BEAM HEAT LOAD AND PRESSURE IN THE SUPERCONDUCTING UNDULATOR INSTALLED AT ANKA

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Abstract

A superconducting undulator is installed in the ANKA (ANgstrom source KArlsruhe) storage ring since March 2005. The beam heat load and pressure on the cold bore have been analysed in the first two years of operation, during which the undulator was operated mainly with open gap. We report here on a larger statistics of beam heat load and pressure data collected in the last years with the undulator operated at different gap positions. The effect of vacuum leaks in the storage ring on the superconducting undulator operation is also described.

INTRODUCTION

A cold bore superconducting undulator built by ACCEL Instruments GmbH, Bergisch Gladbach, Germany [1], is installed since March 2005 in one of the four straight sections of the ANKA (ANgstrom source KArlsruhe) storage ring; the rest of the ring is at room temperature. The beam heat load and pressure on the cold bore have been analysed in the first two years of operation, during which the undulator was operated mainly with open gap [2]. Possible beam heat load sources are: synchrotron radiation, RF effects including resistive wall heating and electron and/or ion bombardment. Synchrotron radiation cannot explain the data since it predicts a linear dependence with current which is not observed. The resistive wall heating predictions are more than one order of magnitude smaller than the observed beam heat load. Moreover resistive effects cannot explain the large variation in the beam heat load [2]. A simple model of electron bombardment appears to be consistent with the beam heat load and pressure rise observed during this time [2, 3].

The dynamic pressure increases nonlinearly with the average beam current [3]. The pressure rise is in some runs quite low and no peak is observed as a function of current. In case of electron bombardment a possible explanation would be the dependence of the peak current on the beam history: it is in fact known that the desorption coefficients and the secondary emission yields of the different gas molecules adsorbed on the vacuum chamber decrease with beam exposure time (electron dose). However we do not observe consistent conditioning, which is not clear to work for cold surfaces exposed to room temperature vacuum chambers and acting as cryopumps [4]. The other possible explanation is that the pressure gauge is not equally sensitive to the local increase of pressure in the different parts of the vacuum chamber. If, for example, the electron bombardment removes the gas from a surface further from the pressure gauge the gas might not reach the gauge since it will be cryosorbed to the surface, which has a much higher pumping speed than the pump located at room temperature close to the gauge. No increase in pressure has ever been observed by heating the vacuum chamber with heaters (used for the calibration of the beam heat load measurements) in absence of beam, which excludes thermal desorption as a possible explanation for the observed pressure rise. The gas dynamic balance in the beam cold vacuum chamber results from two competing effects: the photon and electron stimulated desorption of the gas contained in the surface layer of the chamber wall and of the gas cryosorbed, and the cryopumping by the cold surface. In Ref. [3] it has been shown that photodesorption alone cannot explain the experimental results. Electron multipacting is needed to reproduce the observed pressure rise and can at the same time explain the observed beam heat load.

In this contribution we report on a larger statistics of beam heat load and pressure data collected in the last years with the undulator operated at different gap positions. The effects of a vacuum leak in the storage ring on the superconducting undulator operation is also described.

RESULTS

A description of the experimental setup is given in Refs. [2,3]. The deposited beam heat load is obtained from the increase in temperature of the coils in presence of beam. The calibration was done with a resistor in thermal contact with the coils. For values of the lifetime $\gtrsim 10$ hours the average beam current variation is small compared to the two hours needed to reach thermal equilibrium and the calibration values obtained in static conditions can be applied.

As for the open gap case [2], a large variation of the beam heat load is observed also for 8 mm gap. The data shown in Fig. 1a as green olive diamonds have been taken during three months (January-March 2011) user operation. During this period are observed also a non linear increase of the pressure with average beam current and a correlation between the beam heat load and the pressure (see green olive diamonds in Fig. 1b). A clear correlation between increase of temperature in the coils (related to the beam heat load), the vacuum pressure detected and some bumps in the lifetime are clearly demonstrated in Fig. 2.

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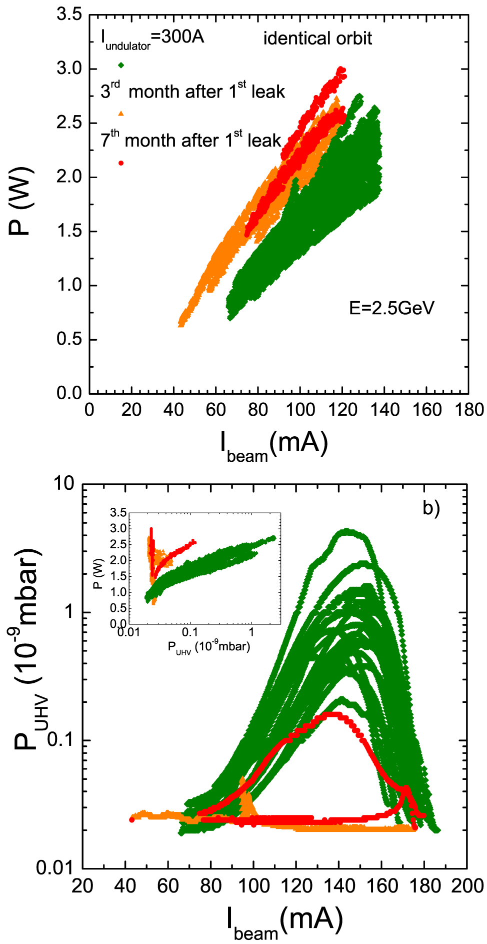

Figure 1: a) Variation over half a year of the beam heat load and b) of the UHV pressure reported as a function of the average beam current. In the inset of plot b), the beam heat load is shown as a function of the UHV pressure. Beam parameters: E = 2.5 GeV, $I_{beam} = 80 - 200$ mA, three trains. Undulator parameters: gap = 8 mm, undulator current = 300 A.

Last year two leaks developed in the ANKA storage ring: one at the beginning of May in the sector upstream and the other at the beginning of September in the sector downstream with respect to the superconducting undulator. No direct correlation of the pressure measured in these sectors and the one measured inside the undulator is observed. However, being the superconducting undulator the only cold section of ANKA, it is very likely that part of the gas introduced by the leaks has been cryosorbed by its cold surfaces. Two months after the second leak, peaks in the measured dynamic pressure of the cold vacuum chamber up to 10^{-8} mbar have been detected. Afterwards two attempts of cleaning the undulator chamber by heating up to 80 K and conditioning with beam have been done: the measured dynamic pressure has been reduced in the successive months to few 10^{-11} mbar but the beam heat load is still comparable to the reported values after the first leak (orange triangles) of Fig. 1.

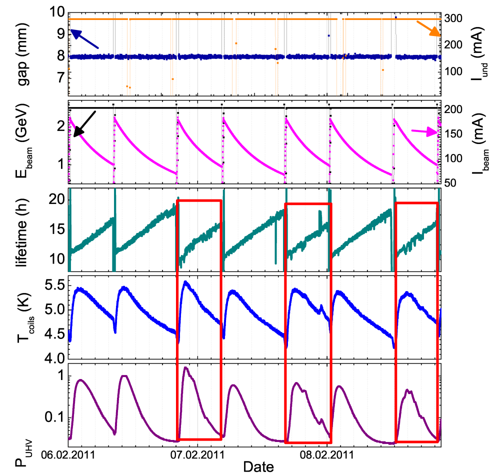

Figure 2: User operation run with 8 mm closed gap an 300 A current in the undulator. The undulator current and gap, the beam current and energy, the lifetime, the temperature of the coils and the UHV pressure are reported as a function of time.

After the first leak, in order not to decrease the beam lifetime to values below 5 hours at $I_{beam} = 150$ mA it was decided to close the gap not lower than 16 mm. The in-

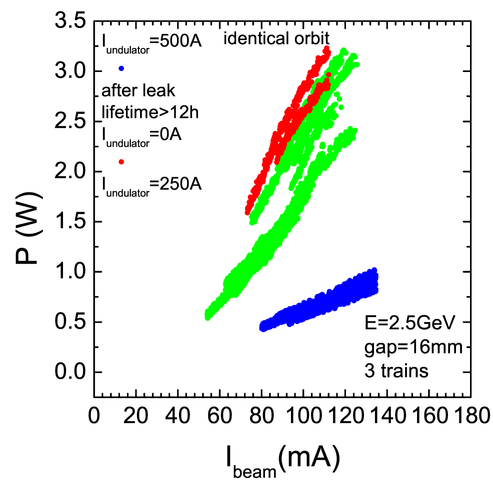

Figure 3: Variation over three years of the beam heat load reported as a function of the average beam current. Beam parameters: E = 2.5 GeV, $I_{beam} = 80 - 200$ mA, three trains. Undulator parameters: gap = 16 mm, undulator current $= 0 - 500$ A.

crease in the beam heat load during the first month after the first leak (May 2011) measured with 16 mm vacuum gap is shown in Fig. 3. The data before the leak have been taken in 2009 over a period of one month. With 8 mm gap the beam heat load is also increased after the first leak and stayed all over the months in the range of values shown after the first and second leak (orange triangles and red circles) up to now. Since the beam heat load does not change by turning on the current in the superconducting coils, we can conclude that there is no significant contribution to the beam heat load from the synchrotron radiation produced by the undulator.

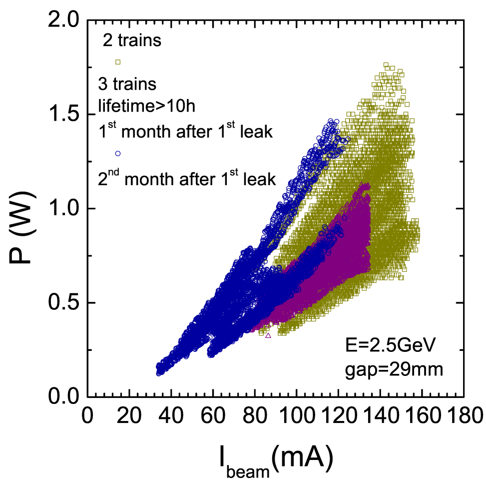

Figure 4: Variation over six years of the beam heat load reported as a function of the average beam current. Beam parameters: E = 2.5 GeV, $I_{beam} = 80-200$ mA. Undulator parameters: gap = 29 mm.

The values of the beam heat load measured with open gap are reported, as a function of average beam current after the first leak, in Fig. 4. The values from the second month after the first leak are in the same range as the ones measured before the leak. The selected data with three trains have all identical orbits. A comparison with the values measured in 2005 and reported in [2] is made. The data from 2005 (dark yellow squares) have also all identical orbits, but different from the ones of most recent data (blue circles and purple triangles). The difference is due to a realignment of the superconducting undulator in the ring made in between; this however does not seem to have affected the beam heat load.

In absence of anomalous pressure conditions in the ring the beam heat load is higher for the smaller closed gap of 8 mm with respect to a closed gap of 16 mm and to the open gap cases. As shown in Fig. 1a, in Fig. 3 and in Fig. 4, the beam heat load with 120 mA average beam current stored in the ring ranges: a) between 1.6 and 3 Watts for 8 mm gap, b) between 0.7 and 3.2 Watts for 16 mm gap, and c) between 0.5 and 1.5 Watts for an open gap of 29 mm.

CONCLUSIONS AND OUTLOOK

The large variation of observed beam heat load values as a function of the average beam current for different gaps confirms the explanation of electron multipacting as beam heat load source at ANKA for normal user operation [2].

Still to be understood is the mechanism responsible for the electron multipacting and the role played by the cryosorbed gas layer. A common cause of electron bombardment is the build-up of an electron cloud, which strongly depends on the chamber surface properties. The surface properties as secondary electron yield, photoemission yield, photoemission induced electron energy distribution, needed in the simulation codes to determine the eventual occurrence and size of an electron cloud buildup, have only partly been measured for a cryosorbed gas layer. Even using uncommonly large values for these parameters, the heat load inferred from the ECLOUD simulations [5] is about one order of magnitude lower than the measurements [6]. While electron cloud build-up models have been well bench marked in machines with positively charged beams, in electron machines they do not reproduce the observations satisfactory. This has been shown at the ECLOUD10 workshop also by K. Harkay [7] and by J. Calvey [8] comparing the RFA data taken with electron beams in the APS and in CesrTA, respectively, with the simulations performed using the electron cloud build-up codes POSINST [9] and ECLOUD [5]. From these comparisons it seems that the electron cloud build-up codes do not contain all the physics going on for electron beams. In order to fit the data with the simulations, the approach at APS and CesrTA is to change the photoelectron model. At ANKA we tried to study if the presence of a smooth ion background (i.e. a partially neutralized electron beam) can change the photoelectron dynamics so that the photo-electrons can receive a significant amount of kinetic energy from the ion cloud plus electron beam system. Following preliminary analytical results by P. F. Tavares (MAXLab), S. Gerstl has included an ion cloud potential in the ECLOUD code: preliminary simulations are encouraging. These beam dynamics studies might as well help us in understanding the correlation observed in Fig. 2 between bumps in the lifetime and abrupt changes in the temperature and pressure in the cold bore.

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