HYDRO FORMING OF TESLA CAVITIES AT DESY

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Abstract

Since several years the development of seamless niobium cavity fabrication by hydro forming is being pursued at DESY. This technique offers the possibility of lower cost of fabrication and perhaps better rf-performance of the cavities because of the elimination of electron-beam welds, which in the standard fabrication technique have sometimes lead to inferior cavity performance due to defects.
Several single cell 1300 MHz cavities have been formed from high purity seamless niobium tubes, which are under computer control expanded with internal pressure while simultaneously being swaged axially. The seamless tubes have been made by either back extrusion and flow forming or by spinning or deep drawing.
Standard surface treatment techniques such as high temperature post purification, buffered chemical polishing (BCP), electropolishing (EP) and high pressure ultra pure water rinsing (HPR) have been applied to these cavities. The cavities exhibited high Q - values of 2 x 10^{10} at 2K and residual resistances as low as 3 nΩ after the removal of a surface layer of app. 100 µm by BCP. Surprisingly, even at high gradients up to the maximum measured values of $E_{acc} \approx 33$ MV/m the Q-value did not decrease in the absence of field emission as often observed. After electropolishing of additional 100 µm one of the cavities reached an accelerating gradient of $E_{acc} \geq 42$ MV/m.

1 INTRODUCTION

The idea of manufacturing seamless niobium cavities for accelerator application is being pursued in different laboratories [1,2] applying different forming techniques.
The development of hydro forming of TESLA cavities from seamless niobium tube has been pursued at DESY for about four years. A review of these development efforts is given in [3].
Fabrication of seamless cavities has potentially several advantages over the standard cavity fabrication technique of deep drawing cavity parts and electron beam welding them into a cavity assembly. These are: **lower costs** and **improved performance** (in detail see [3].
In the following sections we will shortly describe the technical approach and will report on the encouraging cavity performances achieved after various processing steps such as high temperature post purification, buffered chemical polishing, electropolishing and high pressure ultra pure water rinsing.

2 CAVITY FABRICATION

The first step in the cavity hydro forming program at DESY was the development of seamless niobium tubing with satisfactory material properties. The extensive development work is reported in [4]. In summary, back extruded tubing made from lower purity niobium of RRR=100 showed mechanical properties better suited to bulge forming after recrystallization anneals than tubing made form RRR=300. On the basis of stress-strain characteristics it was found that the stress strain behaviour of the tubes is very anisotropic, but that strain before the onset of necking can be markedly increased by deformation with pulsed stress. This new method proved to be advantageous for hydro forming of cavities, too. The measured stress strain behaviour of the tube to be deformed was used to simulate via computer the hydro forming process. During the actual forming process - an internal pressure is applied to the tube and simultaneously an axial displacement, forming the tube into an external mould- the deformation is controlled by computer, which follows the established simulation protocol.
Several single cell cavities have been manufactured so far; because of the inhomogeneous mechanical properties of the tubes, as mentioned above, several forming difficulties arose such as local thinning in the area of minimum yield strength of the material. Other observed anomalies caused by material inhomegeneities were conical deformations, buckling or distortions of the cavity diameter. However, these anomalies could be overcome by intermediate constraints to an ID of 168 mm (tube starting ID was 134 mm with a wall thickness of 2 mm). In a final step the cavities were calibrated in their final hydro forming mould by increasing the internal pressure to 1300 bar.
Three cavities named 1BT1, 1K2 and 1K3 were the subject of the investigations reported in this paper. Cavity 1BT1 was made at the company BUTTING from a deep

drawn RRR250 niobium tube of 3 mm thickness without any intermediate constraints or annealing steps; cavities 1K2 and 1K3 were formed from 2 mm thick RRR100 tubes and required an intermediate cylindrical constraint because of forming anomalies discussed above. Subsequently, cavities 1K2 and 1K3 were post purified at a temperature of 1400°C for 1 hour and 1350°C for 3 hours in the presence of Ti as a getter material; this process increased the RRR - value to RRR > 400 .
Subsequently, beam pipe sections and NbZr flanges [5] were welded to the mono cells to complete the single cell cavities for testing. Figure 1 shows two of the cavities fabricated at DESY.

Figure 1: Mono cell cavities fabricated at DESY.

3 RESULTS AND DISCUSSION

Standard processing procedures such as buffered chemical polishing (bcp) in a solution of equal parts of hydrofluoric(48%), nitric(69%) and phosphoric (86%) acids followed by high pressure ultra pure water rinsing of app. 1 hr and clean room assembly were applied.
The cavities were attached to the test system and evacuated with a 50 l/sec turbo-pump backed by a scroll pump; the pumping system is an integral part of the test stand. This pumping arrangement has the benefit of allowing immediate evacuation of the "water wet" cavity after assembly of the rf input and transmission probes ; a vacuum in the 10^{-6} torr range is reached after only a few minutes. Routinely, the cavities were baked at T ≈ 75 C for ≥ 12 hours in the dewar prior to cool down. This baking improved the vacuum in the cavity - monitored by a RGA from the high 10^{-8} torr range to the low 10^{-8} torr range; the main gas species released during the baking were water, hydrogen, CO and CO_2.
In the case of cavity 1BT1 several experiments were carried out after several small subsequent material removal steps; as can be seen from figure2, each step resulted in an improvement of the cavity performance. In contrast to cavity performances observed with seamless cavities made by spinning [1], the hydro formed cavity 1BT1 did not exhibit a degradation of Q-value with increasing gradient, but showed a high Q-value up to the limiting gradients - in this case, a "quench". It has been speculated that the Q-degradation possibly is caused by cracks in the cavity surface in the case of the spun cavities - the result of the tests on 1BT1 then indicate that the hydro forming process might be much "gentler" on the material and surface fissures of rather large depth as in the case of spinning apparently are absent.

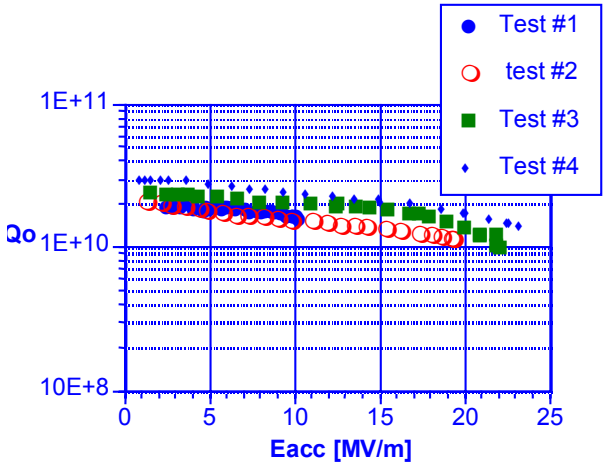

Figure 2: Results for cavity 1BT1; test #1: 40 µm bcp, test #2: ≈ 80 µm bcp, test #3 : ≈ 105 µm bcp, test #4: ≈ 135 µm bcp.
Cavity 1BT1 has so far not been heat treated/post purified after the manufacturing. This post purification will be the next step in evaluating the performance limits of this cavity and it is hoped that further performance improvements can be realised.
Cavity 1K2 exhibited excellent performance after the removal of app. 250 µm of material from the surface ; an accelerating gradient of E_{acc} = 33 MV/m was measured. At this point the cavity was baked at T ≈ 140°C "in-situ" for app. 24 hrs, a process, which had in previous investigations shown on several occasions an improvement in cavity performance. Here, the Q vs E_{acc} behaviour did not change, however, as often observed [6}, the BCS surface resistance improved by 50 %; a residual resistance as low as 3 nΩ was extrapolated from the temperature dependence of the surface resistance.
After this test series, cavity 1K2 was electropolished at KEK by 100 µm and returned to Jlab under vacuum. For the initial test after e-polishing the cavity was only high pressure rinsed and showed field emission loading starting at $E_{acc} \geq 20$ MV/m. In a subsequent surface preparation the cavity was thoroughly cleaned with a surfactant and ultrasound, and high pressure rinsed at 80 bar for 1 hour prior to standard assembly as mentioned above. The result of this test was astonishing: the accelerating gradient had improved to $E_{acc} \geq 42$ MV/m at a high Q-value of > 1.5 x 10^{10} as shown in fig. 3 . During the measurement the cavity showed a mutlipacting level at app. 25 MV/m, which could be passed rather quickly, but never disappeared completely : it sometimes showed up as a burst of x-rays during a decay- measurement, when its

level was passed and also the decay time constant showed a "jump" as the stored energy from the cavity passed through that level.

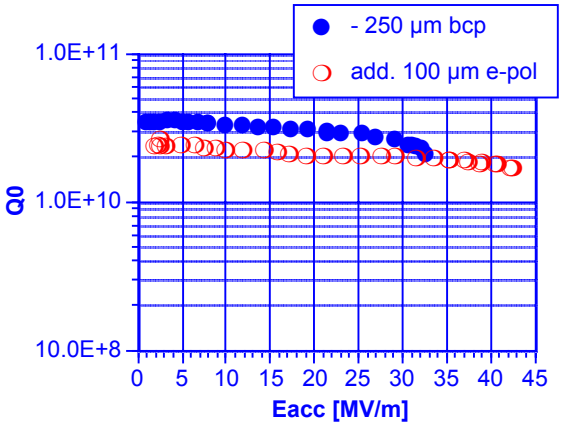

Figure 3: Q vs Eacc for cavity 1K2 after bcp and ep surface treatment.

Cavity 1K3 is still under test and has only been tested once after the removal of ≈ 50 µm, resulting in a gradient of E_{acc} ≈ 10.5 MV/m. In preparation for a second test, an additional 50 µm were removed from the surface; however, during the second test the cavity collapsed under external pressure/axial force and had to be brought back to its old shape. In subsequent tests, the cavity will be constrained by an external support system. Further improvements are anticipated when more material is being removed from the cavity surface.

4 SUMMARY AND OUTLOOK

This investigation has demonstrated that high performance levels in both Q - value and accelerating gradient can be achieved with hydro formed seamless cavities. The measured accelerating field of $E_{acc} \geq 42$ MV/m in cavity 1K2 is among the highest ever achieved with a single cell cavity. The hydro forming process seems to produce rf surfaces with little damage by cracks when compared to cavities formed by spinning since no strong Q-degradation at higher gradients has been observed as often is the case with spun cavities.

However, there are still issues with inhomogeneous material parameters, which led during the manufacturing process to forming anomalies such as e.g. material thinning or buckling. These anomalies could be kept under control by radialy constraining the tube growth at a diameter of 168 mm. A continuously active radial constraint, which is controlled as a function of axial displacement obtained by optimised computer simulations, will provide greater process safety . And this will certainly be needed in forming multi-cell cavities. One of the benefits of the hydro forming process, as mentioned above, is, that exact and reproducible interior dimensions of the cells, which determine their frequency, can be obtained with a high pressure calibration. During this step a pressure of 1500 bar will be applied to the cavity , which is constrained in a mould assembly; this will assure gap-free contact of the cavity wall to the outside mould and will provide a highly accurate resonator with a straight axis. The frequency of the cell(s) is then almost exclusively determined by the wall thickness; if this parameter can be controlled through more homogeneous material parameters, one can hope for a tuned cavity with a flat field profile, which would render room temperature tuning unnecessary.

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