FERMILAB 1.3 GHz SUPERCONDUCTING RF CAVITY AND CRYOMODULE PROGRAM FOR FUTURE LINACS*

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Abstract

The proposed Project X accelerator and the International Linear Collider are based on superconducting RF technology. As a critical part of this effort, Fermilab has developed an extensive program in 1.3 GHz SRF cavity and cryomodule development. This program includes cavity inspection, surface processing, clean assembly, low-power bare cavity tests and pulsed high-power dressed cavity tests. Well performing cavities have been assembled into cryomodules for pulsed high-power tests and will be tested with beam. In addition, peripheral hardware such as tuners and couplers are under development. The current status and accomplishments of the Fermilab 1.3 GHz activity will be described, as well as the R&D program to extend the existing SRF pulsed operational experience into the CW regime.

INTRODUCTION

Work by the International Linear Collider (ILC) [1,2] community, which includes Fermilab, has motivated substantial world-wide infrastructure development and cavity performance progress. At Fermilab, this has translated to a very large commitment of resources for infrastructure and personnel development. The developed capability has led to the possibility to use the 1.3 GHz infrastructure for development of Project X [3,4], although the performance requirements are somewhat different [5]. The Project X 3 GeV CW linac requires high Q_0 at gradients (E_{acc}) in the range $15<E_{acc}<20$ MV/m; 1.3 GHz cavities can be used to investigate high Q_0. In addition, the Project X 3-8 GeV pulsed section operates at 1.3 GHz and requires ILC-like cavities with E_{acc}~25 MV/m. The status of Fermilab 1.3 GHz infrastructure, accomplishments and plans are described.

INFRASTRUCTURE

The cavities are fundamentally of the Tesla design [6], made of high RRR niobium with an elliptical cell shape, for superconducting operation at 2K. Cavity qualification has been described in detail elsewhere [7] and includes cavity inspection, surface processing, clean assembly, and one or more cryogenic qualification tests which typically include performance diagnostics. Cavities which reach the performance requirement in vertical (bare) qualification test, typically E_{acc}>35 MV/m, are dressed and horizontally tested. Cavities which reach the performance specification in horizontal (dressed) qualification test, also typically E_{acc}>35 MV/m, are assembled into cryomodules.

The joint ANL/FNAL facility is the primary infrastructure [7] for surface processing of 1.3 GHz cavities, and includes electropolishing (EP). New infrastructure at Fermilab includes two high temperature furnaces for hydrogen degassing, see Fig.1. In addition, a centrifugal barrel polishing (CBP) machine for 1-cell and 9-cell 1.3 GHz cavities has been introduced for R&D and may be used for production cavity preparation in the future, see Fig.2. CBP may be used in place of the standard bulk electropolishing step, to reduce acid use. CBP has been demonstrated to be a useful repair technique [8], and may have other benefits as well, such as reducing cavity performance sensitivity to minor manufacturing or material defects; these studies are not yet complete. A new R&D surface processing facility [9] is now fully operational for the full suite of standard EP processing for 1-cell 1.3 GHz cavities. The R&D EP tool is shown in Fig.3.

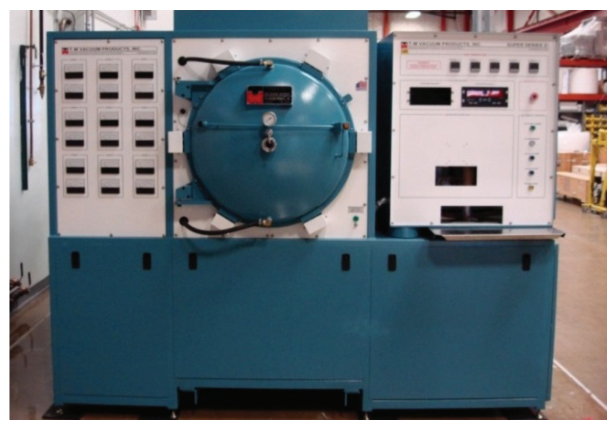

Figure 1: One of the two new vacuum furnaces.

Figure 2: Centrifugal barrel polishing machine.

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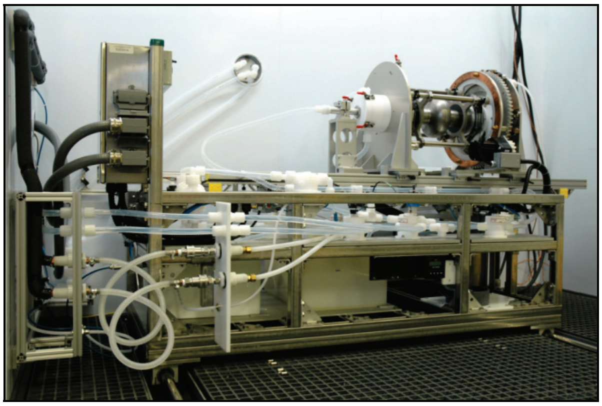

Figure 3: R&D EP tool.

ILC AND CONSIDERATIONS FOR CW

ILC R&D contributed substantially to cavity gradient performance. A worldwide effort by participating laboratories, including Fermilab, to optimize cavity processing and to develop new cavity vendors for high gradient cavities was implemented. As part of this work, a systematic analysis of cavity vertical test data was performed [10]. The data set is comprised of cavities fabricated by established vendors (ACCEL/RI, AES, MHI, Zanon), and processed by established laboratory surface processing (JLab, DESY, KEK), including electropolishing. If a cavity does not reach 35 MV/m after the initial EP processing stage, we assume it would be re-processed. Standard 2nd pass processes may include EP, HPR, or 120C bake, and are selected based on 1st pass performance at the discretion of the laboratory. There are 51 cavities in the 1st pass plot, and 35 in the 2nd pass plot. The difference in number of cavities reflects the fact that the 2nd pass may not have take place yet, or may have been done with a non-standard process. The gradient distribution of cavities which are not included in the 2nd pass yield is the same as those which are included. The ILC gradient yields, representing percentage of cavities reaching either 25 MV/m (blue points) or 35 MV/m (red points) are shown in Fig.4. ILC cavities reach 35 MV/m more than half the time after one or two EP processing cycles. For Project X, the gradient yield at 25 MV/m is of interest. In 1st pass, (69±6)% of all 51 cavities achieve >25 MV/m; and (86±13)% of 7 cavities achieve >25 MV/m considering only cavity tests taking place in 2012. In 2nd pass, (80±7)% of all 35 cavities achieve >25 MV/m; and (92±7)% of 13 cavities achieve >25 MV/m considering only cavity tests taking place in 2010-2012.

Ongoing efforts to improve cavity performance yields, either 1st pass or 2nd pass, include applying localized grinding (pioneered by KEK) to performance-limiting defects, and CBP. Many (~12) cavity repairs have been achieved through these two methods; however, at this time, cavity performance after these repairs has not been included in yield plots.

Two approaches for Q_0 optimization for Project X are being pursued at Fermilab now: venting cavities after hydrogen degassing in a nitrogen atmosphere [11], and using a hydrofluoric acid rinse as the final processing step [12]. Both approaches show promising results.

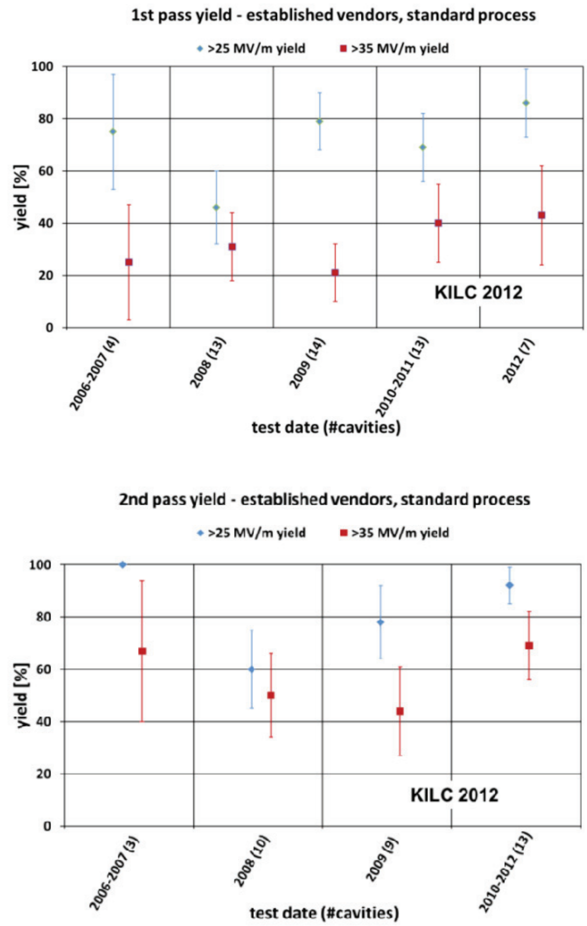

Figure 4: ILC cavity gradient yields: 1st pass (top) and 2nd pass (bottom), as a function of time. Blue points are >25 MV/m yield and red points are >35 MV/m yield.

ACCOMPLISHMENTS

Fermilab provides stewardship for 80 9-cell cavities for the ILC/Americas region. The status of these cavities is shown in Table 1. The bare cavities are processed and tested in strong collaboration with JLab, Cornell and ANL; see Fig.5 for vertical test performance.

Table 1: 9-cell Cavity Status August 31, 2012

ordered	80
received	69
processed	47
vertically tested	47
dressed	22
horizontally tested	19
CM2 installed	8

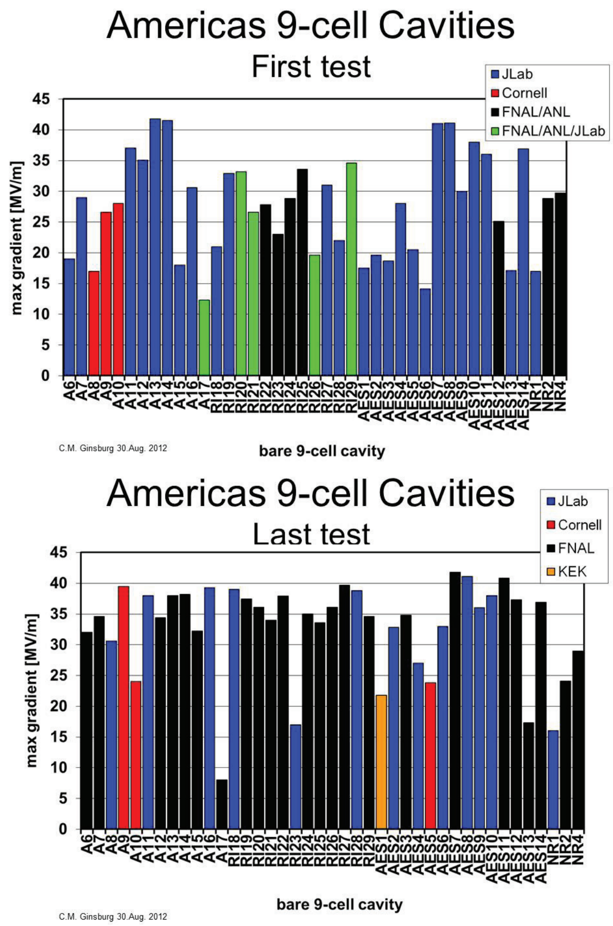

Figure 5: Gradient performance of all Americas cavities in first test (top) and last test (bottom). The test location is designated by the histogram bar color. An overall improvement is seen after additional process and test.

Two 1.3 GHz cryomodules have been assembled at Fermilab: CM1 and CM2. CM1 was built from a DESY "kit" containing parts from DESY and INFN, including surface processed, dressed, tested cavities. The magnet position is occupied by a "dummy" magnet. CM1 has been tested cold with excellent results [13]. CM2 is an 8-cavity string with a quadrupole package. CM2 is comprised of cavities which were surface processed and reached 35 MV/m in vertical test at JLab. These cavities were dressed and horizontally tested at Fermilab, then assembled into CM2. The summary of final cavity performance before CM2 assembly [14] is shown in Fig.6. CM2 will be tested at NML first without beam and then with beam within a year. All components are available for the assembly of CM3, which is expected to proceed within about a year.

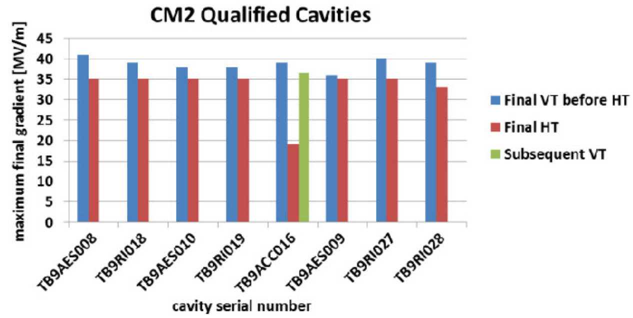

Figure 6: Gradient performance of CM2 cavities in vertical (blue) and horizontal tests (red). In one case, a subsequent dressed-cavity vertical test was performed after failed horizontal test.

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