

# Progress Report on the TESLA TEST FACILITY

The TESLA Collaboration  
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## Abstract

An R&D RF cavity production and test program is underway to evaluate the practicality of superconducting RF cavity systems for future linear collider applications in the 500 GeV energy region. An international collaboration[1] organized by DESY is assembling a TESLA test facility to assess gradient, systems, and manufacturing cost issues of the superconducting RF collider option. Construction of a state of the art cavity processing facility is underway. It is proposed to build four 12 m long cryounits each with eight 9-cell superconducting cavities operating at 1.3 GHz. Two 4.5 Mwatt, 2 msec pulse length klystrons will distribute power to the total 32 cavities. An electron gun and injector section will be included in this test facility, and beam tests with energies of about 500 MeV will be carried out.

## Introduction

There is wide spread consensus among the HEP community that an  $e^+e^-$  collider with a center-of-mass energy of 500 GeV and luminosity of a few times  $10^{33} \text{ cm}^{-2} \text{ sec}^{-1}$  should be considered as the next accelerator after the SSC/LHC. Such a collider would provide for top analysis via  $t - \bar{t}$  production and also have the potential for discovery such as Higgs with mass below  $\approx 350$  GeV.

Within the accelerator community a number of alternate linear collider design efforts are being pursued that meet the above stated energy and luminosity requirements. These designs have many features in common such as the overall linear collider/injector layout, but differ mainly in the choice of spot size, bunch charge and frequency. The differences mainly come down to a trade off between the amount of beam power that is accelerated vs the spot size which has to be provided at the interaction point. The greater beam intensity can be used to balance more relaxed beam emittance and final focusing requirements. Typically, bunch intensities vary by an order of magnitude and vertical spot sizes by more than that. Also the different designs span a variety of rf frequencies from 1.3 to 30 GHz.

The TESLA approach lies at the low frequency, high intensity end of the present parameter range.[2] The use of superconducting rf cavity structures aids in achieving the higher beam intensity design. The resulting beam power could as well be applied toward higher luminosity design values if more stringent emittance and focusing were employed. However the major appeal of the scrf approach is that it allows for the more relaxed tolerances and less ambitious extrapolations from today's state of the art operation at SLC.

The technical advantages of the superconducting rf cavities stem from their high Q values and low wall losses. This allows for the use of large aperture structures operating at relatively low frequency, with relatively long pulse lengths, and low peak rf power requirements. The large aperture of the cavities are perceived to be a major advantage as it results in substantially reduced wake effects for both longitudinal and transverse wake fields. (the longitudinal wake scales with the aperture ( $a$ ) as  $1/a^2$ , and the transverse wake as  $1/a^3$ .) As the aperture of an L band sc cavity is  $\approx 70$ mm diameter, or about ten times larger than in some of the higher frequency designs, relaxed linac alignment and vibration tolerances should result even with the large bunch charge contemplated. With the larger emittance, more dilution can be tolerated in the linac, in the optics after the linac and the final focus. In addition the focusing strength, optical quality and alignment needed is not so stringent because of the higher beam power and larger spot. The result for the detector is more longitudinal space after the last focusing element, a long beam pulse with considerable time between bunch interactions. Just how much easier the alignment/vibration and field quality tolerances will be and how favorable the result will be for the detectors, will require a serious design study employing all the knowledge that has been learned at SLC and with other collider design efforts.

Though the use of superconducting rf cavities appears to greatly reduce the overall technical difficulty of a linear collider, the difficulty has been concentrated in the one area of the sc cavities themselves. Reliable accelerating gradients at the 20 - 30 MeV/m must be achieved in a cost effective cryogenic assembly. Conventional wisdom in the past has used 5MV/m for a reliable operating

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value of the gradient. Costs for production of a few cavities have been typically 200k\$/m, or 40k\$/MV. In order for the superconducting approach to become a viable alternative, this figure of merit must be reduced to the range of about 2k\$/MV (or say 50k\$ per meter with a gradient of 25MV/m). Though this would appear a somewhat daunting goal, it is to be noted that CEBAF is typically achieving averages of 12MV/m on their recent production. New cavity processing techniques such as heat treatment and high pulsed power rf processing show that gradients of 15 - 20 Mv/m can be reached in multi-cell structures. This work is reported in depth in other papers at this conference. Many tests on single cell cavities by the same techniques show accelerating gradients between 25 - 35 MV/m demonstrating that there are no fundamental limitations to the desired gradients for TESLA. Engineering design for economies of scale must be addressed as well, for whereas CEBAF for instance needs 360 cavities a linear collider would require typically 20,000. The goal of the TESLA R&D program is to build a test string of cavities of a modular design suitable for the linear collider application and to address the operating systems issues of the string as well as the all important gradient performance and cost effective design of the cavities and their cryostat. The goal is to have a 50m string of 32 cavities operational with beam in the 97 time scale and to be able to at that point make a rational judgement as to potential achievable gradient and cost extrapolation to mass production scales.

## The TESLA Test Facility (TTF)

The gradient goal of the R&D program is 15MV/m at Q's of  $3 \times 10^9$ . The long term collider design goal is 25MV/m at  $5 \times 10^9$ . Individual cavities are standing wave pi mode 9 cell structures; they are about one meter long and have individual coaxial input couplers and HOM couplers. Needed power for each cavity is 206kW at 25MV/m and 8ma of beam.

As cost savings is a major point of the R&D, it is important to come up with an efficient, simple, and reliable arrangement for the cavity cryostat. To this end, long cryomodules (12m) will be built which contain a linear array of 8 cavities with their associated input and HOM couplers. The end of each module near the interface will contain quad focusing, beam detectors, steering, and an annular space for high frequency HOM absorber cooled to 70K. The magnetic elements are superconducting and operate at 4K.

Each cavity has its own helium container, connected in series to the adjacent components. All vacuum flanges are arranged so there are no helium to vacuum flange interfaces but rather beam vacuum to cryostat vacuum, or cryostat vacuum to air. All helium to vacuum joints are welded. The input couplers are coaxial with two ceramic windows; one at 70K, the other at room temperature. These couplers have bellows which allow for an order of magnitude ad-

justment in the external Q, and for longitudinal thermal contraction of the cavity array over the length of the cryomodule.

The cavities are suspended and aligned off the large 300mm helium gas return pipe. The whole cryostat and shield arrangement is similar to the HERA or SSC magnet cryostats. Three support posts derived from the SSC posts provide the warm to cold support transition from the outside of the cryostat to the helium gas header[3].

The RF system will consist of two 4.5 MW modulators and Thomson Th2104 klystrons capable of 2ms RF pulse at 10 Hz. Each modulator is capable of providing 1.5 times the power needed for 16 cavities under full beam current and gradient (25MV/m).

One of these high power systems will also be used for RF processing at high peak power(HPP) of the individual cavities. It is expected that 1 MW RF levels will be required for HPP. An additional RF system will be used for the TTF injector.

A cryogenic system which supplies 200W at 1.8K and 200W at 5K is envisioned using an existing DESY refrigerator and an additional 1.8K cold box. The budgeted heat load at 1.8 and 4.5K respectively per meter is: static 0.4/1.25 W, total with rf power and beam 1.35/1.45 W. The fundamental RF power is 3/4 W, and HOM power 1/4 W at 2K. (Assuming 15MV/m,  $Q = 3 \times 10^9$ , 10% HOM power at 2K.)

Infrastructure is being set up at DESY. An industrial building is being devoted to the Tesla activity. The final processing and preparation of the industrially produced cavities will be carried out with state of the art facilities. These include or make use of: cleanrooms (classes 100 and 10,000), chemical treatment and high purity water rinse; 1200C vacuum oven for improvement of the RRR and thermal conductivity of the Nb cavities; and vertical dewar high peak power (HPP) RF processing, gradient, and Q measurements of the bare cavity units. Finally the helium containment shell is attached and the couplers and tuners are mounted, and followed by a test of individual "dressed" cavities. This operation is performed in a horizontal test cryostat prior to the final assembly in the 8 cavity cryomodule. As experience is learned at obtaining reliable high gradient cavity performance, simplification and cost savings in the processing steps will be attempted. The initial infrastructure will be as complete as possible in order to assure the highest probability of success.

It should be pointed out that the push to high gradients in multi-cell 1.3 GHz cavities is already underway at Cornell[4] and CEBAF continues to gain experience at 1.5 GHz.

The four cryomodules, consisting of 32 cavities and 4 sets of focusing-steering elements at the cryo interfaces will be configured as a test string for beam as well as engineering systems tests. Two types of injectors, both operating at  $\approx 8mA$  are under consideration. The first would be a low bunch charge injector with a conventional thermionic gun, chopper and buncher section operating at 300kV into one

of the standard 1m sc cavities. The injector beam energy would be 14 MeV. The second injector under consideration would provide the  $5 \times 10^{10}$  bunch charge at 1 microsec spacing. An effort is underway to evaluate this gun; a high gradient rf photocathode gun looks most promising. A thermionic gun will also be evaluated. Simulations with asymmetric emittances will be carried out to see what emittance looks possible. For the TTF tests bunch charge is important but design emittance is not as important. A warm section between the injector and the standard cryomodules will provide an optics match and beam analysis area. Similarly there will be an analysis area after the four modules. Provision will be made to allow for beam offset of 1 cm or more in order to produce large transverse wakes.

## Test Program for the TTF

*Cavity Performance*—Transfer full RF pulse power to beam at full pulse length. Attempt in-situ HPP processing of cavities in the string at the 1 MW level and experiment with different failure modes which might effect the cavity operation (e.g., vacuum failure).

Measure Q vs gradient with and without beam. As this will need to be done calorimetrically in the string, only low Q's below  $10^9$  will be detectable. Most Q measurements will come from the test cryostat data.

Measure the higher order mode power produced by the  $5 \times 10^{10}$  bunches and determine the fraction removed by: the HOM couplers, the microwave absorbers at the interfaces of the cryomodules (every 8 cavities), and that dissipated at 2 K in the helium. Look for transverse mode excitation by the beam as a function of beam position and see if one can measure cavity alignment by looking for a minimum in the transverse excitation. Measure dark current, radiation patterns and energy spectrum without beam and determine the extent of captured dark current transported through the string.

*RF System and Control*—Develop a cavity, coupler tune up procedure to control voltage, phase and coupling of the 16 cavities connected to one RF modulator. Measure the gradient and phase in each cavity as a function of time. Develop a quench, spark detection, protection system that allows for sufficient RF uptime. Develop cavity tune adjustment, radiation pressure compensation, and beam loading compensation. Look for and learn to control microphonics, coupler vibration, and radiation pressure effects that result in cavity tune, voltage or phase variations.

*Beam Measurements*—Measure the beam energy, energy spread, and energy and positional stability bunch by bunch as a function of bunch intensity, RF phase, bunch length, etc. Look for wake field and transverse mode excitation, and perform measurements of emittance blow up of off axis beams. (Many of the wake field measurements will require high intensity bunches.)

*Cryogenics*—Measure heat leak with and without RF and beam to determine static, RF fundamental, and HOM

losses. Be able to detect cavities with low Q ( $10^9$ ) and detect quenches. Measure operating performance as a function of temperature and measure the temperature profile for each cell and coupler on at least one cavity (this might be best done in the horizontal single cavity test cryostat).

*Alignment and Vibration*—Measure the cryomodule alignment stability and reproducibility during cool-down/warm-up. Measure the vibrational properties and transfer function of the cavities and quadrupoles.

*Operation*—Develop tune up procedure, practice beam alignment and focusing, simulate fault conditions for the subsystems. Check the beam position system operation and stability, and try to make precision measurements of beam transmission (or losses).

## Schedule for the TTF

- two model cavities to test infrastructure - summer 93
- infrastructure: cleanroom, chemistry, furnace - fall 93
- cryosystem & HPP rf - winter 93
- treatment/test of first 8 cavities - spring/summer 94
- assembly 1st cryomodule - fall 94
- install and operate 1st cryomodule winter - 94/95
- beam test 1st cryomodule - summer/fall 95
- cavities for 2nd -4th modules - mid 95/mid 96
- install modules 2-4 in test string - 96/97
- beam tests complete TTF - 97

## References

- [1] The TESLA R&D effort (TESLA=TeV electron superconducting linear accelerator) is being carried out by an international collaboration led by DESY. A number of institutions have joined this collaboration and include IHEP Beijing, Tech Univ Berlin, CEN Saclay, CERN, Cornell, TH Darmstadt, DESY, Fermilab, Univ. Frankfurt, INFN Frascati-Milan, Univ. Karlsruhe, KEK, LAL Orsay, IPN Orsay, SETF Finland, Univ. Wuppertal.
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