High Bandwidth Beam Current Monitor*

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Abstract

A stripline directional coupler beam current monitor capable of measuring the time structure of a 30-ps electron beam bunch has been developed. The time response performance of the monitor compares very well with Cherenkov light produced in quartz by the electron beam. The four-pickup monitor is now used on a routine basis for measuring the beam duration, tuning for optimized beam bunching, and centering the bunch in the beam pipe.

I. INTRODUCTION

The RF electron linear accelerator at EG&G/Santa Barbara Operations is used to develop and calibrate detectors sensitive to electron or gamma radiation pulses. The linac is typically operated at energies between 1 and 26 MeV, with peak currents between a few milliamperes and 200 A. Excellent beam bunching (50-ps wide pulse) has made it an especially useful tool for studying detector systems with bandwidths up to 1 or 2 GHz. However, as our detector system bandwidth has increased over the years into the multi-GHz range, the beam pulse waveform has become an appreciable contribution to the measured detector signal. Improved beam measurements are needed not only to correct detector data, but also to improve accelerator tuning. We began a project to develop a beam current diagnostic that would faithfully reproduce the time structure of the electron beam bunch. The goal was a clean response up to and above 10 GHz. Another objective was straightforward use as an everyday measurement, without special setup or checkout required.

The workhorse recorder for most measurements is a four channel sampling oscilloscope (20-GHz HP54120) with the sampling head a few feet from the detector being tested. For our applications, a nonintercepting current monitor permanently installed in the linac vacuum pipe is ideal, because then beam current and detector measurements can be made simultaneously with the same instrument. After some investigation of resistive wall image-current monitors and B-dot probes, we settled on a stripline directional coupler as the most promising technique to achieve our goals of bandwidth and convenience.

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II. THE STRIPLINE DIRECTIONAL COUPLER

The basic principle of the directional coupler monitor is illustrated in Figure 1. The pickup is a simple rod spaced just

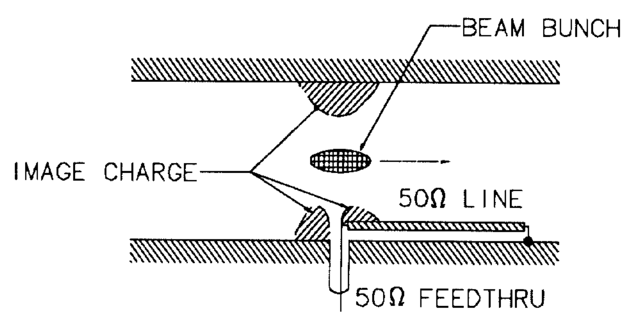

Figure 1. Schematic of beam bunch passing the pickup.

inside the beam pipe wall to create a 15-cm long 50-Ω transmission line, connected to the outside world at the upstream end with a 50-Ω vacuum feedthrough and shorted at the downstream end to the beam pipe itself. For an ultra-relativistic electron traveling inside the beam pipe, the electromagnetic field just inside the wall of the pipe is almost purely transverse, and can be thought of as a thin disk traveling along with the electron. More accurately, the FWHM duration of the fields from a point charge is 1.4 $a/\gamma c$, where a is the radius of the pipe and γ is E/mc^2. For our case, this time is much less than the FWHM of the beam pulse, so the duration of the electromagnetic pulse accurately reproduces the length of an electron beam bunch. As the field sweeps past the upstream end of the pickup rod, the magnetic flux threaded by the loop formed by the pickup rod and the pipe beam wall will rise up to a constant, illustrated in Figure 2. An oscilloscope connected to the coupler by the

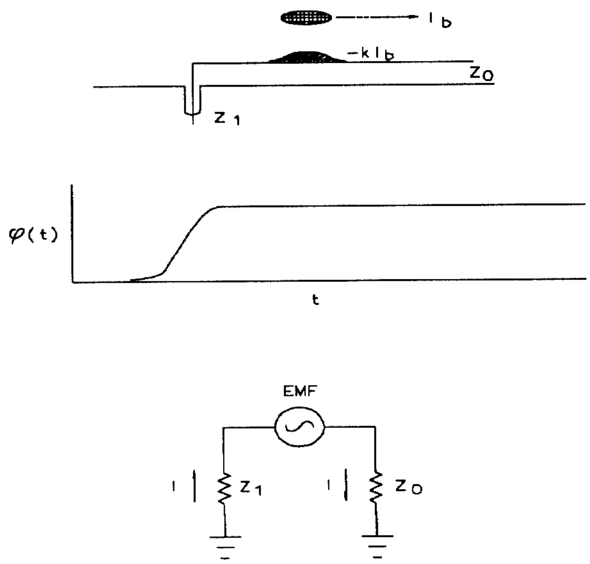

Figure 2. The magnetic flux producing the monitor pulse.

feedthrough detects the resulting EMF as a negative pulse proportional to the beam current. The proportionality constant, k, is approximately equal to the fraction of the beam pipe circumference subtended by the pickup rod. Because the downstream end of the transmission line is shorted, the pulse reflects and appears at the scope as an opposite polarity pulse delayed by twice the transit time.

In reality, of course, the directional coupler response is more complicated than this simple picture, especially at high frequencies. The two main effects muddying the model are wakefields and local resonances associated with the coupling to the feedthrough. We use the term wakefields here very loosely to mean all of the beam-induced electromagnetic fields aside from the main TEM mode. Every discontinuity in beam pipe diameter (collimators, for example) and even the finite resistivity of the beam pipe will generate undesirable electromagnetic fields following the beam down the vacuum pipe waveguide. The directional coupler pickup responds without discrimination to **any** electromagnetic field, so the observed signal will happily reproduce all of the undesirable wakefields as well as the primary beam pulse. Our attempts (admittedly not exhaustive) to dampen the wakefields with RF-absorbing materials created other problems, either lowering the bandwidth of the primary response or creating new sources of wakefields themselves. The simplest solution for us is to ensure that wakefield frequencies are above the rolloff frequency of our recording system. The cutoff frequency of a cylindrical waveguide is inversely proportional to the radius (0.5 cm radius corresponds to a 17.5 GHz cutoff), so we constructed the directional coupler in a small diameter pipe. The 20-GHz recording system then acts as a low-pass filter for any propagating wakefields.

Particular attention was paid to the details of the feedthrough and its coupling to the pickup rod. For example, the exposed dielectric area at the feedthrough penetration of the beam pipe was minimized to avoid cavity resonances. Small diameter pickup rods were chosen to circumvent transverse resonances.

III. RESULTS

Figure 3 illustrates the method used to test some of the prototype direction couplers. The electron beam emerges

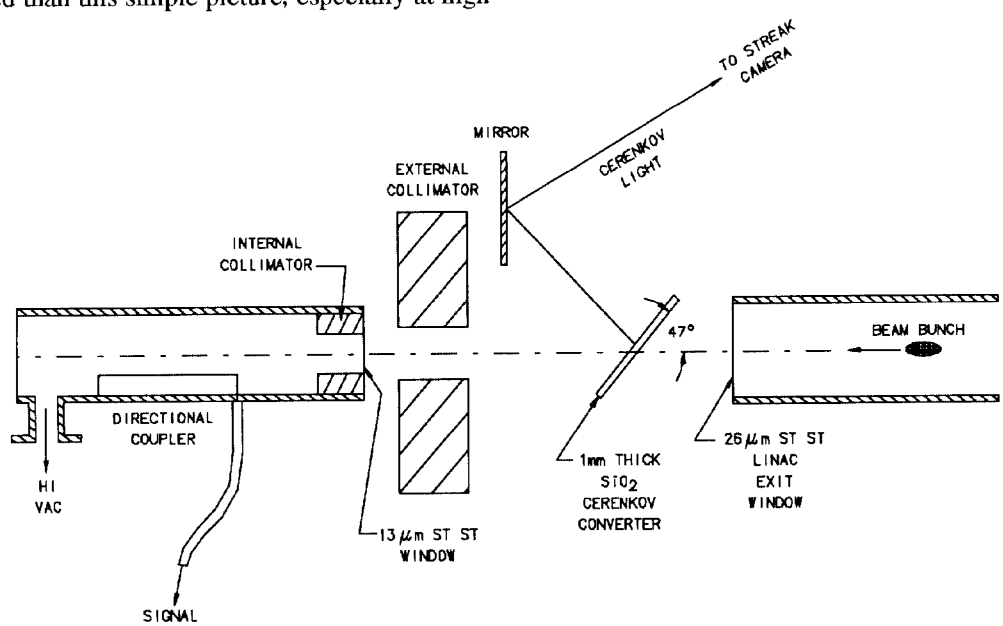

Figure 3. Experimental setup for comparison of directional coupler with Cherenkov light.

into the air through a thin window, and strikes a thin quartz disk at 47°, producing Cherenkov light. The disk is masked to a 4-mm slit to minimize time of flight spreading of the optical pulse, which is then reflected and focused into a Hamamatsu C1587 streak camera. After the streak measurement, the quartz is remotely moved out of the beam, and the directional coupler response is recorded on the sampling oscilloscope. Tests were also made with the directional coupler mounted to the linac exit port, with the quartz radiator at the downstream end of the coupler. Figure 4 shows a comparison of the streak and directional coupler responses. The FWHM of both is about 35 ps.

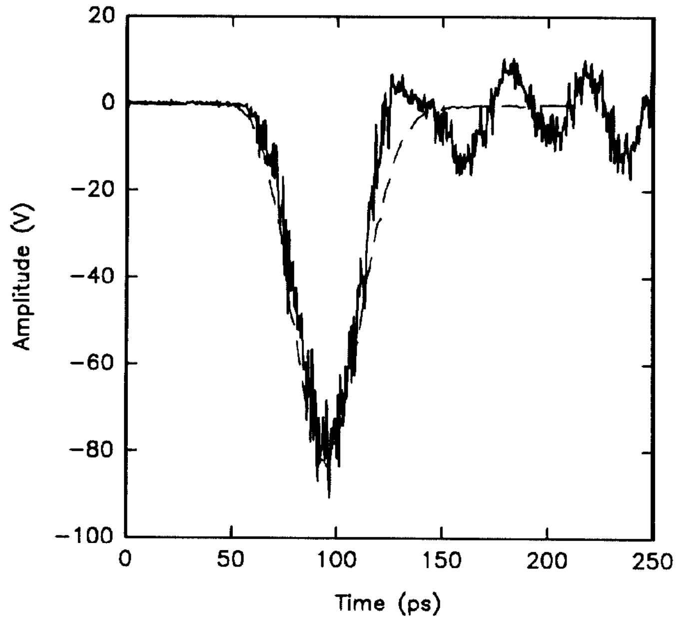

Figure 4. Directional coupler response (solid) and streak of Cherenkov light (dots).