FIRST MEASUREMENTS OF COLDDIAG: A COLD VACUUM CHAMBER FOR DIAGNOSTICS

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Abstract

Superconductive insertion devices can reach, for the same gap and period length, higher fields with respect to permanent magnet insertion devices. One of the still open issues for the development of superconductive insertion devices, is the understanding of the heat intake from the electron beam. COLDDIAG, a cold vacuum chamber for diagnostics was designed and built specifically for this purpose. With the equipped instrumentation, which covers temperature sensors, pressure gauges, mass spectrometers as well as retarding field analyzers it is possible to measure the beam heat load, total pressure, gas content as well as the flux of electrons and/or ions hitting the chamber walls. Here we report about the preliminary measurements and results of COLDDIAG installed in the Diamond Light Source.

INTRODUCTION

In the frame of a running research and development program on superconducting insertion devices (SCIDs) at ANKA (Ångstrom source Karlsruhe) one of the still open questions is the heat deposited on a cold vacuum chamber by the beam. Possible beam heat load sources are synchrotron radiation, RF effects due to geometric effects and resistive wall impedance, and electron and/or ion bombardment. The values of the beam heat load due to synchrotron radiation and resistive wall heating have been calculated and compared for the cold bores installed at different light sources with the measured values. The disagreement between measurements and calculations is not understood [1-3]. In order to gain a quantitative understanding of the problem and to find possible remedies we have designed a cold vacuum chamber for diagnostics (COLDDIAG) [3]. This vacuum chamber was fabricated and assembled by the company Babcock Noell GmbH, whereas ANKA was responsible for the diagnostic components. After successful factory acceptance test [4] and calibration of the beam heat load measurement, COLDDIAG was installed in the storage ring at the Diamond Light Source in November 2011. Due to a mechanical failure of the thermal transition of the cold beam tube, the cryostat had to be removed after 1 week of operation. In the following we describe shortly the experimental layout of COLDDIAG [5], the results of the calibration and some of the preliminary results obtained during the installation at the Diamond Light Source.

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EXPERIMENTAL SETUP

COLDDIAG consists of a cold UHV chamber located between two warm sections, one upstream and one downstream. An overview of the cryostat and of the diagnostics installed is given in Fig. 1. In each of the three

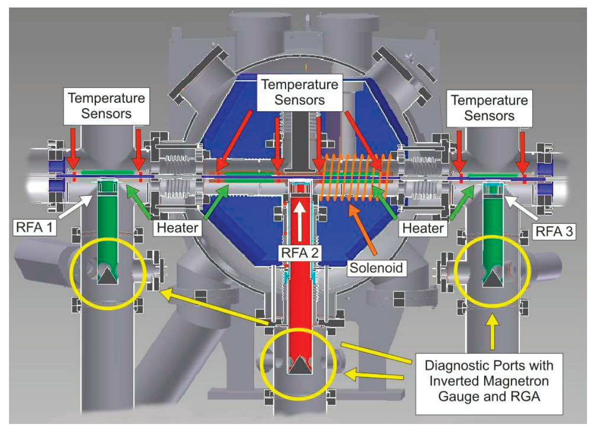

Fig. 1: Overview of the cryostat and the diagnostics installed in COLDDIAG.

sections the electron beam is guided through a 60mm x 10mm elliptical bore fabricated from a high purity copper block. Similar to the surface of the beam tube (liner) of the SCIDs used at ANKA and operated down to 4 K, the inside of this liner is plated with 50 µm copper. The 0.5m long middle section of the liner can be cooled down by a Sumitomo RDK-415D cryocooler to reach a base temperature of about 4K in absence of beam.

In total 40 temperature sensors allow to monitor the status of the chamber and measure the beam heat load: 8 PT100 sensors in each of the warm sections and 16 Lakeshore Cernox 1050-SD in the cold section are placed into the copper block as near as possible to the beam. Each of the three sections is equipped with a residual gas analyser, an Inverted Magnetron Gauge and a retarding field analyser, directly connected to the beam tube, to investigate the residual gas components and electrons or ions impinging the chamber wall. In order to suppress any low energy electrons bombarding the wall, a solenoid on the beam axis producing a maximum field of 100 Gauss is wound around one half of the cold part of the UHV chamber [5].

CALIBRATION OF THE BEAM HEAT LOAD MEASUREMENT

To obtain the beam heat load while the experiment is installed in the storage ring the measured temperature of the beam tube needs to be related to a heat intake. For this purpose COLDDIAG is equipped with four calibration heaters in the cold region. The sensor located on the cooling connection to the cold head is used for the calibration and measurements of the total beam heat load deposited on the cold liner. For the calibration of this sensor the heating power is maintained constant until the cooling power of the cryocooler and the heat intake from the heaters have reached the equilibrium state. To obtain the calibration curve shown in Fig. 2 this procedure was repeated for different values of heating power. To extract only the measured values where the temperature is constant, all data points for which the temperature is within an interval of ±2mK and the power is within ±2mW for 100s are chosen.

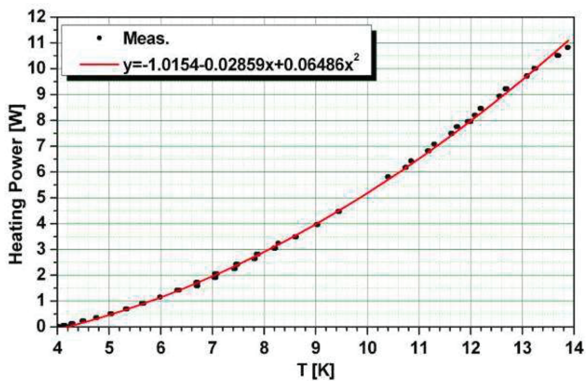

Fig. 2: Calibration curve obtained using the temperature sensor located at the cooling connection.

PRELIMINARY RESULTS OF THE BEAM HEAT LOAD MEASUREMENT

While COLDDIAG was installed, the beam heat load was measured at different beam currents on the machine physics day and at 250mA during normal user operation. In both cases the energy of the stored electron beam was 3GeV and the machine was filled with 900 bunches.

The beam heat load values measured as a function of beam current are displayed in Fig. 3. From the calibration an error of ±0.15W can be derived. For comparison the analytically calculated values of the resistive wall heating for a beam current of 250mA and an rms bunch length of 18.5ps are also indicated [1,2]. As the Residual Resistivity Ratio (RRR) of the copper beam tube is not well known, two different RRR values, 10 and 200, were used for the calculations to assess the sensitivity of the calculated values to RRR value. It is demonstrated in Fig. 3 that the calculated values of beam heat load are much smaller compared to the measured ones.

The temperatures measured with the sensors located on the liner are used for a qualitative indication of the geometrical distribution of the beam heat load.

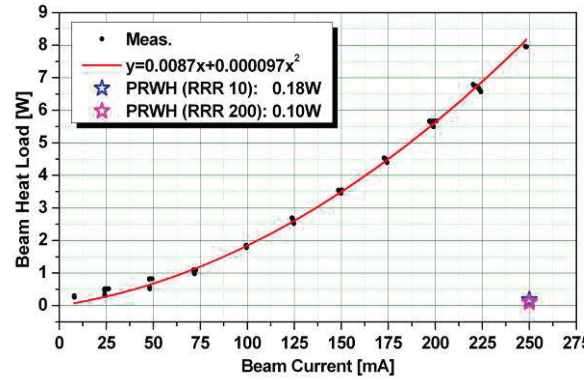

Fig.3: Beam heat load measured for different beam currents. The blue and magenta stars illustrate the beam heat load from resistive wall heating calculated for a 0.5m long copper beam tube with RRR of 10 and 200, for a beam current of 250mA and an rms. bunch length of 18.5ps.

Without beam the temperature values of the sensors placed on the liner at 4.05K are within a range of ±0.15K with an error of ±0.1K on the sensor reading. With beam a change in the temperature distribution on the liner has been observed. As an example the temperature along the beam tube is illustrated at a beam current of 150mA in Fig. 4. The sensors on top of the copper block show a higher temperature on the outer sides of the beam tube cross section compared to the sensors in the middle, whereas this behaviour is not clearly represented in the values measured from the bottom sensors. It can also be seen that the bottom sensors in general show a higher temperature reading than the sensors on top. More measurements are needed to further investigate the beam heat load distribution.

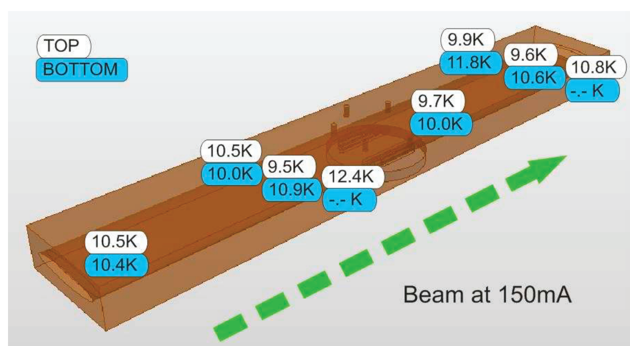

Fig. 4: Temperature distribution on the cold beam tube at a beam current of 150mA. White boxes show the values of sensors on top and blue boxes the values at the bottom of the copper block on the same position with respect to the beam. Without beam all temperature sensors indicate 4.05K±0.15K.

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PRELIMINARY RESULTS OF THE RETARDING FIELD ANALYSERS

In each of the three liner sections a retarding field analyser (RFA) is placed to investigate the charged particles hitting the chamber walls. In addition, to suppress charged particles from hitting the chamber wall a solenoid is installed on the downstream half of the cold liner section. The magnet reaches on axis a magnetic field of around 10mT with a current of 1A.

In order to distinguish if ions or electrons are hitting the wall, while the retarding grid of the RFAs was connected to ground, the collector plate voltage was varied from negative to positive values. The measurements show that that most of the particles hitting the wall have a negative charge.

In the following we present measurements performed with the retarding grid of the RFAs connected to ground and the collector plate biased with +50V. With these settings the RFAs are integrating over all the particles with negative charge hitting the wall. Figure 5 shows the influence of the solenoid on the measured collector current of the three RFAs. When the magnet is powered

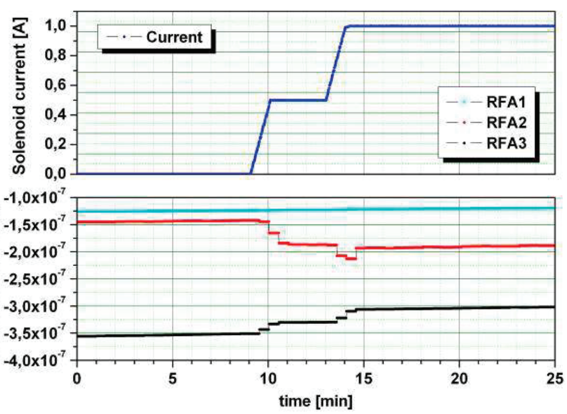

Fig. 5: Collector current of the RFAs with and without solenoid field at a beam current of 250mA.

the current of negatively charged particles, most probably electrons, stays constant in the upstream warm section (Fig. 5, RFA1). At the same time the current on the collector is increased in the cold section (Fig. 5, RFA2) and decreased in the downstream warm section (Fig. 5, RFA3).

The influence of the solenoidal magnetic field can also be seen in Fig. 6. In this picture the distribution of the temperature on the copper beam tube in the cold section is illustrated with (Fig. 6B) and without (Fig. 6A) current in the solenoid. The measurements were taken 10 minutes before and after the solenoid was switched on. Although the changes in the temperature are small, all sensors next to the solenoid show a reduced temperature, when the solenoid is powered. In contrast the values measured by the sensors on the upstream end of the cold beam tube are higher with the solenoid powered. During offline tests without beam the magnetic field of the solenoid and the additional heat load on the cryogenic system at a current of 1A did not cause any influence on the temperature of the sensors. Although more measurements are needed to investigate this effect the magnetic field of the solenoid seems to change the distribution of the temperature which

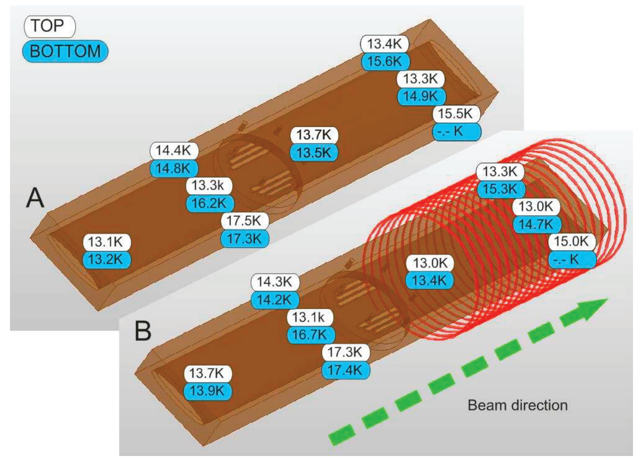

Fig. 6: Comparison of the temperature with (B) and without (A) solenoid field at a current of 250mA. The red spiral indicates the position of the solenoid.

implies a change in the beam heat load distribution in the cold section of COLDDIAG. This effect in the temperature change is most likely due to a redistribution of electrons hitting the chamber wall in the cold section.

CONCLUSIONS AND OUTLOOK

COLDDIAG was installed in the storage ring at the Diamond Light Source in November 2011. Due to a mechanical failure of the cold beam tube it had to be removed after one week of operation. Preliminary results show a superposition of linear and quadratic behaviour of the beam heat load as a function of the average beam current. The measured beam heat load of ~8.2W at 250mA is almost two orders of magnitude larger than the predicted value from resistive wall heating calculations ~0.1-0.2W. The small but visible effect of the solenoid on the temperature distribution points to electron bombardment as at least one component of the beam heat load observed. Currently the design of the liner thermal transition is being changed and a second installation at the Diamond Light Source is under discussion.

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