Abstract

The main facility of the Brazilian Synchrotron Light Laboratory is a 93 meters circumference, 1.37 GeV electron storage ring. Recently, the first superconducting insertion device was tested in the machine. This 4 T ID produces powerful beams that can damage the non-cooled parts of the accelerator vessel in the case of a miss-steered beam, even with a relatively large vacuum chamber cross section. In this paper we present the design details and the first operational results of the electronic beam position interlock system.

INTRODUCTION

The LNLS UVX synchrotron light source has been in operation since 1997. The light source consists of a 93 m long 1.37 GeV electron storage ring, a 120 MeV Linear Accelerator (LINAC) and a 500 MeV booster synchrotron. The machine routinely stores 250 mA of beam current with lifetime exceeding 25 hours. The magnetic lattice has 6-fold symmetry with four straight sections, each one suitable for the installation of insertion devices up to 2.9 m long. The other two sections house the two RF cavities and the injection septa.

The LNLS has currently 16 beamlines, 14 opened for users and 2 under construction. Thirteen of these beamlines use radiation produced in the 1.67 T bending magnets (critical photon energy = 2.1 keV) and are therefore currently limited in the flux that can be used in the harder part of the X-ray spectrum (above 10 keV).

During the 2009 shutdown period, the third ID was performed in the ring, which is a Superconducting Wiggler (SCW). During the firsts tests a high Helium consumption was verified, and the final installation was postponed to the end of 2010. Due to the high power beam produced for this superconducting ID, a beam orbit interlock system was required. In this work we present the adopted topology, the installation layout and the initial commissioning results. Redundancy and reliability engineering will also be discussed.

WIGGLER DESIGN CONSIDERATIONS

The need to improve the photon flux in the 10 to 20 keV spectral range arises from demands set by the materials science community, which plans to perform experiments using absorption, diffraction, scattering techniques and time dependent experiments [1].

To provide the required high flux hard X-ray beams for material science, a 35 pole wiggler with a maximum field of 4T was built and implemented in the LNLS storage ring. This ID was manufactured by Budker Institute (Russia). Table 1 shows the essential parameters.

Table 1: Superconducting wiggler main parameters

<table>
<thead>
<tr>
<th>Wiggler Main Parameters</th>
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</thead>
<tbody>
<tr>
<td>Type</td>
<td>SCW</td>
</tr>
<tr>
<td>Critical energy</td>
<td>4.99 keV</td>
</tr>
<tr>
<td>Max Peak Field</td>
<td>4.1 T</td>
</tr>
<tr>
<td>Period</td>
<td>60 mm</td>
</tr>
<tr>
<td>Number of poles</td>
<td>35</td>
</tr>
<tr>
<td>Vert. beam chamber aperture</td>
<td>14 mm</td>
</tr>
<tr>
<td>Total radiated power @ 4.1T and @ 250mA</td>
<td>4.45 kW</td>
</tr>
</tbody>
</table>

The SCW is optimized to produce a high flux and brightness in the 10-20 keV range for the new materials science beamline (under construction). Figure 1 shows the superconducting wiggler being installed in the ring in 2009 during a shutdown for the wiggler commissioning.

Figure 1: LNLS Superconducting wiggler installation.

Wiggler installation requirements

During the SCW design phase, a thermodynamic analysis was carried out by the vacuum group in order to verify the effect of a miss-steered photon beam hitting the vacuum elements. The results showed the need of special cooling techniques and a complementary photon beam protection system to prevent potential harm of all relevant components and vacuum chambers.

SYSTEM DESCRIPTION

An orbit interlock system was proposed based on a widely used technique which combines beam position measurements, window comparison and finally the actuation. Basically the electronics processes the analog signals coming from the upstream and downstream BPMs of the SCW section, calculates the beam trajectory, compares it with established limits and then takes the decision of dumping or not the electron beam, in case of large orbit excursions. The design and basic operation of
the system presently will be described by referring to the block diagram in Fig. 2.

$$\text{Beam Trajectory} \quad X = X_1 + \left( \frac{X_2 - X_1}{d_1} \right) \times (d_1 + d_2) \quad (1)$$

**Hardware Topology**

The main and standard requirements in a fast protection system are: simplicity, robustness, reliability and maintainability. Several topologies could be applied to satisfy this specification, for example high reliable Programmable Logic Controllers (PLCs), Programmable Automation Controllers (PACs) or proprietary electronics. During the first discussions in the early design phase, the main topic was about the better topology to be chosen. After some studies, a proprietary design using discrete electronics, with high reliability and simplicity was the most cost-effective and strategic.

**Activation System**

For activating the interlock system four conditions have to be satisfied, as showed in Table 2. Three activation signals (NC contacts and analog signals) referred to the storage ring energy, storage ring current and the SCW field are provided by three auxiliary comparator electronics installed far from the interlock system.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Active</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ring energy</td>
<td>&gt; 1 Gev</td>
</tr>
<tr>
<td>Ring current</td>
<td>&gt; 10 mA</td>
</tr>
<tr>
<td>SCW field</td>
<td>&gt; 1.5 Tesla</td>
</tr>
<tr>
<td>Local Bypass</td>
<td>Disable</td>
</tr>
</tbody>
</table>

A bypass input is available in order to allow a wider tolerance on beam displacement. This is important for special machine modes of operation like accelerator physics study shifts.

**Actuation method**

To dump the beam a well-known technique is used. Basically the main RF cavities signal is stopped. After its interruption the beam is dumped in a few microseconds. Figure 3 summarizes the basic functional diagram.

**System Reliability**

Because the module is intended to protect the machine vacuum vessels, it is important to provide a highly reliable system, which would fail going to safe conditions. Some examples of features included in the electronics are:

- Normally closed (NC) logic: all signals must be high (TTL) or closed (contacts) to run. This logic prevents a failure to mislead the system because of malfunctions such as disconnected or broken cables.
- Special power supply: high reliable power supply from Acopian was used.
- Redundancy in most critical parts: parts with major probability of fail, like relays and drivers, were duplicated to improve the reliability.
- High quality components: the components were carefully chosen, some examples are illustrated:
  - Relays: signal relays with bifurcated crossbar and Au plated contact was chosen.
  - Connectors: high quality audio connectors with lock system and Au contacts were used.
- Monitoring system: a monitoring system was designed to supervise the status of the interlock electronics.

**Monitoring system**

For monitoring the system activities, a special multiplexing circuit was designed. Basically the main electronics’ internal signals are continuously monitored and registered into the Accelerator Control System, providing the capability of supervising the orbit calculations as well as dumping the signals. In case of interlock system fail, several alarms are activated and the machine operators are promptly warned.
General considerations

The electronic circuit was assembled in a 1U 19" chassis and now is located near to the MX-BPM module at the section 9, thus avoiding transmission of analog signals through long cables and ground loops problems. Figure 4 shows a picture of the system installed in the ring.

Figure 4: interlock system installed in the storage ring.

FIRST RESULTS

Exhaustive bench tests were performed in order to measure the system’s actuation time as well as to validate its reliability and stability. Figure 5 shows that the time between a bad orbit situation and the interlock system actuation (RF cavities shutdown command) is approximately 3 ms. The time the RF system takes to effectively stop giving energy to the beam after receiving a shutdown command is known to be around 4 ms, what gives a total interlock actuation latency of approximately 7 ms, what is in agreement with the system specifications (less than 30 ms of actuation time).

Figure 5: Time between a bad orbit situation and the interlock system actuation.

Since all logic, timing and stability issues were proven to be appropriate and trustful the system was tested in the ring during machine study shifts. A localized bump was used to force a bad orbit situation for which the interlock system must act. Figure 6 depicts a test in which the electron beam vertical position in both straight section BPMs (downstream and upstream) was varied from its operational value to a bad orbit condition (1.8 mm). The interlock system worked as expected, dumping the beam when it reached the maximum allowed orbit excursion.

Figure 6: Test to evaluate the interlock system.

CONCLUSIONS AND PERSPECTIVES

This work has detailed the design of a high reliable interlock system for protecting LNLS vacuum chamber against high density power beam produced by a superconducting wiggler. The results showed it performed within the specifications thus being ready for operation. The system will be running routinely in 2010 before the final installation of the SCW, which is scheduled for the end of 2010.

Due probably to asynchronous updates of dipoles and quadrupoles power supplies, large orbit distortions can eventually happen during the injection procedure. For preventing activating the interlock in this situation, it is foreseen to establish a smoother injection ramp in the future.

ACKNOWLEDGMENTS

We would like to thank Mr. Elder Mathias from the Canadian Light Source (CLS), for sharing CLS experience with this system and documentations, Mr. Jens Kuszynski from the Bessy-II Diagnostics Group for private communications about Bessy’s interlock system, Mr. Emil Zitvogel and G. Decker for NSLS documentation.

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