STATUS OF SUPERCONDUCTING RF TEST FACILITY (STF)

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Abstract

The superconducting RF test facility (STF) in KEK is the facility to promote R&D of the International Linear Collider (ILC) cavities and cryomodule. The STF accelerator to promote the Quantum beam project was installed, commissioned and operated in 2011-2012. It consists of the L-band photocathode RF-gun, two superconducting cavities, and the Compton chamber, which was combined and utilized 4-mirror laser accumulator. The X-ray generation experiment in the accelerator was successfully performed. Now, the accelerator is under installation of the 12m-cryomodule and another 6m-cryomodule. All of the STF development done in 2012-2013 is summarized in this paper.

1 INTRODUCTION

During STF-phase-2 accelerator construction and installation, we conducted several experiments, such as S1-Global cryomodule experiment, and Quantum-beam experiment for a compact high-flux X-ray generation [1]. 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 was founded by the MEXT (Ministry of Education, Culture, Sports, Science and Technology in Japan), the electron beam source and beam capture cryomodule were demonstrated its performance with high quality electron beam generation and acceleration. That part of accelerator is now used to the STF phase-2 accelerator, as an injector.

To do industrialization R&D study of cavity fabrication, the cavity fabrication facility (CFF) including electron beam welder was commissioned. KEK-#0 cavity was fabricated and tested. KEK-#1 cavity is now the final assembly stage.

In June 2013, the TDR (Technical Design Report [2]) design was published after the several international reviewing. The new international organization LCC (Linear Collider Collaboration) after ILC-GDE (ILC Global Design Effort) was also established.

The power scheme to cryomodule was also changed from the DRFS system to TDR system which is using multi-beam-klystron and Marx modulator, supplying the RF power to 39 cavities with flexible dividing ratio. The demonstration of this new RF scheme is come to a milestone of the STF phase-2 construction and operation.

2 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, named STF accelerator is consist of the electron beam source by the photo-cathode RF gun (normal conducting cavity), two 9 cell superconducting cavities in the capture cryomodule, and the compact X-ray generation beam line by the Inverse-Compton scattering using 4-mirror laser storage cavity. The use of the superconducting cavities is because of the requirement of the long beam pulse train acceleration in order to generate high flux X-ray. The accelerator illustration is shown in Fig. 1, picture of the accelerator is shown in Fig. 2. Before capture 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 and minimization of beam loss were performed after then. The 4-mirror optical cavity was installed in September, and Inverse Compton Scattering experiment took place for November 2012 to March 2013

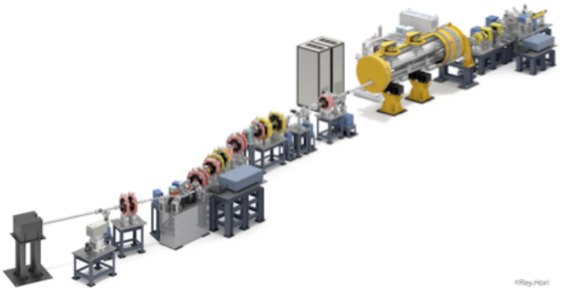

Fig. 1: Installation STF accelerator for use of Quantum Beam experiment.

The beam parameters for the STF accelerator are listed in Table 1 for the quantum beam project and it can be compared to the STF phase-2. 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.

Since almost all the quadrupole magnets used in the focus line are the one reserved in ATF which has small bore diameter, so the aperture of the chamber is limited to 24mm diameter. There are a few rooms 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.

The highest beam current acceleration was demonstrated as shown in figure 3. The beam energy was set to 40MeV. The accelerating beam length was 1ms with 9mA peak current at the head and 6mA in the end. The change of beam current during 1ms train is came from the intensity profile of laser train. Non-flat laser pulse train is mainly caused by the non-flat burst amplifier gain. However the average beam current was 7.5mA, which higher than ILC beam current 5.7mA.

Fig. 2: Picture of STF accelerator in tunnel.

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 digital feedback control by using estimated cavity field vector inside from input RF and reflected RF was adopted and successfully operated. The setting values of the superconducting cavities field were 16MV/m for the first cavity and 24MV/m for the second, with digital feedback for amplitude and phase in the pulse flattop. The accelerated beam was 40MeV energy, 1ms train length, total 162500 bunches in a train with 5Hz repetition.

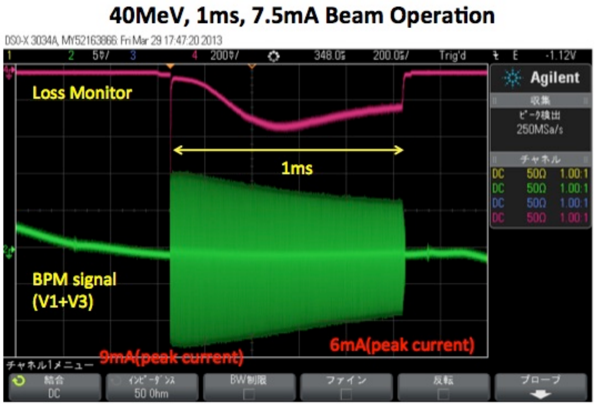

Fig. 3: Scope signal for 1ms beam train with 7.5mA average.

In September 2012, the 4 mirror optical cavity was installed at the collision point, as shown in Fig. 4. The optical cavity chamber was built on the granite basement with 5-axis mover stage controller. The mirror was floating by bellows chamber in their both end to cancel the atmospheric force to get smooth position control. The cavity optical length is controlled by the nm precision in order to store the 162.5MHz laser pulse train synchronized with the accelerator beam master clock. The laser pulse was injected into the 4-mirror cavity with burst amplifier. The feedback control of the optical cavity was applied continuously, except the burst amplified light injection period. Because the error signal of the feedback was greatly disturbed by the bust amplified strong light. So that, only the beam collision period, feedback control voltage was kept just before the strong light injected. The laser storage efficiency was not so high by this reason.

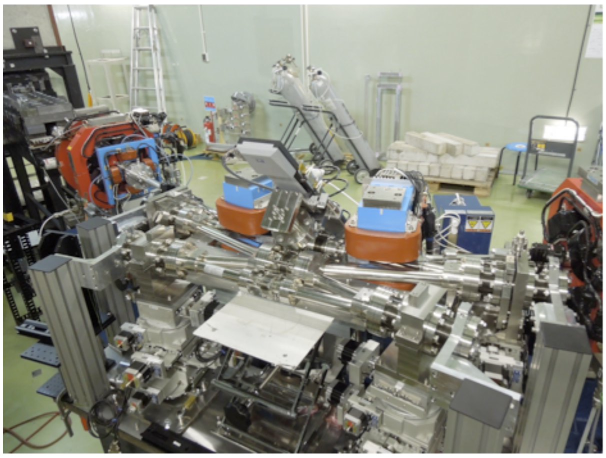

Fig. 4: Installation of 4-mirror Laser accumulation chamber.

After several collision experiments, X-ray signal from the Inverse Compton Scattering was observed, as shown in figure 5. The phase of optical cavity laser relative to the accelerated beam pulse was intentionally swept by introducing slightly different frequency into optical cavity laser. The data taking by pulse-to-pulse basis with synchronizing with beam pulse. Figure 5 plot is the data of laser-on subtracted by laser-off with beam intensity (ICT1) normalized. X-ray yield is much less than the project target, but it is one of demonstration of the X-ray generator working in superconducting accelerator.

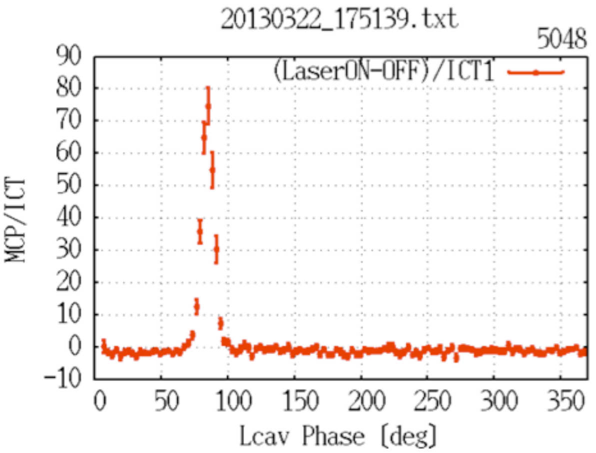

Fig. 5: Observed X-ray signal by Inverse Compton Scattering during phase-scan.

3 ILC-TYPE CRYOMODULE

Since Kamaboko-tunnel was adopted for mountain site in TDR, the RDR-type RF power scheme with control of power dividing ratio and phase became a cost effective baseline for TDR. 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. In order to supply RF power effectively to 20% spread of gradient performance cavities, 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 (loaded-Q) can be controlled by an input coupler insertion length. In order to control each cavity power input and loaded-Q of each cavity among vector-sum controlled cavities, the above variable adjustment (Pk-QL control) are controlled remotely. Figure 6 shows waveguide installation outside the STF phase-2 cryomodule, CM-1, to accommodate these functions.

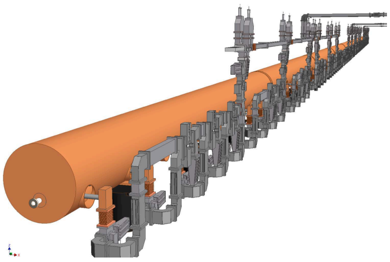

Fig. 6: RF power distribution scheme of TDR, and STF phase-2 cryomodule.

The CM-1 cryomodule, as shown in figure 7, is installed 8 cavities and one superconducting quadrupole magnet, which is compatible design to ILC cryomodule. Since STF accommodate only 4 cavities chain in STF clean-room, so that 4 cavities are connected with two gate valves in both end. Then the 4-cavity-chain is brought into the STF tunnel to connect each other with local clean-room. In between them, a superconducting quadrupole magnet is installed with beam position monitor chamber. Figure 8 shows the schematic diagram of the quadrupole magnet fabricated by FNAL. The magnet uses conduction cooled, splittable structure, which are newly introduced concept in TDR.

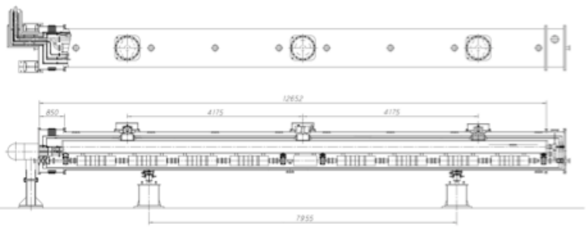

Fig. 7: ILC-type cryomodule, CM-1.

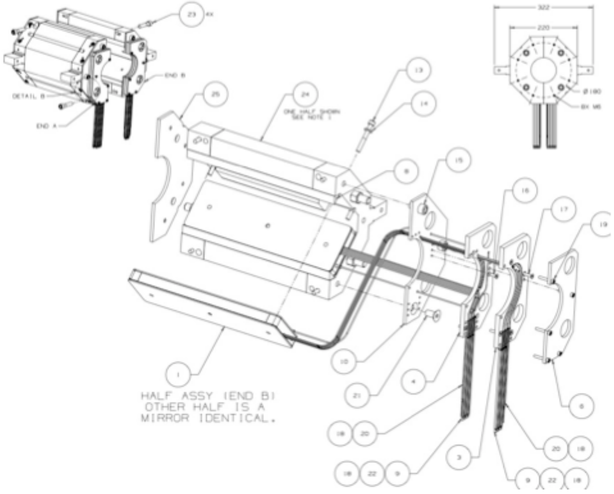

Fig. 8: Conduction-cooled split quadrupole magnet to be installed in the center of CM-1

In STF phase 2 accelerator, the 10MW multi-beam klystron (MBK) is used for the power source (Fig.9). The conventional modulator using bouncer-type compensator now drives MBK. For future demonstration, DTI Marx modulator (come from collaborator SLAC) (Fig.10) is in the test. And SLAC P2 Marx modulator will be fabricated under SLAC collaboration. STF will purchase one more MBK for this purpose, also.

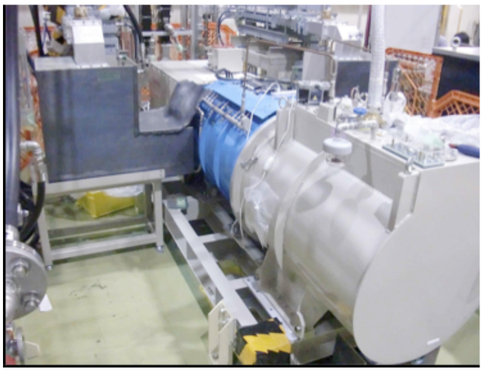

Fig. 9: 10MW Multi-Beam-Klystron.

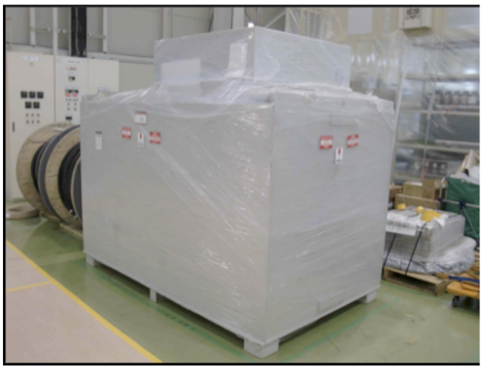

Fig. 10: SLAC-DTI Marx modulator

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7 REFERENCE

[1] Hitoshi Hayano, “KEK-STF status,” Proc. of the 9th Japanese Accelerator Society meeting, 2012.

[2] ILC Technical Design Report; http://www.linearcollider.org/ILC/Publications/Technical-Design-Report