Recent Results from the FEL Driven Two-Beam Accelerator Project at CESTA

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Abstract :

Last year an intense electron beam produced by an induction accelerator was bunched using a Free Electron Laser and used to generate radio-frequency power by its passage through a resonant cavity. An improved version of this experiment has been carried out in the last few months. Our aims were mainly to extract a higher beam current from the FEL and to obtain a longer R-F pulse duration from the cavity.

1 INTRODUCTION

Over the past few years the Free Electron Lasers (FEL) at CEA/CESTA have been used to study the possibility of producing a R-F power source at 35 GHz in the Two-Beam Accelerator (TBA) scheme [1]. A previous experiment made on the PIVAIR induction linac (6.7 MeV, 3 kA) [2] has demonstrated the first production of 35 GHz power in a standing wave cavity driven by a 35 GHz FEL bunched beam [3]. Although the cavities reached satisfactory power levels, the overall current transmission of the beam through the FEL, the focusing system and the cavity, was low (13 %). In addition, the cavity output signal was shorter than the beam pulse, suggesting that both bunching and transmission were decreasing towards the end of the pulse. We present here the results of the new experiment carried out this year.

2 EXPERIMENTAL SET-UP

The experimental layout is shown in Figure 1 with PIVAIR indicated schematically at left In this experiment a smaller cathode was mounted on the injector and the beam energy was reduced to 4.8 MeV, where reliable and stable machine operation at 700 A was obtained with no current filter. Solenoids match the beam into the pulsed bifilar helical wiggler, which has both a six-periods adiabatic entrance, and a similar adiabatic exit required to bring the bunched beam out along the axis. Compared to the previous experiment, the wiggler period was reduced from 20 to 16 cm, and the waveguide radius increased from 19.5 to 30.5 mm, in order to allow easier beam transport and better current transmission. The input magnetron signal is injected into the wiggler via a tungsten grid, while a second is used to deflect the FEL power out of the waveguide after the wiggler exit. With higher injected power (>10 kW) in this new set-up, we hope to minimize the perturbation due to the low FEL resonant frequency [4] and consequently to generate a long stable FEL signal and bunched beam. At the wiggler exit the electron beam is focused by a group of four thick coils down to a narrow waist at the cavity position. Four monitors are used to measure the current at the wiggler's entrance and exit, and at the cavity's entrance and exit.

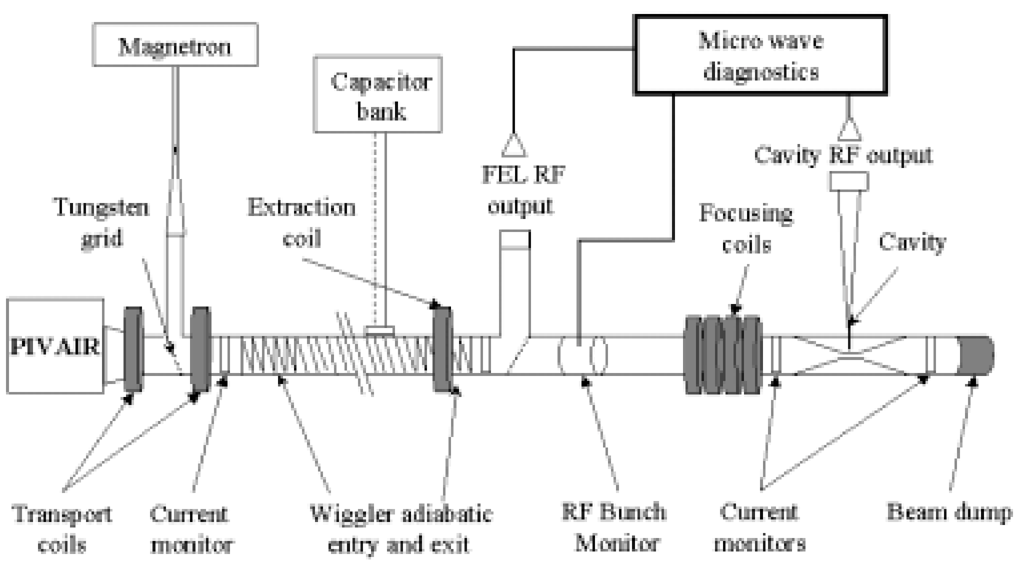

Figure 1 : Experimental Set-Up

[1] Supported by THOMSON ITDS

The FEL and cavity output powers are measured and their frequencies are determined using heterodyne methods. In addition, an indirect observation of the bunching was made by installing a R-F bunch monitor [5], which picks up the 35 GHz R-F signal generated by the modulated beam as it passes through the beam tube.

3 FEL AND BUNCHING RESULTS

The first step in this experiment is to obtain an adequate power level with the FEL, which indicates that beam is bunched. A reproducible FEL power of 90 MW has been obtained in good agreement with the FEL code, "SOLITUDE" [6]. The corresponding bunching parameter has been estimated by the code to be 0.4 at the wiggler's exit.

Figure 2 shows a typical FEL power (a) together with bunch monitor signal (b) placed one meter beyond the wiggler exit. The shots displayed here correspond to two different beam transports after the wiggler end. The asymmetric geometry of the bunch monitor renders the measured power (b) very sensitive to beam position. Nonetheless these signals show that the beam is quite uniformly bunched throughout the FEL pulse duration.

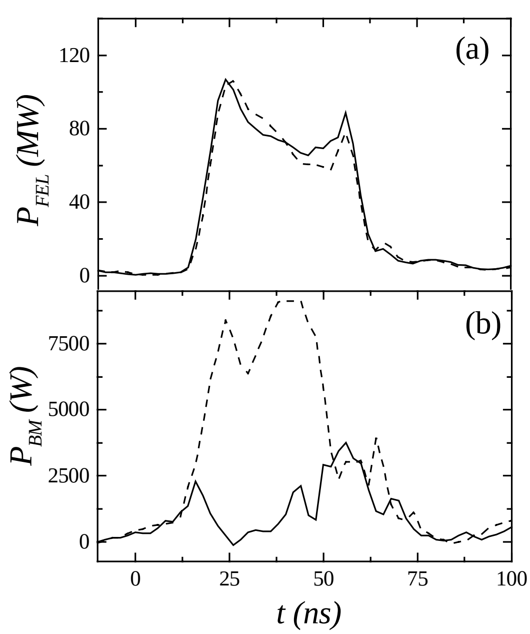

Figure 2 : Reproducibility of the FEL power signal and the sensitivity of the bunch monitor power.

Optical bunching measurements have also been carried out by using a 5 mm-thick silica target and observing the Cherenkov light produced when the beam strikes it. At the FEL exit, 550 A of beam current has been measured, and althoughf this represents a large improvement of the FEL beam transmission compared to our previous results, the Cherenkov light flux was insufficient for an accurate measurement of beam bunching at 35 GHz (28 ps). In such conditions, only noisy photographs were obtained, and without any optical measurement, we had no way to calibrate the R-F bunch monitor signal. Nonetheless, this method, once properly developed, might provide a simple non-destructive measurement of beam bunching. Moreover, the R-F bunch monitor signal has the advantage of lasting throughout the whole beam pulse duration, as compared to the narrow time interval typical of the streak camera images.

4 CAVITY RESULTS

Two standing-wave cavities have been designed at LBNL [7] and built by the CLIC group at CERN, a resonant low-Q cavity (Q = 60, f_0 = 35.18 ± 0.05 GHz) and a detuned high-Q cavity (Q = 230, f_0 = 35.64 ± 0.05 GHz). 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 in order to pass through the 4 mm diameter cavity aperture. In this experiment, the smallest waist we observed was only 6 mm in diameter. To obtain good current transmission through the cavity we have made a large number of shots, changing the alignment of the focusing coils and measuring the beam current after the cavity. With a 550 A, 4.8 MeV beam, the total available energy is around 150 J. In these conditions, when the focused beam hits the wall directly, the energy deposited is enough to produce vacuum fusion and thus damage the cavity.

Figure 3 : Two photographes representing the low-Q cavity entrance , before and after beam heating.

Indeed, that is what we observed with the low-Q cavity, as shown on figure 3. We see two photographs which show the cavity entrance before and after one day of running. The low-Q cavity has been damaged and its characteristics have probably been modified. It was then replaced by the high-Q cavity and we have pursued the test, but with better alignment conditions.

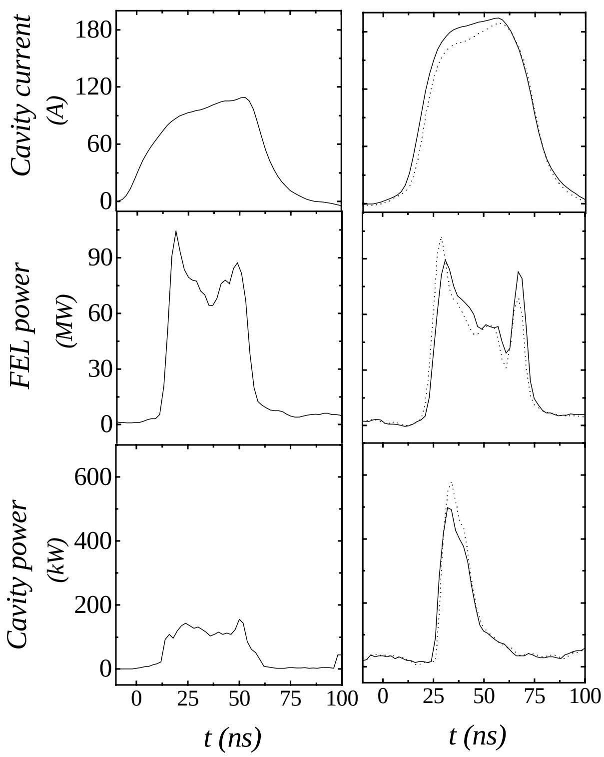

Figure 4 : Cavity output current, FEL output power and high-Q cavity output power for two different focusing configurations

To study the beam cavity interaction we have madeseveral shots in which we have changed the focusing magnetic field, and thus varied the current transmission through the cavity. For two different cases, the measured cavity output current (top) and the R-F output powers (FEL-middle, Cavity-bottom) are displayed in Figure 4. We observe that with 100 A, power of 130 kW was measured at the cavity output. With a current twice as great, the output power is four times higher, which is consistent with a simple beam-cavity interaction theory [1]. This formula may be used to calculate the bunching parameter b in terms of the output power P, the

$$P = (Ib)^2 Q[R/Q]\cos^2(\varphi)$$

current I, the Q of the cavity, the factor *[R/Q]* (=45 Ω) which characterizes the coupling between beam and cavity, and the detuning angle φ. We found a value of 0.32 which has to be compared to the 0.4 bunching parameter calculated by SOLITUDE at the wiggler's end. In the previous experiment [8], the effect of the transport region and the cavity aperture increased the bunching by collimation. In this experiment, the beam characteristics at the end of the wiggler are different and with a lower beam energy and higher current we expect the effect of the debunching forces to increase.

The most surprising feature in figure 4, is the fact that the cavity R-F power gets narrower in time when the R-F power increases. We can see that the cavity power has clearly decreased after 10 nanoseconds. In these conditions, it is hard to clearly identify the phenomena responsible for this effect. Different possibilities could be considered : R-F breakdown, multi-pactoring, ion emission from beam heating, ionisation of the residual gas (5 10^{-6} Torr). Among these possibilitieswe are unable to conclude.

CONCLUSION

In this recent experiment we have measured a 90 MW 40 ns FEL pulse at 35 GHz. A R-F bunching diagnostic has indicated that the beam is bunched over the whole pulse duration. The total current transmission of our FEL-cavity device has also been improved up to 28 %. Nonetheless, the current loss at the cavity entrance is an important problem which proves that beam-cavity dynamic studies at low beam energy would be easier at lower frequencies such as on the RTA machine at LBNL [9].

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REFERENCES

[1] T. Lefevre *et al.*, “Microwave Production by a Free Electron Laser Bunched Beam Driving a Resonant Cavity at 35 GHz”, to be published in IEEE Transactions on Plasma Science, (2000)

[2] P. Anthouard *et al.*, "AIRIX Prototype technological results at CESTA", in Proc. of the PAC Conference., Vancouver, Canada, p. 1254, 1997.

[3] T. Lefevre *et al.*, “Free Electron Laser as a Driver for a Resonant Cavity at 35 GHz”, Phys. Rev. Lett. **84**, p.1188, 2000.

[4] J. Gardelle *et al.*, "High power operation and strong bunching at 3 GHz produced by a 35 GHz free electron lase amplifier", Phys. Rev. Lett. **79**, p. 3905, 1997.

[5] H. Braun and C. Martinez, “Non-Intercepting Bunch Length Monitor for Picosecond electron Bunches“, Proceeding of the 1998 EPAC Conference, Stockholm, p.1559, 1999.

[6] J. Gardelle *et al.*, "Free-electron-laser simulations : Effects of beam quality and space charge", Phys. Rev. E **50**, p. 4973, 1994.

[7] S. M. Lidia *et al*., "RK-TBA studies in Ka band", in Proc. of the XIX International Linac Conf., Chicago, IL, p. 97, 1998.

[8] S.M. Lidia *et al.*, “Analysis of Longitudinal Bunching in an FEL Driven Two-Beam Accelerator”, these proceeding.

[9] S.M. Lidia *et al.*, “The RTA Betatron Node Experiment : Limiting Cumulative BBU Growth In a Linear Periodic System”, these proceeding.