DEVELOPMENT AND RF TEST RESULTS OF A NEW HF AND H_2SO_4 FREE ELECTRO POLISHING METHOD FOR SUPERCONDUCTING NIOBIUM CAVITIES

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Abstract

A new Electro Polishing method for superconducting cavities using an acid mixture without hydrofluoric and sulphuric acid was developed at ACCEL Instruments GmbH based on an exclusive license from Poligrat GmbH in Munich, Germany (patent pending). Two 1.3 GHz single cell cavities were built and are used for qualification of the new Electro Polishing method. After the Electro Polishing at ACCEL, the cavities are transported to DESY for RF testing. At DESY no further surface removal by any means is done, but a high pressure water rinsing is carried out. Very promising test results were achieved right away. During the first RF test of the first treated cavity, Q values above $2 \cdot 10^{10}$ and accelerating gradients above 20 MV/m were measured at a helium bath temperature of 1.8 K.

DEVELOPMENT OF THE NEW ELECTRO POLISHING METHOD

Following a round table discussion at ACCEL, Poligrat GmbH, Munich, studied the possibility to develop a hydrofluoric and sulphuric free acid mixture for electro polishing niobium cavities. ACCEL provided niobium samples and Poligrat proved on those samples that electro polishing with such a new developed acid is possible.

As a next step, a barrel of the new acid was used at ACCEL to establish the hydrofluoric and sulphuric free electro polishing process on niobium cavities. For this purpose ACCEL built two 1.3 GHz single cell niobium cavities (named 1AC9 and 1AC10) out of leftover material from a cavity production from 1997. Spare TESLA shape center cells were reformed to TESLA shape end cells which are needed to manufacture 1.3 GHz single cell cavities. With the first cavity (1AC9) the necessary tooling and the set up of the new electro polishing process was developed. Parameters like current density, acid flow, bath agitation, cavity orientation and operating temperature needed to be optimized to get a shiny appearance of the complete inner cavity surface. After a total removal of 200 µm, measured by weighting the cavity, parameters producing a stable shiny surface were found.

Additional 50 µm were then removed from the inner surface of 1AC9 followed by a high pressure rinsing of the cavity at ACCEL. The cavity was sealed with blank flanges, shipped to DESY, was additionally high pressure rinsed at DESY, equipped in the clean room with RF test antennas and then tested in a vertical test cryostat. No intermediate heat treatment at 800 °C was performed on the cavity 1AC9 after the electro polishing and prior the RF test no baking at 120°C was done.

RF TEST RESULTS OF 1AC9

By measuring the dependence of cavity Q at low cavity field from the helium bath temperature one can deduce some superconductor parameters like energy gap and residual resistance. A residual resistance of 6 nΩ and an energy gap of Δ/k_B of 17.5 K were measured with cavity 1AC9 (Figure 1). Those values are comparable to other results reported from cavities treated with standard electro polishing or buffered chemical polishing methods. Prior the measurement the cavity was cooled down quickly within 4 hours from 300 K to 4 K.

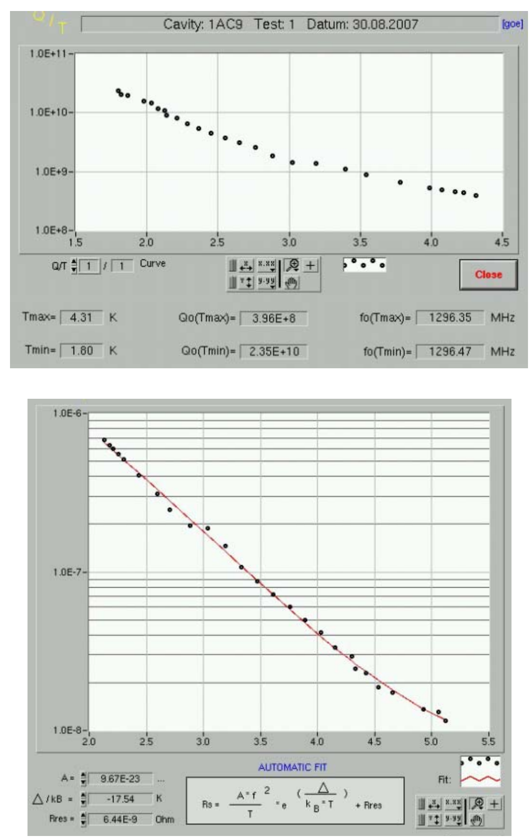

Figure 1: Q(T) curve of cavity 1AC9 after quick cooldown. Standard Q values and residual resistance were reached.

The measured dependence of cavity Q from the accelerating gradient $Q(E_{acc})$-curve is shown in Figure 2. Maximum accelerating gradients of about 22 MV/m with Q values above $8\cdot10^{9}$ were achieved. At 22 MV/m a quench was observed. At fields below 18 MV/m the Q values were above $2\cdot10^{10}$. Temperature maps just below the quench and during the quench were taken (see Figure 3), indicating, that the quench origin is close to the equator. At the moment the reason for the quench is not clear, but multipacting as a source for the quench can not be excluded.

Cavities treated with the standard electro polishing method sometimes suffer from the Q disease problem. In case of hydrogen concentration above some ppm (introduced for example by electro polishing) in the bulk niobium the cavity Q and the reachable fields can be greatly reduced. When cooling down the cavity slowly, surface states are then formed with reduced superconductor properties. The only way to cure the cavity is either a fast cooldown or an intermediate heat treatment at 800 C in a high vacuum furnace to remove the hydrogen from the niobium.

In order to find out, if the new electro polishing method does also introduce hydrogen into the niobium, the cavity was cooled down slowly prior a second RF test. The cavity was parked for 16 hours at about 100 K, the temperature zone, where the surface states with reduced superconductor performance are formed. As can be seen in Figure 2, cavity 1AC9 suffered from the Q disease.

However, one has to keep in mind that cavity 1AC9 was used as a test cavity for finding good electro polishing parameters during the first 200 µm surface removal. Therefore one might imagine that not all parameters were under control during the first tries. Indeed, at some first treatments the acid and the cavity heated up to temperatures more than 50 °C. Therefore, a new test on another cavity with optimized electro polishing parameters was launched.

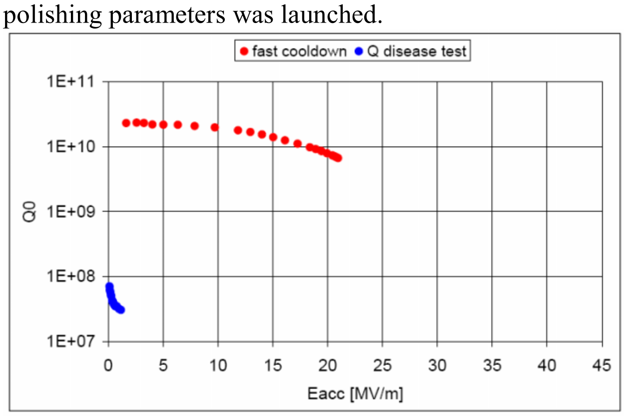

Figure 2: Test result of cavity 1AC9. After a fast cooldown (red dots) the cavity showed good performance and Q values above $1\cdot10^{10}$ for accelerating gradients below 18 MV/m. At 22 MV/m the cavity was limited by quench. For a second test the cavity was cooled down very slowly resulting in very low Q values and gradients, indicating that the niobium of the cavity was contaminated with hydrogen (Q disease).

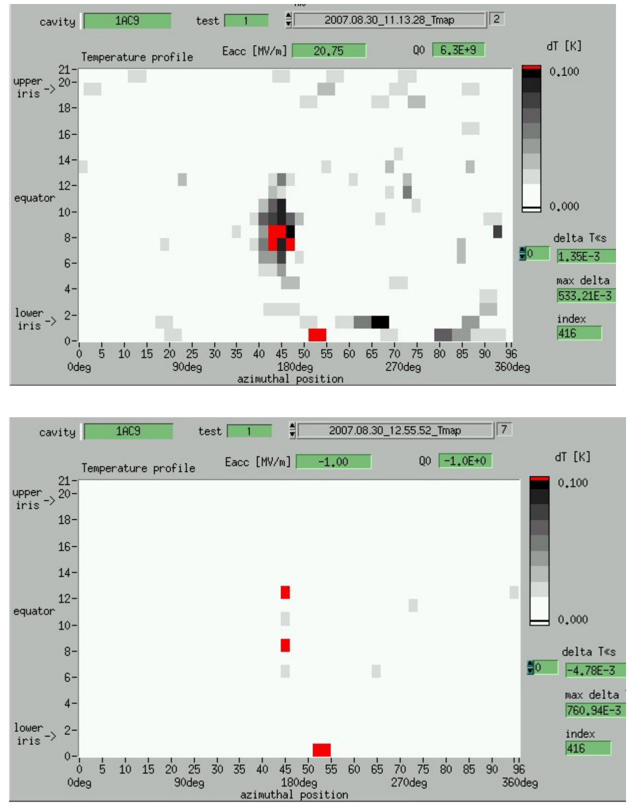

Figure 3: temperature maps taken during (top) and just below the quench (bottom). The maps show the source of the quenc close to the equator. It is not clear if a material defect or multipacting is responsible for the quench.

RF TEST RESULTS OF 1AC1

In order to better judge the potential of the new electro polishing method, DESY provided another cavity, cavity 1AC1. The cavity was treated extensively in the past and the test results are summarized in Figure 4.

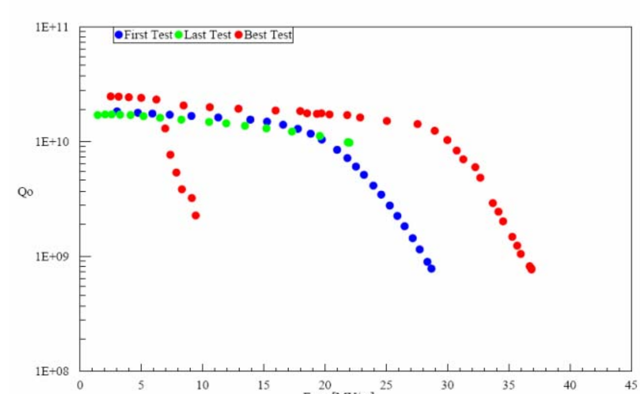

Figure 4: RF test results of cavity 1AC1. First test (blue dots), achieved with standard BCP treatment, Best test (red dots) achieved with standard electro polishing treatment and last test (green dots) achieved with new electro polishing method. During the last test, at 22 MV/m a quench limited the cavity to reach higher fields. Multipacting was observed from 19 MV/m on during that test.

Prior treatment at ACCEL all three cavities 1AC9, 1AC10 and 1AC1 were annealed at 800 °C for hydrogen degassing at DESY. Cavity 1AC1 was then further treated at ACCEL and a layer of 50 µm was removed from the inner surface by means of the new electro polishing method.

The following RF test is shown in Figure 4 (green dots). Cavity 1AC1 reached 22 MV/m and therefore the same field level than 1AC9. During the test multipacting was observed from 19 MV/m on, so it might be, that the final limitation at this cavity is still multipacting, although multipacting was processed for a long time.

Temperature mapping was not applied during this test, but following the same procedure as for cavity 1AC9, the cavity was parked prior cooldown for a second test at the dangerous temperature of 100 K for 16 hours and showed identical RF result than during the first test. Therefore this cavity showed no Q disease and the new electro polishing of 50 µm on this cavity did not introduce significant amount of hydrogen into the niobium.

DISCUSSION AND FURTHER PLANS

Additional 40 µm HF ad H_2So_4 free electro polishing was applied in the meantime to cavity 1AC9. The cavity waits for a RF test at DESY. The aim is to find out, if higher fields than 22 MV/m can be reached. It must also be studied, if multipacting is the limitation. It is well known, that at this field levels multipacting at the equator is observed for TESLA type cavities, but can be processed away relatively easy. It might be possible that the multipacting is not so easy to process for the new electro polishing.

Cavity 1AC10 will receive 200 µm of the new electro polishing and will then be tested at DESY. As 1AC10 was already annealed at 800 C, this test will then show if the new electro polishing can produce Q disease free cavities and if a 800 °C annealing can be avoided.

In case of good results more single cell cavities will be treated to get a better statistics of the RF test results and maximum achievable gradients. It will be also necessary to do electro polishing of nine cell TESLA cavities. ACCEL is currently setting up an industrial electro polishing plant for treating 9-cell 1.3 GHz cavities with the standard electro polishing procedure. This plant can be used also for treating 9-cell cavities with the new HF free and H_2S0_4 free acid mixture.