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L-band Superconducting Cavities at KEK for TESLA

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Abstract

An attractive future application of superconducting cavities is a TeV energy superconducting linear collider (TESLA). Large merits of TESLA comparing to normal conducting linear collider are to loose alignment tolerance and less wake field due to the lower frequency (1.3GHz). The final focus also is easy by the large electron/positron population in bunches. TESLA demands up-grading field gradients of over 25 MV/m. KEK has started R&D on 1.3GHz niobium superconducting cavities since 1990. So far seven single cell cavities and two 9-cell cavities have been fabricated and tested. Parallel to them, input coupler design and niobium material study are being conducted. This paper reports the present status of KEK's efforts for TESLA.

I. INTRODUCTION

After the HEACC '92 three single cell cavities and one 9cell cavity fabricated with MHI were tested. As presented in the HEACC'92 [1] the acceleration field in our single cell cavities is limited to 15-20 MV/m very reproducibly and we are making efforts to understand the limitation mechanism. We suspect three issues; 1) multipacting at equatorial section, 2) arcs from around input coupler or pick-up probe, 3) defects of electron beam welding at equatorial section. A diagnostic system was built up in order to observe heating sites and electron trajectories at the quench. Our cavity test activity was stopped for four months up to this May due to move from the TRISTAN assembly hall to a new sc experimental building. In this while we made a study of clean surface with laser dust analyzer. High temperature annealing $(1400^{\circ}C)$ became usable for single cell cavities in our existing UHV furnace. Niobium samples were annealed in this furnace and the RRR values were improved to 400.

Our TESLA activity is jointed to the JLC (Japan Linear Collider) program from this fiscal year. Our one target will be to test beam quality and reliability of sc operation in the ATF (Accelerator Test Facility at KEK) which is under construction and to be completed in 1995.

II. TEST RESULTS AFTER HEACC '92

Our cavity test results after the HEACC '92 are summarized in Table 1 and the Qo-Eacc curves are presented in Fig.1. The 9-cell cavity as a TESLA prototype was tested twice and the field gradient was limited to 10-12 MV/m by field emission. With single cell cavities except one field gradients were limited to the low field of 8-12 MV/m by field emission. Reason for these field emissions is contamination during high pressure water rinsing [HPR]. Water pressure of the HPR system has reduced from 85 to 65 kg/cm² in the long term operation. Foreign material fragments (50 μ m) were detected on a tested niobium sample in a surface analysis with EPMA. In addition the field gradient of 20 MV/m without field emission was achieved in C2 as before [1] when HPR was not conducted after the chemical procedure. These facts mean that high pressurized water removed nozzle material and contaminated cavity surface.

M1-(II) and M2-(III) have abnormally large residual surface resistance. One third in 151 n Ω of M1-(II) can be explained by the Qo-dropping in 4.2K measurement conducted previous to 2K one, in which field emission made an additional residual surface resistance same as the case of C2-(IV) discussed later. Probably the remained surface resistance and one of M2-(III) were due to Qo-disease by hydrogen [2]. As M1 (RRR=100) had many porosities on the equatorial EBW seam, it was rewelded from inside and annealed at 1400°C for 4 hours at CEBAF. Then it was sent back to KEK, electropolished (EP) 80 μ m and tested. The cavity would picked up again much hydrogen during the heavy EP. Since this cavity was precooled down with liquid nitrogen and held around 100K for one night as usual, it would have the Qo-disease. On the other hand a CEBAF's high RRR cavity with RRR>250 which was



Fig. 1 Qo-Eacc curves with the cavities measured after the HEACC '92.

Table 1. Summary of cavity treatments and test results.

| Cavity | Surface Treatment | Annealing | Rres [nΩ] | Eacc,max [MV/m] | Q ₀ (Eacc,max) |
|-----------|--|------------------------------|--------------|--------------------|------------------------------|
| 9M - (I) | E.P (80μm+10μm), HPR | 760°C, 5 hours | 13 | 9.9 | 2.1×10^9 |
| - (II) | E.P (20µm), HPR | no | 11 | 12.0 | 3.1x10 ⁹ |
| M1 - (II) | E.P (80µm), HPR | 1400 ⁰ C, 4 hours | 151 | 8.1 | 9.0×10^{7} |
| M2 - (II) | Tumbling (100μm), E.P (100μm+30μm), HPR | 765°C, 7 hours | 29 | 12.0 | 1.7×10^8 |
| - (III) | C.P (100µm+5µm) | 760 ⁰ C, 6 hours | 321 | 7.6 | 1.5×10^{8} |
| C2 - (VI) | C.P (35µm) | no, (1400°C) | 22 | 20.2 | 9.0×10^9 |

[9M is the 9-cell cavity; M1, M2 and C2 cavities are the 1-cell cavities.]

annealed at 1400°C for 4 hours dose not show the Qo-disease any more even after heavily electropolished (120µm) [3]. A discrepancy in these facts might be in a difference of the material. M2-(III) was chemically polished (CP) by an unusual chemical procedure in which we cooled the cavity outer surface at 20°C with water during the CP and that resulted in a long CP time (40 minutes for 100 µm removal), then annealed at 760°C for 6 hours and chemically polished by 5 µm, then tested with usual cooldown procedure. Probably the cavity picked up more hydrogen during the unusual CP and our annealing process was poor to degas the hydrogen.

III. PROGRESS IN EQUIPMENTS

We have prepared some tools to understand and improve our field limitation. Several results from them are described here. A. Diagnostic System

A temperature mapping system was built up to observe what happen in our cavity quench. The same data acquisition system in the reference [4] was used but thermometers are different. An Allen-Bradley's 51 Ω carbon resistor is surrounded with Stycast and stuck an aluminum nail (2mm ϕ) on the behind to thread a spring and to be supported by G-10 base plate. This sensor is forced on the cavity outer wall by the spring action. GE-varnish is coated to get a good thermal contact between the sensor and the cavity wall. Thermal sensitivity of the sensor is 5 mK. Apart 10 degree each, 19 sensors are distributed on one meridian at about one centimeter interval. Totally 684 sensors are fixed on the cavity wall.

This system was used first in the test C2-(VI) and temperature rise in the quench at 20 MV/m was observed (see Fig. 2). No temperature rise was detected before the quench (Eacc=20.5 MV/m) within present sensitivity as seen in Fig. A. However, after the quenching one local heating site appeared on the lower iris and the second spot came out on the same iris by the successive RF-processing (Fig.2 B,C). These heating sites were localized on the iris. The temperature rising can be fitted by the F-N plot and Qo-dropping also is explicable by field emission, however, any clear field emission trajectories are not observed in the temperature mappings. Maybe our thermosensor's sensitivity has to be improved more. Probably field emitted electrons from some seed makes the heating spot but we do not yet understand what mechanism makes such a seed which limits the field gradient at 20 MV/m.

Another interesting phenomenon was observed in the measurement of M2-(III) (see Fig.3). During RF-processing at the maximum field of the field emission region, Qo-value degraded 1×10^8 to 2×10^7 and Eacc dropped 7 to 2 MV/m suddenly (we refer it as intermediate state). This state was stable but if RF-power was reduced and the dissipated power loss became small, it changed to the previous field emission state. This phenomenon is very reproducible. Fig. 3 shows the heating maps in the intermediate state. It is estimated that a large area(at least 650 mm², 29mm^{Φ}) of inner wall is normal conducting state. The site of this macro local heating was not fixed and changed three times from the equatorial section to the lower straight section of the cavity. The stationary field emitted electron's bombardments may be a trigger of this phenomena.



Fig. 2 Heating sites after the 20MV/m quench.

C2 had quenched finally at 20.5 MV/m same as before [1]. Qo degraded by the successive RF processing after the quench. The indexes of A,B,C in the heat mappings are corresponding with ones in the Qo-Eacc curve.



Fig. 3 Temperature rise in the intermediate state.

B. High Temperature UHV Annealing

It is well known that high temperature UHV annealing is a very effective tool on high field gradient of sc cavities [5]. We can expected three effects in this treatment, 1) upgrading thermal conductivity in niobium material, 2) reduction of inhomogeneity which weakens magnetic property in the superconducting state, 3) a perfect solution of Qo-disease by hydrogen. We have used a 700-760°C UHV annealing for hydrogen out gassing and a higher temperature annealing furnace became usable recently. We made a sample test using this furnace. Samples with initial RRR value of 54, 117, 159, 213 and 246 were annealed at 1350°C for 6 hours combined with titanium gettering and improved to 273, 308, 351, 383 and 394 with the RRR value, respectively. After this testing, a single cell cavity (M2) was annealed at 1400°C for 6 hours with this furnace.

C. Dust Analysis

Residual micro dust particles on a cavity inner surface have a large influence on field emission. Field emission is the today's most serious problem not in high field sc cavities but also high field copper cavities as JLC. We have just started a study on the ultra-clean surface. We analyzed dust particles in the TRISTAN sc cavity's surface treatment procedure using a laser scattering dust analyzer in cooperation from an semiconductor industry. We simulated the rinsing procedure using silicon wafers (90mm^{ϕ}). This is the same way in the reference [6]. Fig.4 shows the residual dust particle's



Fig. 4 Dust analysis with our chemical process.

The left is a result of the silicon wafer rinsed with our full rinsing procedure. The right is one rinsed with a megasonic agitator (950KHz).

distribution and the number on the silicon wafer which was finally rinsed with ultra-pure water in a hot bath [7]. The dusts of 0.2-3µm were analyzed. Micro particles (>1µm) over one thousand are remaining on the wafer. It shows our dust particle control is poor even ultra-pure water is used. Tools which transfer an energy and remove actively dust particles on the surface have to be developed. One method is HPR. Our HPR system had a contamination problem as mentioned above but CEBAF confirmed recently that it is a very powerful tool against field emission with niobium bulk cavities [3]. A maximum surface electric field over 50MV/m (Eacc>28MV/m) was achieved without any field emission. We are considering a megasonic agitation rinsing as another method to remove submicron particles. Fig. 4 (right) shows a result rinsed with such an agitator (950 KHz). No particle larger than 0.6µm is detected and totally only 8 particles of 0.19-0.6μm are seen.

IV. DEVELOPMENT OF INPUT COUPLER

We are considering wave guide input couplers for TESLA cavities from the TRISTAN operational experience. As the first test we have measured the Qext of such a coupler using a cooper single cell cavity. Enough coupling to 1×10^5 was confirmed if the distance between the iris of the cavity and the edge of the coupler was less than about 55 mm. We have a plan to make a single cell niobium cavity with a wave guide coupler. In this fabrication forming method of the coupler and its influence on the fundamental field distribution and so on will be studied.

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