Proposal to the University Consortium for a Linear Collider

August 21, 2002

Proposal Name

Non-intercepting electron beam size diagnostics using diffraction radiation from a slit

Classification (accelerator/detector: subsystem)

Accelerator: beam diagnostics

Personnel and Institution(s) requesting funding

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Collaborators

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Project Overview

The Linear Collider presents new challenges for beam instrumentation. Some of the beam dimensions are of the order of a few nm (at the i.p.), and to be able to reach these small sizes, the beams have to be tightly controlled and understood from their very inception onward. A number of different techniques are available in the arsenal of beam size and beam emittance measurements (e.g. transition radiation, metal wire, laser wire, laser interferometry, cavity BPM). Experiments of electron bunch profile measurements have been conducted using coherent synchrotron radiation (CSR), coherent transition radiation (CTR), as well as coherent diffraction radiation (CDR) [1-3]. Because the CDR perturbs the electron beam less than CTR and CSR, it is a better choice for monitoring the electron beam bunch shape. The use of diffraction radiation (DR) for measuring the transverse beam dimension is a new non-invasive technique, only partially investigated at the present time [4-5]; for example transverse beam size and emittance measurements have not been performed even though it is apparently possible to make precision measurements of bunch length, emittance at low energies, and the transverse size. This collaborative effort involving physicists and facilities from Cornell and Vanderbilt is aimed toward a comprehensive investigation of the potential use of DR over the broad spectrum of energies to be found at the Linear Collider.

Diffraction radiation is emitted from relativistic electron bunches passing through an aperture in a metal screen. The simplest aperture is a circular hole or a slit. The DR, like the transition radiation, is in the forward direction along the electron path, and in the backward direction along the direction of specular reflection from the the metal screen. The DR intensity is proportional to the square of γ, and it is distributed in angle as $1/\gamma$, where γ is the electron energy factor ($E_{beam}/m_e c^2$); thus, both the intensity and the angular distribution can be used to deduce the beam energy[6]. The DR technique can be developed as a low cost, compact, and non-intercepting monitor which can be very useful for each element of the Linear Collider, starting with the injection linac, the damping rings and the main linac. DR has the potential capability to diagnose multiple beam parameters such as longitudinal and transverse beam sizes, energy, position, divergence and emittance. The DR technique also can be developed as a single shot measurement. As the DR technique measures the spectrum and angular distribution in the frequency domain, it has very high spatial and time resolution, and it is easy to satisfy the requirements of the Linear Collider facility. The goal in spatial resolution in this proposal is less than 1 μm in the longitudinal and transverse beam size measurement. From the analysis of measured data, the error on bunch length is estimated to be of the order of about 20%. One limitation that is apparent is due to the shrinking angular distribution with increasing γ, potentially limiting transverse beam size measurements to energy below 5 GeV(depending on background); however other properties such as bunch length measurement improve with increasing beam energy making this technique very viable at the Linear Collider.

The coherent properties are included in the DR spectrum in which the radiation wavelength is nearly equal to the beam bunch length. In the case of the LC, 100 μm bunch lengths would produce radiation in the 0.1 mm wavelength region. The CDR has a fixed phase relative to the electron bunches, and the measurement of the coherent radiation gives the longitudinal bunch form factor f(ω) and hence provides information about the longitudinal bunch distribution function S(z). Therefore, the electron distribution in a bunch can be obtained from the inverse Fourier transformation of the form factor. In addition, the angular distribution of the DR from an electron passing through a slit in a metal foil has polarization properties because of the interference effects between the two half-planes of the radiator. The polarization shows different properties with the electric field parallel and normal to the plane of slit plane. The electron beam transverse dimension can be measured through the analysis of the angular distribution of the diffraction radiation [4-5].

We propose the measurement of the coherent DR spectrum from a slit in a metal foil. The longitudinal profile will be evaluated from the fast Fourier transform of the autocorrelation function and the use of the minimal phase approximation. The results will be compared to that of intercepting CTR (Coherent Transition Radiation) and non-intercepting electro-optic measurement experiments conducted in the same environment.

In addition, we propose measure the electron beam transverse dimension through the analysis of the angular distribution of DR. A simple CCD camera can measure the angular polarization of DR. The total intensity of normal angular distribution has a minimum value when the beam passes through the center of slit. In practice, this property can be used to center the electron beam in the slit, and it may be a useful tool with which a cavity BPM can be centered on the beam.

It should be noted that much more accurate angular information of DR can be obtained by placing two slits. We also propose to measure interference from the forward radiation off one slit as it interferes coherently with the backward radiation from the other. Analyzing the whole angular distribution in the normal plane and fitting it to the theoretical prediction allows us to determine the transverse dimension of electron beams, beam energy and emittance.

The bulk of the design and construction of the apparatus will be done at the Vanderbilt FEL Center, where there are available experienced scientists, mechanical and design engineers and where, importantly, a minimum of eight hours of beam time per week will be made available to this project. Bibo Feng, who is the accelerator physicist at the Vanderbilt FEL, has performed CDR experiments at the Tohoku University Linac in Japan, and has experience measuring e-beam emittance, beam current as well as transverse and longitudinal beam profiles. Steve Csorna, a physics faculty member, who is a particle physicist, has worked with Don Hartill at Cornell in the measurement of the CESR beam's transverse size from the two slit interference of synchrotron radiation. Bill Gabella, the associate director of the Vanderbilt FEL Center, is an accelerator physicist who has experience in measuring bunch length using coherent transition radiation.

FY2003 Project Activities and Deliverables

In the first year, we will conduct the simulation work of DR which applies to the fundamental description of the bunch length experiment and the beam transverse size experiments. The calculation of CDR and incoherent DR under different conditions will help to understand the principles and to direct the design work of the experimental devices. We will write the calculation codes as well as the data processing programs.

We will design and build a Martin-Puplett type interferometer which will be used for the CDR spectral experiments. Two Golay cell FIR detectors and some optical components are needed for this purpose. We will design and build a radiator as well as its housing chamber for the experiments. The two pieces of thin metal foils or aluminum coated silicon plates can be used as the radiator. The slit of the radiator should be moved to intercept the electron beam by an actuator. The slit width will be adjusted by moving the two half foils in the same plane. It emits transition radiation when the slit is closed, thereby allowing us to directly compare the results from DR and TR techniques.

The first year deliverables will be a Martin-Puplett type interferometer, the DR radiator, and a technical report for DR experiments.

FY2004 Project Activities and Deliverables

In the second year, the CDR measurement devices will be built and commissioned at the Vanderbilt linear accelerator. The linear accelerator at Vanderbilt is a Mark III type linac, which produces electron energy from 25 MeV to 45 MeV with average beam current 200 mA. By measuring the coherent radiation spectrum intensity we will be able to derive the beam bunch length and longitudinal intensity profiles.

We will also measure the DR angular distribution from the radiator to yield the beam transverse dimension according to the angular distribution theoretical calculation. We will measure the interference image from two DR screens with slits to obtain more detail information of the angular distribution of DR, and derive the electron beam properties such as beam transverse size, beam energy and beam angular spread.

The second year deliverables will be a technical report describing the coherent DR and incoherent DR experimental results at Vanderbilt.

FY2005 Project Activities and Deliverables

During in the third year, we will carry out the beam property experiments using coherent DR and incoherent DR at the Cornell accelerator facility with higher electron beam energy. The device for measuring the angular distribution will be designed and built for accommodating different wavelengths and radiation bandwidths corresponding to different beam energy and slit width of the radiator.

The third year deliverables will be a technical report describing the coherent DR and incoherent DR experimental results at Cornell accelerator facility.

Budget justification

The first years activities are limited to design and build an interferometer and a DR radiator, which will involve staff members (not included in the budget shown here). A minimal amount of travel funds is included to cover collaboration meetings.

We expect that the second and third year will be primarily devoted to studying the properties of the DR under varying beam conditions at Cornell and Vanderbilt. Low energy running (50 MeV) can be efficiently performed at Vanderbilt, high energy running will be at Cornell (CESR). The postdoc will have the primary responsibility for scheduling runs, acquiring data and doing a significant portion of the data analysis.

We expect that on the basis of what we learn during the first year, we will need to buy additional specialized equipment and electronics.

Three-year budget, in then-year K$

Institution: Vanderbilt University (Fringe benefits are calculated at 25.6% rate on total salaries, and indirect costs are calculated at 51% rate on total salaries, fringe benefits and travel)

Item	FY2003	FY2004	FY2005	Total
Other Professionals	0	30	35	65
Graduate Students	0	0	0	0
Undergraduate Students	0	0	0	0
Total Salaries and Wages	0	30	35	65
Fringe Benefits	0	7.7	9	16.7
Total Salaries, Wages and Fringe Benefits	0	37.7	44	81.7
Equipment	29	10	10	49
Travel	5	5	8	18
Materials and Supplies	0	0	0	0
Other direct costs	0	0	0	0
Total direct costs	34	52.7	62	148.7
Indirect costs	2.6	21.8	26.5	50.9
Total direct and indirect costs	36.6	74.5	88.5	199.6

References:

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