STATUS OF RF SOURCES IN SUPER-CONDUCTING RF TEST FACILITY (STF) AT KEK

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Abstract

The superconducting RF test facility (STF) at KEK has been operational since 2005, and STF Phase-I, which involves the testing of a cryomodule with four superconducting cavities, was successfully completed at the end of 2008. During the testing in STF Phase-I, the evaluation of the two power distribution systems (PDS), the 3-dB hybrid PDS, and the TESLA-type PDS was conducted. A study in which circulators in the tree-like PDS were eliminated was performed with LLRF digital feedback. In the linear PDS, we inserted a reflector and a phase shifter between the cavity coupler and circulator to change the loaded Q of the cavity. A third RF source with a 10-MW horizontal multibeam klystron (MBK) and a bouncer-type modulator is to be constructed in FY2009. KEK will conduct the S1-global test and the STF-II project in the future; preparations are underway for these tests. This report covers the recent development of the RF source in KEK STF.

INTRODUCTION

The superconducting RF test facility (STF) at KEK comprises two phases, as shown in Figure 1, and has been in operation since 2005 [1]. STF Phase-I involves the use of a cryomodule with a four-cavity structure having a gradient of 35 MV/m; STF Phase-I was successfully completed at the end of 2008. In Phase-I, two types of power distribution systems (PDS) were examined and associated R&D was carried out. The low level RF (LLRF) team tested the digital feedback with vector sum control for two PDS. The interesting test in the RF of STF-I was the evaluation of the PDS that did not contain circulators. This test was important for cost reduction in the ILC project. The next two important tests after the test in STF-I are the S1 global test, scheduled for FY2010—the objective of which is to evaluate the performance of the superconducting cavities provided by Japan and the international collaborators—and the Phase-II test. In STF Phase-II, one RF unit is employed, which is similar to the ILC baseline configuration design (BCD) layout; the Phase-II test is scheduled to begin in FY2012. In FY2009, RF source No. 3 is introduced, which includes a bouncer-type modulator and a 10-MW horizontal MBK. KEK also plans to build an RF unit of the distributed RF scheme (DRFS), proposed recently in ILC GDE.

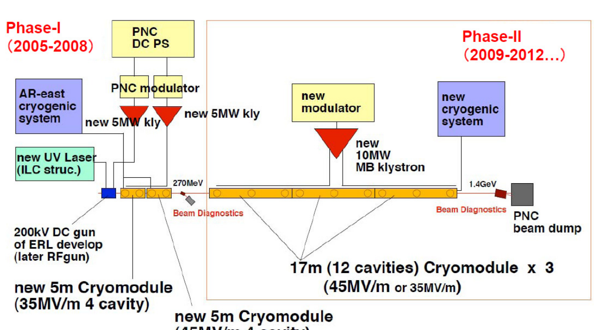

Figure 1: STF layout.

HLRF

Modulator and Klystron

The current STF RF sources comprise two stations. In the first station, a bouncer-type IGBT modulator that includes a pulse transformer with a step-up ratio of 1:6 supplies power to a 5-MW Thomson klystron, TH2104C. This station was operated at an RF power level of 2 MW in the STF-0.5 test, STF-I test, and coupler processing including LAL coupler. After the STF-I test, this station was used for the evaluation of the PDS, the R&D study, and conditioning various types of couplers. The bouncer-type IGBT modulator with a step-up ratio of 1:15 in the second station was repaired after serious arcing due to a water leak from the klystron assembly. Since a numbers of IGBT are broken, the evaluation test for the interlock was performed and completed. The processing of the Thales klystron, TH2104A, up to a peak power of 5 MW with a 1.5-ms, 5-Hz repetition rate was completed at the beginning of 2009 in station No. 2. This station will be used for the S1 global project. The approved supplementary budget in FY2008 enables us to introduce the third RF source station, which comprises a new bouncer-type modulator using an IEGT SW (Injection Enhanced Gate Transistor) with a step-up ratio of 1:15 and a 10-MW horizontal MBK. This station will be operated for the STF-II project. In FY 2009, modulator

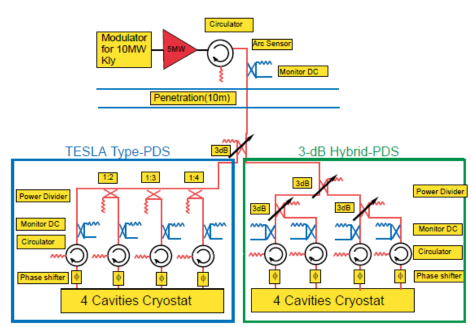

Figure 2: 2 power distribution systems for STF.

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and an MBK will be manufactured and operation will commence in FY2010.

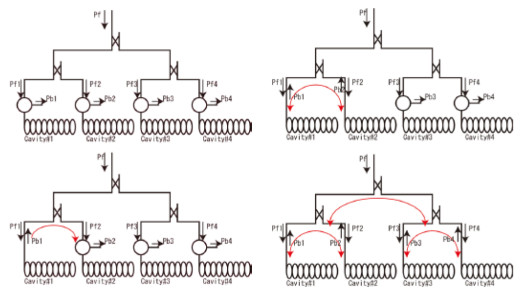

Figure 3: Procedure to eliminate the circulator in 3-dB hybrid PDS.

PDS for STF-I

As described in ref [1], we prepared two types of PDS: a 3-dB hybrid PDS (a tree-type PDS) and a TESLA-type linear power distribution network, as shown in Figure 2. A standard four-cavity system test in a cryomodule for STF-I was conducted using the 3-dB hybrid PDS. Vector sum control of LLRF was successfully performed. Stabilities of 0.007% rms in amplitude and 0.018° in phase are achieved. After this test, the evaluation of the circulator elimination was attempted. This is important for reducing the RF source cost in ILC because the circulator is expensive. Since our 3-dB hybrid has an adjustable button that enables us to change the directivity from 2.5 dB to 3.5 dB, we could vary the power level supplied to the individual cavity. At the same time, this tap-off enabled us to vary the isolation between the two ports in the range 25–40 dB.

The procedure for eliminating the circulators in a 3-dB hybrid PDS is shown in Figure 3. Since the effect of circulator elimination was evaluated by using the results of the LLRF vector sum control, after the vector sum control of LLRF was implemented for the entire system, successive feedback tests without a circulator, without two circulators, and without four circulators were performed separately. The vector sum control results for the PDS with circulators and those without circulators are shown in Figure 4. The stabilities of the accelerator fields (flat-top region of the pulse) are almost the same for all cases. The amplitude stability and phase stability for the PDS with circulators are 0.038% rms and 0.022°, respectively, while those for the PDS without circulators are 0.037% rms and 0.025°, respectively. Therefore, it is possible to eliminate the circulators to aim for the stable beam acceleration. However, we found large differences in the transient region where reflected power exists. As shown in Figure 4, cavity input power was different due to the reflection. The cavity input power existed even after RF was turned off in the case of PDS without circulators. The results of loaded Q measurement for cavity 1 indicated that the difference between the measurements for each case shown in Figure 3 is more than 10%. A possible reason for this discrepancy may be the reflected power from the upstream components, for example, reflection from the dummy load of the hybrids and interference due to poor isolation. In the case of poor isolation (25 dB), this discrepancy was large because of the interference between the reflected powers from the cavities. A complete explanation and quantitative analysis have not yet been successfully provided, even when the low-level cold measurement was taken into account. It is possible that this discrepancy arises from the difference between the high-power operation and the low-level measurement. If cavity diagnosis through LLRF control is required during ILC operation, the use of waveguide components with a low reflected power may be inevitable when no circulators are employed. A more detailed test description is presented in ref. [2]. To consider circulator isolation, a similar attempt was made in SLAC, and they reported that a hybrid isolation greater than 40 dB is required. [3]

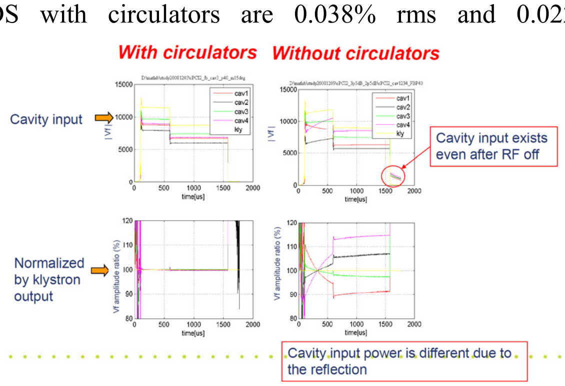

Figure 4: Cavity input amplitude before (left) and after (right) circulator removal.

A TESLA-type PDS was also tested for the STF-I experiment. In this PDS, we introduced two waveguide components: a reflector and a phase-shifter [4] in the downstream of the circulators; this enabled us to adjust the external Q of the cavity. A schematic diagram is shown in Figure 5. By using these components, the loaded Q in the range 1.3×10^6–1.5×10^6 was adjusted to be 3.0×10^6, and we could obtain reasonable results after vector sum control. This system can be used in the future S1 global test in which various types of cavities from international collaborators will be installed in the cryomodule.

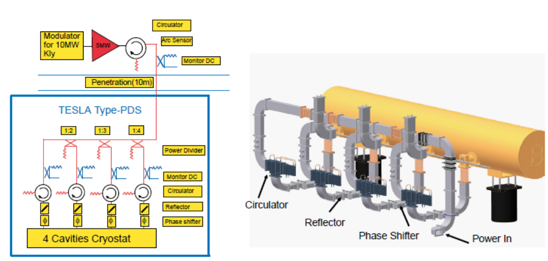

Figure 5: Tesla type linear PDS with a reflector and a phase-shifter in the downstream of the circulator.

Developed Waveguide Components

As described in ref. [4], we have developed various waveguide components. Almost all components exhibit excellent performance for a power of a few MW under the conditions of an air atmosphere. The performances of

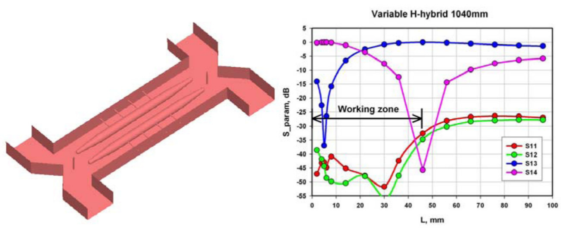

Figure 6: Variable hybrid.

Japanese circulators are almost as satisfactory as those of Russian STP circulators, except for a slightly higher insertion loss. Recently, S. Kazakov proposed a variable hybrid having a high power capability under the conditions in air. This component can be replaced with the variable 3-dB hybrid that is part of the 3-dB hybrid PDS. A schematic and simulation results are shown in Figure 6. This will be manufactured in KEK and tested in FY2009.

LLRF

For LLRF, the results of the vector-sum control for four cavities have already been described in the previous section. Two types of PDS and the evaluation for the PDS without circulators are performed with LLRF feedback control. The measured stabilities in four-cavity vector-sum control are 0.007% rms for the amplitude and 0.018° in phase. These values satisfy the LLRF requirements at ILC [2]. The digital LLRF control system involving the application of an IF-mixture technique was also operated over four superconducting cavities at STF-I. The signal estimated by the IF-mixture technique was consistent with that from direct IQ detection [5]. The instability due to other pass bands such as an $8/9\pi$ mode was measured. For high feedback (FB) gain, the vector-sum FB became unstable in all regions for loop-delay, while for low FB gain, the stable region for vector-sum FB control became wider than that for individual FB control. Operation with quasi-beam utilizing the feed-forward (FF) table was performed with the feed-back control, and the stability at flat-top for beam injection was within the requirement of ILC by adjusting the timing of FF (beam) [6].

PLAN FOR FY2009

In FY2009, a new RF station comprising an IEGT modulator with a bouncer circuit and a 10-MW horizontal multi-beam klystron will be introduced. The extra supplementary budget enables us to obtain waveguide components for STF Phase-II. It is necessary to investigate the possibility of using a VTO or the components that change the cavity loaded Q.

KEK has proposed a new alternating RF scheme for ILC to reduce the ILC cost at LCWS08 and TILC09 [7]. This scheme is the distributed RF scheme (DRFS), where a small klystron supplies power to two cavities. More than a dozen 750-kW klystrons with a modulation anode will be operated by a common DC power supply and an individual modulation anode modulator. Though more than 8000 klystrons and modulators are used in this scheme, cost reduction is expected by mass production. There are a large number of advantages such as simple configuration and easy machine operation. In KEK, a single RF unit will be constructed to demonstrate the feasibility of this scheme. In Figure 7, a rough sketch of one RF unit is shown.

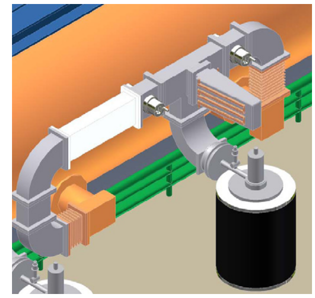

Figure 7: Schematic of the klystron and PDS in DRFS. The DC power supply and modulation-anode modulator are placed under the shielding mount.

SUMMARY

The STF at KEK has been operational since 2005; currently, STF-I, which involves the use of a cryomodule with four superconducting cavities, is successfully operated. Two different PDS were tested with LLRF vector sum control, and stabilities of 0.007% rms in amplitude and 0.018° in phase were achieved. In the 3-dB hybrid PDS, a test in which circulators were eliminated was performed and the PDS performance was evaluated. For the flat-top region of the pulse, equally stable operation was achieved with and without circulators. However, the interaction between cavities is particularly apparent if the isolation of the hybrid is poor. These results are instructive in determining the PDS specifications.

REFERENCES

[1] S. Fukuda, et al., “RF sources of Super-conducting Test Facility (STF) at KEK”, PAC05, Knoxville, TN, USA, pp. 796-798, 2005.

[2] S. Michizono, et al., “Vector-sum Control of Super-conducting RF Cavities at STF”, WE5PFP083, presented in PAC09, Vancouver, BC, 2009.

[3] C. Nantista, et al., “Progress in L-band power Distribution System R&D at SLAC”, LINAC08, Vancouver, BC, Canada, pp.946-948, 2008.

[4] S. Fukuda, et al., “Status of RF Sources in Super-conducting RF Test Facility (STF) at KEK”, LINAC08, Vancouver, BC, Canada, pp. 895-897, 2008.

[5] T. Matsumoto et al., “Evaluation of LLRF Stabilities at STF”, TS5PFP086, presented in PAC09, Vancouver, BC, 2009.

[6] M. Miura, et al., “LLRF Feedback Control Stability at STF”, WE5PFP084, presented in PAC09, Vancouver, BC, 2009.

[7] http://ilcagenda.linearcollider.org/contributionDisplay.py?contribId=219&sessionId=45&confId=3154