Test Results of the International S1-Global Cryomodule
International Team for “S1-Global”

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61 persons from 5 Labs!
Motivation & History of S1-Global
Cavity, Coupler and Tuner in S1-Global
Cavity performance at V.T.
Assembly and Cryomodule test Status
Coupler conditioning at R.T.
Tuner test with low power @2K
LFD measurement
LFD compensation by piezo
7 cavities operation
Dynamic loss measurement (including Static loss)
RF response at Quench for MHI-06
Summary
Motivation & History of S1-Global

Motivation

- Comparison of hardware performance concerning SRF technology for ILC
  - Cavity
  - Power coupler
  - Tuner
  - Cryomodule
- Mutual understanding among SRF researchers, engineers and technicians

History

- This project was launched in a discussion of ILC-GDE in 2008.
- The preparation including V.T. was in progress in 2009.
- The assembly work started at the beginning of 2010.
- The cryomodule test finished on Feb/2011.
Main components in S1-G cryomodule

TESLA Cavity (DESY/FNAL)

Blade Tuner (FNAL/INFN)

Saclay Tuner (DESY)

TTF-III Coupler (DESY/FNAL)

Tesla-like (KEK)

Slide-Jack Tuner (KEK)

STF-II Coupler (KEK)

Comparison of Performance

The coupling is variable for both couplers.
S1-Global Cryomodule

2 Blade tuners 2 Saclay tuners

4 Slide-jack tuners (center or end)

Cryomodule-C
(4 TESLA cavities
4 TTF-III couplers)

Cryomodule-A
(4 TESLA-like cavities
4 STF-II couplers)
Cavity Performance @V.T.

2 cavities from FNAL

- AES004 Cavity
  - $Q_0 = 7.8 \times 10^8$
  - $E_{acc,\text{max}} = 29.4 \text{ MV/m}$
  - by R. Geng (JLab)

- ACC011 Cavity
  - $Q_0 = 8.1 \times 10^8$
  - $E_{acc,\text{max}} = 33.3 \text{ MV/m}$
  - by J. Ozols (FNAL)

2 cavities from DESY

- Z108 Cavity
  - $Q_0 = 9.6 \times 10^8$
  - $E_{acc,\text{max}} = 31.3 \text{ MV/m}$
  - by A. Matheisen (DESY)

- Z109 Cavity
  - $Q_0 = 1.3 \times 10^{10}$
  - $E_{acc,\text{max}} = 30.7 \text{ MV/m}$
  - by A. Matheisen (DESY)

4 cavities from KEK

- MHI-05 Cavity
- MHI-06 Cavity
- MHI-07 Cavity
- MHI-09 Cavity

8 Cavities for S1-Global (ave. 30 MV/m)

- AES004
- ACC011
- Z108
- Z109
- MHI-05
- MHI-06
- MHI-07
- MHI-09

- Vertical Test
- Cryomodule Test

(ave. $E_{acc,\text{max}} = 30.0 \text{ MV/m}$)

E. Kako

28/Jul/2011

SRF’11 @Chicago
Collaboration for Cryomodule Assembly

cavity string assembly (2010, Jan.)

coupler assembly (2010, Mar.)

kek cavity string assembly (2010, Mar.)

Tuner assembly (2010, Feb.)
Collaboration for Cryomodule Tests

Tuner performance tests (2010, July)

Cavity processing (2010, Sept.)

Lorentz detuning tests (2010, Oct.)

Dynamic loss meas. (2010, Nov.)

E. Kako
RF processing of input couplers

Cryomodule-C /KLY#1 (2MW)
Cryomodule-A /KLY#2 (5MW)

0.5 ms, 5 Hz, 500 kW
1.5 ms, 5 Hz, 200 kW

Aug. 25 ~ Sept. 07 (10 days)

E. Kako
RF processing time of input couplers

**Cryomodule-A**
(STF-II couplers)
ave. processing time
\(~ 13 \text{ hours}\)

**Cryomodule-C**
(TTF-III couplers)
ave. processing time
\(~ 21 \text{ hours}\)

Vacuum I/L : 2.\times 10^{-4} \text{ Pa}

The difference of the conditioning time between them is probably due to the structure of RF window.
**Adjustment of frequency** ($f_0$)

$$f_0 = 1299.91 \text{ MHz (operation)}$$

Cryomodule - C  

- $f_0 = 1299.91 \text{ MHz (operation)}$

Cryomodule - A  

- $f_0 = 1300.00 \text{ MHz, limit}$

C2/ACC011; Tuner did not work.  

(A4/MHI-09; 1299.91 MHz, limit)

The cause of these tuner troubles are probably due to the mechanical stress.

E. Kako
The both couplers have a good performance for the adjustment of $Q_L$.

$Q_L = 2.4 \times 10^6$, $\Delta f_{bw} = 542\text{Hz}$
Cavity performance between V.T. and C.T.

Summary of Achievable Gradient for all Cavities at S1-Global

- Ave. 30MV/m @V.T.
- Ave. 28MV/m @C.T. (single cavity)
- Ave. 26MV/m @C.T. (7 cavities)

Unfortunately, the gradient did not achieve the ILC specification!
Cavity performance between V.T. and C.T.

Comparison of Achievable Gradient for all cavities @S1-Global

severe drop!
Status of high power operation

real time detuning monitor

S. Michizono
Frequency shift due to Lorentz detuning

C4/Z109 (29MV/m)

Pre-detuning by motor tuner & piezo tuner with DC voltage

Compensation by piezo tuner in pulsed operation

FB/on, Piezo/off

A2/MHI-06 (38MV/m)

Rise Time

Flat Top

Rise Time

Flat Top

200~500 Hz

Fundamental mode

2~3 kHz

2nd order mode

FB/on, Piezo/off

E. Kako
Pulse-shortening & Data Analysis method

Superconducting RF Test Facility

Pulse-Shortening for MHI#6 at 38MV/m in S1-Global (1500μsec) ('10/11/11)

Piezo comp. for MHI#6 at 38MV/m in S1-G (315Hz/11.3ms/400V/10V) ('10/11/10)

100 Pulses average

50μsec step shortening

F.B. ON / Piezo Off for MHI#6 at 38MV/m in S1-G ('10/11/10)

676.464Hz at 0.0μsec

LFD by Pulse Cut (1500μsec) for MHI#6 at 34.2MV/m in S1-G ('10/9/24)
We can estimate the detuning frequency for the period of rise-up, flat-top and full-pulse.

\[ \Delta f_{\text{rise-up}} = K_{\text{rise-up}} \cdot E_{\text{acc}}^2 \]

\[ \Delta f_{\text{flat-top}} = K_{\text{flat-top}} \cdot E_{\text{acc}}^2 \]

\[ \Delta f_{\text{full-pulse}} = K_{\text{full-pulse}} \cdot E_{\text{acc}}^2 \]

K [Hz/(MV/m)^2] stiffness parameter
Comparison of Detuning Frequency by LFD

Comparison of detuning frequency (rise-up) @S1-Global

Comparison of detuning frequency (flat-top) @S1-Global

Comparison of detuning frequency (full-pulse) @S1-Global

Comparison of Stiffness of Every Cavity @S1-Global

Normalized Stiffness of Every Cavity @S1-Global

TESLA-like cavity package has a stiffer structure than others!

28/Jul/2011 SRF’11 @Chicago
Parameters of Piezo drive pulse

Pre-detuning by motor tuner

Single pulse of inverse cosine waveform

RF Feedback / ON
Result of Piezo Compensation for LFD

Piezo Compensation for MHI#6 with F.B. ON @38MV/m (2010/11/10)

- 150Hz/11.0ms/500V/90V
- 200Hz/11.3ms/400V/140V
- 220Hz/11.3ms/400V/100V
- 230Hz/11.3ms/300V/80V
- 250Hz/11.3ms/200V/70V
- 250Hz/11.3ms/500V/80V
- 300Hz/11.3ms/400V/35V
- 315Hz/11.3ms/400V/10V
- 400Hz/11.6ms/200V/100V
- 400Hz/11.55ms/300V/120V
- 450Hz/11.8ms/220V/220V

Piezo Compensation for ZANON#109 with F.B. ON @29MV/m (2010/11/10)

- 150Hz/10.2ms/160V/20V
- 200Hz/10.5ms/130V/10V
- 200Hz/11.0ms/130V/40V
- 250Hz/10.82ms/120V/30V
- 300Hz/11.05ms/106V/10V
- 350Hz/11.25ms/98V/34V
- 400Hz/11.4ms/94V/48V

Piezo Compensation for AES#4 with F.B. ON @26MV/m (2010/11/11)

- 150Hz/10.0ms/140V/18V
- 200Hz/11.1ms/100V/22V
- 250Hz/11.1ms/100V/5V
- 250Hz/11.1ms/100V/38V
- 300Hz/11.4ms/80V/24V
- 350Hz/11.5ms/80V/26V
- 400Hz/11.7ms/70V/38V

Correlation between Field and Peak-to-Peak of detuning frequency

- MHI#6
- MHI#5
- MHI#7
- AES#4
- ZANON#108
- ZANON#109

$\Delta f_{\text{peak-to-peak}}$
7 Cavities Operation

Long term operation for 7 Cavities at 25.0MV/m in S1-G ('10/12/15)

ACC#11 detuned

6305 pulses

17:08 18:53

AES#4
ZANON#108
ZANON#109
MHI#5
MHI#6
MHI#7
MHI#9

28/Jul/2011
7 Cavities Operation

High Power Test in S1-Global (’10/12/15)

He pressure

He flow

Long term operation for 7 Cavities at 25.0MV/m in S1-G (’10/12/15)

He pressure

He flow
7 Cavities Operation

Long term operation for 7 Cavities at 25.0MV/m in S1-G (*10/12/15)

ACC#11 detuned

REQUIRED rf power for 8-cav. operation

More RF power is necessary for MHI#6 and #7.
This means the inner conductor of the input coupler may be expanded due to the heating.
The couplers lead to more over-coupled situation.
7 Cavities Operation

MHI#6

Long term operation for 7 Cavities at 25.0MV/m in S1-G (10/12/15)

$E_{acc} \uparrow 1.0\text{MV/m}$

$\varphi$

$E_{acc} \uparrow 1.0\text{MV/m}$

$\varphi$

$E_{acc} \uparrow 1.0\text{MV/m}$

$\varphi$
RF response of Quench for MHI#6 @40MV/m
STF-II coupler has more heat loss than TTF-III. This point should be improved in the near future.
Troubles

✓ The performance of the two cavities dropped between V.T. and C.T.

✓ The tuners of the two cavities did not work at 2K.

These problems are investigated in the near future.
Summary

• Assembly work by the S1-Global team was successful.
• 6 of 8 cavities reached the almost same gradient at the cryomodule test as the vertical test.
• Mechanical vibration modes were found to vary from cavity to cavity.
• LFD measurement was successful. MHI cavity turned out to be stiffer.
• Compensation by piezo was successful. All types of the tuners tested have demonstrated good effectiveness.
• Simultaneous operation of seven cavities was comparatively stable. The $Q_L$ decreased gradually during the operation for every power coupler.
• From the results of the dynamic loss measurement, it was observed the STF-II coupler has a larger heat loss.
• Communication among the international members of the S1-Global team worked well.
Thank you for your attention.