PROGRESS ON A SMITH-PURCELL RADIATION BUNCH LENGTH DIAGNOSTIC

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Abstract

A Smith-Purcell radiation diagnostic to measure the micro bunch length of a 20MeV, 17 GHz electron bunch train is being implemented at MIT. The bunch length can be determined by measuring the frequency and angular distribution of the emitted radiation. The beam is produced by a 17 GHz, 50 MeV/m traveling wave accelerator built by Haimson Research Corporation (HRC). The high operating frequency of this accelerator allows for the production of ultra-short bunches of about 180 femtoseconds. At this time we are assembling the experiment and we will present an update on the progress.

1 INTRODUCTION

The HRC accelerator system consists of a chopper-prebuncher injector, and a quasi-constant traveling wave disc loaded accelerating structure consisting of 94 cavities that operate in the $\frac{2\pi}{3}$ mode[1], [2]. The accelerator has achieved a beam energy of 17 MeV at 100mA. Simulations [1] indicate that the phase spread at the exit of the accelerator should be about 1°, or a bunch length of $\sim$ 180 fs. Conventional methods for measuring bunch length consist of using streak cameras or RF de¤ecting structures. While streak cameras have been shown to work down to $\sim$ 200 fs, the bunch length of the HRC accelerator is at the operating limit. Additionally, streak cameras are expensive and the measurement process is destructive. HRC is building an experiment, in parallel with the Smith Purcell experiment, to use an RF de¤ecting structure to measure the bunch length[5], however, this technique also has the disadvantage of being destructive.

Two techniques have been developed that utilize lasers to measure the bunch length: X-ray generation through Compton scattering and an electro-optic technique. The Compton scattering method requires a TeraWatt laser and a high charge electron beam in order to produce enough x-rays. The electro-optic technique requires the laser and electron bunch to be properly phased together. Both of these methods would require a substantial upgrade to the laser system currently in operation at MIT.

Several coherent radiation techniques have been employed to measure bunch lengths, including transition radiation, diffraction radiation and Smith Purcell radiation. These techniques all exhibit qualitatively similar angular distributions of radiated power and have the feature that the radiation intensity scales as the square of the number of particles. However, Smith Purcell radiation has the further advantage over the other two coherent radiation methods in that the intensity of radiation scales as the number of grating periods. In addition, the Smith Purcell diagnostic is non-interfering and non-destructive. Using Smith Purcell radiation as a bunch length was £rst proposed by Nguyen[3] and demonstrated by Doucas[4]. The experiment by Doucas at Frascati was performed on a beam that was 14 ps and the wavelength of the measured radiation was 0.65 mm to 4 mm.

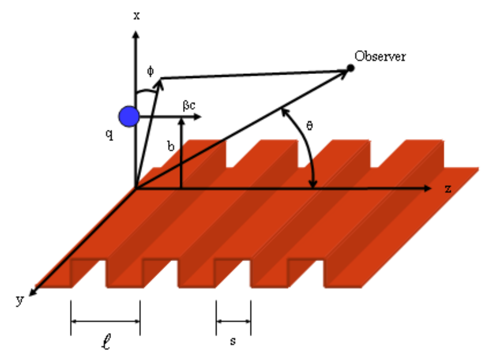

Figure 1: Schematic of an electron bunch, q, passing over a grating of period l, with an impact parameter b.

2 SMITH-PURCELL RADIATION DIAGNOSTIC

An electron passing close to the surface of a metal diffraction grating as in Figure 1 emits Smith-Purcell radiation at a wavelength λ_n given by

$$\lambda_n = \frac{l}{n}(\frac{1}{\beta} - \cos\theta) \tag{1}$$

where l is the grating period, θ is the emission angle with respect to the propagation direction, n is the diffraction order, and β is the velocity of the electron bunch. The angular distribution of power radiated by the electrons is given by [6]

$$\frac{dP}{d\Omega} = N_g \frac{eIn^2\beta^3}{2l\varepsilon_o}\left(1 + N_e e^{-k^2\sigma^2\cos^2\theta}\right) \times \frac{\sin^2\theta}{(1-\beta\cos\theta)^3} R_n^2 \exp\left(-\frac{4\pi\,|n|\,b}{\gamma l\,(1-\beta\cos\theta)}\right) \tag{2}$$

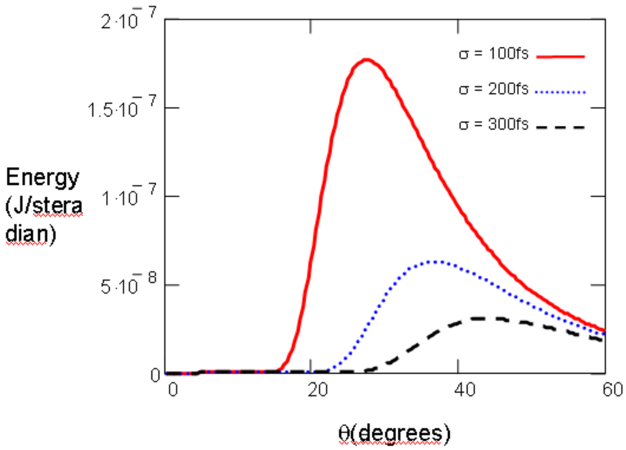

Figure 2: Plot of radiated power as a function of angle for three different bunch lengths (100 fs, 200 fs and 300fs).

where N_g is the number of grating strips, I is the beam current, N_e is the number of electrons in the bunch, ε_o is the permittivity of free space, b is the height of the bunch above the grating surface, γ is the relativistic factor $\left(1-\beta^2\right)^{-\frac{1}{2}}$, k is the wave vector, σ is the bunch length, and R_n^2 is the grating ef£ciency factor.

For radiation at wavelengths shorter than the bunch length the radiation is incoherent. However, at wavelengths longer than the bunch length the radiation is coherent and the temporal coherence of the electron bunch enhances the intensity of the radiation. In general, the coherence term is $(1 + N_e F)$, where F is the form factor given by the Fourier transform of the bunch distribution. For Equation 2 a Gaussian distribution has been assumed giving a coherence term $\left(1 + N_e e^{-k^2\sigma^2\cos^2\theta}\right)$.

The estimated bunch length for the HRC accelerator is 180 femtoseconds or 55 μm. In Figure 2 equation 2 is plotted as a function of angle for three different bunch lengths (100 fs, 200 fs, and 300 fs) and for $b = 0.5$ mm, $\gamma = 35$, $l = 2.1$ mm, $N_e = 1.2\text{x}10^8$, $N_g = 50$, and $|n| = 1$. The bunch length diagnostic involves measuring the angular distribution of the radiation to determine the length of the pulse.

3 EXPERIMENTAL SETUP

3.1 HRC Accelerator

The HRC accelerator is powered by a relativistic klystron which has produced powers up to 26 MW with a saturated gain of 67 dB[7]. The linac consists of a DC thermionic gun, a chopper-prebuncher injector, and a quasi-constant accelerating structure consisting of 94-cavities that operate in the $\frac{2\pi}{3}$ mode. The electron bunches produced by the injector are designed to be accelerated by the linac to energies of 25 MeV. Initial operation of the accelerator with injected RF power up to 10 MW produced beam energies up to 17.5 MeV with up to 100 mA of transmitted beam current. The accelerator is currently being commissioned to full operating parameters.

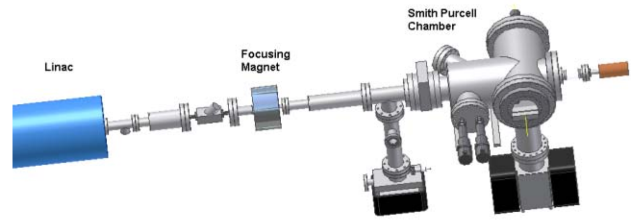

Figure 3: Schematic of the Smith Purcell experimental beamline

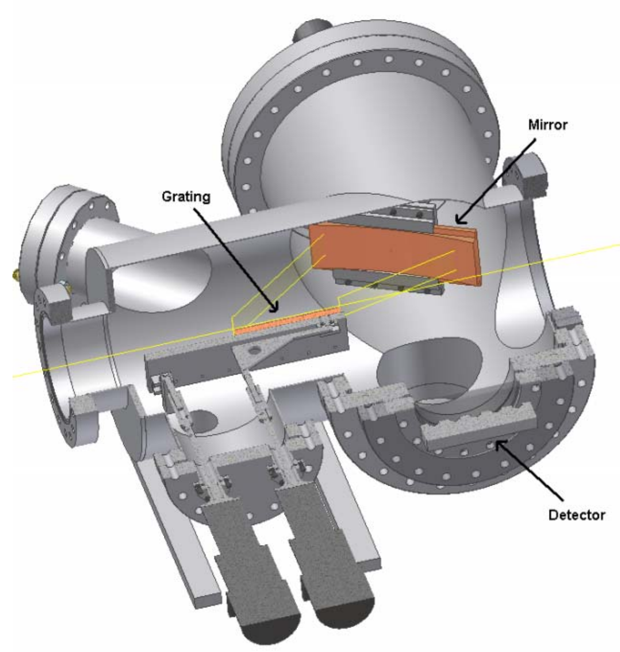

Figure 4: Schematic of the Smith Purcell experimental vacuum chamber

A schematic of the accelerator beamline with the Smith Purcell experiment vacuum chamber is shown in Figure 3. The Smith Purcell experiment will be placed ~ 1 meter downstream from the exit of the linac to allow for the use of a focusing solenoid and steering coils.

3.2 Smith Purcell Diagnostic

A schematic of the Smith Purcell diagnostic vacuum chamber is shown in Figure 4 . The essential components of the diagnostic include the grating, a mirror to capture and focus the radiation, a window through which the radiation passes out of the vacuum chamber and a detector.

The grating parameters have been optimized for the HRC electron beam using the procedure in [8] for an echelle grating. The grating parameters include: a period of 2.1 mm, a blaze angle of $10°$, and a length of 10 cm ($N_g = 47$). The radiation is collected by a mirror with a radius of 48.89 cm and is designed to collect radiation emitted between the angles $15°$ and $40°$ and redirect it out a 10 cm window. Both pyroelectric and bolometer detectors will be implemented to measure the radiation. The experimental chamber has been baked out and will shortly be installed on the accelerator beamline.

4 CONCLUSIONS

The 17 GHz traveling wave disc loaded structure has demonstrated a beam energy of 17 MeV at 100 mA current. To our knowledge this is the highest frequency stand alone accelerator in the world. A Smith-Purcell radiation diagnostic to measure the bunch length of the HRC accelerator is currently being implemented. The estimated bunch length of the accelerator is ~ 180 fs which should produce coherent radiation in the THz regime. The Smith Purcell experimental chamber is currently being installed on the accelerator beamline and operation will commence shortly.

5 ACKNOWLEDGEMENTS

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