R&D Board Task Force on High Gradient SCRF Cavities

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Overview

- ILC R&D framework
 - What has been shown? What not?
- Gradient Task Force Charge
- 'S'-issues
 - What are they?
- Overall organizational ideas
- ILC Program (Preliminary and under discussion)



What has been achieved?

- Data for ILC-like cavities available on
 - Individual cavities
 - Single-cells
 - Multi-cells
 - Full accelerator modules
 - TTF experience so far on etched cavities



Electropolished 1,3 GHz Elliptical Niobium Cavities K. Saito et al. KEK 1998/1999





Example of XFEL Industrialization: Henkel





- Very high gradient (up to 40 MV/m), high Q₀ single-cell cavities have been prepared
- Study on improved quality control measures at DESY and Henkel
 - E.g. Improved parameter-control of electrolytes
- Up to three-cell 1.3 GHz cavities can be treated currently

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Electropolishing Setup at DESY



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Proof-of-Principle: TESLA Nine-cell Test (ILC Baseline Cavity)



TESLA Nine-Cells: Low-Power Results



Cavity Test Inside a Module



- One of the electropolished cavities (AC72) was installed into an accelerating module for the VUV-FEL
- Very low cryogenic losses as in high power tests
- Standard X-ray radiation measurement indicates no radiation up to 35 MV/m



Performance of FLASH Accelerator Modul From H. Weise/ D. Kostin



FLASH Module 6: High Gradient Module



Cavity Position in Module



Work needed: Reproducibility in the Processes



Main Sources of Reproducibility Problems

- Imperfections in final surface treatment,
 - e.g. electropolishing (EP)
 - final rinsing
- Field Emission from particle contamination
 - e.g. assembly processes
- Thermal breakdown of superconductivity from material or manufacturing defects
 - Weld Problems at new industry
 - Deviation from specification
 - Insufficient quality control
 - Industry is improving welding procedures to avoid problems



ILC R&D Framework

- The need of making gradients more reproducible is a top priority
- Single-cell cavities in various labs and also from industry obtain very high performance
 - Yield rates vary between labs
 - Probably we are not far away from the good parameter set
- Looking at the history of TTF some significant effort is needed to transfer results to multi-cells
 - Three cavity production cycles (20-30 each) were done to improve the gradient from the level of 5-10 MV/m to 25 MV/m with classical etching
 - This included especially the training of companies to provide the required niobium and electron beam weld quality
 - Currently, we are in EP Production cycle No.1 at DESY
 - Other regions are in the process of being able to do research, it is not yet a production cycle
- A dedicated facility in each region with sufficient redundancy and flexibility is desirable to have fast turn-around of cavity tests.
 - Waiting for the repair of infrastructure is painful
 - From the TTF experience the bottleneck is typically the cavity preparation, not the cryogenic testing

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'S'-issues: Overview

- S0
 - Achieve 35 MV/m in 9-cell cavity in vertical dewar tests (lowpower) with a sufficient yield
 - Staged approach with intermediate goals to track progress
- S1
 - Achieve 31.5 operational as specified in the BCD in more than one accelerating module
 - ... and enough overhead as described in the BCD.
- S2
 - a string of N modules with full xyz...by date ...
 - Need for a linac ?
 - Endurance testing



Gradient Task Force Charge

- The RDB is asked to set up a Task Force to carry out a closely coordinated global execution of the work leading to the achievement of the accelerating gradient specified in the ILC Baseline.
- A definition of the goals for the cavity performance in terms of gradient and yield and a plan for achieving them should be proposed by this group, which should take account of the global resources available and how they may be used most rapidly and efficiently.
- The accelerating gradient performance and yield should be specified both for an individual 9-cell cavity and for an individual cryomodule, and the plan should cover the demonstration of this performance in both cases.
- The GDE will facilitate the coordination at the global level to achieve this vital goal as soon as possible.



S0/S1 Task Force

- Hitoshi Hayano (KEK)
- Toshiyasu Higo (KEK)
- John Mammosser (JLab)
- Hasan Padamsee (Cornell)
- Marc Ross (FNAL)
- Kenji Saito (KEK)
- Lutz Lilje (DESY)



S0/S1 Task Force Plans I

- Accumulate information of regional programs (has started)
 - E.g. how many cavities are being fabricated
- Assessment of infrastructure (has started)
 - E.g. how many test stands are available
- Data assessment (has started)
 - What has been achieved where?
- Define tests needed on a multi-cell cavity (has started)
 - E.g. setting up temperature mapping for nine-cells
- Proposals on future work (has started)
 - Refine R&D plan and set goals (see below)
 - Definition of scope:
 - » Which parameter range should be pursued?
 - » How much room for alternatives (e.g. large-grain material)
 - Propose coordination:

» Distribution of work load Lutz Lilje DESY -MPY-







Jlab (SNS): 3rd largest Cavity Production



- 23 cryomodules, 81 cavities, 2 year production testing period
- 35 medium beta cavities tested 73 times
 - Field emission was a frequent limitation in early stages
- 48 High beta cavities tested 72 times
 - More multipacting in this geometry
 - (not fully understood, not expected from cell geometry)
- Data from Talk by J. Ozelis, SRF 2005 Lutz Lilje DESY - MPY-



Figure 1. Gradient at $Q_0 = 5 \ge 10^9$. The gradient spec for the medium (high)- β cavities is indicated with the dashed red (blue) line.

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Comparison w/ Cryomodule Performance

Gradient at Q₀ = 5 x 10⁹

Cavity gradients in the CMTF were found to be ~35% higher than those measured in the VTA. This increase is perhaps due to the much lower RF duty factor (6-7%) employed during module testing. Note – no MP was ever observed in CM testing.



Renascence Cavity Fabrication

Production set

efferson G

- -5 HG and 4 LL 7-cell cavities
- —RRR 347 Nb
- —Nb₅₅Ti flanges and helium vessel transition plate
- —Endgroups on HG and LL are identical
- —Developed standard production drawings and procedures
- Refined assembly sequence details for efficiency and QA
- —Mix of internal/external shop machining
- —All in-house chemistry and EBW







Operated by the Southeastern Universities Research Association for the U.S. Department of Energy

Cavity Testing - LL





Thomas Jefferson National Accelerator Facility



Operated by the Southeastern Universities Research Association for the U.S. Department of Energy

S0 Ultimate Goals

- The cavity performance is influenced by the fabrication process and surface preparation process.
 - Effort in all the regions to qualify further vendors for cavities
- Preparation process and vertical test yield for 35 MV/m at $Q_0 = 10^{10}$ should be greater than 90% for a sufficiently large number (greater than 100) of preparation and test cycles.
 - There should be a complete description of the preparation and testing processes (reproducibility in other places). The time scale should be commensurate with the completion of the TDR (middle of 2009).



S0 Ultimate Goals

- After a viable cavity process has been determined through a series of preparations and vertical tests on a significant number of cavities, achieve 35 MV/m at Q₀ = 10¹⁰ in a sufficiently large final sample (greater than 30) of nine-cell cavities in the low-power vertical dewar testing in a production-like operation e.g. all cavities get the same treatment.
 - The yield for the number of successful cavities of the final production batch should be larger than 80% in the first test. After re-processing the 20 % underperforming cavities the yield should go up to 95%. This is consistent with the assumption in the RDR costing exercise.



Original BCD Gradient Distribution

Assumption: Gaussian distribution of cavity performance Center is at Eacc = 37 MV7m, width from 4% to 10 %



Yield instead of Distribution

- In the BCD was a distribution of cavity gradients of 37 +/- 5% MV/m.
 - corresponds to a 95% yield
 - assuming cavities have to perform at more than 35 MV/m in the low-power test before being assembled to modules.
- As the yield is a more important number from project point-of-view, the task force prefers to use yield.
 - The realistic shape of the distribution is unknown.
 - Most likely, it will be non-gaussian (opposed to what was assumed in the BCD) with an asymmetry due to the hard physical limit at high field.



S1 Ultimate Goals

- Final goal (following the BCD definition):
 - Achieve 31.5 MV/m at a Q₀=10¹⁰ as operational gradient as specified in the BCD in more than one module of 8 cavities including e.g. fast tuner operation and other features that could affect gradient performance
 - All cavities built into modules perform at 31.5 MV/m including enough overhead as described in the BCD. The cavities accepted in the low-power test should achieve 35 MV/m at $Q_0 = 10^{10}$ with a yield as described in the S0 definition (80% after first test, 95% after re-preparation).
 - At least three modules should achieve this performance. This could include re-assemblies of cryostats (e.g. exchange of cavities).
 - It does not need to be final module design. An operation for a few weeks should be performed.
- Intermediate goal
 - Achieve 31.5 MV/m average operational accelerating gradient in a single cryomodule as a proof-of- existence. In case of cavities performing below the average, this could be achieved by tweaking the RF distribution accordingly.



S0/S1 Task Force Plans II

• Involve TESLA Technology Collaboration

- Can help in organizing forums
 - TTC Meetings
 - Monthly teleconference with America and Europe started, seeking to integrate Asia soon
 - A lot of expertise is accumulated there
- E.g.: Steps towards accumulation of various parameters of EP has started, proposal for dedicated single-cell program
- Make ILC R&D needs transparent
- Stay online with developments in TTC
- Propose to involve Industry early in preparation processes
 - Based on the TTF experience this is probably just the right time
 - Need also preparation capacity
 - Started for XFEL in Europe, to some degree available in Japan, needs work in America
- Need feedback from GDE
 - WWW page will be setup with documents, talks and data on R&D board page
- First 'formalized' proposal to be finalized at LINAC06

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Existing Proposals for Studies on Electropolishing (TTC,SMTF)

Nb CAVITY EP SUMMARY AS OF DECEMBER 2005

Tsuyoshi Tajima* for the Working Groups at TTC and SMTF meetings

Abstract

This document presents an outcome of the discussions at the TTC meeting at Frascati on 5-7 December 2005, which was a continuation from the SMTF meeting held at FNAL on 5-7 October 2005. Our goal was to identify the cause of the results spread of EPed 9-cell Nb cavities that have been tested mostly at DESY. While the spread might not have been caused only by the EP itself, the fact that the spread is larger than BCPed cavities may suggest that the EP process or EP -related contamination due to such as sulfur may be the cause of the problem. After the discussions on EP parameters and current issues, we suggest that the following be carried out with R&D efforts as highest priority items : 1) further study how important it is to control HF content and what is an appropriate range, 2) establish the best way to eliminate sulfur, a reaction product while EP and is insoluble to water. 3) study how

KEK	High Organi	Energy zation, Japa	Accelerator an.	Researc	
QA	Quality Assurance				
SMTF	Superconducting Module Test Facility				
TTC	TESLA Technology Collaboration				
WG	Workin	ng Group			

<u>Proposal for an R&D Plan towards better Understanding of the</u> <u>Electropolishing of Niobium Cavities</u>

P. Kneisel, K. Saito, D. Reschke Jan. 17, 2006

During the last year issues concerning the electropolishing of niobium cavities have been discussed at various meetings such as the TTC meeting at DESY in March 2005, the ILC Snowmass workshop, the SMTF workshop at FNAL in October 2005 and now at the TTC meeting in Frascati.

A summary report about Electropolishing activities worldwide will be published in the near future [1]

It has become very clear that the major problems have to do with contamination of the electropolished surfaces as well as with unpredictable hydrogen dissolution, resulting in some cases in "Q-disease". Better "on line" monitoring of the process seems to be a desirable QA/QC activity.



Refining the R&D Process

- Need for Intermediate Milestones
 - Ultimate Goals are long-term
 - allow for tracking of progress in cavity preparation cycle
 - Under discussion! Following slides are proposals and need careful evaluation
- Describe type measurement cycles
 - 'Tight-loop':
 - A few cavities over again, demonstrate that spread of process is small
 - Qualification of infrastructure and processes
 - Finally, the full process chain must be looped through
 - 'Production-like'
 - Batches of cavities treated in same manner
- Define measurement best practice e.g.
 - Passband mode measurements
 - Check for Q-disease
 - Temperature-mapping of the niobium surface for multi-cells in all regions
- Need estimation of capacities for testing and cavity production
 - A lot of the testing needs to be done on multi-cell cavities as assemblies and procedures are different for single-cells and multi-cells
 - Define single-cell measurements where they are useful
 - Programm must be integrated into nine-cell effort
 - Leave some room for alternatives (e.g. large-grain material)
 - Overall testing capacity will be limited



Problematic Issues

- Variety of cavity types is not helpful in the long-run
 - Various lengths, flange systems, magnetic shielding, HOM damping etc.
 - For the ultimate goal a single cavity type is needed
 - Can be built and treated in different regions in parallel provided processes are transferable
- Variety of recipes and setups
 - Must develop protocols that guarantee transferable results
 - Monitoring of parameters should make processes more transparent (e.g. HF content)
 - Exchanging cavities can facilitate
 - Setups need to be qualified first (tight-loop)
- Many process steps from niobium to cavity in accelerating module
 - New vendors will have to learn
 - separate final process reproducibility from cavity reproducibility (includes fabrication)
- Cavity development is ongoing
 - Staging of cavity production is necessary to allow for evolution in cavity design and process improvements
- Ultimately the number of cavities being built and treated will be small compared to the ILC number of cavities



For Discussion: S0 Intermediate Goals

- Feedback is welcome
 - Would like to get comments within the next few weeks (before Linac06)



S0 Intermediate Goals:2006-2007

- Qualification of multi-cell setups and procedures (start now)
 - Improve process monitoring: e.g.
 - High pressure rinse parameters
 - Acid quality control
 - HF content
 - 'Tight-loop' processing of a few (1-4) cavities over and over again.
 - The goal is to demonstrate gradients after new 10 preparations are within less than 10% of the (acceptable) average gradient of each cavity.

23.07.2006

- Definition of the single-cell effort has started by TTC and SMTF
 - Must be following the prioritized proposals
 - Multi-Lab participation possible
 - Processes must be transferable to multi-cells
 - Process monitoring
 - S-deposition studies
 - H- contamination studies
 - Limited room for basic studies is needed
 - Field emission studies
 - Control of particulate contamination
 - Material studies
 - Need to set a deadline to allow feedback into nine-cell process

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Single-cell Prioritized Program (TTC)

Problem	Proposed Activity	Priority
Contamination	Rinsing studies with samples	1
Field Emission	(XPS,SIMS)	
	Rinsing studies with single cell cavities	
Non-reproducible	Test any electropolished cavity for Q-	1
appearance of	disease	2
Q-disease	Can overheating during initial rinsing	2
	cause Q-disease?	
	Optimizing studies for cathode/screening	
	geometry	
Monitoring and	Implementation of "on line" monitoring	1
control	and data logging of polarization curves	
	and HF concentrations	1
	Exploitation of EP simulation program	
	Investigation of the cause for non-uniform	2
	material removal	
Acid composition/	Chemical analysis of acid mixture (2
decomposition	nominally equal)	
	Polarization curves on samples	



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Final Process Reproducibility: until 2008

• Stage 1: Tight-loop (finish mid-2007) :

- Start with a batch of 20 cavities globally. Carry out the full treatment once.
- Pick out the best 9 cavities and distribute 3 per location. These 9 cavities have a starting average gradient and spread.
- Show reproducibility of "final process" with 3 best cavities at each location by using the tight loop EP 20 um/HPR/Test. 3 cavities x 3 cycles = 9 tests per location.
- Determine spread and best gradient for final treatment process.
- Stage 2: Improved tight-loop (finish mid-2008):
 - Include improvements from the parallel/coupled R&D program.
 - Repeat the first stage with the same 9 cavities, get smaller spread with higher gradient.
- By this time we will have additional information from the production-like tests (see below)



S0 Intermediate goals: 'Bottom line'

- The results should
 - ... be an improvement over the TTF experience with EP production cycle 1
 - ... provide data for a decision on the baseline gradient
- All the above mentioned preparations and tests can serve to fulfill the first of the ultimate goals.
 - The production and preparation of the cavities can be dispersed over the regions provided the processes are well enough defined to make them comparable.
 - Different cavity shapes might be acceptable for this goal provided sufficient confidence has been achieved for each shape under consideration.



Cavity Reproducibility: until 2009

- Stage 3 'Production-like' (start in 06)
 - Order a large number of cavities starting as soon as possible in 06 and 07.
 - According to first assessment, the total number of cavities in hand by end of 2007 could be ~50-60.
- Stage 4 'Final Production' (finish mid-2009)
 - Carry out full treatment. Apply best recipe from Stage 2 to the large batch of cavities
- This implies a minimum of 2-3 production cycles until end 2008



Summary and Outlook

- Several multi-cell cavities have met ILC specifications
 - In production mode yield of multi-cells is not yet sufficient
 - Single-cells have achieved much higher gradients
- Program to address this issue is being developed e.g.
 - Define goals
 - Make Results more comparable
 - Develop common set of parameters
 - Assess global capabilities
 - Synchronize efforts
- Outcome should give confidence for the technical design phase
 - Staging i.e. intermediate goals can help to account for progress
 - Overall cavity count and test capacity for R&D program is small compared to ILC numbers

This should demonstrate an effective model of international coordination of R&D efforts

Lutz Lilie DESY -MPY 23.07.2006