STATUS OF SUPERCONDUCTING RF TEST FACILITY (STF)

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Abstract

The superconducting RF test facility (STF) in KEK is the R&D facility for the International Linear Collider (ILC) cavities and cryomodule. The surface treatment and field test of fabricated 9-cell cavities are performed for the cryomodule installation. As an international project, S1-Global cryomodule test was conducted and successfully performed various studies on different type of cavities and on cryostat, as well as DRFS (Distributed RF Scheme) power system test. In parallel, as part of STF phase-2, a photocathode RF gun and a capture cryomodule are designed and under construction. All of the STF development done in 2010-2011 is summarized in this paper.

INTRODUCTION

The SB2009 (Straw man Baseline 2009) design modification from RDR [1] for acceleration unit design and other accelerator scheme become a new design as part of TDR in ILC-GDE [2][3]. For the single tunnel design of the ILC main linac in SB2009, KEK proposed the DRFS using 750kW small klystrons powering two cavities stand next to the cryomodule in the same accelerator tunnel. The demonstration of this new RF scheme is come to a milestone of the STF phase-2 construction. During phase-2 unit construction, we conduct several experiments, such as cryomodule thermal test for 5K-shield removal, S1-Global cryomodule experiment, and compact X-ray generation experiment [4]. In the S1-Global cryomodule experiment, we demonstrated ILC-like cryomodule built by the international collaboration. The automated cavity-tuning machine by the collaboration of DESY-FNAL-KEK was introduced into STF in 2010. In the compact X-ray generation demonstration referred as 'Quantum Beam experiment' which is founded by the MEXT, the electron beam source and beam capture cryomodule will be demonstrated. To do industrialization R&D study of cavity fabrication, the new cavity fabrication facility including electron beam welder is under commissioning.

S1-GLOBAL CRYOMODULE EXPERIMENT

The S1-Global cryomodule consists of two short cryomodule, named cryomodule-A and cryomodule-C. Cryomodule-A is from STF phase-1 experiment. INFN Milano-LASA has designed cryomodule-C, and an Italian company, ZANON, built its cold-mass components. Cryomodule-C stores four cavities from FNAL and DESY: AES-004, ACC-011, Z108, and Z109. Cryomodule-A stores 4 of Japanese-made cavities, which have been newly built for this experiment. They are MHI-05, -06, -07, and -09. The laboratories FNAL, DESY, and KEK contributed their top-performance cavities: AES-004 (29.4 MV/m, FNAL), ACC-011 (33.3 MV/m, FNAL), Z108 (31.3 MV/m, DESY), Z109 (30.9 MV/m, DESY), MHI-05 (27.1 MV/m, KEK), MHI-06 (27.7 MV/m, KEK), MHI-07 (33.6 MV/m, KEK), and MHI-09 (27.0 MV/m, KEK).

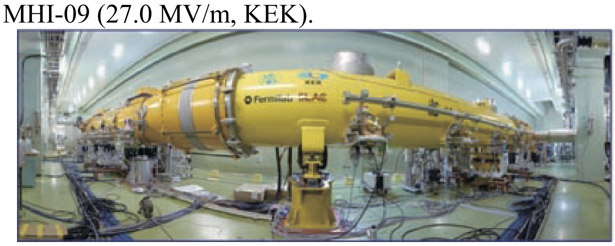

Figure 1: S1-Global cryomodule experiment setup in STF tunnel. Two cryomodule and the cold box were connected.

The S1-Global experiment aims to demonstrate the operation of these cavities in their common cryomodule in a pulsed RF operation with an average acceleration gradient of 31.5 MV/m, which is the design value of the ILC. The S1-Global experiment also aims to compare the operation of input couplers and cavity tuners from around the world and to validate their performance. RF operation is scheduled to begin in June 2010 and continue until February 2011. Other than DESY, FNAL and INFN, SLAC supplied variable ratio of power distributer (VTO). These two 6m cryomodule were connected together, and the 2K cold box was also connected as shown in Figure 1. The participation of researcher and engineer from FNAL, DESY and INFN were made in the cryomodule assembly, and every step of cryomodule operation. The thermal performance of the cryomodule, cavities gradient performance and the Lorentz Force detuning compensation were measured and tested. Average gradient in the individual field test before cryomodule installation was 30MV/m, however, average gradient in the cryomodule with supplying power individually was 27MV/m. Average gradient 26MV/m was attained in combined vector-sum operation with 7 cavities combination. 8 cavities combination by tuning of the resonance to one frequency was not possible, because of tuner trouble in the two cavities, ACC011 and MHI-09. The results are summarized in Figure 2. Meanwhile, Lorentz Force detuning compensation was successfully demonstrated within 10-20Hz on pulse flattop using piezo actuators. For the study of Lorentz Force Detuning Compensation, new algorithm of piezo tuner control was also developed and tested by FNAL team. The control is adaptive feed-forward and feedback control for RF pulse filling and flattop to flatten the detuning change to its minimum. The best detuning control by this advanced concept was achieved in FNAL cavity operated at 22MV/m, and the similar result was achieved in KEK cavity operated at 35MV/m.

In this experiment, the amplitude and phase of pulsed RF flattop are controlled by newly developed fast digital feedback in PCI board. The digital board employed FPGA circuit and sophisticated software to maintain short latency and fast response. In the development, IF-mix method sampling and direct 1.3GHz signal sampling were also tried. The developed FPGA control board reduces the amplitude fluctuation down to 0.006%rms and 0.0017degree-rms in phase. Long-term drift of these stabilities on 6300 seconds duration was measured and the result was within 10 ppm in amplitude and within 2 milli-degree in phase.

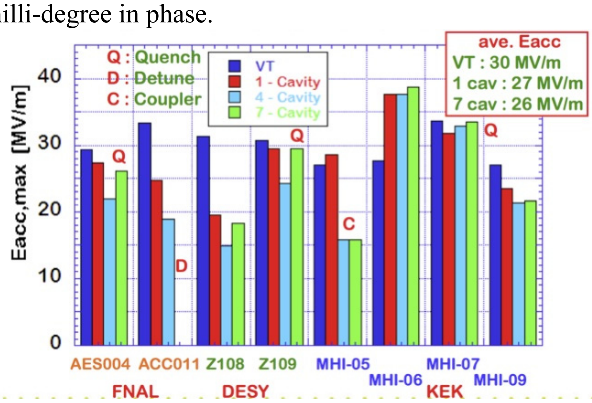

Figure 2: Reached cavity gradients are summarized in this bar graph.

Figure 3: DRFS installation in the S1-Global experiment.

The first demonstration of the concept of the DRFS was performed in the last stage of the S1-Global experiment. Two DRFS klystrons were installed in STF tunnel side by the S1-G cryomodule as shown in Figure 3. Two sets of two cavities are powered by 750kW DRFS klystrons with one HV-DC power supply in the first floor and the modulation anode power supply in the tunnel. The pair of the cavities is connected to the one DRFS klystron without circulator by splitting RF power with magic-T junction. The digital control unit was installed in the tunnel, and operated from remote. Results of this performance test were similar to the results of S1-Global cavity test. The DRFS system was demonstrated successfully.

CAVITY TUNING MACHINE DEVELOPMENT

Since 2007, members of KEK, FNAL, and DESY have engaged in a collaborative effort for the automated cavity tuning machines. The tuning machine is capable of frequency-tuning each of the cells, as well as correcting the alignment of the cells and the straightness of a 9-cell cavity. The automated frequency and bend-tuning machine for 9 cell superconducting cavity is essential for high performance acceleration. The niobium cavities are made by deep drawn and electron beam weld, not by lathes. The precision of accelerating field axis and its frequencies, and Higher Order Mode field axis are not well aligned just after fabrication. The automated tuning machine measures them and corrects them in quick and in easy way. The development program was started by the collaboration of three laboratories, DESY-FNAL-KEK. DESY fabricated 4 unit of the main part of the machine, FNAL made control hardware and software and received one unit, and KEK joined them and helped using accumulated experience, and received one unit. In 2010 FNAL has completed the control units and the control software development. One full set of the tuning unit was sent to KEK STF in July 2010. The installation and start-up work were done by the joint work of KEK and FNAL on November 2010. Two FNAL cavities and one DESY cavity were loaned to KEK for the use of the start up. Total 7 physicist and engineers from FNAL visited to STF for several weeks. After the installation, KEK received the instruction and had training course. Then KEK started its modification work to make KEK cavity possible to apply. KEK cavity has different outer shape from TESLA cavity, so that the mount modification and jaws modification is necessary. Figure 4 shows the final software set up work done by FNAL team in STF.

Figure 4: Installation team from FNAL has started up the cavity-tuning machine at STF.

STF PHASE-2 DEVELOPMENTS

On a way of the STF phase-2 construction, using the photocathode RF gun and two superconducting 9-cell cavities in the capture cryomodule, the accelerated beam up to 40MeV is used for the Quantum Beam experiment. The L-band room-temperature cavity for the RF gun and its input coupler were built through DESY–FNAL–KEK collaboration. The RF gun cavity and the input coupler were fabricated by FNAL. The Cs_2Te photocathode preparation chamber was designed, fabricated and installed into FNAL RF gun assembly as shown in Fig. 5. The RF gun cavity was connected to 5MW klystron of STF #1 power station. Since klystron and klystron power supply capability is not enough, only 1.7MW 1ms pulsed RF power was delivered to RF gun cavity. RF process was carried out to reach 1.7MW input power. The reached cathode field was 29MV/m and took 109 hours RF process. Since the dark current captured by the downstream faraday cup reached to 284μA at 27.7MV/m cathode field, and it was too much, so, we applied the surface treatment by sponge-wipe method with ethanol filled. By this rinsing, the dark current reduced one order below after the second RF process. The process time in the second was only 15 hours. The field enhancement factor also reduced to 149 from 352 before rinsing.

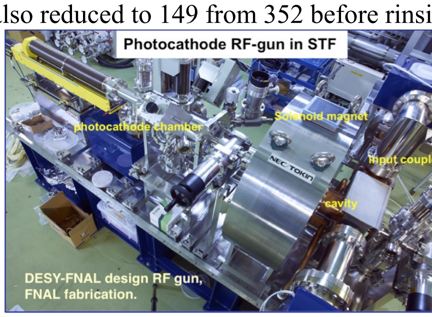

Figure 5: The RF gun system in STF.

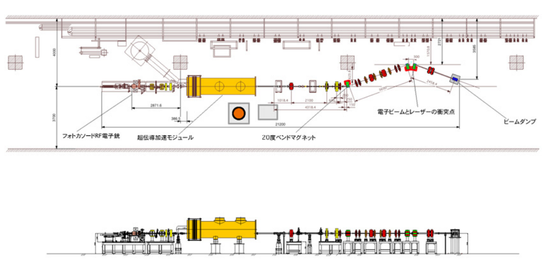

Figure 6: Layout of compact X-ray generation experiment setup.

The setup of Quantum Beam experiment is illustrated in Fig. 6. The beam is bent to the focus line at first, then put into two bending magnet line where laser collision chamber is located, and collide to the accumulated laser beam in the 4-mirror resonator with head-on angle. The high intensity Compton scattered X-ray is generated and detected at the down stream for the demonstration. The experiment is scheduled on spring to summer of 2012. The phase-2 cryomodule assembly will be started in the fall of 2012. The operation will be early 2013. Two 9-cell cavities were successfully tested and reached its gradient up to 40MV/m and 32MV/m, where one is beyond ILC qualification level 35MV/m. The cavities are now with the helium jacketed and delivered to STF. They are waiting to be installed into the cryostat of capture cryomodule.

CAVITY INDUSTRIALIZATION R&D

The cavity fabrication facility (CFF) was constructed in the utility building of the former proton synchrotron accelerator. The clean room was built inside of the utility building. It includes an electron beam welder (EBW), a press machine, a trimming machine, a chemical room, and several instrumentations. The delivery of EBW was on April 12, 2011 (Figure 7), however, the development study was already started for EBW parameter optimization using the same type of EBW at job shop in Tokyo. The press machine optimization study was also done together with press-die optimization. The fabrication cavity without HOM named KEK-#0 was started a year ago through these optimization, and the center cell part of 8-dumbbells were completed their welding in July 2011. The end group part will be fabricated and connected to the center cell part in September 2011.

Figure 7: EBW machine commissioning at Cavity Fabrication Facility.

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REFERENCE

[1] ILC Reference Design Report, ILC-Report-2007-001 (2007); http://www.linearcollider.org/cms/?pid=1000437
[2] R&D plan in TDP-2, release 4 (July, 2010); http://ilc-edmsdirect.desy.de/ilc-edmsdirect/file.jsp?edmsid=*813385
[3] ILC A Technical Progress Report, 2010; http://www.linearcollider.org/about/Publications/interim-report
[4] Hitoshi Hayano, "KEK-STF status," Proc. of the 7th Japanese Accelerator Society meeting, 2010.