OBSERVATION OF ELECTRON CLOUDS IN THE ANKA UNDULATOR BY MEANS OF THE MICROWAVE TRANSMISSION METHOD *

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Abstract

A superconducting undulator is installed in the ANKA electron storage ring. Electron clouds could potentially contribute to the heat load of this device. A microwave transmission type electron cloud diagnostic has been installed for the undulator section of the ANKA machine. Several tests were first performed to optimize the transmission of the microwave across the hardware in the absence of a beam. Initial tests with beam indicated the presence of side bands in the output microwave spectrum at harmonics of the the revolution frequency. While such side bands are expected to be created by electron clouds, one cannot discount the presence of inter modulation caused by the beam, which also creates a similar effect. Work is underway to detect the extent of inter modulation and also minimize this undesired effect.

INTRODUCTION

Cold bore wigglers or undulators provide higher fields for a given gap and period length compared to magnets at room temperature. In light sources, the usage of these devices offers the advantage of providing higher brilliance at a lower cost. Their use has also been proposed for linear colliders, namely the ILC and CLIC. An important issue faced by these devices is the heat load on the cold vacuum chamber caused by the beam. The proper understanding of the heat load mechanism is of paramount importance in optimally designing these devices. There is considerable evidence that the formation of low energy electrons makes a significant contribution to the overall heat load. Current data obtained at various facilities cannot be explained on the basis of heating from synchrotron radiation or resistive wall heating [5]. Besides this, low energy electrons have been observed and their effects been studied at the superconducting undulator at the ANKA storage ring. Further, it has been recently shown that pressure rise in the ANKA cold bore superconducting undulator can be explained on the basis of electron multipacting [6].

We are currently working on studying these low energy electrons using the technique of microwave transmission. This technique was first proposed for the SPS at CERN [1, 2] and was demonstrated at the PEP II low energy ring for varying electron cloud densities [3]. The low energy electrons cause the microwave to undergo a phase advance that is different from that in the absence of the electrons, leading to a so called ”Phase shift” that depends upon the electron density, which can be quantified under certain idealized conditions [4]. Due to a gap in the bunch train, a periodic clearing of the electrons occurs leading to phase modulation in the microwave propagating across the section. One can thus observe this ”Phase shift” in the form of modulation side bands in the spectrum of the microwave after it propagates through the section of interest.

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THE FACILITY

ANKA is an electron storage ring used as a synchrotron radiation source. The maximum achievable energy is 2.5 GeV and the maximum current is 200 mA. The revolution frequency is 2.7 MHz and the machine is normally operated with three trains, each composed of 32 bunches separated by 2 ns. The cold bore superconducting undulator built by ACCEL Instr. GmbH, Bergisch Gladbach, Germany, is installed in one of the four straight sections of the ring. The rest of the ring is warm, while the temperature of this device is maintained at about 4.5 K.

Possible heating mechanisms of the cold bore device are: (1) synchrotron radiation from upstream magnets, (2) high frequency image currents on the cold surface also called resistive wall heating, (3) ions and electrons accelerated to the walls by the transverse field of the ultra-relativistic beam. The condensed gas layer adjacent to the surface, which is formed at low temperatures is a likely source of electrons impacting back into the chamber walls. The vacuum chamber surface is very similar to one of the LHC beam screens (300 m stainless steel with 30 m of electroplated copper). For such a surface the dominant desorbed gases are H_2 , CH_4 , CO, CO_2 and H_2 and O_2 [7].

MICROWAVE TRANSFER IN THE ABSENCE OF A BEAM

The cross section of the device is close to a rectangle, with chopped corners. The vertical gap of the chamber can be varied in steps of 16, 12, and 8 mm respectively. The width of the cross-section is 66.2 mm and the undulator is 1.5 m long, with 100 periods. Using the formula for rectangular waveguides as an approximation, the cutoff frequency for the fundamental mode was estimated to be about 2.3 GHz. Both sides of the insertion device are equipquiped with 4 Beam Position Monitors (BPMs) each. The ones on the same side of the chamber cross-section were connected and the two pairs were used as electrodes for launching the wave on one end and receiving the wave at the other respectively. The transmission was examined in the absence of a beam for different frequencies using a network analyzer. We found enhanced signal at around 2.54 GHz. This corresponds to a trapped mode where the transfer of the signal from the BPMs into the vacuum chamber is well matched.

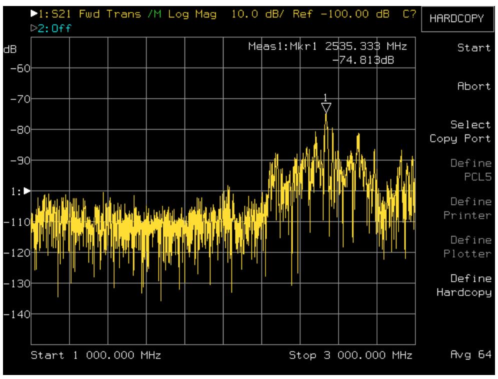

Figure 1: Enhanced transmission at trapped mode

OBSERVATIONS IN THE PRESENCE OF AN ELECTRON BEAM

Measurements of the transmitted spectrum were made with a beam at 2.5 GeV with a set up shown in Fig. 4. The input frequency of the microwave was 2.52 GHz from an HP 86608 synthesized signal generator. We had 180 deg hybrids connected to the input and output segment of the circuit. The output was amplified using a an Avantek solid state amplifier before being fed into an HP 8562E spectrum analyzer. The magnetic field of the undulator was switched off.

Figure 2 shows the output spectrum. We see that the carrier frequency is well above the noise floor displaying sufficient transmission. The side bands are visible at harmonics of the revolution frequency upto the sixth order on the right and the with order on the left of the carrier signal. This disparity is most likely due to loss in transmission at the 6th lower frequency sideband. The signal from the electron beam itself is clearly visible at harmonics of the revolution frequency. The 180 deg hybrids serve the purpose of minimizing the signal from the beam affecting the spectrum analyzer, amplifier and the signal generator. This could be be further improved by using front end filtering which eliminates unwanted frequencies. Also, the use of an isolator/circulator would further minimize the transmission of the beam signal generator. As explained below, it is essential to minimize the signal produced by the beam.

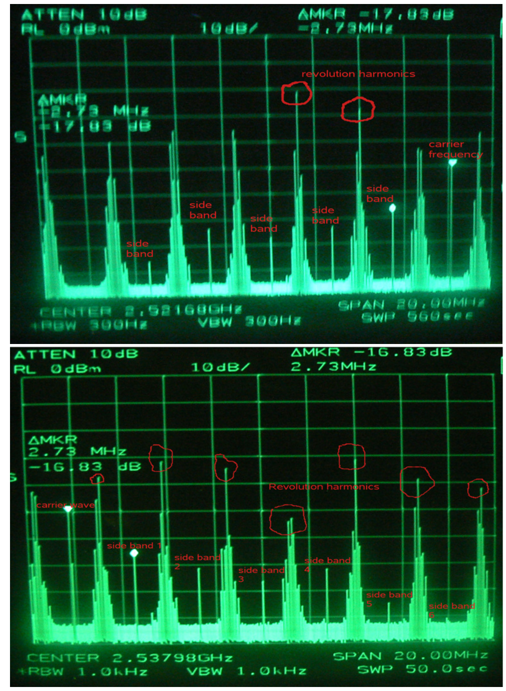

Figure 2: Left and right sidebands with carrier signal in the presence of beam

While it is well known by now that the low energy electrons or electron clouds produce side bands, the same sidebands could also be attributed to the nonlinear mixing of the carrier signal and the beam signal, leading to undesired inter modulation effects. Despite all measures to minimize the signal from the beam, one can never eliminate its presence. Several tests have been planned for the future where the conditions producing these low energy electrons can be varied. We will be able to analyze the signal at different beam currents and beam energies. This would vary the intensity of the synchrotron radiation produced in the undulator and thereby also vary the extent of low energy electrons produced. Another planned test is to repeat this across a warm, straight section where we believe the presence of low energy electrons is negligible. If the properties of these side bands vary based on the extent of low energy electrons believed to be produced, we can conclude that the sidebands are indeed produced by the low energy electrons. In this process, we would obtain an independent confirmation of the presence of these electrons, already done with the help of a retarding field analyzer [6].

The experiment will need to be repeated with the undulator magnetic field on. This can influence the side bands in two ways. The enhanced synchrotron radiation from the undulator could influence the creation of low energy electrons. Besides this, the external magnetic field could lead to cyclotron resonance leading to amplification of the side bands. This effect occurs when the cyclotron frequency due to the external magnetic field is equal to the carrier frequency, which was demonstrated through simulations and later in an experiment carried out at the PEP II high energy ring [8]. Several factors will need to be considered before expecting to see this resonance effect in this system. First of all, the fundamental mode of propagation of the microwaves in this geometry corresponds to a case where the wave electric field has mostly a vertical component. This is because the cross section of the beam pipe is much wider and relatively short. In such a case, the external magnetic field will need to have a horizontal component, perpendicular to the wave electric field in the area where low energy electrons are present. This corresponds to the so called extraordinary wave or X-wave, necessary to create the cyclotron resonance (which is the same as upper hybrid resonance in low plasma frequency limit). An ideal undulator field would offer only ordinary, or O-wave propagation at lower modes which are unaffected by undulator magnetic fields (which are parallel to the wave electric field). On the other hand, several practical features such as fringe field effects and alterations near the surface of the chamber could produce conditions leading to the cyclotron resonance.

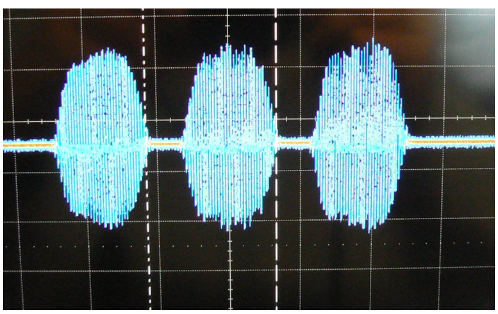

Figure 3: The bunch fill pattern captured by an oscilloscope (span = 300 ns)

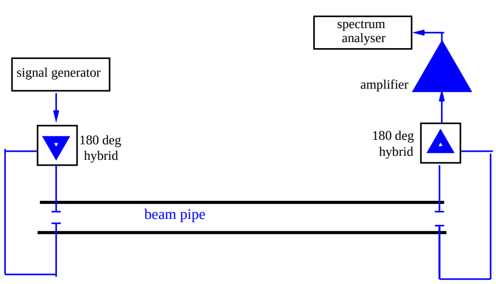

Figure 4: Schematic of the layout of the experiment

A DEMONSTRATION OF THE UNDESIRED INTER MODULATION EFFECT

To demonstrate the inter modulation effect from the beam, which also leads to side bands, we conducted the following test. An RF generator was pulse modulated with a 3 pulse sequence that was 500 MHz sinusoidal with a 2.7 MHz repetition frequency that resembled the bunch filling pattern in the storage ring (Fig.(5). This signal was superimposed upon the the 2.53 GHz carrier signal used in the experiment. The output of this mixed signal was fed into the same receiver that was used in the microwave transmission experiment. There were clear signs of inter modulation producing sidebands as shown in Fig(5). These results suggest that the sidebands produced by the low energy electrons could be contaminated by inter modulation effects. More work needs to be done to eliminate the inter modulation of the two signals in the real experiment so that the side bands are created entirely from the low energy electrons present in the undulator section.

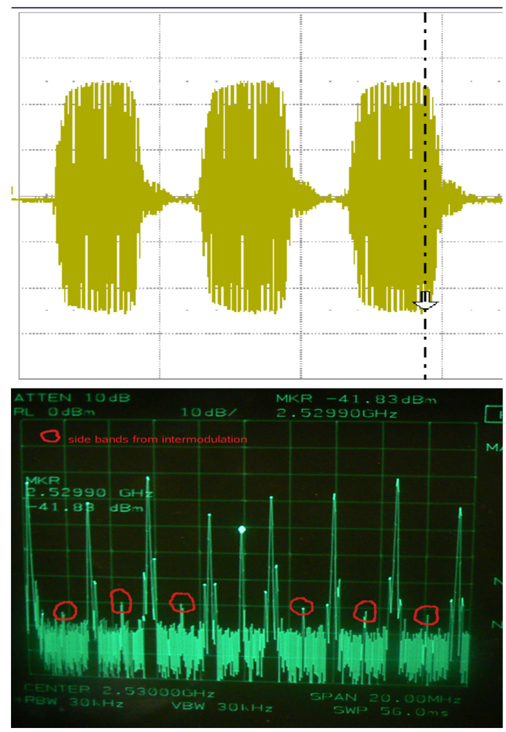

Figure 5: Signal generated to resemble fill pattern of beam, and demonstration of sidebands produced purely from inter modulation

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