STATUS OF SUPERCONDUCTING RF TEST FACILITY (STF)

Hitoshi Hayano, and STF group
High Energy Accelerator Research Organization (KEK), Tsukuba, Japan

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 superconducting cavities are performed for the cryomodule installation. As an international project, S1-Global cryomodule test was successfully completed for the various studies on different type of cavity system. The construction of the Quantum-Beam experiment accelerator, as part of STF phase-2 development, has started in 2011, after the S1-Global cryomodule dis-installation from the tunnel. The photocathode RF gun and the capture cryomodule are constructed, installed and commissioned. All of the STF development done in 2011-2012 is summarized in this paper.

1 INTRODUCTION

During phase-2 component fabrication and construction, we conduct several experiments, such as S1-Global cryomodule experiment, and Quantum-beam experiment for a compact high-flux X-ray generation [4]. In the S1-Global cryomodule experiment, we demonstrated ILC-like cryomodule built and operated by the international collaboration. In the compact high-flux X-ray generation demonstration referred as 'Quantum Beam experiment' which is founded by the MEXT (Ministry of Education, Culture, Sports, Science and Technology in Japan), the electron beam source and beam capture cryomodule are demonstrated its performance with high quality electron beam generation and acceleration.

To do industrialization R&D study of cavity fabrication, the new cavity fabrication facility including electron beam welder was commissioned. KEK-#0 cavity are fabricated and tested.

The TDR (Technical Design Report) design change from RDR (Reference Design Report) [1] and SB2009 (Straw-man Base line in 2009) for the linac acceleration unit has been done [2][3]. The RDR-like accelerator scheme becomes a new baseline design of TDR in ILC-GDE (ILC Global Design Effort). Instead the single tunnel design of the ILC main linac in SB2009, KEK newly proposed a Kamaboko-tunnel as a cost-effective excavation method in mountain region. The power scheme was changed from the DRFS system back to RDR system which is using multi-beam-klystron and Marx modulator but supply the rf power to 39 cavities instead of 26 cavities. The demonstration of this new RF scheme is come to a milestone of the STF phase-2 construction and operation.

2 DISASSEMBLY OF S1-GLOBAL CRYOMODULE

For the S1-Global cryomodule experiment, the conclusion of gradient performance of the contributed cavities was average 30.0MV/m before cryomodule installation, 27.7MV/m for single cavity operation after installation, and 26.0MV/m for 7 cavities simultaneous operation. The other goal is to perform plug-compatibility concept by building one set of cryomodule from brought-in cavities and couplers of each laboratories. The half-size cryomodule-C was its demonstration built from INFN cryostat, DESY cavities and couplers, and FNAL cavities and couplers. The connection of cryomodule-C and KEK cryomodule-A was also another aspect of plug-compatibility (Fig. 1). The 3D CAD base discussion in the design stage was efficient to realize plug-compatibility.

During the experiment, the cavity gradient degradation happened on TB9ACC011 and Z108 cavities. The gradient was reduced 27% and 38% each. The coupler break-down happened on MHI-05 and the available gradient was limited to 16MV/m. The tuner mechanics malfunction troubles happened on TB9ACC011 blade tuner and MHI-09 lateral slide-jack tuner. Both cavities were unable to control coarse frequency tuning, so that the simultaneous operation of 8 cavities, which required to align the cavity frequency, was limited to 7. The one of piezo element out of two in TB9ACC011 had discharge problem and could not use it in the nominal voltage.

The dis-assembly of the cryomodules was started from April 2011 through December 2011. In between, the assembly of Quantum beam cryomodule were inserted for several month. The dis-assembly was also done by collaboration effort with participation of collaborator researchers as shown in Fig. 2. The cavities and input couplers from FNAL and DESY were extracted and sent back to the origin laboratories for further study. The full report of this collaborative effort was also completed, and is waiting for final check.

The S1-Global program was the truly international cryomodule experiment by the effort of GDE members and GDE participation laboratories. The program has demonstrated to realize the international cryomodule and their performance close to ILC specification. The issues of the current cryomodule technologies and what we need to solve in the next were identified.

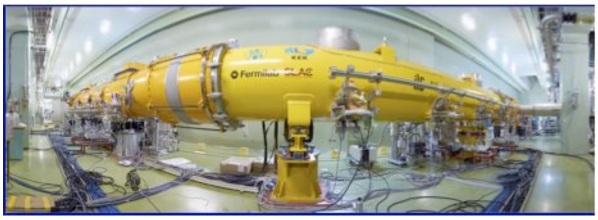

Fig. 1: S1-Global cryomodule experiment setup in STF tunnel. Two cryomodules and the cold box were connected.

Fig. 2: Dis-assembly of S1-Global cryomodule by INFN and FNAL team.

3 CONSTRUCTION AND OPERATION OF STF ACCELERATOR

The demonstration of the compact high-flux X-ray generation named "Quantum-Beam Accelerator project" is conducted as a part of the injector construction for the STF phase-2 accelerator. The project is one of the assignments of the MEXT program to develop and demonstrate the future compact X-ray source with high brightness. The application target is for life science, medical science, and micro-lithography. The Quantum-Beam accelerator is consist of the electron beam source by the photo-cathode RF gun, two 9 cell superconducting cavities in the capture cryomodule, and the compact X-ray generation beam line by the Inverse-Compton scattering with 4-mirror laser storage cavity. The use of the superconducting cavities is coming from the requirement of the long beam pulse train acceleration in order to generate high flux X-ray. The accelerator illustration is shown in Fig. 3, the accelerator layout is shown in Fig. 4, and the picture is shown in Fig. 5. Before cryomodule installation, two 9-cell cavities were tested and successfully reached its gradient up to 40MV/m and 32MV/m. The cavities were installed in the capture cryomodule and connected to the 800kW DRFS klystron power system. The capture cryomodule cooling pipes are connected to the newly fabricated 2K cold-box, and then connected to the existent STF cryogenic system. The cryomodule construction was started from 2010, the assembly and installation to the STF tunnel in 2011. The beam source and the beam line were installed in autumn 2011. The beam source consists of the photocathode RF gun cavity and the ultra-violet (UV) laser system. Synchronized 162.5MHz seed laser output of infrared is amplified and cut out to 1ms train, and then converted to UV. The UV pulse train is injected into the Cs_2Te photocathode on the molybdenum cathode base, and the electron beam train is extracted. The commissioning of the RF gun followed by the RF process for reduction of dark-current was started on February 2012. The 1ms beam train was successfully extracted from the RF gun in March 2012. The beam acceleration by the two superconducting cavities was successfully performed in April 2012. The beam focus tuning at the laser-electron beam collision point is in progress.

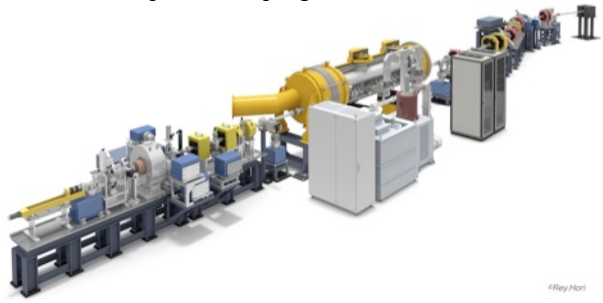

Fig. 3: Installation STF accelerator for use of Quantum Beam experiment.

The design parameters for the Quantum-Beam accelerator and the STF phase-2 accelerator are listed in Table 1. The main difference of the electron beam is the bunch spacing and the charge in the bunch. The Quantum-Beam accelerator uses 162.5MHz bunch repetition frequency, that is, 6.15ns spacing with 62pC/bunch. The peak current of the train is 10mA. On the other hand, STF phase-2 accelerator uses 2.708MHz bunch repetition frequency, that is, 369.27ns spacing with 3.2nC/bunch. The peak current of the train is 8.7mA. The different RF gun laser systems are used in these accelerators. The energy of the beam is 40MeV for the Quantum-Beam accelerator, 21.5MeV for STF phase-2.

	Quantum Beam Project	STF Phase2
Pulse length	1ms	0.9ms
Repetition rate	5Hz	5Hz
Bunch Spacing	6.15ns (162.5MHz)	369.27ns (2.708MHz)
Number of bunch/pulse	162500	2437
Bunch charge	62pC	3.2nC
Total charge /pulse	10,000nC	7,798nC
Beam current	10mA	8.7mA
Bunch length	12ps(Laser, FWHM)	10ps(Laser, FWHM)
Max. beam energy	40MeV	21.5MeV
Beam power	2.0kW (40MeV beam)	0.8kW (21.5MeV beam)

Table 1: beam parameters of STF accelerator.

The beam line for the focusing and collision with laser is designed. Three 20 degree bending magnets are used for this purpose. The electron beam has to come in and out to the 4-mirror laser accumulation optical line (Fig. 6) by using two 20 degree bending magnets. In the centre of the two bending magnet, the electron beam is focused around 10μm beam size by the upstream optics. In order to tune the beam size easy, the optics between the first bending magnet and the second bending magnet is designed as the symmetric transferred optics. The beam size in the first focal point will be transferred to the second focal point automatically by the symmetric transferred optics. The focal point tuning just before the first bending magnet will therefore give the tuning of the collision point beam size. The beam focus tuning is monitored by the 10μm tungsten wire scanners for their beam size. Since almost all the quadrupole magnet used in the focus line are the one reserved in ATF, so the aperture of the chamber is limited to 24mm diameter. There is few room for the loss-less beam transmission for the large beta function region. The careful orbit tuning is required in order to reduce the background noise into the X-ray detectors.

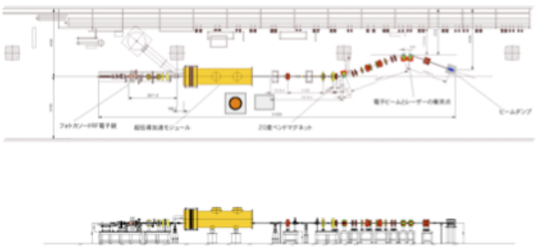

Fig. 4: Schematic diagram of STF accelerator.

Fig. 5: Picture of STF accelerator in tunnel.

The commissioning of the STF accelerator followed by the capture cryomodule cool-down and tuning of the superconducting cavities, was started on April 2012. The optics of the beam line was set to the 'commissioning optics' which has relatively small beta function for the transportation part, and has large beta function in the collision point, in order to make beam transportation easy. The beam energy was set to 40MeV. The accelerating field of the superconducting cavities were adjusted for beam to go through the bending magnet with 40MeV setting. In order to match the beta function at the downstream of the cryomodule, the solenoid field of the RF gun was adjusted. As a result, the accelerated beam was 40MeV energy, 41pC/bunch of intensity, total 28 bunches in a train with 5Hz repetition. The input power of the gun cavity was 2.2MW. It corresponds to 34.6MV/m of extracted field at the cathode. The energy at the gun exit was measured to 3.3MeV. The setting values of the superconducting cavities field were 20.15MV/m for the first cavity and 21.5MV/m for the second, without digital feedback for amplitude and phase in the pulse flattop.

In June 2012, the digital feedback of the amplitude and phase for the RF gun cavity and superconducting cavities were successfully applied with reasonable small control accuracy including beam loading. The 1ms long beam train was successfully accelerated up to 40MeV. The intensity was 15pC/bunch, 1/4 of the target intensity as shown in Fig. 7. The detailed beam study will be performed in 2012.

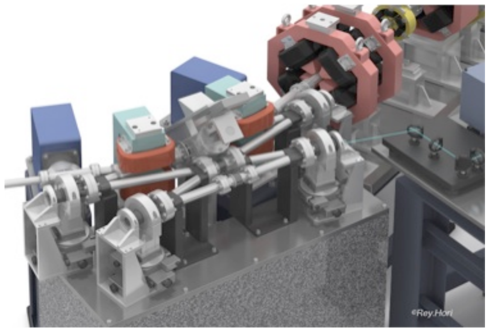

Fig. 6: Illustration of Laser accumulation chamber.

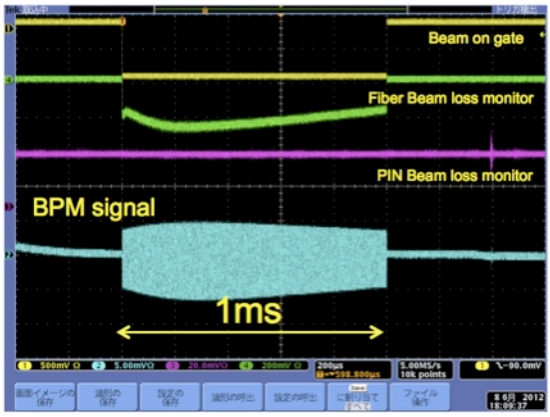

Fig. 7: Scope signal for accelerated1ms beam train.

4 TDR POWER SCHEME

Since KEK newly proposed Kamaboko-tunnel (Fig. 8) for Japanese mountain site, the RDR-type RF power scheme became a cost effective baseline for TDR rather than DRFS (Distributed RF System) small klystron system. Kamaboko tunnel has thick concrete wall in the centre makes the room divided to the accelerator tunnel and klystron tunnel. The RF power source consist of a 10MW multi-beam klystron and a Marx modulator, supply 1.3GHz 1.6ms pulse RF power into 39 cavities with circulator in each input (Fig. 9). The power can be split with flexibility by a variable hybrid. Also, a phase of RF input can be controlled by a phase shifter in each of cavity input line. A coupling of cavity can be controlled by an input coupler insertion length. In order to control each cavity power input and loaded-Q of each cavity (Pk-QL control) among vector-sum controlled cavities, the above variable adjustment are controlled remotely.

In STF phase 2 accelerator, this type of new RF power scheme will be installed and demonstrated. The 10MW multi-beam klystron (MBK) is used for the power source (Fig.10), and DTI Marx modulator (coming from collaborator SLAC) (Fig.11) drives the MBK. The system will be tested in this autumn. STF will purchase one more MBK and one more Marx modulator, as a replacement of #1 power station.

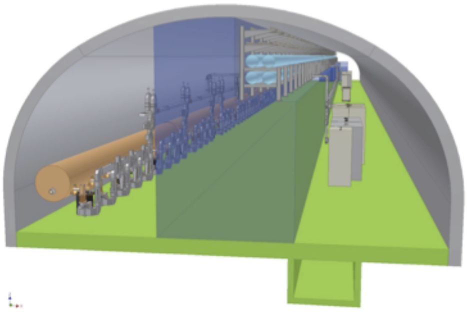

Fig. 8: Kamaboko-tunnel design for Japanese mountain site.

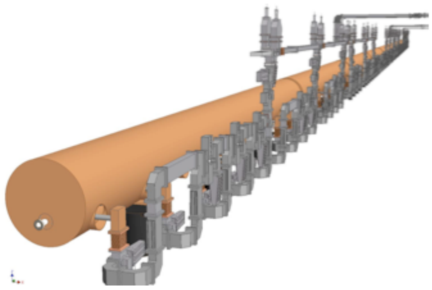

Fig. 9: RF power distribution scheme of TDR.

Fig. 10: 10MW Multi-Beam-Klystron.

Fig. 11: SLAC-DTI Marx modulator

5 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, however, the development study was already started for EBW parameter optimization using the same type of EBW at job-shop company in Tokyo. The press machine optimization study was also done together with press-die optimization. The fabrication cavity without HOM named KEK-#0 (Fig. 12) was started a year ago through these optimization, and the center cell part of 8-dumbbells were completed their welding in July 2011 using job-shop company. The end group part was fabricated and connected to the center cell part by using CFF EBW. The performance of this first produced cavity was 29MV/m, close to ILC qualification gradient. KEK-#1 cavity under fabrication has HOM couplers in both end beam pipes. It is ILC cavity with full-use of CFF machines. The completion of this cavity will be in October 2012.

Mass-production study for EBW process, HOM coupler and end-group pipes are in progress. It will be explained in other paper.

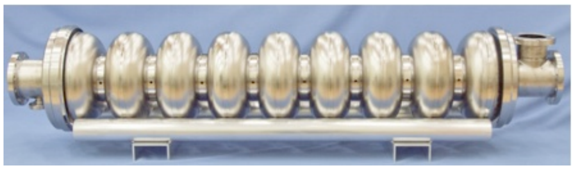

Fig. 12: KEK-#0 cavity fabricated at Cavity Fabrication Facility and job-shop.

6 ACKNOWLEDGEMENT

The author would like to thank all the members of STF group for their effort to develop ILC superconducting accelerator technology. The support of the LC supervisor, S. Yamaguchi, and the support of Accelerator Laboratory director, K. Oide, trustee of the executive board, Y. Kamiya, F. Takasaki, and director general of KEK, A. Suzuki, are gratefully appreciated.

7 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 8th Japanese Accelerator Society meeting, 2011.