PROGRESS OF STF ACCELERATOR DEVELOPMENT FOR ILC

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Abstract

The STF (Superconducting RF Test Facility) accelerator is a test linear accelerator using superconducting cavities (SC cavities) and cryomodules of ILC (the International Linear Collider) design. The injector of the STF accelerator consists of the L-band photocathode RF-gun (normal-conducting cavity), two superconducting 9-cell cavities for pre-acceleration of electron beam to 40MeV. The 12m-cryomodule (8 SC cavities and 1 SC quadrupole magnet with beam position monitor and 6m-cryomodule (4 SC cavities) are followed after the injector. They will be powered by 10MW multi-beam klystron and the distribution wave-guide system. The accelerator field and phase in the SC cavities are controlled precisely by the fast digital feedback at low-power level. The recent developments of the STF accelerator such as cryomodules performance test results, high power components development, are discussed and summarized in this paper.

INTRODUCTION

In the program STF-phase-2, the purpose of construction and operation of STF accelerator under is to demonstrate the ILC Main Linac accelerator technology and to experience operation of high current and high beam power superconducting accelerator. During STF accelerator construction and installation in the STF-phase-2 program 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]. A part of the Quantum Beam accelerator is still maintained and used as the STF accelerator injector. The main accelerator by the long cryomodules were constructed from 2013, assembled in to the STF tunnel in 2014. Two times of the cool-down test of these new cryomodules were performed in 2014 and 2015.

The powering scheme of cryomodule is to use TDR (Technical Design Report [3]) system which is using 10MW multi-beam-klystron and 120kV 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. The gradient performance of the cavities in the newly installed cryomodule were tested each by each using single waveguide system during cooled state. In 2016, the waveguide system which distribute RF power into 8 cavities with amplitude and phase control was developed and installed. Also heat load improvement of the SC quadrupole magnet was done in 2016.

STF ACCELERATOR

The injector part of the STF accelerator consists of Cs-Te photo-cathode RF gun (1.3GHz DESY/FNAL design normal conducting gun cavity), and the capture cryomodule. The RF gun is operated by 5MW pulsed klystron, with around 3MW RF power input. The energy of gun output beam is around 4MeV. Two 9-cell superconducting cavities in the capture cryomodule were tested and successfully reached its gradient up to 40MV/m and 32MV/m. The operation is done with 16MV/m and 24MV/m, for 40MeV accelerated beam energy. They are powered by 800kW pulsed klystron (DLDS klystron). The downstream of the injector includes ILC-type cryomodule, CM-1, the half-size cryomodule, CM-2a, connecting beam lines and the beam dump. So far, beam lines and beam dump are not installed yet. Bird's eye view of the STF accelerator plan is illustrated in Figure 1 [4].

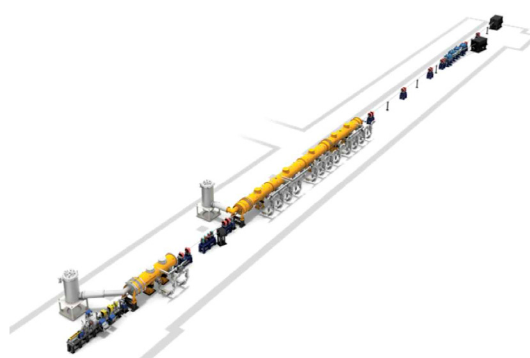

Figure 1: Planned view of the STF accelerator in 100m length of the STF tunnel. Left side is photo-cathode RF gun, followed by capture cryomodule, bunch compressor 1, CM-1, CM-2a, then bunch compressor 2 and the dump.

The accelerator will include two stage bunch compressors for future 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. For undulators and user area of FEL, the tunnel is necessary to be expanded 100m more to the downstream. The connecting beam line is under design, not yet installed. The 2K cold-boxes for 2K liquid helium supply liquid-helium to CM-1 and CM-2a is installed at the front of CM-1, the left-wall-side.

The current installation picture of the STF accelerator is shown in figure 2. The RF power distribution system are installed in the side of the cryomodules. 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 train length is 0.9ms with 5.7mA peak intensity and 2.7MHz bunch repetition in a train with 5Hz train repetition, which are met with ILC beam specification.

Figure 2: Current view of the STF accelerator, as of July 2016. The RF power distribution system is installed in the right side of capture cryomodule, CM-1 and CM-2a, also at the side of the capture cryomodule.

CRYOMODULE PERFORMANCE

Superconducting Cavities

Total number of the cavities used for the STF accelerator was 14, while 15 cavities were fabricated and tested in the vertical cryostat. They are 2 for the capture cryomodule, 8 for CM-1, and 4 for CM-2a. The left one is a spare cavity. In STF, the inner surface treatment and the field test were allowed maximum 4 set of treatment and field test. The summary of the final gradient performance is shown in figure 4 of blue bars. The average gradient in the final field test was 34.2MV/m. The maximum gradient was 41MV/m and the minimum gradient was 12MV/m.

They were tested the gradient performance in the cryomodule in October 2015. Figure 3 shows the connecting waveguide to one of cavity in the cryomodule.

Figure 3: One half of the splittable quadrupole magnet. 4 coils are attached to inside of the steel body.

After the cooled down the cavities to 2K, tuning the resonant frequency by the tunes and tuning the QL by the coupler insertion adjustment were done, and then RF power was supplied by the single waveguide. The red bars in figure 3 shows the gradient performance at 100us short flat-top pulse. The green bars in figure 3 shows the gradient performance at 1ms full flat-top pulse. The cavities, MHI-19, MHI-20 and MHI-21 were degraded greatly. MHI-22 was also degraded about 10%.

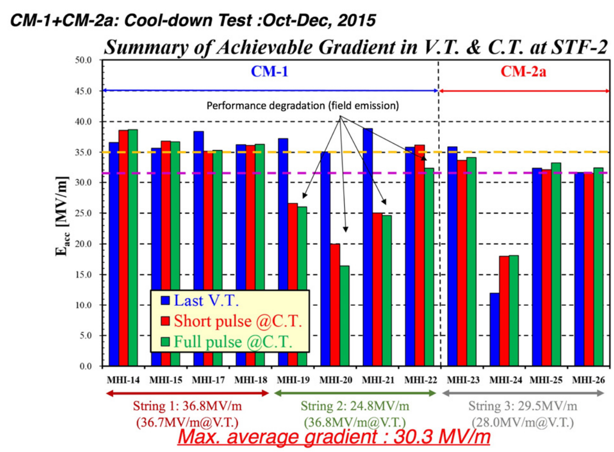

Figure 4: The cavity gradient performance result during cool-down. Blue bars show the performance at vertical test. Red bars and green bars show at the cryomodule test with short (100us) RF pulse and full-length (1ms) RF pulse.

The reason of degradation seems to relate the gate-valve operation or the connection work inside CM-1. For CM-1, two set of the 4 cavity train which was connected in the clean-room with both-end of the gate-valves, were connected in the tunnel using local clean-booth. After the connection and hung the connected cavities on the gas-return-pipe, the gate valves in the connected portion were opened, but not opened at the both end valves. In this operation, contamination blew through to the downstream cavities seemed to happen. The detail is not known yet.

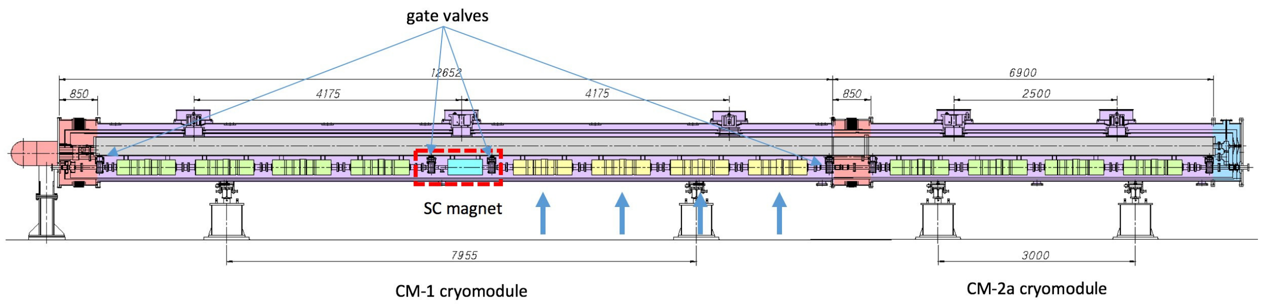

Figure 5: Cavities configuration scheme of CM-1 cryomodule, and CM-2a cryomodule. In the center (red dot box) of CM-1, BPM chamber with SC magnet was connected between two gate valves. Blue arrows show degraded cavities.

Superconducting Quadrupole Magnet

The CM-1 includes 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 done [5].

In the first cool-down test of 2014, the conduction cooled splittable quadrupole magnet was cooled only at 9K, while the target temperature was 5K. The reason was analysed after warm-up, and was to be insufficient thermal anchor or thermal shield for incoming heat from the current leads. The modification to improve thermal shield from current lead was done during 2015 spring to summer time, introducing several thermal anchors and HTS (High-Temperature-Superconductor) leads.

In the cool-down test on October 2015, the coil temperature reached to 7.1K, which was 2K improvement. It was improved but not enough. Current excitation went up to 25.6A then quench, while it was expected to 50A. The quench was happened at around splice between coil-1 and coil-2 inside magnet. Further improvement is undertaken toward the next cool-down test.

RF POWER DISTRIBUTION

The RF power distribution scheme with control of power dividing ratio and phase is adopted as a cost effective baseline of TDR, as shown in figure 6 upper scheme. The TDR RF power source consist of a 10MW multi-beam klystron (MBK), a Marx modulator, and waveguide system which distributes 1.3GHz 1.6ms pulse RF power into 39 cavities with circulator in each input. In order to supply RF power effectively to the cavities which have 20% spread of gradient performance, 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 lower scheme shows detail side view of this waveguide system realized in CM-1 at STF.

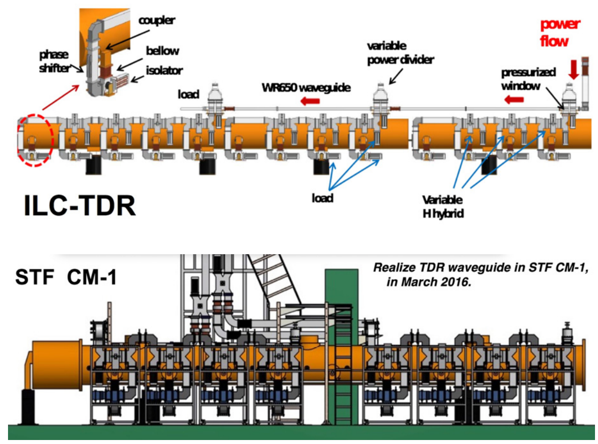

Figure 6: Upper: TDR RF power distribution for 13 cavities in cryomodule, out of 39 cavities. Lower: In STF CM-1, as a realization of TDR scheme, 8 set of this waveguide packages are used for 8 cavities.

Figure 7: Realized RF power distribution scheme of STF phase-2 cryomodule, according to TDR design.

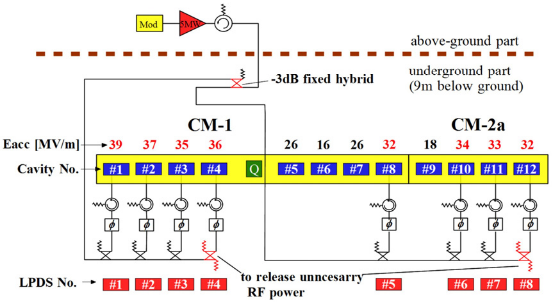

Figure 8: RF power distribution scheme for 8 cavities which were selected according to the gradient performance order. The cavity numbers are the slot number in the cryomodule.

Figure 7 shows a picture of the RF power distribution system which was installed at the STF cryomodules. It was placed to about 1m away from the cryomodule, because of easy build-up and maintenance, and cost effective system design using existing waveguide components. The block diagram of the local power distribution system (LPDS) and its connection detail are shown in figure 8. The RF power from the klystron is divided 2-way in the first, that is, upstream flow and downstream flow. In each power flow line, there are 4 of variable hybrid power splitters (-1.5 to -15dB divided ratio), which divide the RF power into each cavity branch. In each cavity branch, there are phase shifter (+/-35degree variable range), circulator (<-20dB isolation), and then connected to the power coupler of the cavity.

Figure 9: Close picture of the RF power distribution for 4 LPDS system. The one unit consists of variable hybrid, phase shifter, circulator, and RF loads. Behind this LPDS, there is cavity power coupler which is connected to the #2 port of the circulator. RF power flow is from the left to the right.

MARX MODULATOR DEVELOPMENT

As a cost-effective, compact klystron modulator with good maintainability, Marx-type modulator was selected in TDR. SLAC developed P1 and P2 Marx modulator for evaluation of performance. STF began to develop Marx modulator to be used in the STF phase-2 program. The new design consists of 20 units of MARX cell which include 4 charging/switching blocks. Each switching block controlled by flexible switch timing to accommodate pulse width control for the output voltage sagging compensation. The single unit test was succeeded to produce 6.4kV, 1.7ms pulse generation. The 20 unit combined test is under performing. So far, around 70kV with +/-0.28% ripple at the flat-top was attained, while 120kV, 140A are required for multi-beam-klystron operation.

Figure 10: picture of Marx modulator under test at STF.

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