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THE SIRIUS HEATING SYSTEM FOR THE IN-SITU NEG ACTIVATION

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Abstract

Sirius is a 3 GeV fourth-generation synchrotron light source under commissioning in Brazil, with 518 m circumference and a bare lattice emittance of 0.25 nm.rad. This ultra-low emittance machine is based on approximately 700 magnets with 28 mm typical gap. The standard vacuum chamber, that makes up around 80% of the circumference, is a 26 mm external diameter copper tube. Due to the small conductance of the chambers and the limited space between the magnets, the vacuum pumping will be based on distributed concept and then non-evaporable getter (NEG) coating will be extensively used. To activate the NEG coating, the chambers must be heated at 200°C for about 24 hours. The solution for Sirius was the development of an ultra-thin heating tape, 0.4 mm thick, which allows an in-situ bake-out. The developed tapes are able to operate continuously at 220°C and have in their design a thermal shield that reduces the radiation heat loss to the magnets. This paper describes the development of the heating tape, its power supply, the control software and the operation of the system during the NEG activation at Sirius.

INTRODUCTION

Sirius, like other 4th generation machines, is based on the concept of multi-bend-achromat (MBA) [1]. This model impacts several subsystems of the accelerator in a chain reaction which, in the case of vacuum, implies in reduction of the diameter of the chambers and limitation of space for localized pumping. An alternative is the use of the NEG coating, which provides a distributed pumping. In addition to the challenges of achieving NEG coating in narrow chambers, there is still the challenge of activating the film at 200 °C.

In the case of Sirius, it has been chosen to develop an in-situ activation system, with heating tapes permanently installed in all vacuum chambers, providing indirect temperature measurements and a reduced quantity of temperature sensors. Crates containing power supplies, data acquisition system and control software were also developed in-house, along with graphical user interface.

HEATING TAPES

The Sirius storage ring has a circumference of 518 m, of which about 80% is filled with cylindrical geometry copper vacuum chambers with a 26 mm outer diameter. The other 20% is formed by special chambers, such as the photon beam exit pipes, bellows, valves, beam-position monitors (BPMs) and vacuum instrumentations.

For regions with enough space, more traditional solutions were adopted, with heating jackets, tailor-made for each component, equipped with Pt100 type sensors for monitoring the temperature.

For the majority of the chambers of the storage ring, where there is a very limited gap to the magnets, ultra-thin tapes (thickness less than 0.4 mm) were developed for both round and complex geometry chambers. The temperature control of the ultra-thin tapes is based on the variation of the tape's electrical resistance.

The ultra-thin tape is based on a multilayer concept (Fig. 1) that uses the Dupont HT 8525R material, commonly used for manufacturing flexible circuits. This material is composed of a polyimide film of 50 µm in thickness, covered with a copper film of 18 µm in thickness. The copper side is chemically milled leaving a copper track whose length and width were calculated according to the desired power density. The apparent copper side is then glued to a polyimide bonding film. Finally, on the top of the bonding film is glued a 75 µm aluminum foil. The complete multilayer joining process is done in a heated press according to the manufacturer's instructions.

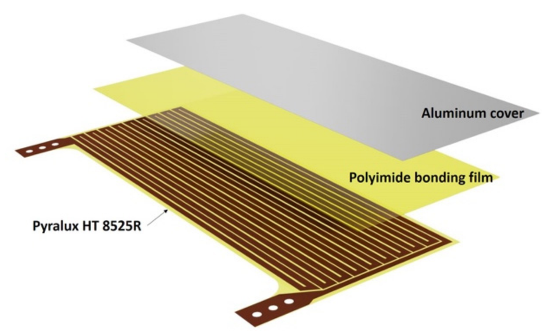

Figure 1: Developed ultra-thin heating tape.

The aluminum cover is used to uniformize the tape temperature, reducing the chances of hot spots, reducing radiation heating loss to the magnets and helping to shape the ribbon geometry. Once wrapped around the chamber and heated, it tends to maintain the shape of the chamber (Fig. 2). In this way, the tapes are fixed to the chambers by using few polyimide adhesive tapes in a way that the heating tapes are free to slide on the chamber. This fixing concept allows both materials to freely expanding due to their different thermal expansion coefficients.

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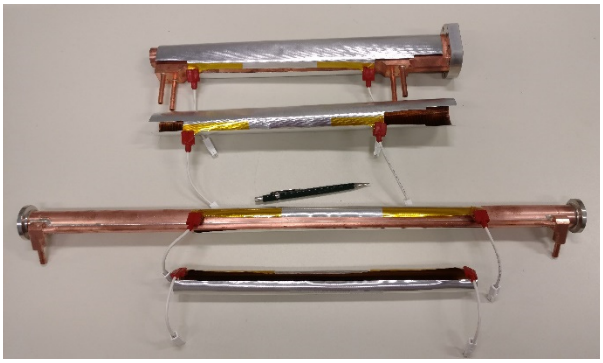

Figure 2: Tapes covering two different shapes of chamber along with the shape-memory after a heating process.

Electrical Characteristics

Heating tapes are made of copper strips whose resistances can be associated with a resistivity coefficient ρ that is temperature dependant [2]. Therefore, temperature can be indirectly measured through tape resistance, eliminating a significant amount of temperature sensors and cables along the heating process.

Several experiments were performed to demonstrate that reading resistance variation would be a reliable way of measuring the average tape temperature, correlating its temperature coefficient α, according to eq. (1).

$$\frac{dR}{R_o} = \alpha . dT \qquad where\ \alpha = \frac{d\rho}{dT} . \frac{1}{\rho_o} \quad (1)$$

One of them is shown in Fig. 3 and Fig. 4. Thermocouples were added to each element (boundaries, open places, quadrupoles and sextupoles) in order to compare temperature values to mean temperature through resistance measuring.

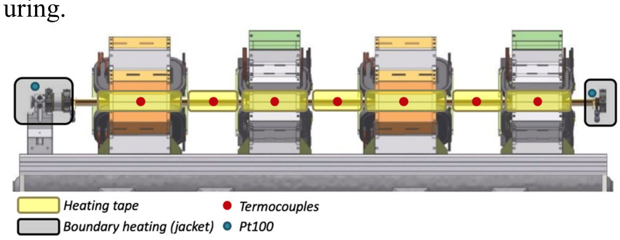

Figure 3: Experiment layout with thermocouples.

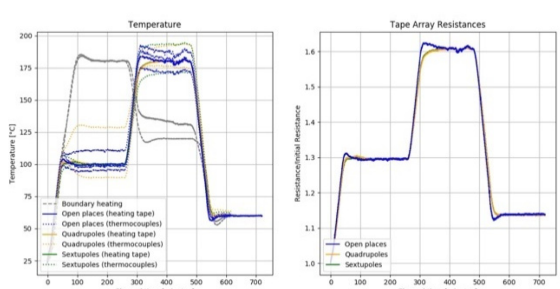

Figure 4: Temperature and tape resistances acquisitions during development of resistance heating control. Mean temperature readings reached an accuracy of ±8 °C.

An important effect occurs when the tape is mounted in a region of the vacuum chamber within the magnets. In these regions, the power required to reach the desired temperature is 40% greater than in the regions outside the magnets, due to its thermal mass. Serial grouping of tapes of different sizes can only be done with similar installation conditions.

A detailed analysis of the entire circumference of the ring allowed the selection of 8 different lengths of ribbons (50 mm, 80 mm, 110 mm, 165 mm, 190 mm, 225 mm, 330 mm and 530 mm) for the standard chambers that have circular cross section of 26 mm external diameter. These tapes have been specified to have resistance of 6.6 Ω/m.

Considering mechanical installation, tapes positioned outside the magnets can be grouped in series up to a maximum length of 1.2 m, reaching the 300 W, limited by the chosen power source.

Tapes positioned inside the magnets can be grouped into maximum lengths of 0.8 m.

BAKING POWER CRATES

Designed and built in-house, the Baking Power Crate is able to control up to eight channels independently, configurable to have temperature feedback via Pt100 sensors or tape resistance.

The system main core is based on an open-hardware inexpensive single-board computer, a Beaglebone Black. Some units are in operation in UVX accelerator [3] and have been largely used in Sirius Controls System [4]. Reading Pt100 sensors is done by a developed electronic device, designed and manufactured for Sirius applications, that monitors up to eight Pt100 sensors.

For delivering power to heating elements, each channel has a dedicated commercial programmable power supply that can be externally controlled. Each power supply has its current (max. 6.25 A) and voltage output (max. 48 V_{DC}) acquired through proprietary hardware (Fig. 5).

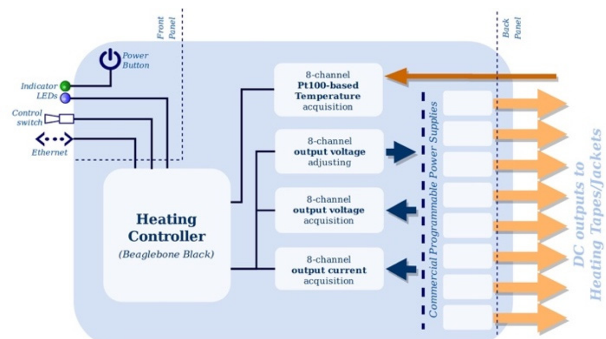

Figure 5: Block diagram of Baking Power Crates.

Once it is needed to calculate tape resistance precisely to control tape temperature with minor errors, an optimization was made by calibrating all channels reading analogical data from power supplies.

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CONTROL SOFTWARE

Embedded Software

Heating control software runs in a Beaglebone Black, inside each crate. Source code is written in Python and it has three main threads: (1) external communication (ethernet), (2) power supplies data acquisition and adjusting and (3) control loop for all channels independently.

Graphical User Interface

A graphical user interface was developed in PyQt to make the Baking Power Crate's control simple and objective, communicating with up to eleven crates simultaneously. Grouping channels into three different heating configurations is available and user can predefine each heating stage.

Monitoring the heating can be performed through displays or graphs that show all real-time measurements of temperature, current, power or voltage of each connected and configured channel. Also, a log file is generated during the heating process, creating a complete data history. These files can be post-processed in order to implement system improvements.

INSTALLATION AND FIRST BAKE-OUT

For each achromatic arc of the storage ring, there are 104 ultra-thin heating tapes, 21 heating jackets and 21 Pt100 temperature sensors. The heating tapes are grouped according to their boundary condition, i.e. groups of heating tapes under dipoles, sextupoles, quadrupoles and open places. This configuration allows a better temperature control and uniformity and minimizes the number of needed power supplies. The heating jackets are individually powered and controlled.

A total of 68 power supplies are needed for heating one machine achromatic arc. Fig. 6 shows the first achromatic arc installed and prepared for the bake-out process, with baking power crates and vacuum pumping stations.

Figure 6: Bake-out system for one achromatic arc.

The bake-out system must follow specific thermal cycles for 3 different groups of components: (1) NEG-coated components, (2) non-NEG-coated components (i.e. bellows, BPMs and radiation masks), and (3) sector gate valves.

During first arc bake-out, pressure measurements were integrated with Controls System and continuously stored for graphical real-time monitoring and further analysis. This will be replicated to next ones.

Figure 7 shows the standard heating program, according to each group configuration, and the pressure evolution during the NEG activation of the chambers of the first achromatic arc installed in the storage ring.

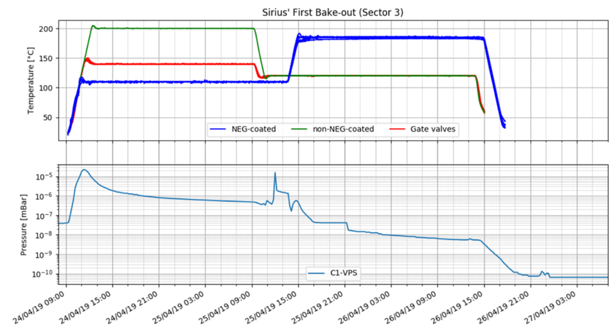

Figure 7: Experimental heating stages of some channels and pressure evolution during the NEG activation of the first achromatic arc installed.

The obtained temperature uniformity of the chambers stayed in a margin of ±15 °C, which was cross-checked with an infrared camera.

CONCLUSION

The vacuum pumping concept of the Sirius storage ring is mainly based on NEG film. For the film activation, it has been developed a complete heating system consisting of special ultra-thin heating tapes, power crates and a control software. The temperature control of the tapes is based on the variation of the tape's electrical resistance. The obtained temperature measuring accuracy is ±8 °C and the temperature variation in the first installed achromatic arc stayed under ±15 °C. The complete system has been extensively tested and has already been successfully used in the first achromatic arc installed in the storage ring.

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