EXPERIMENTAL COUPLING OF 35 GHZ RF-CAVITIES WITH AN INTENSE BUNCHED ELECTRON BEAM

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Abstract

We present the first utilization of a FEL-bunched electron beam in the framework of Two Beam Accelerator (TBA) studies. A 2.2 MeV, 800 A electron beam, produced by the induction accelerator LELIA, is bunched at 35 GHz by the FEL interaction. Then it is extracted from the wiggler by a suitable adiabatic exit. A solenoid is used to produce a narrow beam waist downstream at the position of a 35 GHz resonating cavity. First, we test the so-called "idler" cavity, a closed RF-structure which can be slightly detuned from the resonant frequency in order to enhance bunching. In a second step, open cavities will be tested in order to study the production of high frequency RF-power by an intense bunched beam.

1 INTRODUCTION

Research and development on several e^+-e^- collider projects in the TeV range are in progress at various laboratories throughout the world, most of which aim at ultimately achieving accelerating gradients of 100 MeV/m. While the solution adopted by NLC and JLC is to develop high power klystrons at 11.4 GHz [1], an even more ambitious increase in operating frequency to 30 GHz lies at the heart of the CLIC project being studied at CERN [2]. There are no suitable high power sources at this frequency, so the project has adopted an innovative scheme originally developed at Lawrence Berkeley National Laboratory (LBNL), the TBA [3]. In the TBA, the main beam, which is to be accelerated to TeV energies, runs in a structure parallel to the drive beam (DB), an extremely intense electron beam of much lower energy, typically a few GeV in the CLIC design. The drive beam is bunched at the desired operating frequency, and upon passing through appropriately designed resonant cavities, generates RF power which is transmitted to the accelerating cavities on the main-beam line through a series of waveguides.

Among the means under study for generating the intense bunched drive beam needed for the CLIC design, the use of a Free-Electron Laser (FEL) has been proposed by Shay and co-workers at Lawrence Livermore National Laboratory (LLNL) [4]. In a FEL, a relativistic electron beam passing through the periodically varying field of a wiggler magnet amplifies an electromagnetic signal whose frequency is resonant with the undulatory motion of the electrons. Provided such an interaction occurs, the electron beam, initially uniform along the axis, forms small bunches in the troughs of the co-propagating electromagnetic wave. The generation of high output power in a Radio Frequency (RF) FEL indicates that considerable bunching of the electrons has indeed taken place. Direct optical evidence for this bunching has been obtained at CEA/CESTA at 35 GHz [5],[6]. In the first part of this paper, we summarize this experiment and give its most recent results. The second part is devoted to the study of RF cavities. The aim is to demonstrate the ability of this scheme to generate the required amounts of RF power by the passage of the bunched beam through the extraction cavity. The present work is done in active collaboration with two laboratories, particularly for the design of RF cavities: the Relativistic Klystron Two-Beam Accelerator (RK-TBA) group, a collaboration between LBNL-LLNL and the CLIC group at CERN.

2 PRODUCTION OF AN INTENSE BUNCHED ELECTRON BEAM

Intense emission from the far infrared to the millimetric range is due to the strong electron bunching which appears in high gain FELs which utilize low energy but very intense electron beams (≈1 MeV, ≈1000 A). This bunching mechanism occurs at the FEL wavelength so that electrons are able to emit radiation in phase leading to higher peak power levels [7].

At CESTA we have observed this bunching in a 35 GHz FEL amplifier. The electron beam is produced by the induction linac LELIA which delivers a 800 A, 2.2 MeV, 60 ns electron beam in single shot-operation. After exiting LELIA, the beam is transported and matched into a 12-cm period helical wiggler where it amplifies a co-propagating 35 GHz, 10 kW electromagnetic wave (EM) generated by a magnetron. The set-up of the experiment is shown in Figure 1. The FEL resonance condition is obtained when the wiggler magnetic field amplitude is 1100 G. In that case we obtain the best amplification of the external 35 GHz signal. The gain is exponential and the FEL saturates at 80 MW after 20 periods of interaction.

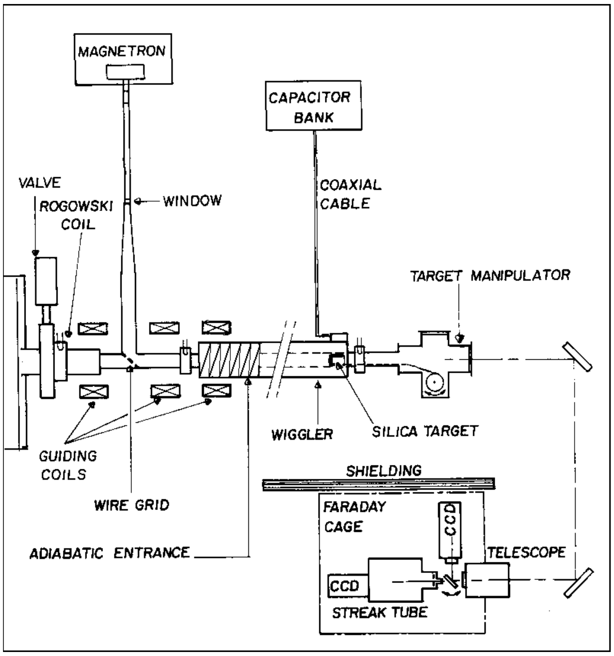

Figure 1: General experimental set-up

In order to measure electron beam bunching, a fast streak camera collects a small part of the Cerenkov light emitted by the electrons when they are stopped in a movable fused silica target. Bunching quality can be described by the bunching parameter b which is defined by the ratio of the Fourier component of the current profile divided by the value of the average. Figure 2 shows the best photograph of the bunches we have obtained. They are more pronounced than in a previous

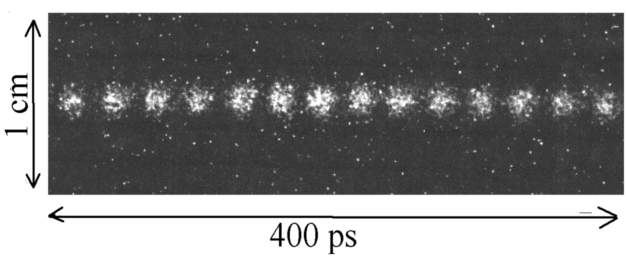

Figure 2: Example of a streak camera image showing 14 bunches at 35 GHz.

experiment [5] and b has been increased from 0.2 to 0.5 as shown in Figure 3, thanks to a higher current propagating inside the wiggler. Measurements as a function of distance inside the wiggler have shown bunching is maximum just before FEL saturation as expected from numerical calculations [8]. At this one needs to extract it from the wiggler to perform tests of RF cavities.

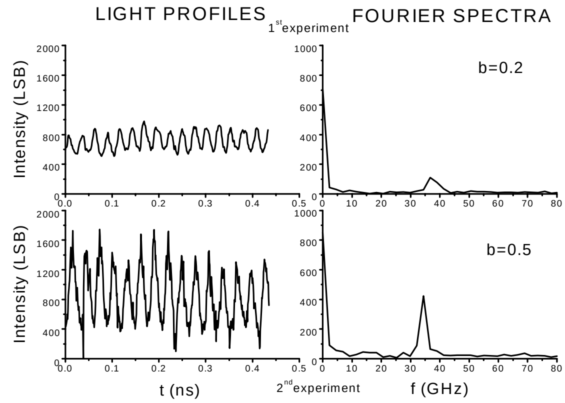

Figure 3: Comparison between bunching measurements in the two amplifier experiments

3 TESTS OF RF-CAVITIES

In the same way that for proper beam injection in the wiggler, where the first 6 periods are adiabatic with a linear magnetic field increase from zero to 1100 G, the last 5.5 periods of the wiggler are strapped in order to decrease the magnetic field from 1100 G to zero. In such a way, the transverse momentum acquired by electrons in the wiggler is lost and propagation on axis is possible behind the wiggler if an external force is applied to compensate the defocusing effects of emittance and space charge. In our case we also require the beam to traverse a small RF cavity located as close as possible to the wiggler exit. We have to minimize the longitudinal space charge effects which rapidly debunch the beam as it propagates downstream. Figure 4 gives the experimental configuration we have adopted where a solenoid has been inserted to produce a small waist at the cavity location. A PARMELA [9] calculation has shown the beam remains bunched while passing through the cavity.

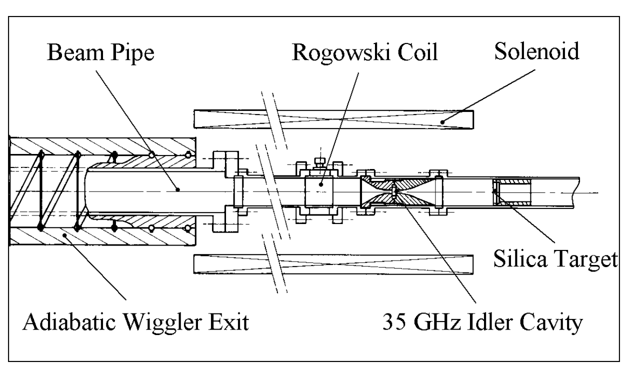

Figure 4: Detail of the end of the experimental line which shows the end of the wiggler at left, the focusing solenoid, the idler cavity and the movable silica target.

Two kinds of cavities are experimented. The first has no output port (see Figure 5) and acts as a re-buncher if it is slightly detuned from the driving 35 GHz frequency. Detuning can be obtained and adjusted by placing rings of different thickness inside the cavity resulting in a variation of its internal radius. Optical measurements will be performed to analyze the effects of the beam-cavity interaction on the longitudinal profile of the electron beam. A challenge is to propagate and to focus the beam in such a small cavity inside a beam pipe whose diameter decreases from 40 to only 4 mm at the cavity position. The second kind of cavity has one output port to a standart Ka-band waveguide in order to extract electromagnetic power. We plan to test a low-Q cavity and a medium-Q cavity. They differ mainly by

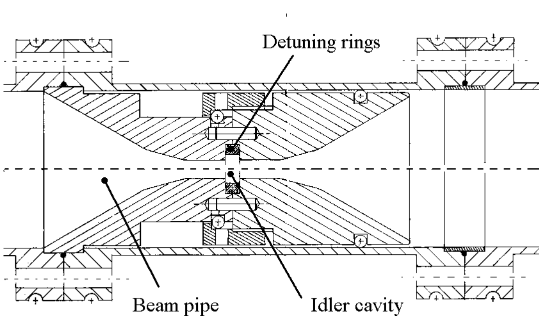

Figure 5: Drawing of the idler cavity which shows in detail the mechanism used to change internal rings

the size of the aperture between the cavity itself and the output waveguide. Calculations have been made with the GDFIDL code [10] and an example of the mesh used is given in Figure 6. Measurements of emitted power as well as frequency and phase of the output signal will be performed as a function of electron beam parameters and compared with the computed expected values.

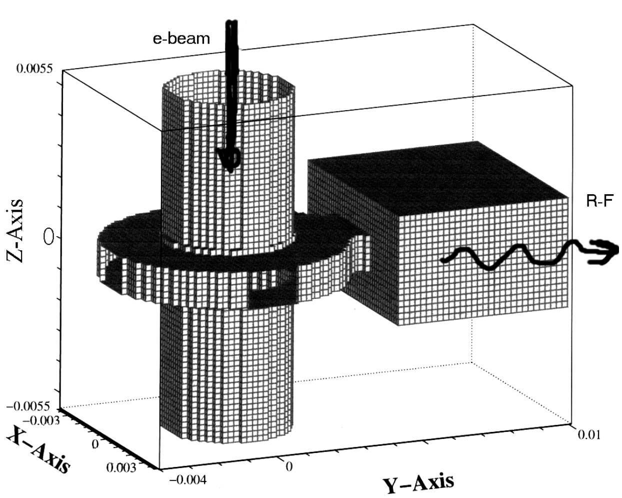

Figure 6: Example of the mesh used for the open cavity calculations with the GDFIDL code

4 CONCLUSION

We have presented the recent results of the CESTA experiment where an induction linac based FEL is used to produce an intense bunched electron beam to test high frequency RF cavities for TBA research. We are now optimizing beam extraction from the wiggler and beam transport to the cavity location. The quality and intensity of the bunches obtained will allow us to study the behavior of an idler cavity which is an essential part of the RK-TBA project at LBNL. Open 35 GHz cavities will be also tested by analyzing the emitted radiation. It is important both for the CLIC and the RKTBA projects where the production of power at high frequency as well as the knowledge about breakdown limits are of prime importance. This experiment will be upgraded in the future by using the more powerful electron beam produced by the PIVAIR induction linac (7 MeV, 3 kA) [11]. Simulations have shown that the high quality bunched beam at 30 GHz produced by the new wiggler will propagate long enough to obtain a test bench for various components of the TBA projects.

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