping. The renewed control system allows for an easy setup of asynchronous alarms and a very effective monitoring of the SCW. The TANGO historical database has been setup to store the SCW relevant operating parameters that can be easily correlated to the accelerator parameters.

SCW COMMISSIONING

Liquid Helium Consumption

After the refurbishment, the pressure inside the LHe vessel, as foreseen, was "negative" (compared to the atmospheric pressure) and in the range 0.7-0.9 bar. In the period July-December 2013, we always observed zero LHe consumption, also with magnetic field set to 3.5 T and an accumulated electron beam of 300 mA (2.0 GeV). Unfortunately, in January this year, we observed a strong lack of cooling efficiency in one of the cryo-coolers and consequently we had to switch it off. It will be replaced free of charge by the manufacturer this July, during the yearly cryogenic maintenance.

Tests with Electron Beam

During the FAT, a complete set of magnetic measurements were carried out to verify the magnetic peak field along the electron beam direction, the first and second field integral during the magnetic field ramping up and down which permitted to generate a new current table (I_s, I_c) [1] that minimizes the first field integral variation. In figure 4, the closed orbit distortion (at 2.0 GeV) as a function of the magnetic field is shown. The residual orbit distortion can be well compensated, during ramping, by the Elettra global orbit feedback.

In the range 0 - 0.5 T we observed an unstable closed orbit due to the instability of the power supplies: therefore, during user operation, if not used, the SCW will not be switched off but left with a magnetic field larger than 0.5 T. Figure 5 shows the tune shift during ramping (starting from 0.5 T). The measured variation is about 0.01 smaller than the measurement taken about ten years ago [2].

Figure 6, shows the tune shift with the tune feedback on (one correction every 16 sec.): as can be seen the feedback easily compensates the tune variation, but also in this case the instability of the power supplies is visible at low field.

Preliminary tests did not show any problem in accumulating the beam in top-up mode. No beam vibrations on the electron beam, induced by the cryo-cooler were visible.

CONCLUSION

The main scope of the refurbishing has been met: the SCW is operating with zero LHe consumption and therefore is fully compatible with the top-up mode of operation. However we observed a marked "quench sensitivity" to the electron beam dump: even with quite low current (30 mA) a beam dump can induce a quench if the beam gets lost on the liner. We had also observed micro-quenches in case of bad injection with zero accumulated current. The installation of a scraper, to protect the SCW from the e-beam, is planned for this summer.

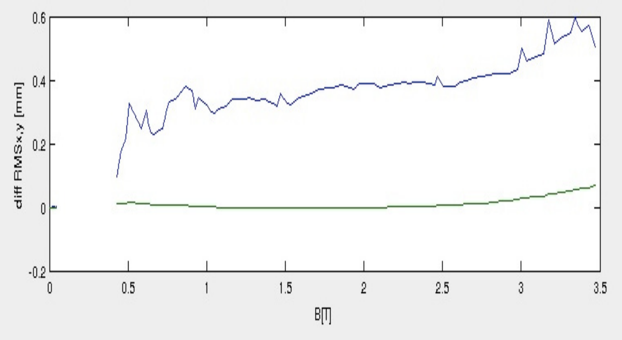

Figure 4: Horizontal (blue) and Vertical (green) closed orbit distortion (RMS).

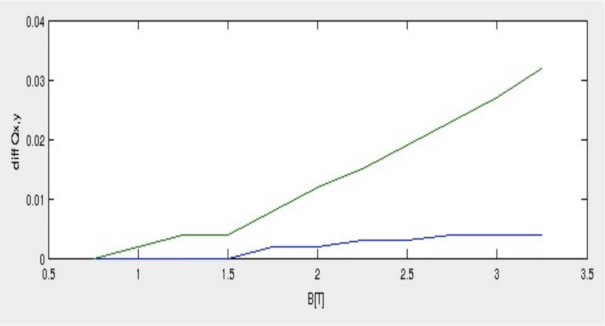

Figure 5: Horizontal (blue) and Vertical (green) Tune Shift.

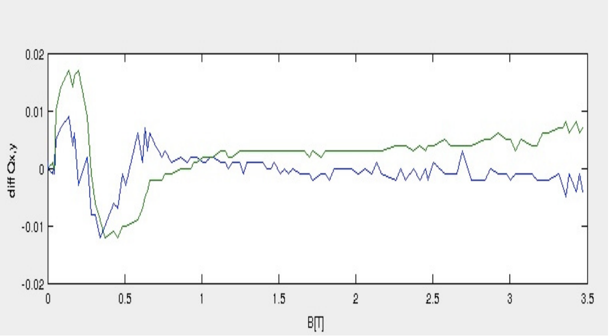

Figure 6: Horizontal (blue) and Vertical (green) Tune Shift (Tune feedback ON).

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