STUDY OF THE SURFACE AND PERFORMANCE OF SINGLE-CELL Nb CAVITIES AFTER VERTICAL EP USING NINJA CATHODES

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Abstract

A 1.3 GHz single-cell niobium (Nb) coupon cavity was vertically electropolished (VEPed) with three different Ninja cathodes which were specially designed for VEP of 1.3 GHz superconducting RF elliptical (ILC/Tesla type) cavities. The cathodes were fabricated to have different surface areas and different distances between cathode surface and the equator. The Ninja cathode prepared with an enhanced cathode surface area was covered with a meshed shield to avoid bubble attack on the surface of the cavity cell. It has been turned out that the anode-cathode distance and the cathode area affect surface morphology of the equator. A smooth equator surface was obtained in the cases in which the cathode surface was geometrically close to the equator or instead the cathode surface area was sufficiently larger. Two 1.3 GHz ILC/Tesla type single-cell cavities VEPed with the Ninja cathodes and using optimized conditions showed good performance in vertical tests.

INTRODUCTION

Electropolishing (EP) is a promising technique for final surface treatment of niobium (Nb) accelerating cavities. In order to prepare 17,000 cavities for the proposed ILC project a simple and inexpensive EP system is required. EP of a cavity with vertical EP (VEP) technique can be carried out with a simple and less expensive setup as well as at a higher EP rate in comparison to horizontal EP technique. However non-uniform removal of Nb, bubble traces and non-uniform surface roughness are the serious issues in VEP. We are making our effort for the last few years to solve these issues. In our study accumulation of H_2 bubbles on Nb surface was found the main cause of asymmetric removal [1]. We could successfully minimized asymmetric removal in 1-cell cavity and obtain smooth surface of a cavity with our unique i-Ninja cathode [2,3]. Here we report VEP of 1.3 GHz ILC/Tesla type Nb single-cell coupon cavity with three different types of Ninja cathodes which maintain different distances from Nb surface in a cavity cell and contain different surface areas. Vertical test (VT) results are shown for two vertically elecropolished (VEPed) 1.3 GHz ILC/Tesla type single-cell cavities.

NINJA CATHODES AND CAVITIES

Three types of Ninja cathodes, namely Ninja cathode 1, 2 and 3, were prepared. The Ninja cathode-1 consisted of 4 insulating wings while the Ninja cathode-2 was designed with 4 partial metallic wings acted as a cathode and remain near equator surface. The Ninja cathode-3 developed recently contained insulating wings like Ninja cathode-1 whereas a surface area of the cathode was intentionally kept larger compared to the Ninja cathode-1 and 2 both. Moreover the cathode-3 was covered with a meshed shield so as to guide the H_2 gas bubbles along the cathode in upward direction. Schematics of the Ninja cathodes are shown in Fig. 1.

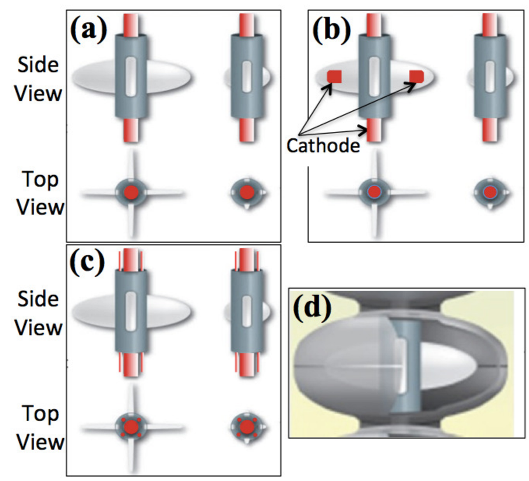

Figure 1: (a) Ninja cathode-1, (b) Ninja Cathode-2 (c) Ninja Cathode-3 and (d) A Ninja cathode in a cavity cell.

A coupon cavity having 6 coupons at its different positions [1,3] was used for VEP experiments to obtain adequate VEP parameters. Other two 1-cell cavities NR1-2 and C1-19, which belong to Cornell University and CEA-Saclay, respectively, were also VEPed using the Ninja cathodes and our adequate VEP parameters. A VEP system used for VEP of the coupon cavity and the C1-19 cavity was detailed elsewhere [3]. The NR1-2 cavity was VEPed with a VEP setup at Cornell University.

RESULTS AND DISCUSSION

Polarization Curves

In order to compare effect of the Ninja cathodes polarization curves were obtained for the coupons and cavity while the cathodes were rotated at a speed of 50 rpm. The speed was chosen based on the previous VEP experiments as found effective to reduce asymmetric removal of Nb along the cavity length [2,3].

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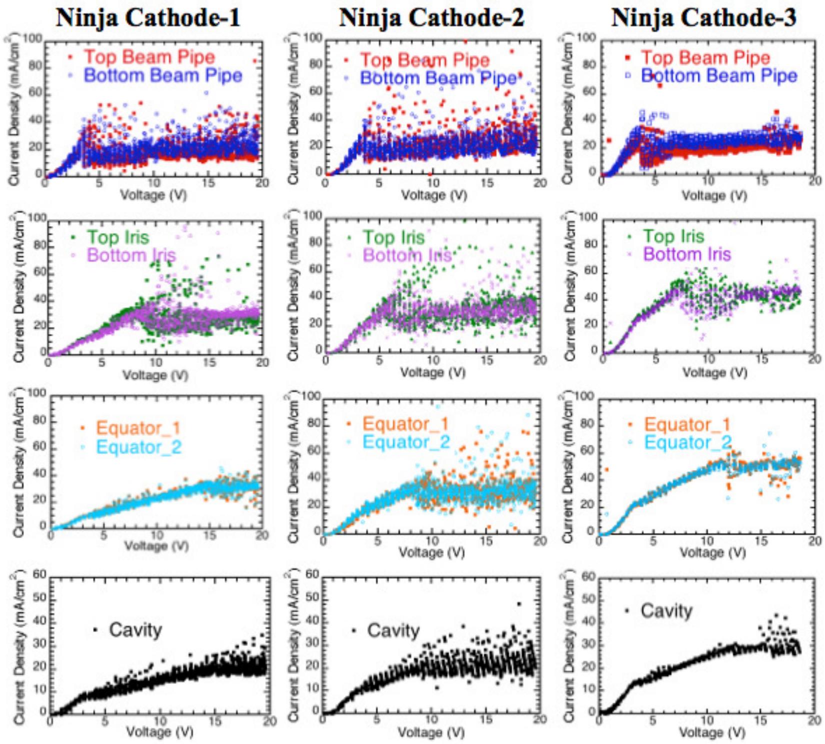

Figure 2: Polarization curves obtained for coupons and the coupon cavity with three different types of Ninja cathodes.

The polarization curves are shown in Fig. 2. EP plateaus, the region in which EP should be performed, for the beam pipe and iris coupons were obtained with all three cathodes. An EP plateau for equator coupons could not appear clearly with Ninja cathode-1 even at an applied voltage of 20 V. An EP plateau for the equator coupons was clearly found from ~11 V with the Ninja cathode-2. The Ninja cathode-3 could also provide EP plateaus for equator coupons from ~13 V. The results revealed that to find an EP plateau for the equator in a reasonably lower voltage range (say about 10-15V) either a cathode should be close to the equator surface or a cathode surface area should be sufficiently large.

VEP of Coupon Cavity with Ninja Cathodes

The coupons used in VEP experiments had similar initial surfaces with rolling marks as received from Tokyo Denkai and with typical roughness Ra and Rz of ~0.5 and 4 μm, respectively. VEP experiments with Ninja cathodes-1 and 2 were carried out at a cathode rotation of 50 rpm and at applied voltages of 14-16 V and ~13 V, respectively. Since Ninja cathode-3 was covered with the meshed shield almost all the bubbles can move upward along the cathode. A rotation speed lower than 50 rpm might be sufficient to remove bubbles from the upper iris. Therefore two VEP experiments with Ninja cathode-3 were carried out at different cathode rotation of 50 and 20 rpm, and at an applied voltage of ~13 V.

Average removal thicknesses of 43 to 55 μm were calculated from weight losses of the cavity in the VEP experiments. Surface features of the iris and equator coupons are shown by optical microscope images in Fig. 3. Roughness results Rz (RzJIS) are compared in Fig. 4. The trend of roughness Ra (RaJIS) was also found to be similar as that of Rz. The Ninja cathode-1 resulted in a very rough equator surface. Smooth surfaces were obtained for all the coupons VEPed with the Ninja cathode 2. However the top iris surface was influenced by H_2 bubbles generated from Al partial wing cathode. The Ninja cathode-3 was found to be effective to get smooth surfaces of all the coupons including the equator coupons without footprints of the bubbles on the upper iris surface. The equator surface was found smoother with Ninja cathode-3 rotating at 20 rpm. Some bubble marks were seen on the upper iris surface at 20 rpm. However these were not deep. A rotational speed between 20 and 50 rpm might be more appropriate with the Ninja cathode-3 and needs to be investigated further.

In Ninja cathode-1 the larger anode-cathode distance and cathode surface screening due H_2 bubbles reduced electric field on the equator and ion transportation on the cathode. Therefore an EP plateau for equator was not seen at the applied voltage and equator surface became rougher. The partial metal wings of Ninja cathode-2 enhanced an electric field on the equator while the Ninja cathode-3 might reduce cathode surface screening due its larger surface area. Therefore both the cathodes showed clear EP plateaus for equator coupons. A smooth equator surface could be obtained with Ninja cathode-2 and 3 because EP was performed in the EP regions.

Ninja cathode-2 may not be appropriate for VEP of a 9-cell cavity because the bubbles generated from the cathode wings would finally accumulate in upper cells of the cavity to result in asymmetric removal and rough surface. The Ninja cathode-3 which could guide H_2 bubbles along the cathode while providing a smooth equator surface may avoid asymmetric removal in VEP of a 9-cell cavity. A 9-cell Ninja cathode made on the same concept of Ninja cathode-3 has been applied for a 9-cell coupon cavity. Fabrication of 9-cell coupon cavity and preliminary results of VEP using the 9-cell Ninja cathode are reported in this conference [4,5].

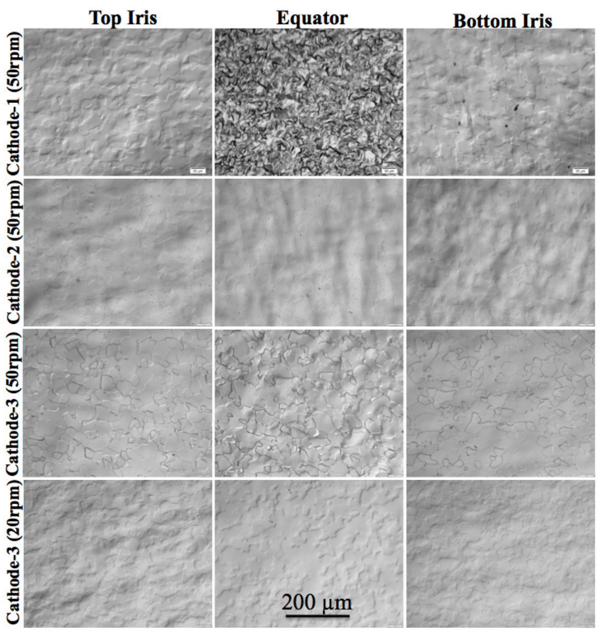

Figure 3: Optical microscope images of the coupons after the VEP experiments for similar removal between 43 and 55 µm.

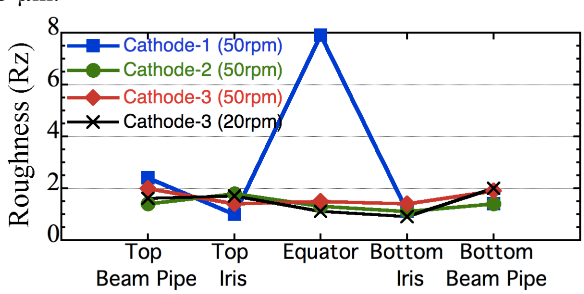

Figure 4: Roughness Rz of the coupons after the VEP experiments.

VEP and VT Results of NR1-2 and C1-19 Cavities

The NR1-2 cavity surface was initialized by 40 µm removal in tumbling and 60 µm removal in buffered chemical polishing (BCP). The cavity was degassed at 800 °C. The cavity was VEPed first with the Ninja cathode-2 and then with the Ninja cathode-3 at Cornell University. VEP parameters optimized with the coupon cavity at Marui were applied in the both VEP experiments. A cathode rotation of 50 rpm was set in the both VEP experiments. A thickness of 20 µm was removed in each VEP. VEP detail was presented elsewhere [6]. The cavity was baked at 120 °C for 48 h and tested in a vertical cryostat at a temperature of 2 K at Cornell University. The cavity achieved a field gradient of 35 MV/m at Q_0 of 9×10^9 before quench happened (see Fig. 5).

The C1-19 cavity surface was treated with BCP at Saclay and sent to Marui for VEP. The cavity was VEPed for three times with Ninja cathode-3 rotating at 30 rpm. First two VEPs were carried out for removal thicknesses of 31 and 55 µm followed by high pressure rinsing (HPR) and degassing at 750 °C for 3 hours. The third (final) VEP was carried out for removal thickness of 11 µm followed by HPR. HPR and degassing were carried out at KEK. The cavity was sent back to CEA-Saclay where VT was carried out at 1.6 K. The test was performed up to when the cavity achieved a field gradient of 21 MV/m at $Q_0=1.4\times10^{10}$ as shown in Fig. 5. The test was stopped because vacuum leak occurred during the VT. The cavity will be re-assembled and tested again. Both the cavities showed good performances after VEP carried out with the Ninja cathodes even though the VEP system made with PVC material was used.

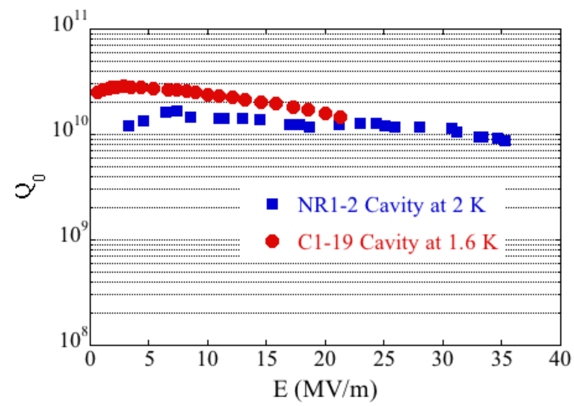

Figure 5: Vertical test results for NR1-2 and C1-19 Cavities.

CONCLUSION

VEP experiments for a coupon cavity were carried out with three different types of Ninja cathodes to know effect of anode-cathode distance and surface area of cathode. In order to achieve a smooth equator surface either cathode should be near to Nb surface or alternatively a cathode should have a larger surface area to avoid its surface screening by H_2 bubbles. Two other single-cell cavities (NR1-2 and C1-19) were VEPed with the Ninja cathodes at 50 and 30 rpm, and tested in vertical cryostats. The cavities have shown good performance in VT.

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