

Development of Seamless Niobium Cavities for Accelerator Application*

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Abstract

In a recent contribution to PAC '99 we reported about results from experiments with single and a 5-cell seamless cavities, which had undergone various surface treatments such as buffered chemical polishing, tumbling , grinding and high temperature heat treatments. Q-values as high as 10^{11} and accelerating gradients up to $E_{acc} \approx 30$ MV/m had been measured.

In the last several months we have carried out several more experiments on additional cavities made from seamless tubes and the results are discussed in this contribution. Also, one of the cavities mentioned in the PAC - contribution was electropolished and was tested after only high pressure rinsing and "in-situ" baking. Results from these experiments are reported in this contribution.

1 INTRODUCTION

The idea of manufacturing seamless cavities is not new, because this technology offers potentially several benefits:

- elimination of electron beam welds
- streamlining of QA procedures
- significant reduction in manufacturing costs
- reduction of necessary infrastructure for mass production because of "speedy" manufacturing

In a previous investigation [8] we had reported about the results obtained with several seamless niobium cavities made from both high purity niobium and reactor grade niobium. Even though the cavity performances were very encouraging and gradients as high as $E_{acc} \approx 33$ MV/m were achieved, several problem areas were identified as listed below:

- Cracks in the material in areas of large deformation (beam pipe transition)
- Possible lubricant contamination during the spinning process and material inclusions from the mandrel
- Good cavity performance was only achieved after the removal of large amount of material from the surface
- Non-uniformity in the material thickness
- Control of tolerances for multi-cell cavities

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In this contribution improvements in the fabrication process developed over the last year at INFN LNL and measurements on two cavities manufactured by these processes are reported below.

2 CAVITY FABRICATION

Several attempts have been made in the past to form cavities without welding either by hydroforming [1,2] or by explosion forming . Hydroforming was only successful for copper as the base material and needed two intermediate annealing steps; it failed when niobium was used mainly because of structural non-uniformity of the niobium tubes . Despite these earlier setbacks groups at DESY [3] and at Saclay [4] are pursuing this technology—backed by computer modelling— with encouraging results.

Initial tests on explosive formation of cavity shapes showed also discouraging results . Therefore the work at INFN Legnaro , which started several years ago, concentrated on developing the well known spinning technique for manufacturing of seamless niobium cavities. The process developed at INFN LNL involves basically two steps: in the first step a tube is formed from a sheet of material either by spinning it onto a frustrum-shaped mandrel of proper dimensions or, more recently, by deep drawing a tube with a diameter equal to the outside diameter of the cavity; in the second step the tube is then spun onto a demountable die of the true shape of the cavity, which is either made of precision machined nylon or stainless steel.

When the spinning process is completed—it takes typically one hour to spin a single cell cavity and the better part of a day to spin e.g. a 5-cell cavity—the mandrel is extracted by collapsing the "keyed" elements of it. The main advantage of this process lies in the possibility of avoiding intermediate annealing and even multicell cavities can be cold formed straightforwardly from a planar disc. More details can be found in ref .[5-7].

Figure 1 shows schematically the various manufacturing steps needed for conventional cavity fabrication and the reduced number of manufacturing steps for fabrication of seamless cavities.

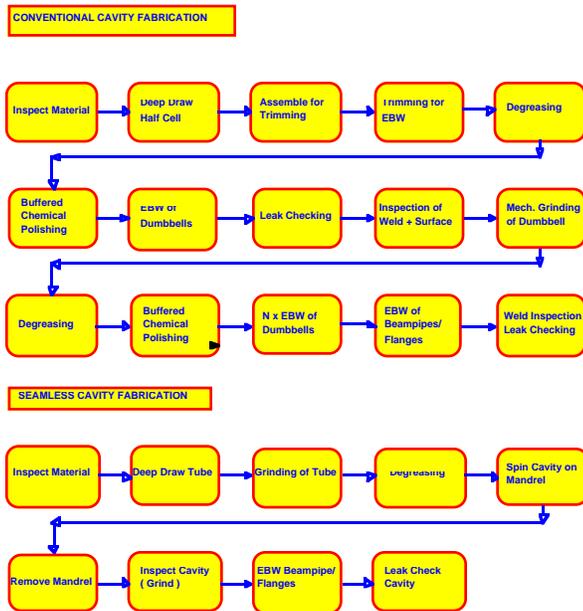


Figure 1: Schematic of Cavity Fabrication

Figure 2 shows a snap shot of the forming process for a multicell niobium cavity from a deep drawn tube. One can clearly recognize the subsequent forming of the cells onto the mandrel.

The cavities of this investigation named P6 and P7 were fabricated from high-purity niobium. In contrast to the earlier cavities, the results of which were reported in ref. [8], the initial tube for the forming was made by deep drawing and not by spinning a sheet onto a mandrel. This process results in a better control of the wall thickness of the material and seems to introduce less stresses and defects in the material.

3 RESULTS AND DISCUSSION

During the fabrication at INFN LNL of both cavities some distinction were made in the sequence of the fabrication steps :

for cavity P6 the deep drawn tube was ultrasonically cleaned prior to the spinning of the monocell and subsequently the cavity surface was mechanically ground by app. 40 μm to remove surface imperfections and cracks in the material;

for cavity P7 the tube was mechanically ground by app. 30 μm after the deep drawing, ultrasonically cleaned and then spun onto the mandrel; no further mechanical grinding of the monocell was done.



Figure 2: Spinning of a multi-cell cavity

After the spinning was completed at INFN Legnaro, the cavities were sent to TJNAF, where beam pipe sections and flanges were electron beam welded to the cavities[9]. Subsequently, standard processing procedures such as buffered chemical polishing (bcp) in a solution of equal parts of hydrofluoric, nitric and phosphoric acids followed by high pressure ultrapure water rinsing for up to 2 hrs and clean room assembly were applied. In order to learn as much as possible about the benefits of the different fabrication steps applied to these cavities and their impact on the surface damage layer, we wanted to carry out a series of small subsequent material removal steps prior to each measurement of the cavity performance. In the case of cavity P6 only 20 μm of material were removed from the surface in preparation for test #1; the result of the test was very poor. Because of a communications deficiency (not realizing that the final step in fabrication had been a mechanical grinding step, during which most likely some of the grinding compounds were embedded in the surface) one of us (PK) continued with a vacuum annealing of the cavity at 850 $^{\circ}$ C for two hours after the first test. Additional material removal of \approx 100 μm did not improve the cavity performance. After a further heat treatment at 1400 $^{\circ}$ C and more bcp the cavity finally exhibited some decent results, which improved further by "in-situ" baking at 140 $^{\circ}$ C for 45 hrs and by He processing.

For test #7 the cavity was electropolished by 40 μm at KEK [11], sent to Jlab and after high pressure rinsing for 1 hr retested with improved performance as indicated in figure 3.

To cavity P7 a sequence of small material removal steps by bcp were applied. After a removal of only \approx 105 μm —much less than the standard material removal for conventionally fabricated cavities—the cavity reached a gradient of $E_{\text{acc}} \sim 30 \text{ MV/m}$. As can be seen in figure 4, also the strong degradation of the Q-value at higher gradients in the absence of field emission loading was drastically reduced. A visual inspection of the cavity surface revealed that the usually present surface cracks in

spun cavities [8] at the iris of the cavity had been drastically reduced in comparison to the earlier cavities. Most likely the elimination/reduction of these deep cracks by the applied manufacturing process of deep drawing and mechanical grinding of the tube has led to the improvements in cavity performance. Figure 3 below shows the surface preparation steps and performance of cavity P6:

- Forming of tube
- Ultrasonic degreasing
- Spinning of monocell
- 40 μm mechanical grinding
 - ~20 μm bcp (test #1, very bad)
 - 850 ° C for ≥ 2 hrs
 - ~ 30 μm bcp (test #2, very bad)
 - ~ 100 μm bcp (test #3, very bad)
 - ≥ 1200 ° C for 1 hr
 - cavity collapsed under vacuum, straightened
 - 5 μm bcp (test #4,bad)
 - 5 μm bcp (test #5, Q-value ok)
 - 10 μm bcp (test #6)
- baseline test
- baked @ 145 ° C for 55 hrs
- exposed to filtered N₂ gas
- add. 35 hrs baking @ 145 ° C
- 40 μm electropolishing (test #7)
 - baseline test
 - baked @ 145 ° C for 55 hrs

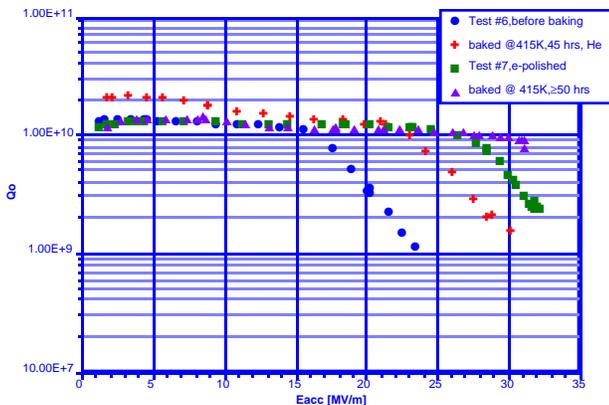


Figure 3 : Performance of Cavity P6 after various Surface Preparations. Measurements are carried out at 2K.

Figure 4 depicts the performance of cavity P7 for the different treatments.

- Forming of tube
- 20 -30 μm mechanical grinding
- ultrasonic degreasing
- Spinning of monocell
 - ~25 μm bcp (test #1)
 - ~30 μm bcp (test #2)
 - ~20 μm bcp (test #3)
 - ~30 μm bcp (test #4)
 - ~30 μm bcp (test #5)

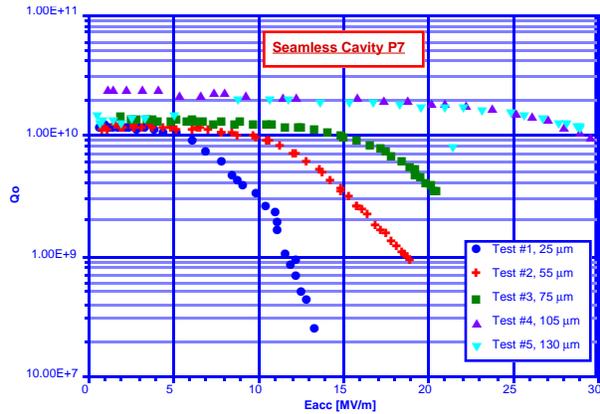


Figure 4: Performance of Cavity P7 after various Surface Preparations. Measurements are carried out at 2K.

The best performances of all the tested monocell cavities made from high purity niobium (a total of 5 cavities) including the one's discussed in ref. [8] are shown in figure 5 for completion. Obviously high performance levels with gradients as high as $E_{acc} \sim 33$ MV/m comparable to the best performances of conventionally fabricated cavities can be achieved rather consistently.

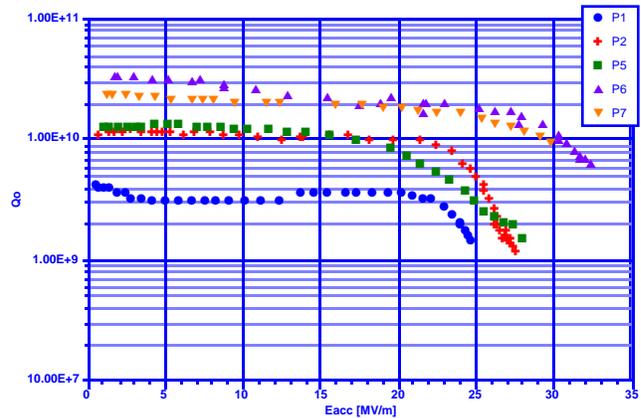


Figure 5: Summary of the best performances achieved with 5 seamless monocell cavities made from high purity niobium of RRR ≥ 250 . All Q_o vs E_{acc} dependencies are taken at a temperature of 2K.

4 SUMMARY

It has been demonstrated in this and our previous investigation that the fabrication of seamless cavities with its potential benefits of lower costs at high performance levels is feasible. By replacing the first stage of the fabrication process from spinning of tubes onto a frustrum-shaped mandrel with deep drawing of the tubes, better material uniformity was achieved. A mechanical grinding of the tube prior to spinning of the cavity is beneficial and apparently reduces the amount of cracks in the high stressed areas of the cavity near the beam pipe transition.

This subsequently results in a much reduced material removal thickness necessary to achieve good cavity performances. Future work will concentrate on further improvements of the surface conditions of the as fabricated cavities by e.g. mechanical brushing, which has already shown encouraging results [10]. For multi-cell cavities future efforts have to concentrate on stringent control of mechanical tolerances to maintain good electrical field flatness. In addition it seems quite prudent that the skillful manual spinning process so far applied for the fabrication of these cavities needs to be transferred to mass production equipment..

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