CRYOMODULE TEST FACILITIES AND MULTICELL CAVITY PERFORMANCE FOR THE ILC

Hitoshi Hayano, High Energy Accelerator research organization (KEK), Tsukuba, Japan

Abstract

To address the ILC Main Linac gradient, which are greater than 35MV/m at vertical test and greater than 31.5MV/m in the operation of the cryomodule, ILC-GDE organized several task forces in the R&D board. They are S0 task force, S1 task force, and S2 task force. The charge of S0 is to achieve 35MV/m in the qualification with reasonable yield. S1 is to achieve 31.5MV/m operation of cryomodule. And S2 is to estimate how large test facility is required to test chain of cryomodules and to make industrialization of cryomodule production. The paper reports the task force activities status together with existing R&D of multicell cavity performance and cryomodule test facility status. The test facilities for the ILC design are the place of the key technology demonstration and realization.

INTRODUCTION

The baseline configuration of the International Linear Collider (ILC) and the international organization for the ILC design (GDE) were both established in end of 2005. The baseline ILC configuration is illustrated in figure 1. The 1st stage is for 250GeV+250GeV collision energy plan, and the 2nd stage is for 500GeV+500GeV. In the BCD (Base-line Configuration Document)[1], the 31.5MV/m as an initial main linac gradient is adopted with 35MV/m qualification in the vertical test. The GDE organization, established at the same time, has two main charges. One is the design of ILC accelerator and the estimation of their cost with enough precision. The other is the promotion and coordination of R&D to achieve ILC performance demonstration. The major laboratories in the world, except DESY and TESLA Technology Collaboration (TTC), began to plan or to start ILC R&D developments of superconducting technologies for their production capability promotion and for bit to host ILC.

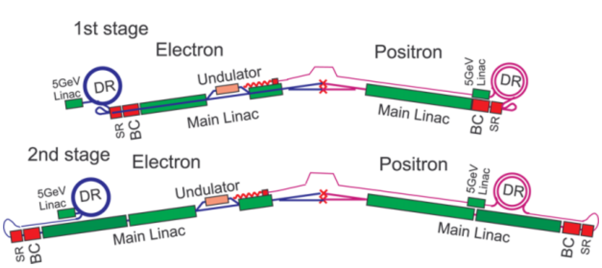

Figure 1: Baseline ILC accelerator configuration.

The development of 1.3GHz superconducting RF technologies for linear collider was initially conducted by DESY and TESLA collaboration. The TESLA design gradient 23.8 MV/m has been attained on average with cavities of the standard chemical treatment (BCP). By application of new electro-chemical polish (EP) method to 9-cell cavities, 8 cavities have reached gradients between 25 and 35 MV/m, which is close to ILC specification, and were assembled into the cryomodule #6 in the FLASH facility (former TESLA Test Facility 2 (TTF2)).

As test facilities of ILC cryomodule, FLASH conducted by DESY and TTC, ILCTA (ILC Test Accelerator) conducted by FNAL, JLAB, ANL, Cornel, SLAC and many US laboratories and universities, STF (Superconducting RF Test Facility) conducted by KEK, PAL and IHEP are briefly summarized in this text.

ILC MAIN LINAC

The ILC main linac configuration is briefly introduced. The superconducting acceleration cavities of the ILC main linac are powered to operate 31.5MV/m as the average operation gradient by the 10MW multi-beam pulse klystron. The bouncer modulator and the pulse transformer generating 120kV, 140A, 1.57ms of width, 5Hz repetition pulse for the 10MW klystron are the baseline design of RF power source. Beam is injected after filling time of 500μs from the start of RF fill into the cavities. The loaded beam current is 10mA during about 900μs beam pulse train. The klystron has two RF output ports. Their RF outputs are combined and then divided to the three-way waveguide system, then transported to the linear distribution system of the three cryomodules. RF power branch to each cavity 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 8 cavities in each cryomodule. Total 24 cavities are in one RF unit. The RF unit configuration is illustrated in figure 2, below.

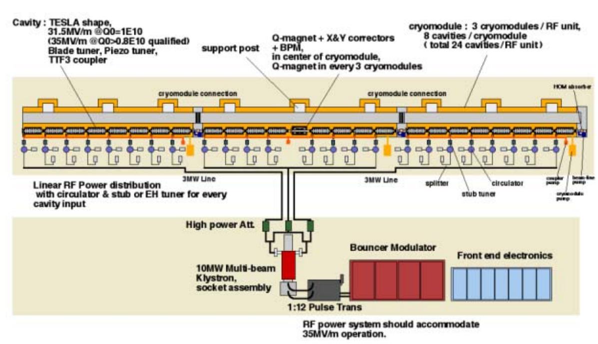

Figure 2: RF unit configuration of ILC main linac.

CAVITY PERFORMANCE DEVELOPMENTS IN TTF

The accelerating gradient of the superconducting cavity is one of the most concerning issue in the ILC. Recent achieved gradient of the TTF 9 cell cavities with EP processed are demonstrated well beyond 35MV/m of ILC qualification level. However, considering whole cavities production, they are scattered from 5MV/m to 40MV/m and its average is around 25MV/m to 30MV/m [2]. On the other hand, the BCP processed cavities have about 5MV/m lower than EP processed one. To look the development history in TTF, which is shown in figure 3, will bring some insight for achieving well controlled gradient performance.

TTF has been made major 4 production cycles with 26~33 cavities in each production in the last 10 years. The many vertical tests have been done for more than 100 cavities in total. The first production 26 cavities were using no eddy-current scanned materials, with no matured welding technique, with BCP+1400 degree heat process. Test results were 2~20MV/m which were limited by field emission and defect heating. Defect in the material found in 3 cavities, wrong welding happened in 9 cavities. The second production 27 cavities used eddy-current scanning, the same procedure of BCP+1400 degree process. Test results were 15~30MV/m, limited by field emission. Defect in the material found in 6 cavities, wrong welding happened in 1 cavity. The third production 33 cavities used eddy-current scanning, and BCP+1400 degree process for 22 cavities, EP+1400 (or 800) degree process for 11 cavities. Test results was 15~32MV/m for BCP and 10~40MV/m for EP limited by field emission for both surface treatments. Cold leak happened in 1 cavity, Q-disease on 2 cavities, wrong fabrication happened in 1 cavity. The fourth production 30 cavities used eddy-current scanning and EP+800 degree process for all cavities. Test results were 5~35MV/m limited by field emission for 15~35MV/m, Q-disease for 5~10MV/m. Welding defect happened in 4 cavities, Q-disease on 2 cavities. Major problems are field emission and Q-disease. However KEK cavities have not met Q-disease.

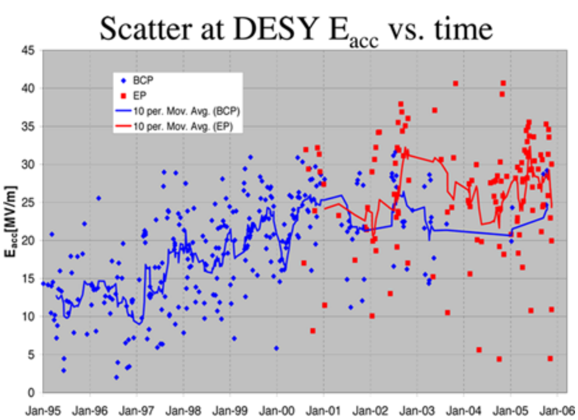

Figure 3: Eacc development history in DESY.

Even TTF cavity fabrication has qualification procedures in their each steps, like material defect scanning, welding point qualification, keeping cleanness for whole procedure, etc, the gradient performance scatter by the field emission. It means there is something that they could not control yet. Possible sources are maybe contamination of particles during assembly, contamination in the EP acid, residuals after EP and HPR, etc.

GDE-RDB EFFORT

One of the task of GDE organization is to promote and coordinate ILC R&D of the world. The Global R&D Board (RDB)[3] is taking care of the task by assessing and providing guidance to the overall R&D program. The RDB has made the ideal R&D list which supports the baseline design and includes the alternative design R&D. The list also includes the priorities on each item. The advise for FY07 US R&D list to the regional director by making it prioritize were made recently. The mission also include global assessments and recommended priorities for the detector R&D program and evaluate the balance between accelerator and detector R&D.

The RDB will develop a proposal driven program, structured in the sense of defined goals, and milestones, and resources evaluated on a common basis to allow comparison across different regions and national funding systems. It will conduct reviews and identify gaps in coverage of topics, resource or technical issues, duplications, and other concerns.

R&D TASK FORCES IN RDB

The several task forces were organized by RDB to address several R&D issues. The 'S0' task force [4] has the charge to achieve accelerating gradient of the ILC baseline qualification test. The 'S1' task force is for achieving the operational gradient performance of the cryomodule. The 'S2' task force consider how much scale of cryomodule test facility is necessary before ILC construction. The task force for klystron developments has made the first report of the world-wide discussion by the klystron people. They are for main linac R&D. Other task forces are also under formulation, such as for damping ring, for BDS, for positron, and for detectors.

The 'S0' task is planned as three steps; the tight loop test for a few cavities, 1st production-like process for about 60 cavities among three regions, and 2nd production-like process for another same amount of cavities. The final goal is to achieve 35MV/m at Q0=1E10 with greater than 80% yield in the first test, and re-process the rest 20% to achieve 95% final yield. The time scale of this goal is set to the completion of TDR, most likely middle of 2009. The intermediate goals are also set as follows; the goal of the tight loop test is to demonstrate 10% gradient spread for new 10 preparations. The goal of the first production like processing is the same as the ultimate goal except the number of re-process up to 3-4 allowable. During these two intermediate steps, the process should be improved using various diagnostics installed, such as 9 pass band measurement capability, temperature mapping capability, and x-ray mapping capability. The necessary test during 'S0' work are; hydrogen contamination check, Q vs. T measurement, 9 pass band measurement, pass band spectrum check to avoid cavity deformation, temperature mapping measurement, etc. The detailed planning for each region is under discussion.

The 'S1' task is planned as straight forward extension of the 'S0' task. The final goal is to achieve 31.5MV/m at Q0=1E10 as operational gradient at least three cryomodules including fast tuners and other features that could affect gradient performance. All the cavities for this final goal should have 35MV/m qualification defined by 'S0' final goal, and operation of a few weeks should be performed. As an intermediate, average 31.5MV/m in a single cryomodule by tweaking RF distribution should be achieved as a proof-of-existence. TTF module 6 will be the most probable candidate for this intermediate goal.

In order to answer the question of what kind of cryomodule string test is necessary and should it be a test linac or not, 'S2' task force was organized. The goals, specifications and a time scale for string test facility and for the test linac facility if it is necessary are analyzed and discussed. The specifications are, for example, the number of modules needed in the string, the performance specifications, the purpose and duration of the tests, the rules for the deviations from the final production specifications and final environmental conditions. It is likely to be large enough number of cryomodules so that industrialization is required to become their production practical. To show how the transitions from proof-of-principle to the S2 Milestone and start of main linac production should be accomplished. The relationships between the functions of the string, the operation of the string in realistic conditions, and the use of a Test Linac as a facility for beam measurements are also addressed by 'S2'. The collection of information, analysis and discussion are just started.

FLASH FACILITY

The hall III at DESY includes large scale of infrastructure for superconducting cavity treatment, vertical and horizontal test stands, the accelerator module assembly and a test linac (FLASH facility [5]) for an integrated system test of the XFEL accelerator prototype with beam. The functions of this facility are development of accelerating module compatible to XFEL, integrated system test of the linac components with beam and application of SASE FEL in the VUV wavelength regime. The facility includes BCP and EP treatment rooms, HPR system, clean room, vertical test stand, horizontal test stand, coupler power test stand, as well as cryomodule assembly facility. The power test of cryomodules were done in the accelerator. However, for XFEL production, the cryomodule test stand has been built in the next of the hall III. The performance of the TESLA superconducting cavities are well advanced by applying the electro-polishing (EP) processing, high temperature treatment at 800degC, and high pressure rinsing with ultra-pure water. The performance history is already summarized in the previous section. Among them, 8 cavities reached gradients between 31 and 35 MV/m were selected and assembled into module #6 (figure 4). The installation of #6 into the accelerator is scheduled in autumn 2006.

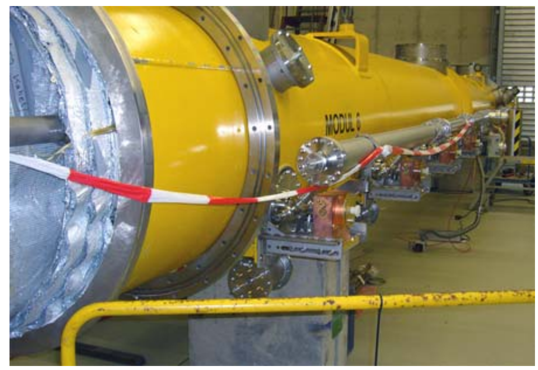

Figure 4: Assembled Module #6 in DESY Hall III.

The FLASH facility is the only test accelerator to be used for the study of ILC accelerator and ILC-like beam. The FLASH accelerated a beam up to 730MeV and succeeded 13nm lasing in April 2006. The user beam time is allocated in between VUV user run. The HOM read out study, LLRF control study, instrumentation development study and high gradient study are currently took place. Some of them are assembled into the TTF cryomodule.

The cavity and cryomodule R&D for ILC will be done by synergy with XFEL construction. The project schedule is as follows; the industrialization of the linac part will be done in 2007 to middle of 2008. About one year will spent for the set ups in the industries. In the year 2009 to 2012 (3 years), the main construction will be done for 928 cavities with 116 cryomodules. As a part of industrialization, 30 cavities as the 5-th production cycle are ordered in 2006. The R&D for these cavities will benefit both XFEL and ILC.

ILC TEST FACILITY AT FNAL

In US region, FNAL will become a center of main linac R&D for superconducting cavity and cryomodule. This is extension and framework of SMTF collaboration. FNAL test facility for ILC part was changed their name to 'ILCTA at FNAL' [6]. Whole ILCTA consist of several buildings spotted in FNAL. Material scan, cavity inspection, tuning for field flattening, qualification by vertical test will be done at Industrial Buildings (IB1, IB4). Clean room for cold mass assembly is located in MP9 building. Cryomodule assembly for inserting cold mass into long cryostat will be done in Industrial Center Building (ICB). Capture cavity test stand and Horizontal test stand "Chechia" are in Meson Area building. ILC

Test Accelerator itself will be at New Muon Building (NM). These R&D activities will be operated under a shared infrastructure of the several cryogenic facilities.

The significant infrastructure also exists at other US laboratories and will be upgraded for ILC R&D work. ANL has built BCP facility and will install EP facility under collaboration with FNAL. This will be one of the cavity treatment facility operated jointly by ANL and FNAL. There are two more surface processing (BCP, EP and HPR) R&D facilities for processing and vertical testing of the cavities. These facilities are located at Cornell and Jlab. The assumed processing capacity of these two facilities is 12-18 cavities per year. These three facilities will be main driving stream for the cavity treatment and for the most part of the gradient performance R&D.

The ILC RF unit test (ILCTA@Fermilab) facility at NM building (figure 5, 6) will be capable of testing completed cryomodules at high accelerating gradients. The goal is to produce a single RF unit with two Type-III+ and one Type-IV cryomodules by end of UFY09, and a second RF unit with all Type IV by about a year later. The dedicated study of dark currents, HOM extraction, alignment, LLRF and control issues, cryogenic issues, RF power distribution, reliability and system recovery issues, etc will be conducted. In UFY06, the cryomodule engineering knowledge is being transferred from DESY/INFN to FNAL in order to produce the first US assembled Type-III+ Cryomodule with parts provided by DESY/INFN in early 2007. All their cavities with expected average gradient 28MV/m will be tested and sealed at DESY. The first cryomodule will be assembled by March 07. During the assembly of the 1st cryomodule, the Type-IV cryomodule will be designed. FNAL is in process of buying parts in UFY06 to build the 2nd Type-III+ with US processed cavities, couplers, coaxial tuners, Helium Vessel and Cold mass.

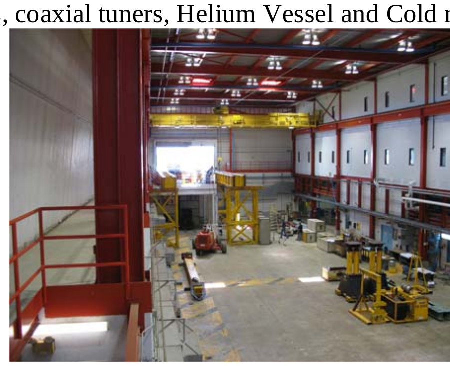

Figure 5: Inside of NM building. ILC Test accelerator will be installed.

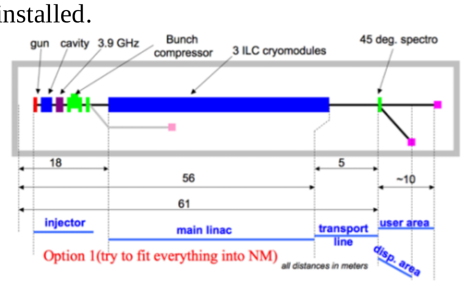

Figure 6: Current plan of ILC test accelerator in NM.

The orders for all cavities are already done. 4 TESLA type III cavities fabricated by ACCEL are delivered. In addition, 4 more TESLA type III cavities from AES, and two from Jlab are ordered. All these cavities use fine grained Nb. FNAL has also ordered from Jlab two large grain cavities with beam tubes shortened for Type IV cryomodule and with improved HOM extraction. FNAL plans to order 16-20 (UFY06) and 24-36 (UFY07) additional cavities. These cavities will come from vendors both in the US and Europe, as well as Jlab. About 40-60 cavities will be available for processing and tests by end of UFY07 for developing cavity process parameters to achieve 35MV/m with small spread.

The cavities produced by industries, are processed and vertically tested. They will be dressed with He vessels, couplers and tuners at FNAL and will be horizontally tested with full power at FNAL. The horizontal test facility under construction at Meson Area is important for development platforms of LLRF electronics, slow and fast tuner development, and microphonic studies.

STF AT KEK

The construction of the test facility for the ILC superconducting RF technologies (STF) has been started in KEK since 2005 [7]. The main role of STF is to establish the industrial design of linac unit and to promote Asian and Japanese industrial level towards ILC component production. STF will be a base of Asian region and the international collaboration for superconducting RF technology. The R&D on the cavity gradient to achieve more than 35MV/m stably is also another urgent item of STF.

Based on existing KEK superconducting RF technologies, the new ILC superconducting RF test facility (STF) was planed. The first stage (STF Phase 1) is aiming quick start up of 9-cell cavity production, having experience of assembly engineering of half-size cryomodule, and having RF power handling technologies and capabilities. The infra-structure such as EP facility and clean room are constructed in parallel for preparation of more cavity handling capability. The main goal of the second stage (STF Phase 2) is to build one RF unit of ILC main linac and to have long-run operation. Figure 7 illustrates the plan. The schedule of these two steps are planned for years 2005 - 2009. Phase 1 for 2005 – 2007, Phase 2 for 2007-2009 are scheduled.

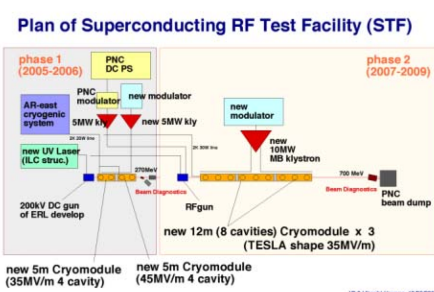

Figure 7: STF phase 1 and phase 2 plans.

STF is constructed in the building of former proton linac facility for J-PARC in KEK. The installation of He cryoplant was already done in April 2005. Towards the middle of 2007, the Phase-1 of STF expects to start operation of two units of 5m-long (half size of ILC) cryostats, each containing four 9-cell cavities of LL-design and TESLA-style, and a low intensity beam source, which are driven by 5MW L-band klystron. The high-power testing and processing of fundamental mode input couplers need to be performed, also. Two of the half size cryostat were fabricated and delivered as shown in figure 8. They are now under magnetic field measurement inside of them to see how much reduction of the field.

Figure 8: Half size cryostat vessels to be used in STF phase 1 accelerator are delivered to STF.

"High-gradient" cavity development and "TESLA -style" cavity development, are performed in parallel. The "high-gradient" cavity development focused on achieving a high accelerating gradient in excess of ~45MV/m with a cavity shape that has been optimized ("low-loss" – LL-design) to reduce the surface current near the cavity "equator". As an initial step, several 1 cell cavities with LL-design were fabricated and tested. After resolving the issues of quality degradation of hydrofluoric acid for electro-polishing and contaminations during rinsing with ultra-high purity, high-pressure water, three kind of cavities have reached well above 45MV/m. And three cavities out of six LL-design 1 cell cavities recorded an accelerating gradient of higher than 45MV/m in a vertical test. Four 9 cell cavities of LL-design together with coaxial tuners, capacitive coupling input coupler were fabricated. The extension of treatment to 9 cell cavities was not straightforward. They met multipacting at 20-30MV/m, and HOM coupler troubles. The cures for them are in progress. However the input couplers of this new design are successfully powered up to 2MW level.

Another cavity development program is on a so-called "TESLA" design which is now ILC baseline design and expected to offer a gradient reach up to ~35MV/m. An emphasis of this program is to have a large industry involved in cavity fabrication so that both the industry and the laboratory could start exploring the issues associated with large-scale fabrication of the cavities that are required for ILC. Four 9-cell cavities for "TESLA-style" have been built with required active tuners, and jackets, together with the disk window input couplers and HOM absorbers. Early testing with three 9-cell cavities in a vertical setup indicates that there are issues of multipacting when the accelerating gradient reached at 20MV/m is tried.

SUMMARY

To address the ILC cavity gradient goal, 'S0' and 'S1' task forces are initiated by GDE-RDB. Each major test facility in the world is asked to support them. The status and readiness for cavity R&D are summarized briefly below;

FLASH: The industrialization of cavity and cryomodule production for XFEL is underway. The R&D on the 4-th production cycle of cavities is on going with the fixed treatment procedure using EP. Several analysis like temperature mapping, acid measurement are applied to them. The 5-th production cycle cavities are already ordered. The module #6 to achieve average gradient more than 31.5MV/m is already assembled, and waiting for installation into FLASH accelerator.

ILCTA: FNAL has tried to form lab-to-lab collaboration for cavity and module R&D. The big three stream of cavity treatment are under forming with constructing infra-structure at FNAL, ANL, Jlab and Cornel. Total 12 cavities are ordered, and 4 cavities out of 12 are already delivered and started the test and treatment. Additional 16-20 (UFY06) and 24-36 (UFY07) cavities will be ordered. The cryomodule III+ kit will delivered to FNAL from DESY in 2006. It will be assembled till early 2007. One more type III+ module will be build by US, and one type IV module will be designed and built by US for the next.

STF: The phase 1 module is two connected half size cryomodules which contain 4 cavities each. The phase 2 is the construction of 1 ILC RF unit. 4 TESLA-shape and 4 LL-shape cavities are delivered and under testing. In parallel, infrastructure for cavity treatment is under construction.

REFERENCES

[1] ILC BCD http://www.linearcollider.org/wiki/doku.php?id=bcd:bcd%20home
[2] Lutz Lillie "TTF cavity productions" http://www.linearcollider.org/wiki/doku.php?id=rdb:rdb_external:rdb_s1_home
[3] GDE-RDB http://www.linearcollider.org/wiki/doku.php?id=rdb:rdb_home
[4] Lutz Lillie "VLCW06 Vancouver" http://www.linearcollider.org/wiki/doku.php?id=rdb:rdb_external:rdb_s1_home
[5] TTC http://tesla-new.desy.de/content/index_eng.html FLASH http://flash.desy.de/
[6] Fermilab ILC web-site http://ilc-dms.fnal.gov/
[7] ILC-Asia web-site http://lcdev.kek.jp/