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# S1-GLOBAL MODULE TESTS AT STF/KEK

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*Abstract*

S1-Global collaborative effort recently successfully finished at KEK as a part of ILC-GDE is an important milestone for the ILC. International collaboration of three regions, Asia, North America and Europe, proved to be efficient on the construction and cold tests of the accelerating module consisting of 8 SRF cavities; 2 from FNAL, 2 from DESY and 4 from KEK. Three different cavity tuning systems were tested together with two types of high power couplers. The module was cooled down three times which enabled extensive high power tests with cavities, performance limits investigation, Lorentz force detuning tests, simultaneous multiple cavities operation and other activities such as an operation test of distributed RF scheme with low level RF feedback. The results of this S1-Global module test are presented and discussed.

## INTRODUCTION

One of the important aspects of the design of the International Linear Collider (ILC) is the demonstration of stable operation at an average accelerating gradient of 31.5 MV/m in a cryomodule. A test project aiming to build and operate eight units of 9-cell L-band cavity in a common cryostat was undertaken with considerable success through the international collaboration of INFN/LASA (Italy), DESY (Germany), FNAL (USA), SLAC (USA) and KEK (Japan). This project, referred to as the S1-Global project, was hosted by KEK and was conducted under the framework of the Global Design Effort (GDE). The S1-Global system actually consists of two half-length cryomodules, each containing four cavities. Cryomodule-C [1], which was one of the two cryomodules, was prepared by INFN/LASA to contain two TESLA-type cavities [2] from DESY and two similar cavities from FNAL. Cryomodule-A [3], the other cryomodule, was built by KEK and contained four TESLA-like cavities [4] developed by KEK. Different types of associated components such as cavity enclosures, frequency tuners (Blade tuner [5], Saclay-type tuner [6] and Slide-jack tuner [7]), and high-power input couplers (TTF-III coupler [8] and STF-2 coupler [9]) were installed in the cryomodules. The comparative study of these cryomodules in a common operational setting is one of the important tasks undertaken by the S1-Global project. Assembly work of the cryomodules (Figure 1) started in January 2010, and they were installed in the underground STF tunnel (Figure 2) in May of the same year [10]. The operational period, which continued for 9 months, was organized in the following three blocks: low-power RF tests during the first cool-down [11 and 12], high-power RF tests during the second cool-down [13, 14, 15 and 16] and an operation test of distributed RF scheme (DRFS, [17]) during the third cool-down, [18, 19 and 20].

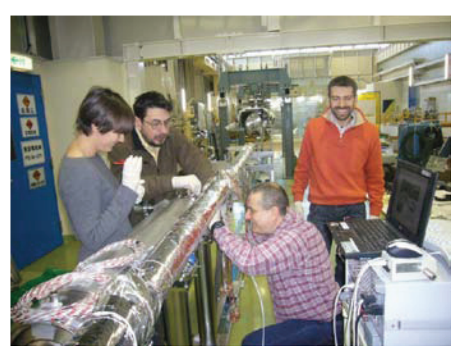

Figure 1: String assembly of four TESLA-type cavities by DESY/FNAL/KEK team (top), and tuner assembly by INFN/FNAL team (bottom).

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Figure 2: S1-Global cryomodule installed in the underground STF tunnel at KEK.

## HIGH GRADIENT PERFORMANCE

High-power tests to investigate the best performance of the cavities were carried out by first operating the individual cavities, one at a time. Figure 3 shows the attained maximum accelerating gradient, $E_{acc,\ max}$, at the time of the vertical test (VT) at FNAL, DESY, or KEK prior to the installation in the S1-Global cryomodule. The red bars in Figure 3 show the performance of the same cavities when they were operated by turns in the S1-Global cryomodule. The average $E_{acc,\ max}$ of the eight cavities was 30.0 MV/m in VT and 27.8 MV/m in the cryomodule tests (CT) with 1-cavity operation. Compared to the VT, the CT saw a reduction in the average gradient by 7%. Significant degradation of the cavity performance was observed in the C2 and C3 cavities. Similar degradation problem was also observed at DESY and is under investigation, [21]. Contamination of the cavity interior during shipping or during the string assembly of the cavities in a clean room is suspected to be responsible. Conversely, the A2 cavity achieved a stable operation at 38 MV/m with an input RF power of 500 kW, exceeding the record during the VT. Conditioning, which occurred at a higher-power, and the short-pulse operation in the S1-Global test, may have facilitated this improvement. With the other five cavities, there is good agreement in the calibration of the $E_{acc}$ during the VT and CT.

Unfortunately, the simultaneous operation of 8 cavities turned out to be impossible, since the slow frequency tuners of two (C2 and A4) cavities got stuck, prohibiting the eight cavities to be simultaneously driven by RF power with a single frequency. However, by tuning the resonance frequencies of the remaining cavities with functional tuners, the simultaneous operation of 7 cavities was attempted. Since the individual cavities had different maximum gradient performance, the input RF power to individual cavities was adjusted accordingly with variable power dividers to distribute the RF power from a 5-MW pulsed klystron. In the 7-cavities simultaneous operation (light blue and green bars in Figure 3), the achieved average $E_{acc}$ was 26.2 MV/m (without C2) and 25.4 MV/m (without A4). Deterioration of a vacuum pressure during RF pulses occasionally occurred at the STF-2 input coupler in the A1 cavity. Therefore, the operational $E_{acc}$ in the A1 cavity was reduced from 28 MV/m to 16 MV/m to achieve a stable operation with 7 cavities. The cause is supposed to be due to a re-activation of multipacting after an accidental warm-up due to a trouble of the cryogenic system. It is expected that the operational $E_{acc}$ could recover by careful RF conditioning of the input coupler, if there was enough time.

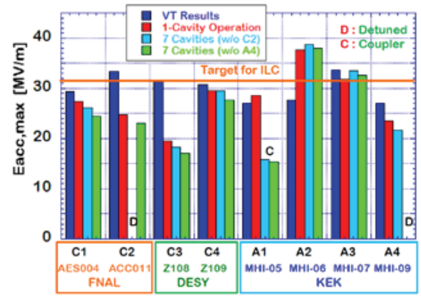

Figure 3: Summary of the maximum accelerating gradient that has been reached in the S1-Global experiment.

## LORENTZ FORCE DETUNING

The Lorentz force detuning of the cavities during pulsed RF operation was studied. Figure 4 shows the effect of this detuning, which was observed with the C4 cavity (DESY) in operation at 29 MV/m and with the A2 cavity (KEK) at 38 MV/m. In both cases, the detuning develops as a function of time during an RF pulse. The kinks mark the change in the RF power level from the pulse rise time to the flat top. The detuning frequency, $\Delta f$, in the pulse rise time was -350 Hz and -700 Hz for the C4 and A2 cavities, respectively. Likewise, the detuning frequency in the 1 ms flat top was -550 Hz and -200 Hz for the C4 and A2 cavities, respectively. The $\Delta f$ during the rise time is compensated by offsetting the resonant frequencies of the cavities in advance. However, the $\Delta f$ at the flat top has to be compensated with the operation of an active piezo tuner. Figure 5 compares the Lorentz force detuning coefficient “K”, ($\Delta f = -K \cdot E_{acc}^2$), which characterizes the specific cavity and tuner design. The KEK system gives an average K value of 0.2 at the flat top, which is much smaller than the values of FNAL (0.45) and DESY (0.65). This is considered to be due to the larger stiffness in the cavity supporting system of the KEK cavities [4], which restricts the deformation of the cell-shapes to a smaller level due to the Lorentz force. A smaller $\Delta f$ at the flat top helps reduce the stroke that is required for piezo tuners. It also tends to reduce the residual frequency error remaining after the active frequency compensation.

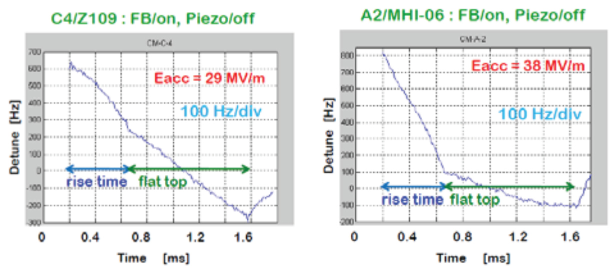


Figure 4: Detuning due to Lorentz force during an RF pulse in C4 and A2 cavities without piezo compensation.

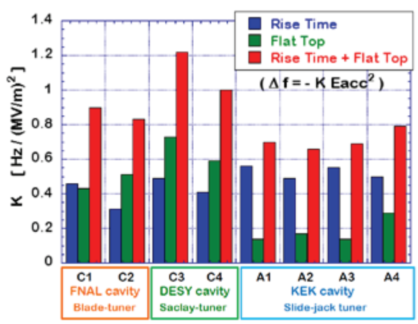


Figure 5: Comparison of the Lorentz force detuning coefficient, K, in three different cavity-tuner systems.

An important demonstration in this operation is the use of RF feedback based on a vector-sum control [18] and compensation of Lorentz force detuning by a piezo tuner. The offset-detuning frequency and parameters for the piezo drive, such as the voltage, waveform, frequency, and timing, were optimized for each of the cavities. All the three types of cavity-tuner systems showed similar excellent performance in compensating the $\Delta f$ at a flat top of 1 ms, and the residual frequency error of few Hz level was achieved in each piezo tuner, [14, 15 and 16]. Stable operation at an average $E_{acc}$ of 25 MV/m was successfully maintained for 2 hours, [18].

## SUMMARY

- The cryomodule tests in the S1-Global project were extensively carried out, and the stable 7-cavities operation was successfully confirmed at 25 MV/m in average $E_{acc}$ with an excellent compensation by the three types of piezo tuners.
- The cause of the deterioration of the high-gradient performance of two cavities (C2 and C3) and the problem of the slow frequency tuners (C2 and A4) will be investigated after disassembly of the cryomodule.

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