SUPERCONDUCTING ACCELERATOR DEVELOPMENT FOR ILC

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Abstract

The superconducting RF test facility (STF) in KEK is the facility to promote R&D of superconducting acceleration cavity and cryomodule for International Linear Collider (ILC). The STF accelerator is a test accelerator using the developed superconducting cavities and cryomodules of ILC technologies to demonstrate stable and high power electron beam acceleration. The injector part of the STF accelerator was installed, commissioned and operated in 2011-2013 as the Quantum Beam Project. It consists of the L-band photocathode RF-gun (normal-conducting cavity), two superconducting 9-cell cavities, and the Compton chamber which was utilized 4-mirror laser accumulator. The X-ray generation experiment in the Quantum Beam Project was successfully performed and reported in 2013. Now, the accelerator is under installation of the 12m-cryomodule and 6m-cryomodule for further beam acceleration. All of the STF accelerator developments together with future prospect of ILC are summarized in this paper.

1 INTRODUCTION

The purpose of construction and operation of STF accelerator under the planned program STF-phase-2 is to demonstrate the ILC Main Linac accelerator technology and to experience operation of high current and high beam power superconducting accelerator. Under this program, to encourage the superconducting accelerator expert is also the purpose. During STF accelerator construction and installation starting from 2009, we conducted several experiments, such as S1-Global cryomodule experiment [1], and Quantum-beam experiment for a compact high-flux X-ray generation [2]. 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. The Quantum Beam accelerator part is now used to the STF accelerator, as an injector.

The powering scheme of cryomodule is to use TDR (Technical Design Report [3]) system which is using multi-beam-klystron and Marx modulator, supplying the RF power to 39 cavities with flexible dividing ratio. The demonstration of the TDR RF scheme is one of milestone of the STF accelerator construction and operation.

2 STF ACCELERATOR

The Inverse Compton Scattering (ICS) experiment line, which was build under the program, "Quantum-beam project" was disassembled on April-May 2013. The injector part of the Quantum-beam accelerator, which consists of photo-cathode RF gun, and the capture cryomodule, are used as an injector of the STF accelerator. Two 9-cell superconducting cavities in the capture cryomodule 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 in the tunnel. Their klystron system is now moved to the 1-st floor of the STF building, in order to make more open space in the tunnel. The beam source consists of the photocathode RF gun cavity, which is normal-conducting 1.3GHz cavity, and the new ultra-violet (UV) laser system. Synchronized 40.625MHz seed laser output of infrared is thinning out to 2.708MHz, amplified by 2-stage photo-amplifiers of 1ms length and then converted to UV by the crystals. 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 and operation of the RF gun was done in ICS experiment on 2012-2013 using the Quantum-beam UV laser system. By using the new UV laser system, beam extraction test is under operation successfully but with 1/10 beam intensity.

The downstream beam-line of the injector includes ILC-type cryomodule, CM-1, the half-size cryomodule, CM-2a, and the beam dump. Overall view of the STF accelerator plan is illustrated in figure 1.

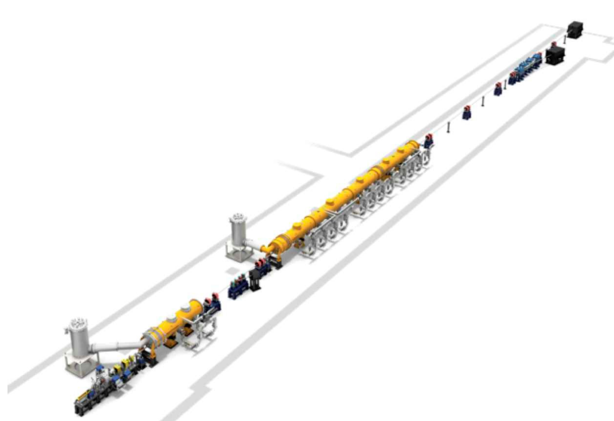

Figure 1: Planned view of the STF accelerator.

The accelerator will include two stage bunch compressor for future use as a FEL application. The first stage bunch compressor is a chicane at the entrance of CM-1. The second stage compressor is a chicane in front of the beam dump. The beam line is under design, not yet installed. It will be installed in 2015.

Another 2K cold-box for 2K liquid helium supply to CM-1 and CM-2a was installed at the front of CM-1 but at the wall-side.

The current installation of the STF accelerator is shown in figure 2. The accelerated beam energy will be 418MeV, assuming 31.5MV/m gradient for 12 cavities in CM-1 and CM-2a, and 40MeV energy at the exit of the capture cryomodule. The accelerating beam length will be 1ms with 5.7mA intensity, which are met with ILC beam specification.

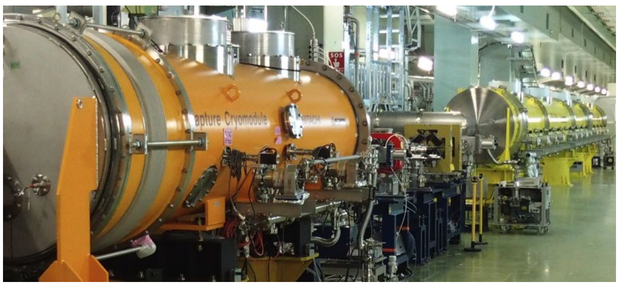

Figure 2: Current view of the STF accelerator.

3 ILC-TYPE CRYOMODULE

The CM-1 is the ILC design cryomodule which contains eight 9-cell superconducting cavities and a conduction-cooled splittable superconducting quadrupole magnet together with a beam position monitor in the center position. The magnet uses conduction cooled, splittable structure, which are newly introduced concept in TDR. The fabrication of the conduction-cooled quadrupole magnet by the collaboration with FNAL was completed in September 2013. The beam position monitor using re-entrant cavity structure was also fabricated. Since we can accommodate only 4 cavities chain connection in the existing cleanroom, and also can accommodate only half-size of the ILC cryomodule cold mass at the tunnel carry hatch, then, we have done the ILC cryomodule assembly in the STF tunnel by connecting the two 4 cavities chain, and inserting the connected 8 cavities into the 12m-cryomodule vacuum vessel. The infrastructure such as rail system for the ILC cryomodule assembly, which requires more than 24m length space, was constructed in the downstream part of the STF tunnel.

The plan was also changed to connect one more half-size cryomodule, CM-2a, together with ILC-size cryomodule, CM-1. The assembly of the connected cryomodule with 8+4 cavities was finished at end of June 2014.

The picture of CM-1 cold-mass assembly is shown in figure 3. The installation of conduction cooled splittable magnet is shown in figure 4.

Figure 3: Picture of the ILC-type cryomodule CM-1 assembly in the tunnel, by using rail-system.

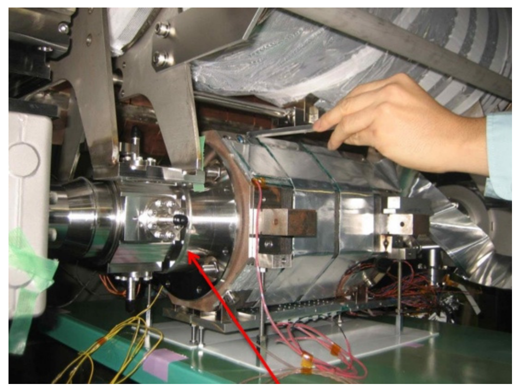

Figure 4: Conduction-cooled splittable quadrupole magnet was installed in the center of CM-1, together with BPM chamber.

Figure 5 shows installed CM-1 and CM-2a in the STF tunnel, at downstream of the capture cryomodule. The 2-nd cold box supply a liquid helium into these connected cryomodules. The vacuum vessel of these connected cryomodule is pumped down together by the one pumping system. Many temperature sensors, two set of the wire position sensors are installed to monitor temperature of various points and position movement during cool-down and warm up.

Figure 5: Picture of ILC-type cryomodule followed by the 6m cryomodule in the STF underground tunnel.

The RF power scheme with control of power dividing ratio and phase is adopted as a cost effective baseline of TDR. The Kamaboko-tunnel has thick concrete wall in the centre makes the room divided to the accelerator tunnel and klystron tunnel. The TDR RF power source in the klystron tunnel which consist of a 10MW multi-beam klystron (MBK) 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 (Pk control). 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, QL) 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 cryomodule, CM-1 and CM-2a, to accommodate these functions.

Figure 6: RF power distribution scheme of STF phase-2 cryomodule, according to TDR design.

As a RF power source, the 10MW MBK is used in the STF accelerator. The conventional modulator using bouncer-type compensator now drives this MBK, for a while. For demonstration of TDR klystron driver supply, SLAC P2 Marx modulator is under fabrication by SLAC and KEK collaboration. STF will procure one more MBK for this purpose, also.

4 CAVITY DEVELOPMENT

Total number of the cavities for the STF accelerator was 14, while 15 cavities were fabricated. They are 2 for the capture cryomodule, 8 for CM-1, and 4 for CM-2a. The rest one is spare. The inner surface treatment and the field test are allowed twice in TDR. However, in STF, maximum 4 treatment and field test were done for the purpose of research and development. The field gradient performance in the first treatment, and the final gradient performance are shown in figure 7. Some of the cavity stopped their treatment at the first treatment, some of the cavity in the second.

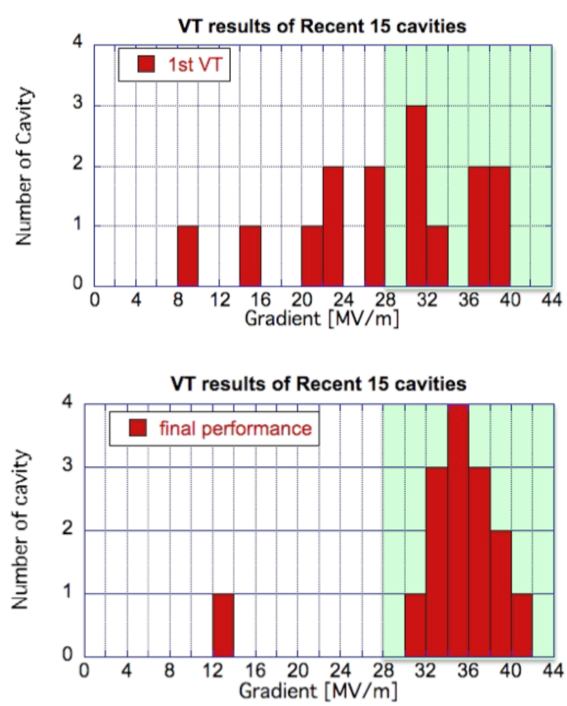

Figure 7: Cavity gradient performance of the cavity used in the STF accelerator.

The condition to stop treatment was to perform greater than 35MV/m, however, some of the cavity proceeded once more again to see what happen in the next. The transition of the gradient performance is plotted in figure 8. One cavity stayed at low gradient, never improved with 4 treatments cycle. Other cavities improved drastically.

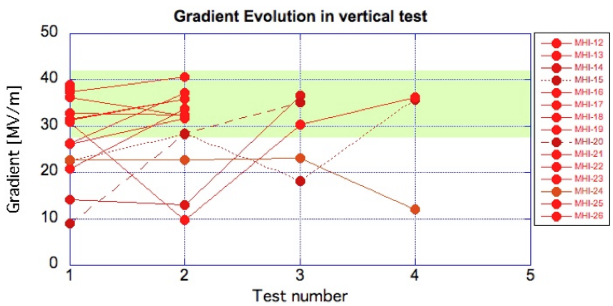

Figure 8: Transition of cavity gradient performance of each cavity.

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The improvement of the performance has been achieved by the full use of temperature mapping, X-ray mapping during the field test, and use of high resolution inner surface camera and local grinder repair method. The electro-polish technology advance is also contributed to the performance improvement [4]. The technology advance is supported by the use of the surface analysis instruments and their technologies. SEM, EDX, micro-XPS, TOF-SIMS, Raman-spectroscopy, ICP, laser-micro-scope, are used for the understanding of the Nb surface after several treatment method and machined method [5]. We can judge the treatment method is good or not by using coupon attached single cell cavity at the surface treatment facilities.

5 ILC PROSPECT AND STF

After TDR publish, the international linear collider study team (GDE: Global Design Effort) was changed to the LCC, Linear Collider Collaboration. LCC requests to the Japanese Government (MEXT) to host the ILC in Japan, and recommend the reasonable ILC construction site. MEXT start to explore the project procedure, such as asking to Science Council of Japan, forming knowledgeable council (Yushikisha-kaigi), etc. It will take one or two years. In parallel, LCC promote the engineering study of ILC with more detailed and with site specific.

STF accelerator construction and operation is concurrently proceeded with movement. The result of the STF accelerator will strengthen the TDR and the engineering design of ILC. Since the use of FEL application after ILC study in STF is unavoidable, the preparation of FEL should be included in the design from the beginning.

6 ACKNOWLEDGEMENT

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