Superconducting Cavity:

{Draft given by Rongli Geng, as of June 10, 2011}
Draft for ILC R&D plan for TDP release 5 – SCRF cavity gradient R&D
RG, Last revised 9jun10

The main effort of the ILC cavity gradient R&D is to improve gradient yield and reduce gradient scatter toward the TDP-2 goal of reaching 90% production yield.

In the past several years, two post-EP rinsing methods, namely ethanol rinsing and ultrasonic cleaning with detergent, have been used in all major SRF facilities in three regions. The optimal detergent concentration has been found through trial cavity cleaning followed by cavity RF testing as well as sample cleaning studies. Alternative detergents are also found and now in routine use. EP processing procedures and cavity handling and assembly procedures at various SRF facilities have been improved. Simplicity and repeatability in optimal 9-cell cavity EP processing have been demonstrated. Focused surface R&D has revealed that the key contaminants on the electropolished niobium surface are sulfur and niobium oxide granules. These efforts result in significant reduction of field emission in 9-cell cavity RF testing, a major success of the globally coordinated S0 program. A gradient yield of 50% at 35 MV/m with a $Q_0 \geq 8\times10^9$ has been achieved up to a second-pass processing.

The success of field emission reduction has allowed us to unveil remaining gradient scatters caused by quench limit. A fraction of 9-cell cavities turn out to be quench limited at a rather low gradient of 15-25 MV/m. This causes the gradient yield dropping to 65% at 25 MV/m for the first-pass processing. A top priority of ILC gradient R&D for TDP-2 is to raise the gradient yield and reduce scatter by overcoming quench limit below 25 MV/m in 9-cell cavities.

Temperature mapping and optical RF surface inspection have been routinely used in all major labs since 2008 in association with RF testing of 9-cell cavities. These efforts have provided new insights into the nature of the quench limit at 15-25 MV/m in 9-cell cavities. It is clearly shown that in most cases a local defect in only one cavity cell is the source of the quench limit. Other cavity cells when preferentially excited by pass-band modes show far superior capability equivalent to a gradient of 30-40 MV/m. Most defects responsible for quench limit around 20 MV/m are found to be sub-mm side geometrical defects, such as pits or bumps as revealed by optical inspection. Initial SEM studies of samples cut out from 9-cell cavities have shown complex 3D structure as well as foreign elements at quench locations. It is also fairly well established that re-processing for a second-pass electropolishing is not effective in raising the quench limit at 15-20 MV/m in 9-cell cavities. In comparison, as shown by recent successful experience with targeted grinding of 9-cell cavities, local defect removal results in significant gradient improvement. It has been even shown that it is possible to predict whether an initially observed feature will ultimately evolve into a gradient limiting defect in a 9-cell cavity. All the known facts about the quench limit between 15-20 MV/m in 9-cell cavities strongly imply that responsible defects have an origin from cavity fabrication and/or starting niobium material.

An increasing number of 9-cell cavities quench limited above 30 MV/m have been studied also recently using T-mapping followed by optical inspection. In this case, no defect (down to the spatial resolution of the optical inspection tools) is observable at quench location predicted by T-mapping. And a second-pass electropolishing is often time effective in raising the quench limit up to 40 MV/m. This implies that re-electropolishing remains a usable method for raising gradient performance from 25-30 MV/m to above 35 MV/m. Repeatability and reliability of electropolishing process is necessary for reliable gradient improvement by using a second-pass electropolishing (it is noted that sometimes the cavity gradient degradation occurs when a second-pass electropolishing is applied).

Based on the improved understanding mentioned above about the quench limit in electropolished 9-cell cavities, R&D paths are identified and should be pursued toward the realization of the ILC cavity gradient goal of 90% yield by 2012 and beyond.

1. **Fabrication QA/QC and fabrication improvement and optimization**

Fabrication QA/QC is expected to result in improved gradient yield. Production cavities for the XFEL project are unique opportunities in this direction, particularly in the context of cavity mass production. QA/QC tools such as optical inspection for production control should be improved and implemented. Despite the goal gradient of XFEL is different from that of ILC, overcoming the quench limit for 15-20 MV/m in the mass production context is a shared challenge. The European ILC-HiGrade cavities will be an integral portion of the XFEL cavity production and will be processed using the ILC-style recipe.

The established fabrication technology such as forming, machining and electron beam welding have room for improvement and optimization. New vendors have particular motivation and opportunities to pursue. KEK pilot plant is expected to play a unique role in this direction. R&D cavities should be built in collaboration with industry. R&D cavities should also be built in-house where expertise and facilities exist to allow inspection at intermediate fabrication stage. These R&D cavities should allow post-test cavity destruction for microscopic studies of cut-out samples from the known defect locations.

Alternative fabrication technology such as seamless cavity should be pursued. Seamless cavity technology eliminates weld prep machining and electron beam welding and hence offers a unique opportunity for improved gradient yield as well as potential for reduced cavity fabrication cost. Recent seamless cavity experience at DESY in collaboration with Jefferson Lab has shown very good 9-cell cavity results.

2. **Material improvement and optimization**

Improvement in the gradient yield is also expected from material improvement and optimization. Niobium of different Tantalum concentration as well as different RRR should be pursued through 1-cell cavity testing and basic material characterization.

Large-grain niobium material directly sliced from ingots eliminates intermediate handling steps as compared to the standard sheet material. This alternative material offers opportunities for reduced defects introduced by rolling and forging steps. Excellent 1-cell cavity results are well demonstrated in all three regions. The level of effort for 9-cell large-grain cavities should be increased. Existing 9-cell large-grain cavities at DESY and JLab should be tested timely and new 9-cell large-grain cavities should be built particularly in the context of multi-wire slicing successfully demonstrated recently at KEK.

3. **Post-fabrication improvement, optimization and remediation**

Post-fabrication improvement and optimization are expected to provide expeditious improvement in the cavity gradient yield because this path offers improvement opportunities for cavities fabricated with the present standard fabrication technology and standard material.

Mechanical polishing prior to heavy EP eliminates weld irregularities. It reduces or may even eliminate the need of surface removal by heavy EP. A significant fraction of the near future 9-cell cavities should be mechanically polished prior to main electropolishing.

Post-fabrication heat treatment provides important material property improvements such as hydrogen removal and metallurgical recovery. There are presently three main recipes for cavity heat treatment in a vacuum furnace. Optimal heat treatment parameters should be investigated with cavity testing as well as material characterization.

Effort for cavity remediation such as targeted repair should be continued. This path not only offers a cost-effective solution for gradient recovery of under-performing 9-cell cavities but also provide knowledge about the nature of localized defects. Success of 9-cell tumbling repair at Cornell and the more recent success of 9-cell local grinding at KEK clearly show the value of cavity remediation. Success of 1-cell cavity local re-melting with laser beam and electron beam at FNAL and JLab respectively should be extended to 9-cell cavities.

The new ILC main linac baseline design allows some cavity gradient spread. Some cavities may need to be operated at very high gradients say over 40 MV/m. This increases the field emission risk. Effort should continue for further suppression of field emission in 9-cell cavities. From the linac operation point of view, dark current is an important issue. Efforts should start to quantify field emission during cavity vertical test and correlate field emission in cavity vertical test with dark current in cavity/cavity string horizontal tested and linac beam operation. Field emission measurements should allow direct comparison across SRF facilities. One possible way is to place X-ray detectors at suitable locations on the cavity outer surfaces or at locations inside the vertical dewar where no material (other than liquid helium) is present

----

{Draft from Camille Ginsburg, as of June 11, 2010}

Cavity Performance Evaluation

The tool for evaluating cavity performance, the ILC cavity database, has been successfully implemented, and includes cavity test data from all participating labs from the last few years and two standard yield plots. For the plots shown in this document, cavities must be from established vendors (ACCEL/RI, ZANON, or AES 2nd batch or later), and made from fine-grain material. The cavities must have undergone one standard EP process at either DESY or JLab for the 1^{st} pass. If the cavity does not reach 35 MV/m, it is assumed to need a 2^{nd} pass, the details of which may vary depending on the performance; if the cavity reaches 35 MV/m it is assumed not to need a 2^{nd} pass. All cavities reaching the 35 MV/m gradient specification also reached the Q0 specification; however no explicit Q0 cuts are made on the data. Cavities in the 2^{nd} pass plot are defined to be a subset of the 1^{st} pass plot; if a cavity has not yet received a 2^{nd} pass though it should, it is not in the 2^{nd} pass plot. Only cavity tests with cavity limitations (as opposed to test infrastructure limitations) are used. The cavity yield as a function of maximum gradient is shown in Fig.1, and the raw number of cavities as a function of maximum gradient is shown in Fig.2. The sample averages and standard deviations are shown as a function of the minimum accepted gradient in Fig.3. These data samples shall continue to be updated periodically as additional test data become available.

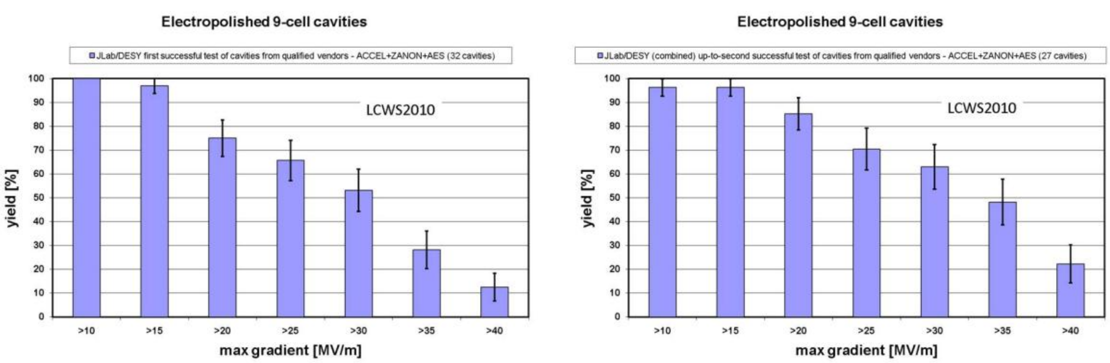

Figure 1: First-pass (left) and second-pass (right) yields as a function of maximum gradient. [To be replaced with updated data by June 30.]

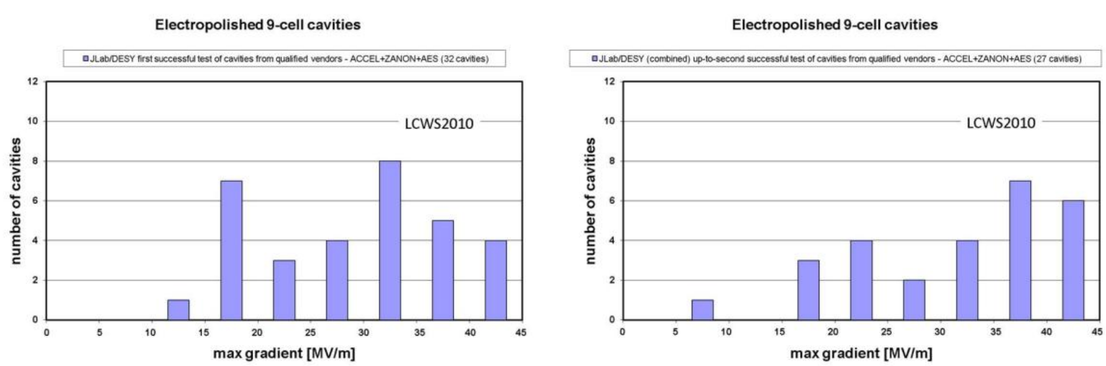

Figure 2: Number of cavities as a function of maximum gradient, for first-pass (left) and second-pass (right) data samples. [To be replaced with updated data by June 30.]

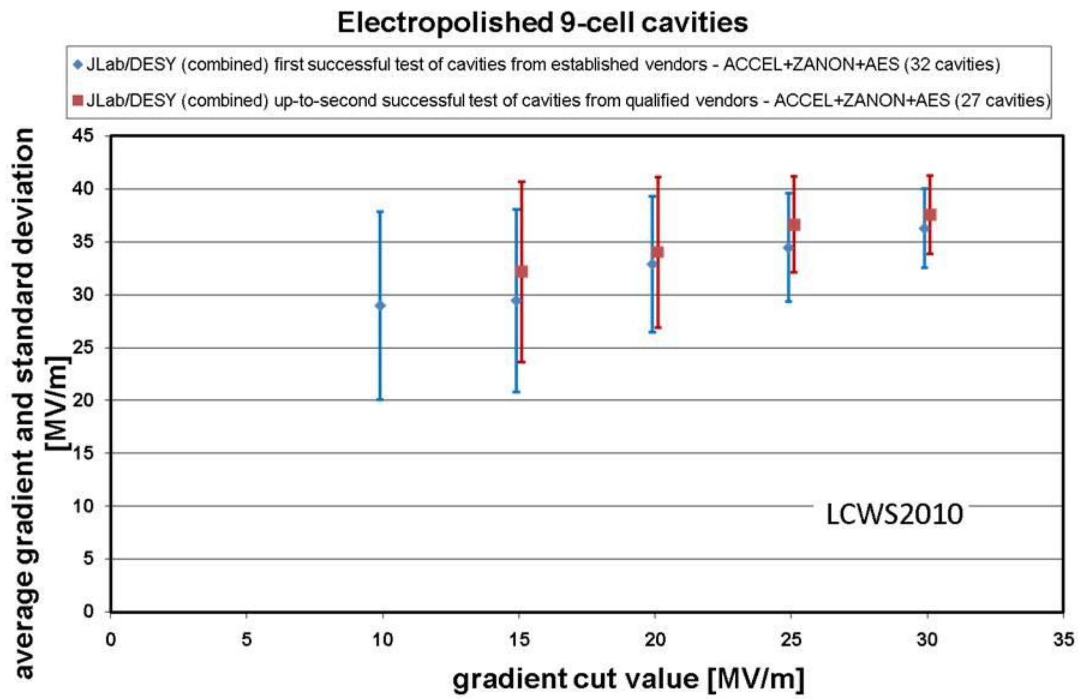

Figure 3: Average gradient (data points) and standard deviation (error bars) of the first-pass and second-pass data samples after excluding cavities which fail to meet the minimum gradient shown on the horizontal axis. The two data samples have been artificially offset from each other for clarity. [To be replaced with updated data by June 30.]

By the Baseline Assessment Workshop, the key issues we plan to address for cavity performance evaluation are:

1) Whether the horizontal bin size might be reduced, if justified by gradient measurement error, and
2) How the cavity performance tracks from vertical test to horizontal test to cryomodule test in current data samples.

The primary tasks we plan to complete by the Baseline Assessment Workshop are:

1) To create a standard plot tracking cavity performance for new vendors, and
2) To study Q0 at the 31.5 MV/m operating gradient and Q0 at the 35 MV/m vertical qualification gradient for data in the first- and second-pass data selections, for cavities which reach these gradients. This requires the adoption of a common algorithm to interpolate between measurements. As a later step, we will include this information in the ILC database.

{Draft prepared by Akira Yamamoto, as of June 11, 2010}

Systematic Design Sudy of the ILC Accelerating gradient

Based on the R&D plans described above, further systematic design study need to be carried out to figure out a systematic balance of R&D target values and operational parameters. It should require reasonable difference between individual cavity/component performance and the system performance with beam acceleration. Table ** summarize how we need to update our system design in the field gradient in coming TDP-2 phase.

Table: Cavity gradient balance to be re-optimized in TDP-2.		
	Consideration in RDR/SB2009	Re-optimization required in TDP-2
R&D goal: S0 - 9-cell cavity gradient	35 MV/m (≥ 90%)	35 MV/m (≥ 90 %): kept for forward looking
R&D goal: S1 - Cryomodule gradient w/o beam	31.5 MV/m in average	31.5 in average or higher to be optimized for reasonable cryomodule operational margin, inclusive
R&D goal: S2 - Cryomodules gradient with beam acceleration	Not specified	Likely to be the same as ILC operational gradient
ILC-ML design value: - Accelerating gradient	31.5 MV/m in average	31.5 in average or lower to be optimized for reasonable accelerator operational margin, inclusive

An appropriate balance should be re-considered with better definitions of milestones in R&D stage and specification in the Project Stage, and a set of specification for the SCRF cavity performance (for the project and not yet for procurement) should be well established.

A new guideline in TDP-2 may be proposed as follows:

- R&D goal for the 9-cell gradient to be kept at 35 MV/m at a production yield of 90 % or more,
- Project performance for the ILC accelerating gradient with allowing the spread;

Table ***: A possible balance of gradients in various stages in the ILC ML cavity production stage (to be studied and established)		
Single 9-cell cavity gradient	String Cavity gradient in cryomodule w/o beam	String cryomodule gradient in accelerator with beam
35 MV/m, in average w/ spread above a threshold	33 MV/m, in average or (or to be further optimized)	31.5 MV/m, in average (or to be further optimized)

The following two specific subjects to be further studied in the TDP-2 as follows:

- How wide cavity gradient spread may be acceptable in balance of additional HLRF power source capacity and efficiency to be required?

- How large operational margins are required in the single cryomodule gradient (without beam), and in the accelerating gradieng in cryomodule strings in the ILC main linac (with beam) ?

The above studies are crucially important to optimize the ILC ML SCRF design in balance of the HLRF design.

(end)

Cavity Integrataion:

Draft: TDP R&D plan for 'cavity integration'   06102010 H. Hayano

The main R&D items of cavity integration area for the TDP term are;
(1) Tuner R&D including integration into He jacket,
(2) Coupler R&D,
(3) Industrialization of cavity and associates.

There are three kind of design for the tuner, that is, lever-arm tuner, blade tuner, and slide-jack tuner. The lever-arm tuner is used for the FLASH cryomodule and XFEL cryomodule. It has a lot of experience and performance demonstration around 35MV/m operation. It is installed into the beam pipe location, so that the beam pipe length of the tuner installation side should have enough longer length than ILC cavity design. On the other hand, the blade tuner is designed to install in the middle of Helium jacket and with much consideration on the mechanics simplicity for cost reduction. The slide-jack tuner design has been done by the point of view of enough stiff structure to reduce piezo stroke for long life and reducing risk of failure. The performance experience will be accumulated in FLASH and XFEL pre-series cryomodules for the lever-arm tuner, in the project-X cryomodules for the blade tuner, and in STF phase2 cryomodules for the slide-jack tuner. In 2010, the S1-Global cryomodule experiment at KEK-STF supplies a good R&D opportunity to compare these three tuners in the same place and the same condition. During S1-Global test, frequency tuneablity including sensitivity, backlash, and stability, heat-load, maintenability will be tested and compared. For piezo actuator, performance of Lorentz Force Detuning compensation will be directly compared, together with frequency control sensitivity, performance of multiple pulse compensation action.

The R&D for the coupler will be done for the compatible design between tuneablity function, easiness of mechanical installation, and low heat load. The loaded Q control for each cavity is essential for the combination use of various Q cavities. The unification of Q control which is now done by both of three-stub tuner and input coupler control should be done in this TDP. The ceramics window R&D for less stress for thermal contraction, for more stable brazing and more short time RF processing are also considered. In S1-Global cryomodule, four of TTF-III coupler and four of KEK disk window coupler will be operated and compared their performance, in the same condition.

As a good experience of an industrialization study, ILC will have a benefit from XFEL construction, that is, 4% cavity production of ILC. The other effort will be done in both of US region and in KEK, in collaboration with industry. Especially, KEK will construct the cavity fabrication facility (CFF), where the cost-effective production technology will be developed. The electron beam welder (EBW), press machine and trimming machine as well as chemical treatment room and various inspection tools will be installed during 2010-2011. The first production of 9-cell cavity without HOM coupler will be done in 2010, before EBW machine delivery, as a start-up. The next cavity production from 2011 will be installed in the STF cryomodule. The production technology development can be done in parallel for these cavities production during TDP.

SCRF-ML Test Facilities:

S1-Global Test Plan (to be prepared, as part of Cavity Integration and Cryomodule)) :

{added, June 21, prepared by H. Hayano, June 17}

Draft: TDP R&D plan for 'S1-Global cryomodule experiment' 06172010 H. Hayano

The project of 'S1-Global' for aiming of more than 31.5MV/m average gradient in the 8 cavities cryomodule and for demonstration of the international cooperation of workable cryomodule assembly and operation by the in-kind contribution, are scheduled its cool down experiment from June 2010 to December 2010 at KEK-STF. The cryomodule consists of the two half-length cryostats which house 4 cavities in each. They are two DESY cavities and two FNAL cavities. Two DESY cavities install lever-arm tuner, two FNAL cavities install blade tuner, and four KEK cavities install slide jack tuner. As for the input coupler, DESY and FNAL cavities use TTF-III coupler and KEK cavities use KEK coupler which has double disc window. The experiment items for these cavities are as follows;

(1) Evaluation of mechanical tuner and piezo tuner performance in low power
(June 2010 to July 2010; INFN team and FNAL team participation)

(2) Perform input coupler conditioning in room temperature and in cooled state
(August 2010 to September 2010; by only STF team)

(3) High gradient operation of each cavity to its maximum to check the maximum allowable gradient of each cavity.
(September 2010)

(4) High gradient operation with supplying the power to 4 cavities group, and with supplying the power to the all of 8 cavities from the 1 klystron.
(November 2010)

(5) Study of Lorentz detuning and its compensation control
(October 2010; with FNAL team participation)

(6) Static heat load measurement and dynamic heat load measurement of the cryomodules
(July 2010, November 2010 for static, and October, November 2010 for dynamic; with FNAL team participation)

(7) LLRF study on feedback performance, IF mixture method, adaptive feed-forward method, RF power fluctuation measurement

(November 2010)
(8) DRFS system test using 2 set of the system consist from one 750kW klystron with two cavities
(December 2010)

DRFS system in the tunnel to be tested is the basic system which consists of the HV-DC power supply and the modulation anode power supply that are connected to the two klystrons, together with LLRF control rack in the tunnel next to the cryomodule. The klystron will be connected to two cavities with the simple waveguide eliminating the circulators, and they placed in the aisle side of the cryomodule.
The end point of the S1-Global experiment is determined to the end of December, 2010, because of the STF phase-2 accelerator construction schedule will be started on January 2010, aiming of the injector part operation from October 2011. The cryomodule operation and the study must keep the schedule and should be done with efficient manner.

S1/S2 Programs:
FLASH: Request for J. Cawardine in communication with N. Walker
NML: Request for M. Ross in communication with J. Kerby
STF2: Request for H. Hayano

Cryogenics:
→ Request for Tom Peterson in communication with H. Nakai
(specially for technical feasibility of cryogenics installation under ground

----

HLRF:
→ Request for Shigeki Fukuda and Cris Nantista for DRFS and KCS R&D
- 10 Hz operation at 250 GeV,
- upgrade scheme
- Accommodation in single tunnel,

ML Integration:
→ Request for Chris Adolphsen in communication with Jim Kerby, specially on split conductive cooling quadrupole R&D (for cryomodule quadrupole), and ML accelerator alignment and the tolerance issues.
