Proposal to the
University Consortium for Linear Collider

August 30, 2002

Proposal Name

RF Breakdown Experiments at 34 GHz.

Classification (accelerator/detector: subsystem)

Accelerator: structure

Personnel and Institution(s) requesting funding

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Project Overview

An experimental program is proposed to study rf breakdown in mm-wavelength accelerating structures. This research is expected to have relevance to fundamental issues in accelerator structure design, as well as to near-term issues for NLC.

Rf breakdown limits the accelerating gradient and thus determines the collider length. One of the most important questions in collider design is the frequency dependence of the maximum achievable accelerating gradient. Presently, and in some cases, breakdown experimental data are contradictory, incomplete, and inconclusive as the following indicates: (*a*) Experiments by Loew and Wang [2-4] demonstrated a square root dependence of maximum surface gradient on frequency in the microsecond pulse length range; independent experiments on single cavities under similar conditions show maximum surface fields of 190 MV/m for S-band and 350-400 MV/m for X-band, in conformity with the square root dependence [8,13]. (*b*) For X-band accelerating structures such as those under extensive study in several research groups at SLAC, the maximum surface field is always lower than in a single cavity, and the spread of maximum surface gradient depends on the structure type and parameters. Some recent theoretical investigations at SLAC also indicate that one may expect an increase of the gradient with frequency [5-7]. (*c*) CERN experiments [9,10,11] do not match the SLAC results, as follows. For 20, 30 and 40 GHz, the maximum surface gradient for a single cavity excited by the beam doesn't depend on frequency, and equals about 380 MV/m for very short pulse width [12] (at SLAC, the same surface gradient was achieved in a single X-band cavity for pulse width more than 10 times longer). These differences are not understood, but it is suggested that the CERN experiments were done under different conditions using different methods, as compared to other experiments performed at SLAC, KEK, and Budker INP. In further contradiction to the SLAC results, no significant difference was found at CERN between the maximum surface field for single cavities and various accelerating structures. . It is not possible to develop the next generation (multi-TeV) of linear colliders without careful investigations of the maximum achievable accelerating gradient for higher frequencies. This point has been enunciated repeatedly, within the accelerator community (e.g., Snowmass2001). This knowledge is important for NLC because exact information on the maximum accelerating gradient available and what the optimal operating frequency should be, may allow design of a collider upgrade to a center-of-mass energy which enhanced X-band technology will not allow. In addition, the breakdown investigations under way at SLAC include development of models of this phenomenon, and validation of these models will require experiments over a range of frequencies including frequencies higher than X-band, but carried out under similar conditions. To be able to compare measurement results for S, X and Ka bands and to exclude extraneous effects, these measurements must be done using the same method used at SLAC: high-power RF amplifier, waveguide system, pulse compressor, variable pulse width, flexibility of conditioning process, etc.. The Yale Beam Physics Laboratory's 34-GHz program to establish a Ka-band accelerator test facility satisfies these requirements. The main component of this facility is 34 GHz, 1 μsec magnicon amplifier with the design power of 45 MW [1]. The tube is already assembled at Yale and it is under vacuum. We expect to start conditioning as soon as the tube magnet is ready (which should be within a couple of months). Support for development of high-power 34 GHz transmission line components (including those which are required to feed the test structure) has recently been approved by DoE. During the proposed experiments, coordination with SLAC is planned.

In order to achieve the maximum gradient, one should make correct choices for details of the accelerating structure. We propose a test structure with both strong defenses against rf electrical breakdown, and low peak surface magnetic field (in order to prevent pulse heating leading to metal fatigue). The improvements are based on the following innovations: (*a*) elliptical irises which reduce the maximum surface electric field: elliptical irises were suggested by the authors [14,15]; (*b*) the first cell of the structure [16] that will operate in the TM_{020} mode, so as to eliminate an additional overvoltage caused by the input coupler. Also, there is no magnetic field enhancement near the coupling slot. The structure has a group velocity $v_{gr} = 0.05c$. This turns out to be a reasonable choice in light of experiments with various X-band accelerating structures at SLAC. Details of the current structure design are given in [16].

It is important to emphasize that some of the design features of the test structure can be directly applied to the NLC X-band structure, namely elliptical irises that will reduce surface electric fields and consequently may allow an increase in accelerating gradient of up to 15-20%, and the use of a coupling cell operating in the TM_{020} mode that will allow lowering the risk of breakdown and overheating.

Successful operation of the Omega-P Ka-band magnicon (anticipated to occur by the end of 2002) will allow development to proceed for the 34.272 GHz accelerating structure even before the availability of a full set of high-power Ka-band components such as pulse compressors, mode converters, etc. This is possible because it is proposed to apply the technique commonly used in evaluation of accelerating structures, namely to operate the structure first in a standing-wave mode. In the standing-wave mode, it is expected that surface fields and accelerating gradients of 690 MV/m and 180 MeV/m can be realized using 30 MW of rf drive power fed directly to the structure from the magnicon. At a surface gradient of 690 MV/m in the traveling-wave mode, the accelerating gradient would be more than 340 MeV/m.

The research team has decades of rich experience which includes design, building and putting into operation three magnicons in the decimeter and centimeter wavelength domains having up to 10's of MW's of output power; and design, building and operating of electron accelerators based on various structure designs. Individual resumés are available upon request.

FY2003 Project Activities and Deliverables

During the first year, we will develop a design of the test stand, which besides accelerating structure will include 34 GHz high power feeding system and diagnostics. Together with the selected vendor, we will start mechanical design and fabrication of the test structure. An annual report will be presented and engineering drawings of the accelerating structure will be completed.

FY2004 Project Activities and Deliverables

During the second year, the manufacturing of the test structure must be completed and the cold test of the structure will be performed. The mechanical design of the diagnostics will be completed, and the part of diagnostics which is necessary to complete vacuum assembling of the structure (e.g., source of the probe electron beam) will be manufactured. During this year, the final choice of the feeding system will be done and required high power components will be manufactured. An annual report will be presented. The accelerating structure will be completed and delivered.

FY2005 Project Activities and Deliverables

During the third year, the accelerating structure will be assembled and connected to the magnicon. Then, the structure conditioning and experiments will be started. The components of the test stand will be delivered and assembled together with the accelerating structure. The final report will be presented.

Budget Justification

The first year's activities are limited to design studies and manufacturing which involve staff members (not included in the budget shown here), vendors and designers. A minimal amount of travel funds is included to cover trips for consultations with vendors.

During the second year, the design and construction of the structure and diagnostics will continue and post-doc support will begin.

During the third year, construction will be completed. Experiments will be conducted mainly by the post-doc.

Indirect costs are calculated at Yale's rate of 63.5% on modified total direct costs.

Three-year budget, in then-year k$

Institution: Yale University

Item	FY2003	FY2004	FY2005	Total
Other Professionals	0	30.0	45.0	75.0
Graduate Students	0	0	0	0
Undergraduate Students	0	0	0	0
Total Salaries and Wages	0	30.0	45.0	75.0
Fringe Benefits	0	10.5	15.8	26.3
Total Salaries, Wages and Fringe Benefits	0	40.5	60.8	101.3
Equipment	30.0	70.0	40.0	140.0
Travel	1.5	1.5	1.5	4.5
Materials and Supplies	3.5	3.5	3.5	10.5
Other direct costs	20.0	10.0	0	30.0
Total direct costs	55.0	125.5	105.8	286.8
Indirect costs	3.2	28.9	41.8	73.9
Total direct and indirect costs	58.2	154.4	147.6	360.2

Notes: *Equipment* includes only fabrication of accelerating structure and diagnostics.
Other direct costs include only procured design and engineering services.

References.

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