SUPERCONDUCTING RF CAVITY PRODUCTION PROCESSING AND TESTING AT FERMILAB*

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Abstract

The superconducting RF (SRF) cavity production program at Fermilab supports 9-cell 1.3 GHz cavity qualification and preparation for assembling cavities into cryomodules, in support of Project X, ILC, or other future projects. Cavity qualification includes cavity inspection, surface processing, clean assembly, and one or more cryogenic qualification tests which typically include performance diagnostics. The overall goals of the program, facilities and accomplishments are described..

INTRODUCTION

Fermilab is engaged in a program to provide 9-cell 1.3 GHz cavities for assembly into cryomodules in support of Project X and International Linear Collider (ILC) R&D, or other future projects.

The cavities are fundamentally of the Tesla design [1], made of high RRR niobium with elliptical cell shape, for superconducting operation at 2K.

This program is carried out by a collaboration of Jefferson Lab (JLab), Cornell University, Argonne National Lab (ANL), and Fermilab (FNAL), with overall responsibility for program coordination at FNAL. The focus of this paper is on those aspects of the work done at FNAL and at the joint FNAL/ANL facilities.

PROCESS OVERVIEW

The cavity process sequence is shown schematically in Fig.1. Depending on cavity performance, one or more steps may be repeated. An internal optical inspection is sometimes performed at various stages in the process, to record the status of the cavity surface.

Fabrication

Cavities are purchased from outside vendors and are built to print from Fermilab drawings. We are currently working with cavities from three cavity vendors: ACCEL/Research Instruments (RI), Advanced Energy Systems (AES), and Niowave-Roark (NR).

Incoming Inspection

Incoming inspection of a production cavity involves four steps. First, the external surfaces of the cavity are visually inspected for their condition. Any indications of handling errors or potential weld or flange sealing surface problems are documented. The remaining three steps may occur in any order: a measurement of room temperature field flatness, a confirmation the cavity is vacuum leak tight at room temperature, and confirmation using a coordinate measuring machine that the cavity's dimensions agree with the design drawings.

In serious cases, deviations from fabrication or handling requirements are relayed back to the vendor for possible remediation.

Cavity Surface Processing

Cavity surface processing follows the general scheme of ILC RDR [2]: (1) bulk electropolishing (EP) for ~120-150 μm removal, ultrasonic detergent rinse, high-pressure ultrapure water rinse (HPR), (2) 2 hour 800C furnace treatment for hydrogen degassing, (3) room temperature RF tuning, (4) final chemistry of ~10-30 μm removal, ultrasonic detergent rinse, first HPR, first class-10 cleanroom assembly, second HPR, second class-10 cleanroom assembly, cavity evacuation and seal, and (5) a 120C bake-out under vacuum for 48 hours.

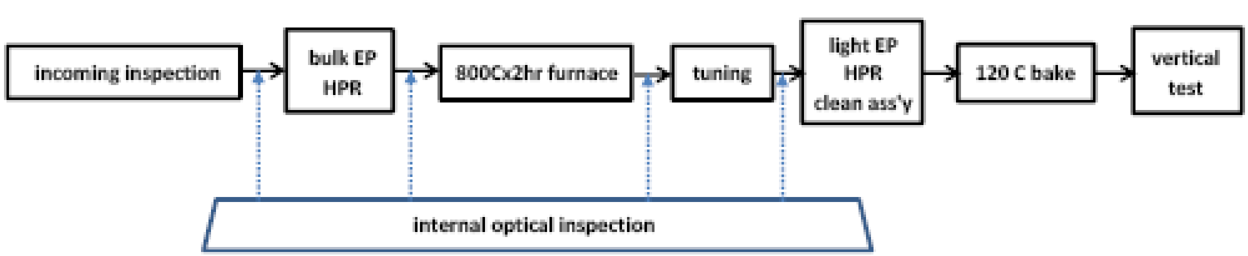

Figure 1: Overview of the production process for bare 1.3 GHz 9-cell cavities.

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Cavity Qualification

The bare cavity RF qualification test consists of a measurement of cavity Q0 as a function of gradient at 2K. The cavity residual resistance, and performance at other temperatures may also be measured.

FACILITIES

ANL/FNAL Cavity Processing and Assembly Facility

A facility at ANL for 1-cell and 9-cell Tesla-style cavity processing and assembly [3] was recently designed and built jointly by FNAL and ANL staff. The facility houses an EP room, and an HPR room containing an HPR tool in which the cavity moves vertically and the wand rotates. The facility also contains cleanrooms of class 10, 100, and 1000, an ultrasonic rinse tank in the anteroom, and a cavity vacuum system for post-assembly evacuation.

Additional Fermilab Facilities

Additional facilities used in the production process are located at Fermilab. A high-temperature vacuum furnace is installed and being commissioned; presently all 800C furnace treatment is performed at JLab. The new furnace will substantially reduce the cavity handling and overall duration of cavity surface processing. An automated cavity tuning machine [4] built in collaboration with DESY and KEK was recently installed and commissioned, and has been in operation for a few months. Internal optical inspection using a KEK/Kyoto inspection tool [5] is sometimes used as an intermediate diagnostic tool at various stages in the cavity processing procedure. A low-temperature baking system using heaters and blankets is integrated with the mechanical support structure and vacuum system at the vertical test facility described later.

Cavity Qualification Facility

A vertical cavity test facility at Fermilab [6] has been in operation since 2007 for bare cavity performance qualification. One radiation shielded and magnetically shielded cavity test cryostat is currently in operation, and typically operates at 2K. Performance diagnostics available for tests now routinely include a new second sound system [7] for quench location.

The test throughput of the single vertical test cryostat is up to two 9-cells per week, under ideal conditions. Two additional larger cryostats are currently under construction, and are expected to increase the test capability to more than three times the current throughput.

ACCOMPLISHMENTS

Currently forty-six 9-cell cavities are at various stages in the production process. Four more are in partial fabrication at the vendor, and 40 more were recently ordered through ARRA funds.

Cavity Vendor Development

Any scenario for future projects currently envisioned at Fermilab involves a ramp up of cavity production at U.S. vendors. Therefore, development of U.S. cavity vendors is critical to the production process plan. Within the last few years, in collaboration particularly with JLab, we have worked closely with U.S. cavity vendors to improve their capabilities to produce high-quality cavities.

AES delivered 10 cavities to FNAL, a first batch of 4 and a second batch of 6, which were inspected, processed and tested. . The performance of the second AES batch is shown in Fig.2; inspection was performed at FNAL, and processing and testing using standard procedures at JLab. Because this cavity batch achieved gradients and Q0 on par with those from experienced vendors, AES was subsequently declared an experienced vendor for ILC cavities by ILC management. Six additional cavities were recently delivered and are in incoming inspection. Twenty more cavities were ordered through American Recovery and Reinvestment Act (ARRA) funds.

Within the last few months, NR has delivered two 9-cell cavities which have been inspected and are being processed at FNAL/ANL and JLab. An additional four cavities will be delivered as part of this order, and 10 more have been ordered through ARRA funds.

PAVAC, a vendor not yet experienced in 9-cell Tesla-shape cavity fabrication, will build 10 ARRA cavities.

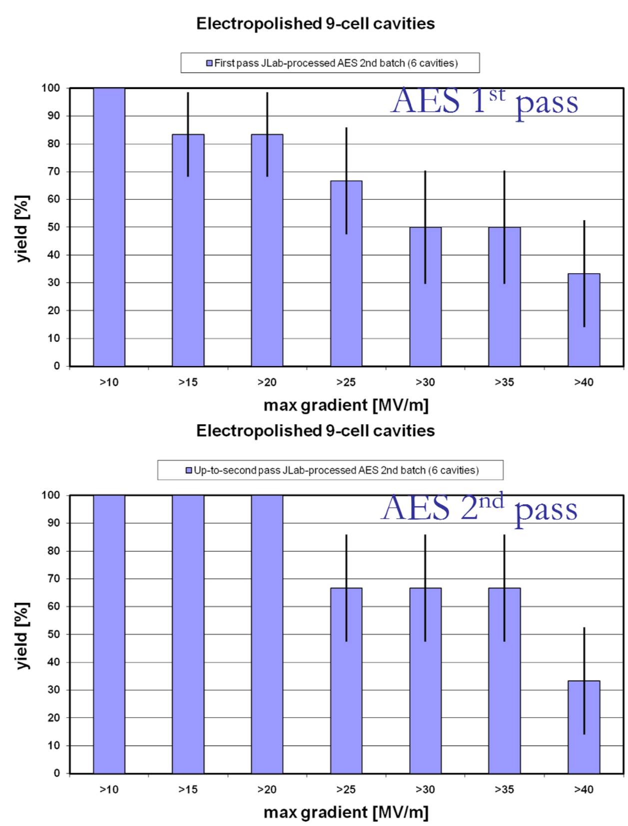

Figure 2: Vertical test yield for AES 2nd batch after 1st process (top), or 1st process if gradient>35 MV/m and Q0>8E9 are achieved or 2nd process if not (bottom).

Production Throughput

Our facilities have achieved very high throughput this year. Twelve new 9-cells from RI were received, went through inspection, and are at an advanced phase of the process/test phase. Two new cavities from NR are being processed and tested, and six new cavities from AES have just been received and have started incoming inspection.

The FNAL/ANL cavity processing facility has performed 30 electropolishing processes through August 2010, of which 16 were for 9-cell cavities. More than 40 EP cycles are anticipated for the calendar year 2010.

The VCTF has performed 51 cavity tests through August 2010, of which 22 were for 9-cell cavities. A total of ~75 vertical tests are anticipated for 2010.

Cavities for Cryomodules

The destination for well performing cavities is Fermilab cryomodule CM2 [8]. Eight cavities have been identified as candidates for CM2. These eight, plus two spares, have reached a gradient 35 MV/m with Q0>8E9 requirement to be qualified for dressing in a helium vessel and will be horizontally tested (HT) [9]. The performance of these cavities is shown in Fig.3. One of the cavities shown in Fig.3, TB9RI029, was processed and vertically tested at FNAL/ANL facilities; the remainder were processed and vertically tested at JLab. All horizontal tests are performed at FNAL. Cavities passing horizontal test will be qualified for cavity string assembly for FNAL Cryomodule CM2, expected to occur by the end of 2010.

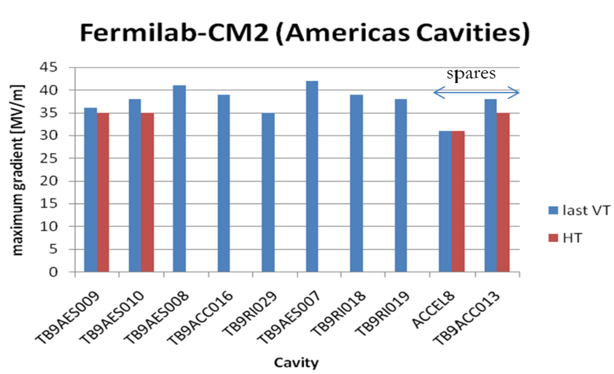

Figure 3: Performance of CM2 candidate cavities in last vertical test and horizontal test, if available.

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