The FEL Driven Two- Beam Accelerator Studies at CESTA

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Abstract

During the past few years, a demonstration that a free electron laser driven by an induction accelerator can furnish an intense bunched beam for use in a two-beam accelerator has been performed at CESTA. Earlier work, which concentrated on observing bunching by optical means, and the more recent production of R-F power obtained by passing the bunched beam through a standing-wave output cavity will be reported.

1 INTRODUCTION

In the Two-Beam Accelerator (TBA), the R-F power source is provided by an extremely intense electron beam, the so-called drive beam. It is bunched at the desired operating frequency, and upon passing through appropriately designed resonant cavities, generates microwave power to supply the accelerating cavities on the main-beam line.

If the stringent requirements on the high frequency (11.4 - 30 GHz) R-F power source can be met, the goal of 100 MeV/m gradients should be reached, making the TBA a prime candidate for the multi-TeV collider.

The mature technology of induction accelerators is capable of repeated generation of electron currents in the kiloampere range, as required by the TBA. Furthermore, in a Free Electron Laser (FEL) Amplifier the electron beam, initially uniform along the axis, will form small bunches in the troughs of the co-propagating electromagnetic wave. The generation of high output microwave power indicates that electron bunching has occurred.

In a series of experiments performed at CEA/CESTA on behalf of the CLIC [1] collaboration, and sponsored by CERN, the capacity of a FEL, powered by an induction accelerator, to generate an intense bunched beam has been demonstrated [2]. With the LELIA induction linac (800 A at 2.2 MeV) [3], direct optical evidence for bunching at 35 GHz was observed, and the objective of a proof-of-principle was attained. However, a major difficulty was encountered, the tendency of a tightly bunched beam to debunch after leaving the wiggler under the influence of longitudinal space charge forces and velocity dispersion. In consequence, the bunching should be carried out at the highest feasible energy. The accelerator PIVAIR [4], capable of generating a beam of 3 kA at energy 7 MeV, was better suited for this than LELIA. The principal advantage of using PIVAIR resides in the increased debunching distance, roughly a factor of 15 greater than for LELIA. In the present article we summarize our previous bunching observations using LELIA and we present our results on power extraction obtained by passing the bunched beam from PIVAIR through a simple 35 GHz resonant pillbox cavity.

2 LELIA EXPERIMENT

The bunching experiments on LELIA were performed on a FEL consisting of a pulsed helical wiggler of pitch 12 cm which operated in the single pass amplifier mode. The input electromagnetic signal was provided by a magnetron of frequency 35 GHz. The experimental power growth as a function of wiggler length is shown in Figure 1, where for comparison the predictions of the simulation code "SOLITUDE" [5] in the TE_{11} mode are also displayed. To obtain these data we used a kicker magnet movable along the wiggler in order to stop the interaction by deflecting the beam into the pipe. Good agreement with the experiment is observed because we used the measured electron beam initial conditions in the code.

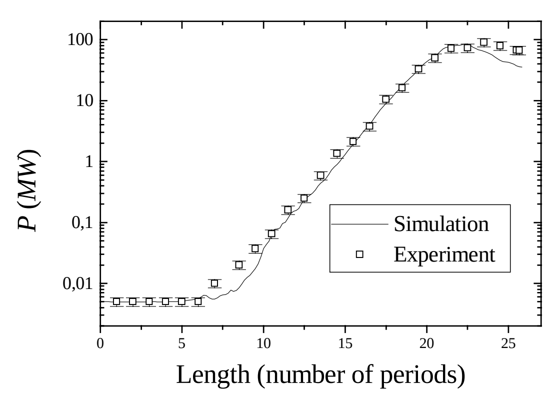

Figure 1: Comparison between experimental and calculated power growth in the wiggler.

[1] Supported by Thomson I.T.D.S

The bunching of the electrons was observed by producing Cherenkov radiation using a 2 mm-thick fused silica target and observing it with a high-resolution streak camera (2 ps). Figure 2 shows the best photograph of the bunches we have obtained. Here, the sweep speed of the streak tube is 25 ps/mm so that we are analyzing a 419 ps long slice. We found a bunching parameter of 0.25.

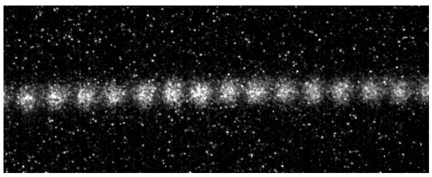

Figure 2: Example of a streak camera image showing 14 bunches at 35 GHz.

Having shown that the FEL is capable of bunching a beam sufficiently for use as a drive beam in the TBA, we carried out tests of extraction and focusing using LELIA [6]. While these showed that bunching was preserved reasonably well, the advantage of obtaining higher beam energy led us to choose PIVAIR for the cavity test.

3 PIVAIR EXPERIMENT

Two distinct experiments PIV-1 and PIV-2 have been performed with the accelerator PIVAIR in 1999 and 2000 respectively. The experimental layout, shown in Figure 3, was similar in both experiments, with PIVAIR indicated schematically at left. On the right two alternative ends of the beam line are shown, the upper for measuring the cavity output power, and the lower for Cherenkov measurements (beam position and size with an inclined thin mylar target and bunching measurements with a thick fused silica target). The FEL properties are listed in Table 1. In order to bring the electron beam onto the ideal helical trajectory, an adiabatic section six-periods long is used to increase the wiggler magnetic field from zero to its nominal value. Similarly a six-periods adiabatic exit is employed to extract the bunched electron beam along the axis at the end of the wiggler. These adiabatic sections are essential components of beam transport, and they are described in details elsewhere [7]. The microwave power produced in the wiggler is deflected out of the beam line by a thin tungsten wire mesh, identical to that used to inject the magnetron signal into the beam tube. Upon leaving the wiggler the bunched beam is focused by a group composed of four thick coils. The aim is to obtain a centered narrow waist at the cavity position, and the coils may be displaced or tilted in order to achieve this.

	PIV-1	PIV-2
Beam Energy (MeV)	6.7 ± 0.05	4.8 ± 0.05
Current (A)	830 ± 30	700 ± 30
Wiggler period	20 cm	16 cm
Wiggler length	640 cm	400 cm
Adiabatic entry and exit	6 periods	6 periods
Beam pipe radius	19 mm	30 mm
Magnetron frequency	35.04 GHz	35.04 GHz
Magnetron injection power	5 kW	10 kW

Table 1: FEL Parameters

The first step in these experiments was to obtain an adequate power level with the FEL. In PIV-1, the output power at 35 GHz attained its peak value only during the early part of the pulse, just as we observed in the LELIA experiment. Thanks to the low FEL frequency bunching and microwave power measurements we made [8], we conjecture that the competition between the two frequencies may be responsible for the decrease in the 35 GHz signal towards the end of the pulse. In PIV-2 the FEL parameters were chosen to minimize this undesirable effect. In the top of Figure 4 we compare the FEL output power in the two experiments. We observe a significant increase of the signal duration in PIV-2 (40-50 ns).

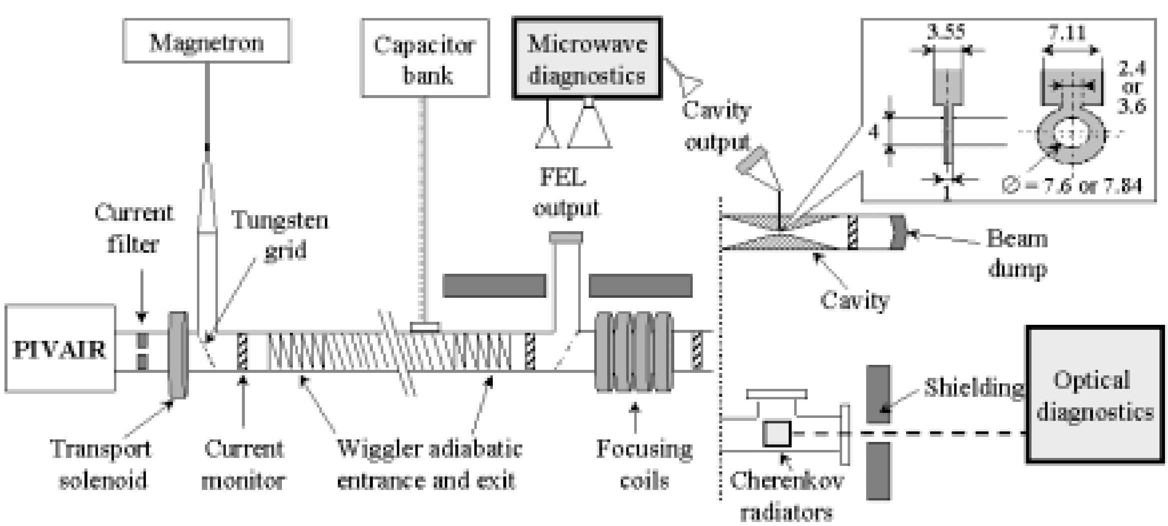

Figure 3 : PIVAIR Experimental Set-Up

Once suitable operation of the FEL was achieved, the optical detection line, with a thin mylar target placed at the cavity location, was installed in order to get the smallest centered beam waist. Its diameter was about 8 mm in PIV-1 and 6 mm in PIV-2. Although two resonant cavities have been designed at LBNL [9] and built by the CLIC group at CERN, we report here only the results concerning the detuned high-Q cavity (Q = 230, f_0 = 35.64 ± 0.05 GHz).

Experiment	PIV-1	PIV-2
Wiggler magnetic field (Gauss)	1580 ± 40	1820 ± 40
FEL Power (MW)	110 ± 20	100 ± 40
Cavity input current (A)	210 ± 20	550 ± 30
Cavity output current (A)	100 ± 30	190 ± 20
Cavity RF power (MW)	0.7 ± 0.5	0.6 ± 0.4

Table 2 : Detuned high-Q cavity results

The main results are displayed in Table 2. More details concerning the PIV-1 and PIV-2 experiments can be found in [10] and [11] respectively.

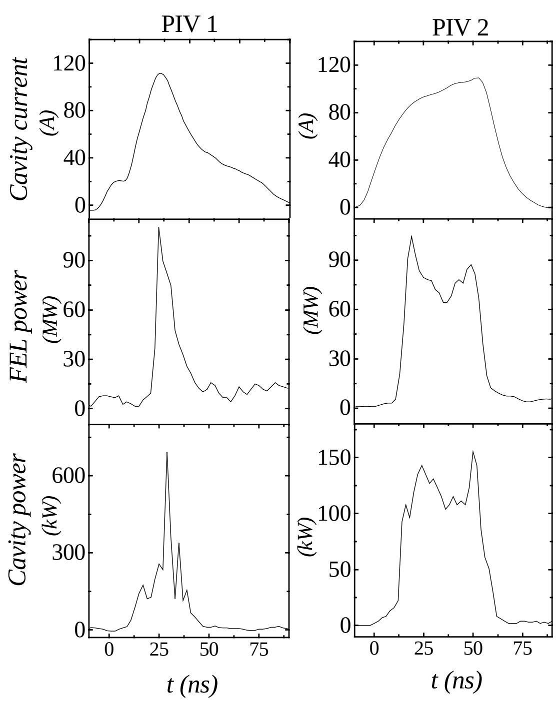

Figure 4 : Cavity output current, FEL output power and High-Q cavity output power in PIV-1 and PIV-2.

The measured output current and output power for the 35 GHz high Q cavity output power are displayed in Figure 4. We point out here that all the modifications made in PIV-2 (higher R-F injected power inside the wiggler and better beam transport to the cavity using a larger beam tube), succeeded in increasing the time duration of both R-F power signals. Furthermore, in PIV-2, the bunching parameter at the cavity position was lower than in the previous experiment. An explanation has be found by coupling the SOLITUDE and the RKA transport codes [12].

CONCLUSION

The use of a FEL driven by an induction linac has definitively demonstrated its capability of generating a high R-F power signal over more that 40 ns of pulse duration. Unfortunately, at relatively low beam energy, it's a difficult task to extract correctly the beam from the wiggler and to focus it in a 4 mm diameter aperture. In such conditions, beam dynamics studies will be easier at lower frequency, as in the RTA experiment [13]. Furthermore, the large accelerating field required for a TBA points out the possibility of R-F breakdown, and an alternative way to study this at high frequency will be to directly feed an accelerating cavity with the FEL power.

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