S1-GLOBAL COLLABORATIVE EFFORTS 8-CAVITY-CRYOMODULE: 2 FNAL, 2 DESY AND 4 KEK

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Abstract

In an attempt to demonstrate an average accelerating gradient of 31.5 MV/m as in the design of the ILC, the S1-Global project [1,2] is a cryomodule being constructed and tested by an international collaboration hosted by KEK and including INFN, FNAL, DESY and SLAC. The S1-Global system joins two half-length cryomodules, each 6 m in length and containing 4 cavities, Module-C contains cavities from FNAL and DESY and was constructed by INFN. Module-A contains four KEK cavities and was constructed by KEK. The assembly of the cryomodules was completed in May 2010, and the cold test started from June 2010. In this paper, the international collaboration efforts of the S1-Global cryomodule are presented with the preliminary cold test results and the following test plans.

INTRODUCTION

The ILC main linac consists of 1815 cryomodules [3] which have two designs, one has 9 cavities in the 11.83 m cryomodule and the other has 8 cavities and one quadrupole package in the module center. For developing the main linac, the ILC General Design Effort has the R&D programs of S0, S1 and S2 [4]. S0 is for production yield of 9-cell cavity over 35 MV/m, S1 is for operation of the cavity-string at 31.5 MV/m as the design of the ILC, and S2 is for the beam test by an accelerator unit of the cryomodule string. The S1-Global is the project to make the R&D of S1 reality with the international research collaboration and the main target of the S1-Global cryomodule is aimed to be the 'Realization of an average accelerating gradient of 31.5 MV/m with 8 cavities'.

The construction of the S1-Global cryomodule was proposed and approved as an international collaborative effort at the SC-RF technical meeting of the ILC General Design Effort in April 2008. The eight cavities were contributed from FNAL, DESY and KEK, and installed in two 'half cryomodules' each 6 m long: a new one designed and constructed by INFN and a modification of the existing 6-m STF cryomodule by KEK.

The collaborative framework of S1-G is demonstrated in the contributions of the participating laboratories:

- INFN: Design and construction Module-C and production of the blade tuners for the FNAL cavities.
- FNAL: Two TESLA type cavities [5], power couplers and integration of the INFN blade tuners in the cavity packages.
- DESY: Two TESLA type cavities, including Saclay-type tuners, and power couplers.
- SLAC: Two set of VTO power distribution for Module-C, and aging of FNAL couplers.
- KEK: Four TESLA-like cavities, with two types of tuner design, Module-A for KEK cavities [6], power distribution for Module-A, and infrastructure for tests.

SCHEDULE OF THE PROJECT

Figure 1 shows the general schedule of the S1-Global project. The cryomodule design work started in May 2008 with the joint team of INFN, FNAL and KEK, and the design of this cryomodule was completed at the end of 2008. In 2009, the construction of Module-C components by INFN and the modification of Module-A by KEK were performed. The productions and the tests of 8 cavities were carried out by DESY, FNAL and KEK in 2009. Assembly of the S1-G cryomodule and the installation of this cryomodule in the KEK-STF tunnel were scheduled from January to May 2010. At present, the cold tests are scheduled from June to December 2010.

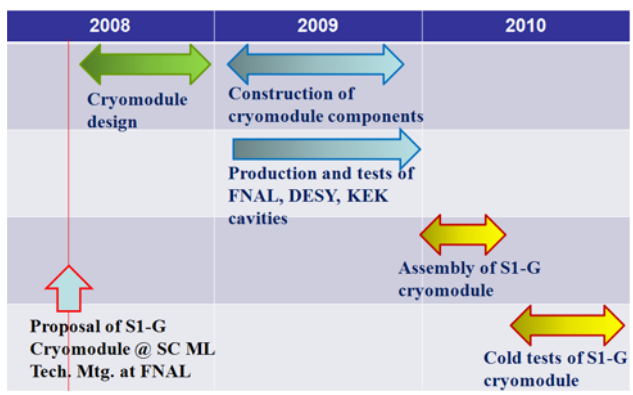


Figure 1: General schedule of S1-Global project.

CRYOMODULE DESIGN

The S1-Global cryomodule consists of two 6-m cryomodules, Module-A and Module-C, shown in Fig. 2. Four cavities from FNAL and DESY are installed in the Module-C, and four cavities of two type cavity-jackets by KEK are installed in Module-A. The total length of the S1-Global cryomodule is 14.9 m. The parameters of the two 6-m cryomodules are listed in Tab. 1.

Table 1: S1-Global Cryomodule Parameters

	Module-A	Module-C
Vacuum vessel length	6087 mm	5800 mm
Vacuum vessel O.D.	ϕ 965.2 mm	ϕ 965.2 mm
Gas return pipe length	5830 mm	6000 mm
Gas return pipe O.D.	ϕ 318.5 mm	ϕ 312.0 mm
2K LHe supply pipe O.D.	ϕ 76.3 mm	ϕ 76.1 mm
5K shield pipe O.D. [F/R]	ϕ 30/ ϕ 30 mm	ϕ 60/ ϕ 60.3 mm
80K shield pipe O.D. [F/R]	ϕ 30/ ϕ 30 mm	ϕ 60/ ϕ 60.3 mm
Cool-down pipe O.D.	ϕ 27.2 mm	ϕ 42.2 mm
Distance between couplers	1337.0 mm	1383.6 mm
Cavity package	KEK-a/KEK-b	FNAL/DESY
Cavity type	TESLA-like	TESLA-type
Tuner type	Slide jack	Blade/Saclay
Input coupler type	Disk window	Cylindrical window
Magnetic shield	Inside jacket	Outside jacket
Package length	1247.6	1247.4/1283.4

Figure 3 (a) shows the cross section of Module-C, and this design is almost the same as the DESY TTF-III cryomodule[7]. The Module-C length is 5.8 m, and the DESY and FNAL cavities are attached to the gas return pipe, and this pipe is supported by the two composite cylindrical posts to the vacuum vessel. The cold components are thermally insulated with 5K and 80K thermal radiation shields. The FNAL cavity has the Blade tuner in the center of the cavity jacket, and the DESY cavity has the Saclay tuner at the opposite end of the input coupler. The Module-A cross section is shown in Fig. 3 (b), and the design of this module was based on the TTF-III cryomodule. Module-A was used for the cold tests in STF phase-1 [8], and it was modified for S1-G. The KEK cavities have two designs as to the tuner location. The cavity-package of type-A has the tuner at the center of the helium jacket. This configuration is the same as the FNAL cavity design which has the Blade tuner in the center of the helium jacket. The B-type cavity-package has the tuner placed at the opposite end of the jacket with respect to the input coupler. This design is close to that of the DESY cavity.

While the FNAL and DESY cavities have different lengths of 1247.4 mm and 1283.4 mm, respectively, they locate with the same coupler pitch of 1383.6 mm in Module-C. The KEK cavity length is 1247.6 mm, and the coupler pitch is 1337.0 mm. Four types of cavities have a different design in the magnetic shield; the magnetic shields of FNAL and DESY cavities are assembled outside of the cavity jackets, and those of KEK cavities are inserted between the jacket and the 9 cell-cavity.

In the design stage, one of the difficulties was handling of CAD data. Even by using the same CAD software between the collaborative laboratories, the data on the different version of the software were not able to use directly between the laboratories. This point should be thoroughly considered before begin of design work in the international collaborative research.

CONSTRUCTION OF THE CRYOMODULE

Production of Cryomodule Components and Cavities

Production of the Module-C components started from January 2009, and the process of manufacturing was kept

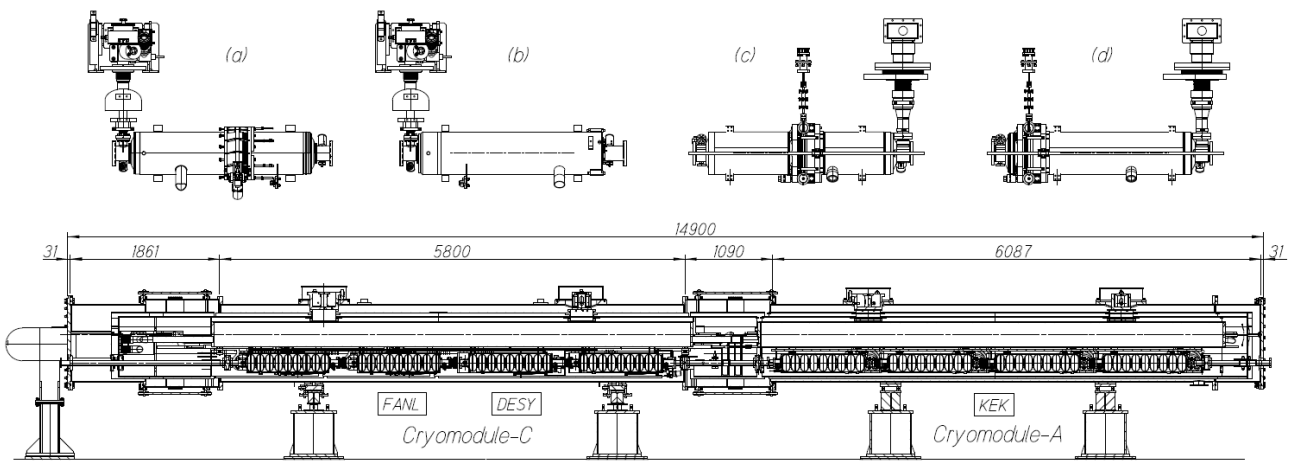
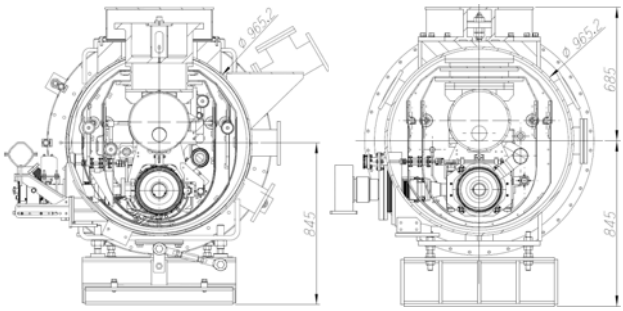


Figure 2: S1-G cryomodule and cavity package of each laboratory. (a): FNAL cavity with Blade tuner, (b): DESY cavity with Saclay-type tuner, (c): KEK-a cavity with slide jack tuner and (d) KEK-b cavity.



(a) (b)

Figure 3: Cross sections of Module-C (a) and -A (b).

Figure 4: Completed gas return pipe and support posts for Module-C in the company of Italy.

on time under the supervision of INFN. Production of all components was completed in the middle of October, and they arrived at KEK by ship on December 25, 2009. Figure 4 shows the completed gas return pipe with two support posts. The DESY and FNAL cavities are held from this pipe. As an example of international collaborative work, 24 strain gauges, 8 thermal sensors and 5 wire position monitors were assembled on this gas return pipe in order to measure the thermal and mechanical behaviors of this gas return pipe, by working together with KEK, INFN and the technicians of the company in Italy.

The productions and tests of cavities for S1-G started from 2009. Eight cavities were tested in the vertical test stand in each responsible laboratory. Two DESY cavities, Z108 and Z109, and two FNAL cavities, AES004 and ACC011, reached at the field gradients from 29 MV/m to 33 MV/m. Four KEK cavities reached the field gradients from 27 MV/m to 33 MV/m. The results are shown in Fig. 5. The average field gradient of 8 cavities was 30.0 MV/m.

Assembly of S1-Global Cryomodule

Two DESY cavities, Z108 and Z109, arrived at KEK on December 4, and the two FNAL cavities, ACC011 and AES004 arrived at KEK on December 25 and January 8, respectively. The cavity string assembly started on January 15 by the joint team of three FNAL, two DESY and two KEK personnel, and the assembly was successfully completed on January 20 as shown in Fig. 6 (a). This team is shown in Fig. 7.

After moving the FNAL/DESY cavity-string out of the clean room, INFN and FNAL colleagues mounted the

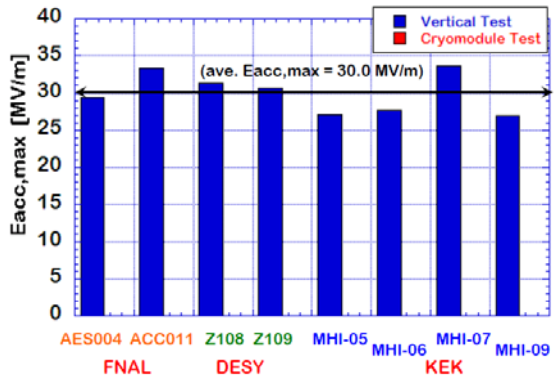


Figure 5: Field gradients of 8 cavities for the S1-Global cryomodule.

(a) FNAL/DESY cavities (b) KEK cavities

Figure 6: Assembly of four cavities in the clean room.

Figure 7: DESY/FNAL/KEK cavity assembly team.

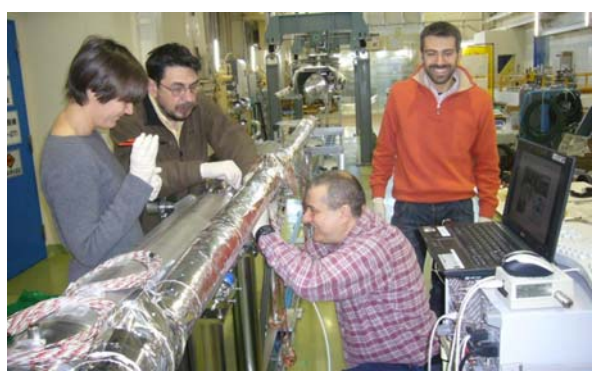


Figure 8: Mounting tuners on DESY/FNAL cavities by the INFN/FNAL team.

Blade and Saclay tuners and magnetic shields on the four cavities from February 9 to 12, shown in Fig. 8.

The string of four KEK cavities, MHI-05, 06, 07 and 09 was assembled in the clean room from February 22 to March 8 by the KEK team. This work is shown in Fig. 6 (b). Figure 9 shows the KEK S1-G team after completing four KEK cavity string.

The Module-C cold mass was assembled from January 25 to March 19. The main assembly processes were:

- Assembly and connection of cooling pipes.
- Supporting the cavity string from the gas return pipe with C-clamp with being instructed by the INFN colleague.
- Attaching thermal sensors and wiring.
- Assembling and welding 5 K and 80 K thermal radiation shields with the multi-layer insulation.
- Inserting the cold mass assembly into the vacuum vessel, shown in Fig. 10.

The completed Module-C was moved down to the KEK-STF tunnel on March 12.

Figure 9: KEK S1-Global team.

Figure 10: Inserting the Module-C cold mass into cryostat.

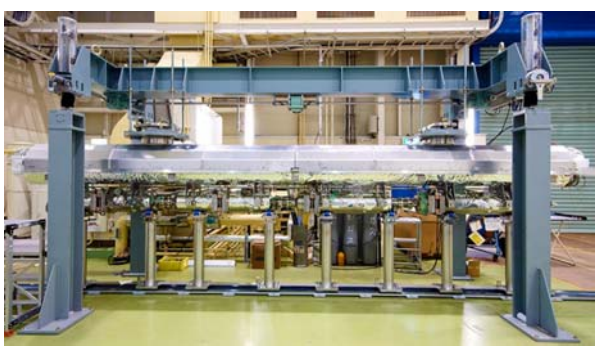


Figure 11: Four KEK cavity string supported from gas return pipe.

Figure 12: Installation of Module-A and Module-C in the KEK-STF tunnel.

The Module-A assembly was proceeded in the same way as the Module-C in April. Figure 11 shows the four KEK cavity string supported from the gas return pipe. The Module-A was moved down to the tunnel on April 30. Connection of the Module-C and the Module-A were completed in May as shown in Fig. 12. The helium leak test of the 8 cavities with the liquid helium pipe was executed, and the system was confirmed to be able to cool down to 2 K.

COLD TEST OF THE CRYOMODULE

The cold test schedule of the S1-G cryomodule is shown in Fig. 13. The test period is scheduled from June to December 2010, and it is divided into two terms including the summer shut-down.

In the first test term from June to July, the measurements of the thermal and mechanical performances of the cryomodule and the RF tests of 8 cavities at the low power [9] were scheduled

The first cool-down of 8 cavities is shown in Fig. 14. It took 5 days to cool the 8 cavities down from 300 K to 4 K. At 4 K, the heat load to cavities was measured and it turned out to be 9 W. The main heat sources are signal wires of more than 330 sensors and RF cables connected to cavities from room temperature. The heat load by these wires is calculated to be about 5 W. After confirming thermal performance of the cryomodule, the 8 cavities were cooled down to 2 K. While cooling down from 200 K to 4 K, the stretched wires of the wire position monitors had damages by the thermal deformation of the gas return pipe. The thermal deformation of the gas return pipe between the center and the ends reached about 9 mm in the vertical direction. The 18 wire position monitors were installed for measuring the positions of the gas return pipes of Module-C and Module-A and the four KEK

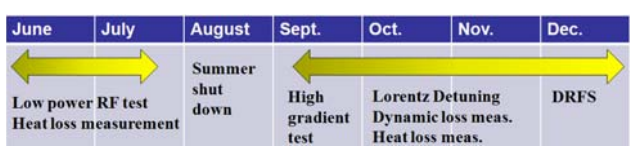


Figure 13: General cold test schedule in 2010.

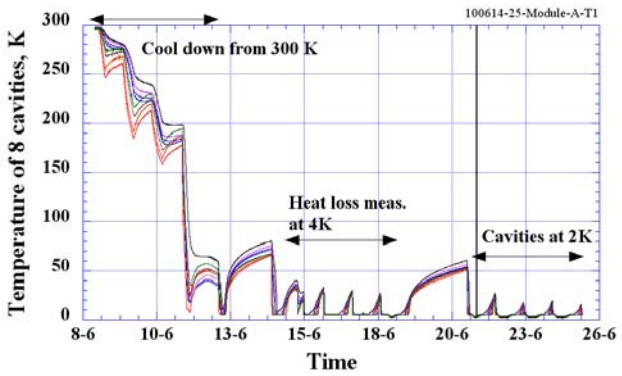


Figure 14: First cool-down of 8 cavities in S1-G cryomodule from June 8 to June 26.

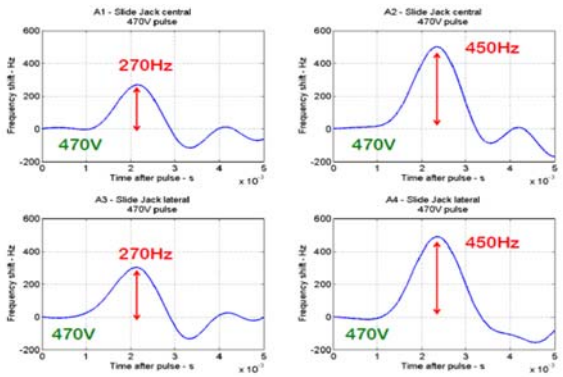


Figure 15: Single pulse response of four KEK cavities by Piezo tuner.

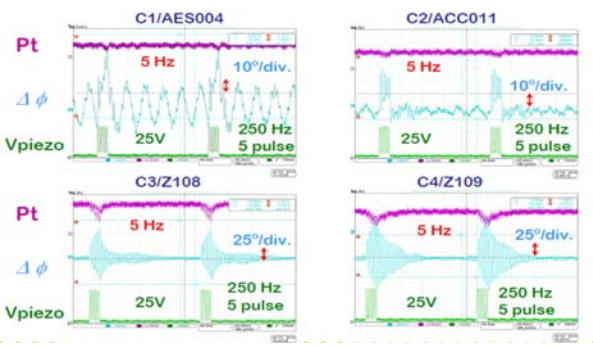


Figure 16: Mechanical vibration mode of four FNAL/DESY cavities by 5 continuous pulses of Piezo.

cavities through the whole cold test. They were repaired during the summer shut down.

At 2 K, the RF tests of 8 cavities at low power were performed by the joint team of INFN, FNAL and KEK. The following subjects were measured:

- Stroke of motor tuner.
- Stroke and hysteresis of Piezo tuner.
- Calibration of Qt, monitor coupler.
- HOM filter property.
- Multi-cycle hysteresis of Piezo tuner.
- Single pulse response of Piezo tuner.

In Figs. 14 and 15, the single pulse response of four KEK cavities by Piezo tuner and mechanical vibration mode of four FNAL/DESY cavities by 5 continuous pulses of Piezo are shown as one of the test results.

The second test term is scheduled for 15 weeks from September to December. The cool down of the S1-G cryomodule has been started on September 8. The scheduled test subjects are listed in the followings:

- Operation of 8 cavities at 31.5 MV/m.
- Static heat loss measurements at 4 K and 2K.
- High gradient test for the individual cavities.
- Lorentz detuning measurements and compensation.
- Dynamic heat loss measurements at single cavity, four cavities and 8 cavities.
- LLRF.
- Distributed RF system (DRFS) test [10].

FNAL and INFN colleagues will participate in the Lorentz detuning measurements and the dynamic heat loss measurements.

SUMMARY

As the leading project of ILC, the S1-Global cryomodule was successfully constructed on schedule under the international research collaboration of INFN, DESY, FNAL, SLAC and KEK.

In the first cold test, the S1-G cryomodule was cooled down to 2 K, and all functions were confirmed. The S1-G cryomodule has started to be cooled down again, and the cold tests will be continued until the end of 2010.

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