PROGRESS AND PLANS FOR R&D AND THE CONCEPTUAL DESIGN OF THE ILC MAIN LINACS

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Abstract

The International Technology Recommendation Panel (ITRP) recommended a superconducting technology for the main linac design of the International Linear Collider (ILC). The basis for this design has been developed and tested at DESY, and R&D is progressing at many laboratories around the world including DESY, Orsay, KEK, FNAL, SLAC, Cornell, and JLAB. The parameters for the ILC Main Linac are discussed and described. The status and role of the different linac test facilities are discussed, and the critical items and R&D program to support a Baseline Configuration and a Conceptual Design are outlined.

INTRODUCTION

The development of 1.3GHz superconducting RF system for linear collider main linacs was pioneered by DESY and TESLA collaboration. The outcome of the R&D was integrated into the technical design report of TESLA, and published in 2001[1]. The performance of the TESLA superconducting cavities are well advanced by the electro-polishing (EP) processing as well as chemical etching of the inner surfaces, high temperature treatment at 1400degC, and high pressure rinsing with ultra-pure water. The TESLA design gradient 23.8 MV/m has been attained on average with cavities of the standard chemical treatment. By application of new EP method to 9-cell cavities, another 6 cavities have reached gradients between 31 and 35 MV/m. Some of them are assembled into the cryomodule in the TESLA Test Facility (TTF). The other components for the main linac have also been developed by TESLA collaboration. Their designs are well advanced and have reasonable performance as construction ready technologies. The ILC main linac design should be based on the TESLA technology. The effort of the main linac design should change the direction toward a design for industrialization and cost reduction.

This paper discuss the choice of the ILC main linac parameters and technologies for the base line design, and review the major test facilities of the ILC superconducting RF technologies and its plan and role.

ILC PARAMETERS

Since the Baseline Configuration Document is supposed to be written in 2005, the main linac configuration has to be considered using the technology with currently available and using the stably achievable performance. The availability of tunnel length should be also considered among the three regions, that is, Europe, North America, and Asia.

The overall parameters for the ILC are listed in the ILC Scope document from the ILCSC [2]. This specifies the integrated luminosity goals. A model for the luminosity evolution after construction is described in the US LC Technology Options Study (USTOS)[3]. According to the model of USTOS, a peak luminosity of $2\mathrm{x}10^{34}$ $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ will provide the specified $500\mathrm{fb}^{-1}$ with a 10% margin by the first four years. A nominal parameter set which is very similar to that in the TESLA TDR and the USTOS is lead by this peak luminosity. In choosing the gradient and the average current in the linac, the following points are assumed:

1) A 10 MW maximum klystron output with 15% overhead for feedback and 6% for RF distribution losses;
2) A cryomodule with 8, 10, or 12 cavities installed;
3) A linac bunch spacing is consistent with a sub-harmonic bunching frequency, and consistent with having twice as many bunches with exactly 1/2 the spacing;
4) An injector system has no major upgrade in average current or emittances for the 1 TeV upgrade.

Three possible examples that meet these requirements are 40MV/m option, 35MV/m option and 30MV/m option in the table [4]. These three options have different linac lengths, AC power consumptions, and capital costs. Using the USTOS cost model, it appears that the capital cost of the cases with 40 and 35 MV/m are comparable but 30 MV/m costs more, as shown in Figure 1. The 1 TeV site length will be roughly 8 km longer at 30 MV/m than at 35 MV/m and 13 km longer than at 40 MV/m. However the linac AC power consumption at 500 GeV for 30 MV/m will be 15 MW less than at 35 MV/m and about 40 MW less than at 40 MV/m.

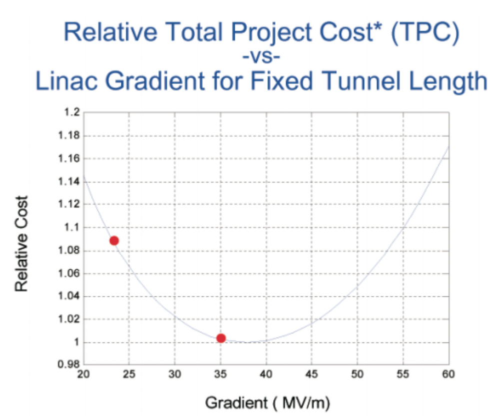

Fig. 1: Estimated Cost vs. gradient [5].

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Keeping the same gradient for the energy upgrade to 1 TeV has advantages of no modification of injector system and longitudinally separated dog-bone damping ring. However, it will likely require greater installation in the tunnel during the upgrade and may also require restarting cryomodule production which could increase the total project cost of the 1 TeV collider.
Given the gradient choice, the operating range is defined with five parameter sets: Nominal, Low Charge, Large Spot, Low Beam Power, and High Luminosity. The Nominal set is quite close to the parameters in the TESLA TDR and the US Options report. These parameters provide a guideline for the consideration and choice of the design in each ILC Working Group.

DESIGN CHOICE OF RF UNIT COMPONENT

The choice of the acceleration gradient is the major concern for the configuration of the main linac RF unit. 24MV/m by the BCP process and 30MV/m by the EP process seems to be in hand according to the TTF experience. However, the gradient of each cell for EP process cavities are spread from 30 to 40MV/m, and have 35MV/m in average shown in Figure 2. The performance of EP cavity is also shown in Figure 3. To adopt 35MV/m for ILC baseline gradient seems to be feasible.

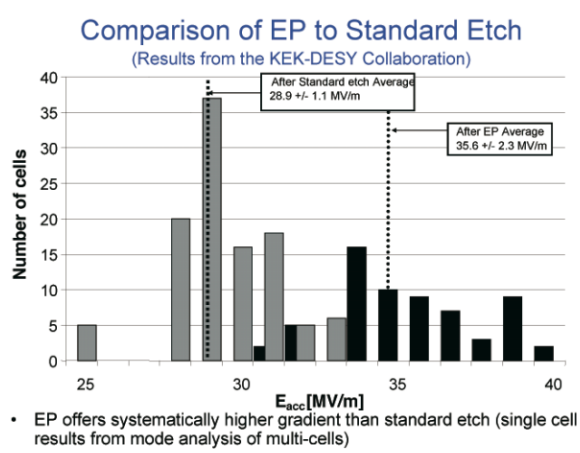

Figure 2: Accelerating gradient by EP process [6].

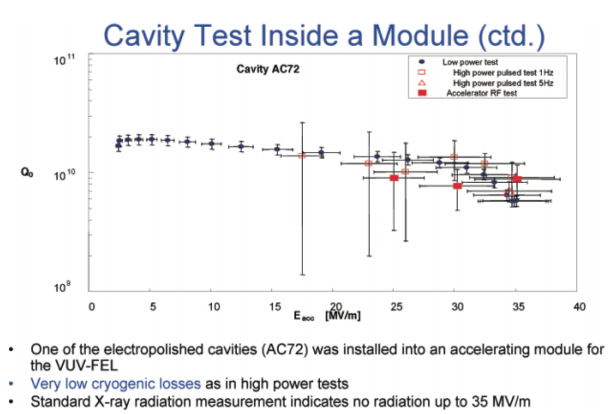

Figure 3: EP cavity performance at TTF [6].

The advantages of 35MV/m gradient rather than 30MV/m are as follows;
1) There is at cost minimum.
2) Shorter linac length expands a selection of site.
3) Number of cavities in one cryomodule is smaller.
The disadvantages, on the other hand, are as follows;
1) The performance of the cavity seems to be not in hand. Continuous R&D for surface process is still required.
2) There seems to be small margin from the critical limit.
3) AC power consumption will increase.
STF will build new EP facility and build more than 20 cavities will give a reliable performance data. SMTF will also do similar number of cavities with EP. During fabrication of many cavities, the surface process will be confirmed and the gradient performance will be in hand within following 4 years before TDR.

Once the gradient is fixed, the RF unit configuration is determined according to the suggested parameter table [4]. The choice of technologies in each device should be made to avoid unproven design. In order to create reliable design and realistic cost estimation, the most cost driven part which is the main linac should be designed using only established and demonstrated technologies for the BCD, CDR and TDR. The new design or the alternate design will be adopted and replaced the baseline design only after demonstrated and established.
The 10MW multi-beam klystron, the 1:12 pulse transformer and the modulator with bouncer circuit should be chosen for the power source. The linear distribution wave-guide system with the circulator in each cavity input should be chosen, because of its compactness. To make more precise RF amplitude and phase control, the digital feedback and feed-forward LLRF control should be chosen.

To get more margin of the cavity control bandwidth, over coupling of the cavity should be considered [7]. Over coupling factor about 1.3 gives the best power efficiency. Compared with 1.3 over coupling, the exact matching has 1.3% lower power efficiency, over coupling factor 2 has 4.4% lower efficiency. Considering the difficulty in cavity tuning, factor 1.5 or more will be desirable.

To determine the alignment tolerance and the number of quad in the RF unit, emittance dilution due to misalignment of quads and cavities of ILC main linac was estimated by using the tracking simulation SLEPT [8]. The optics which is FODOs of the 60degree phase advance per cell leads one quad for every two cryo-modules up to beam energy of 125 GeV and one quad every three cryo-modules from 125 GeV to 250 GeV. One cryo-module has 10 cavities with 35MV/m. Assuming quad and Cavity misalignment 0.4 mm, Quad-BPM offset 20 micron, 1μm BPM resolution and the orbit corrections with BPM and collector in each quad, expected emittance dilution was 16% (normalized emittance 0.46 E-8 m). This is reasonably small dilution.

POSSIBLE SCHEME OF RF UNIT

The main linac parameters in choosing 35MV/m are shown in Table 1. The proposed RF unit configuration according to table 1 is visualized in Figure 4.

E_cms	500 GeV
N	2.0 E+10
Nb	2820
T_sep	295.4 ns
Buckets at 1.3GHz	384
I_ave	10.8 mA
Gradient	35 MV/m
Cavities / 10MW klystron	20
Q0	1.0 E+10
F_rep	5 Hz
Linac overhead	5%
Total number of cavities	14240
Total number of klystrons	712
Active two linac length	14.8 km

Table 1. ILC Main Linac parameters

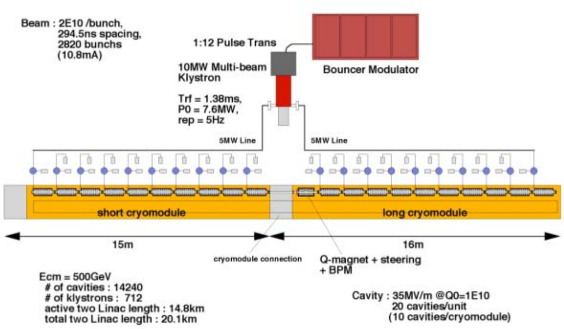

Figure 4: RF unit configuration of ILC main linac.

The bouncer modulator and the pulse transformer generate 120kV, 140A, 1.57ms of width, 5Hz repetition pulse for the multi-beam klystron. Beam is injected after filling time of 500µs from the RF fill into the cavities. The klystron has two RF output. Each of RF output is transported to the linear distribution waveguide system of the cryomodule. RF power branch to each cavity in cryomodule is done by the hybrids, which have different coupling ratio for each cavity input. The circulator of each cavity input ensures the matching condition of waveguide system. There are 10 cavities in each cryomodule. Total 20 cavities are in the unit.

MAIN LINAC TEST FACILITIES

There will be three test facilities in the world for the R&D of the ILC main linac RF system. They are TTF at DESY, SMTF at Fermi lab, and STF at KEK. The three regions have test facilities. This is natural because each region has superconducting RF technology in the laboratories and enough funding to build test facility. The role of these facilities is to have an ability of SC-RF technology integration into ILC cryomodule, and to promote regional industry and laboratories for ILC module production. Since the module production will be shared by three regions at the ILC construction, each facility should have a leadership in the production by the basis of module design and production experience. They are not duplication, the technology will be shared from the beginning of construction, experience of design, construction and operation will become three times more and the opportunity of researcher promotion will also be expanded three times.

TTF

The TTF at DESY includes infrastructure labs and shops for superconducting cavity treatment, test stands and the accelerator module assembly and a test linac for an integrated system test with beam. The functions of this facility are development of accelerating module compatible to TESLA, integrated system test of the TESLA linac components with beam and application of SASE FEL in the VUV wavelength regime. The performance of the TESLA superconducting cavities are well advanced by the electro-polishing (EP) processing as well as chemical etching of the inner surfaces, high temperature treatment at 1400degC, and high pressure rinsing with ultra-pure water. The design gradient 23.8 MV/m has been attained by the standard treatment. By application of new EP method, another 6 cavities have reached gradients between 31 and 35 MV/m. Some of them are assembled into the TTF cryomodule. TTF linac is now in the phase 2 construction. Total 5 cryomodules are installed and currently operated with average 11MV/m. The beam is so far attained around 2µm of emittance with 1nC intensity by upgraded laser-driven photocathode RF gun. Lasing and saturation of FEL at a wavelength of around 32nm by the beam energy of about 450MeV for the start-up was confirmed. The FEL light is now transported to the downstream user experimental area [9]. A 1 GeV by adding 2 more cryomodules each containing 8 of 9 cell cavities, and 50µm RMS bunch length by 2 stage bunch compressors is the final goal. A FEL light of 6.4nm wavelength will be generated by the 27m modified undulator magnets.

The TESLA technology collaboration for SC technology of TTF and new construction XFEL is now expanded to include SLAC and KEK. The role of TESLA collaboration for ILC becomes very important to serve ILC base-line technologies for SMTF and STF.

SMTF Plan

The object of SMTF [10] is to learn how to reliably fabricate and process high quality SCRF cavities and assemble the cryomodules utilizing the combined knowledge of international collaborators and US experience. SMTF located in Fermilab meson area includes the four main SCRF areas of R&D: the 1.3 GHz, β=1 ILC Cryomodule test facility, the CW test area for next-generation CW light source, and the $\beta < 1$ test area for PD, and the RIA facility. ILC test bed in SMTF will be important for industrialization of cryomodule production in North America region. These R&D activities will be operated under a shared infrastructure

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of the Meson cryogenic facility, pulsed RF and modulator power sources, and controls. The significant infrastructure also exists at other US laboratories and will be upgraded for SMTF collaboration work.

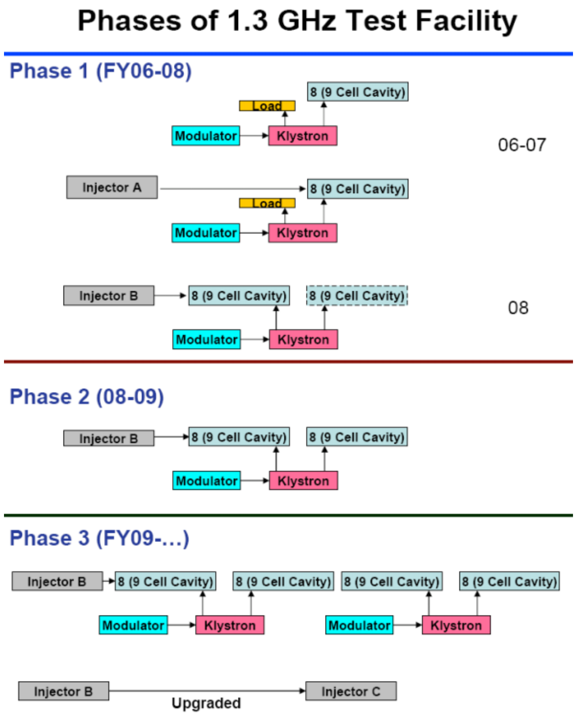

Figure 5: SMTF 3 steps for ILC module test.

There will be three main phases in the development of an ILC module test bed (See Figure 5). Initially, in FY05, the SMTF-ILC collaborators will begin the fabrication of four SCRF cavities in the US, begin construction of a "Chechia" horizontal test facility, develop infrastructure needed in Meson East experimental area for "Chechia", and commission the 25 MV/m Capture Cavity for use with the photoinjector A0.

Phase 1 (FY06-FY08): The goal is to fabricate and assemble two cryomodules over the next two years. One will be fabricated as a US-ILC cryomodule, and another one obtained from the Tesla collaboration. To get started quickly, a TTF eight-cavity cryomodule provided by TESLA collaboration will be used. In parallel, construction of cavities, dressing components, and cryomodules will be done in the US. KEK plans to provide cavities to this US-ILC cryomodule. Out of these two cryomodules, at least one available will be for beam tests in FY06-07. The photoinjector will be upgraded in two steps: for step IA it will consist of a gun, and two capture cavities (FY06-07); in step IB, two 3.9 GHz cavities, (one accelerating, one deflecting) will be added (FY08).

Phase 2 (FY08-09): A second cryomodule will add to the first for a total of two cryomodules in FY08-09. Subsequent iterations are envisioned to improve the performance. Two additional cryomodules will be continued to build.

Phase 3 (FY09-…): Eventually four cryomodules, three built in the US, will be demonstrated in a low energy electron beam with ILC properties in FY010-011.

The Cryomodule Assembly Facility at MP9 shown in Figure 6 will be also constructed. This facility will provide the infrastructure for mechanical assembly of cryomodules. High power RF and beam testing of the cryomodules will be conducted at SMTF.

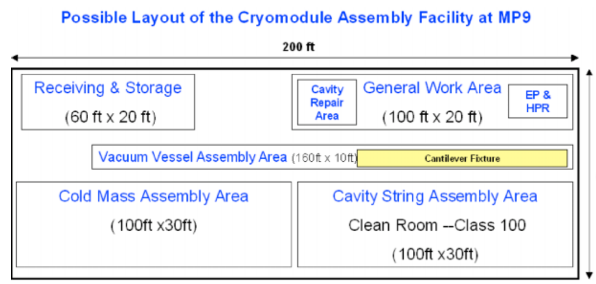

Figure 6: SMTF cryomodule assembly facility plan.

The MP9 facility assumes that SRF bare cavities are fabricated in industry and processed, dressed and tested in collaborating laboratories, universities, and/or industry. After passing the test the cavity with helium vessel and cold part of the input coupler is sealed and shipped to the MP9 facility. Under this concept, the facility consists of the receiving & storage area, the cavity string assembly area, the cryomodule assembly area and the general work area.

STF plan

The KEK activities on SRF for LC were quite small, however several surface treatment and vertical test facilities exist and work inefficiently. Ramping GLCTA down and to start construction of new ILC SRF test facility were decided. Since KEK does not have experience of a 9-cell cavity production and an ILC like cryomodule assembly, the test facility plan [11] is divided two stages. The first stage (STF Phase 1) is aiming quick start up of 9-cell cavity production and having experience of assembly engineering of half-size cryomodule. The second stage (STF Phase 2) is to build one RF unit of ILC main linac (Figure 7).

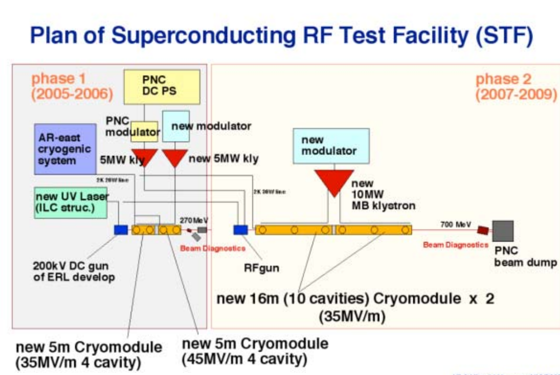

Figure 7: STF plan.

Higher gradient greater than 35MV/m is essential for KEK to host ILC in Japan, because of limited length of site candidates. The demonstration of high gradient by changing cavity shape is thought to be high priority. Four of LL-type 9 cell cavity aiming 45MV/m have being fabricated for phase 1 half-sized cryomodule. Another half-sized cryomodule has been fabricated in parallel to accommodate four of TESLA-type cavities aiming 35MV/m. The fabrication of LL-type cavities has being done by deep contribution of KEK scientist, on the other hand, TESLA-type cavities will be done by industry. The cryostat also will be fabricated by industry. The surface treatment and performance check by the vertical stand will be done by using the existing L-band test facility only for phase 1. STF will be constructed in the building of proton linac facility for J-PARC in KEK. The most of J-PARC linac components in there will be moved to Tokai site till September 2005. The installation of He plant and RF power source will start after moving. The installation of two half-sized cryomodule will begin June 2006. The cool down of cavities are scheduled in October 2006, and turning on beam in December 2006. Other than cryomodule, the new production or the new purchase for phase 1 are one modulator, one 5MW klystron and laser for electron DC gun. All other components are existing one with some modification.

Once the ILC baseline configuration is determined at Snowmass workshop or by the time of BCD, STF phase 2 configuration will follow it. The phase 2 cryomodule construction will be done using the new EP facility, the new assembly clean room and the new cryomodule installation stand. The infrastructure of STF will be one of ILC module assembly facility in the beginning of phase 2 stages. The engineering design of phase 2 will begin in April 2006. The fabrication will begin in April 2007. In November 2008, the ILC RF unit will become operational. The schedule of STF is shown in Figure 8.

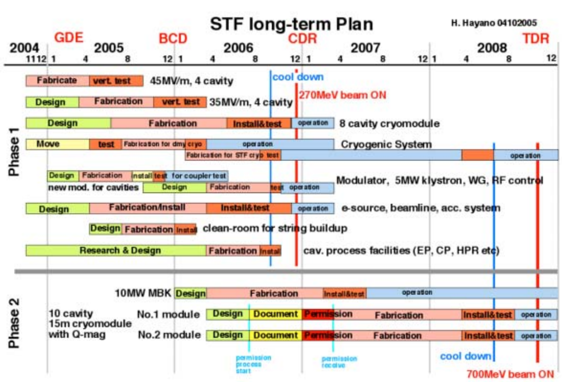

Figure 8: Schedule of STF.

STATUS OF TEST FACILITIES

Major achievement and status of each test facilities are summarized briefly below;

TTF: Accelerating gradient of superconducting L-band cavity reached up to 35MV/m with applying EP method. Acceleration demonstration with TESLA like beam loading was already done. SASE-FEL application with TTF-II is underway towards lasing at 6nm in 2006. A 32nm SASE-FEL lasing with 450MeV beam energy was demonstrated in 2004. Industrialization of cavity, dressed components and cryomodule is started to prepare a mass production of XFEL and ILC.

SMTF: The SMTF collaboration was formed among US laboratories and universities. The proposal of SMTF was submitted to FNAL director. The spokespeople were decided by the election among the member. The proposal will be reviewed for coming fiscal year budget.

STF: The fabrication of four LL-type 9 cell cavities are underway. Another four TESLA-type cavities will be fabricated by industry in 2005. The installation of two half-sized cryomodule, which include 4 cavities, will begin June 2006. The cool down of cavities are scheduled in October 2006, and turning on beam in December 2006.

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