DEVELOPMENT OF CENTRIFUGAL BARREL POLISHING FOR TREATMENT OF SUPERCONDUCTING CAVITIES

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Abstract

The technological process and a machine for centrifugal barrel polishing (CBP) of the RF surface of single cell, two- and three cell cavities of TESLA shape were developed. The influence of technological parameters on the removal rate and the surface quality is investigated. The maximal removal rate of Nb layer is > 25 µm/h. The highest accelerating gradient achieved on single cell cavities after CBP, electropolishing and baking was E_{acc} = 32 - 39 MV/m with a quality factor of up to Q= 1.4 x 10^{10}.

INTRODUCTION

It is well known that a rather thick niobium layer of ca. 150 µm (so called damage layer) should be removed from the inner surface during cavity preparation in order to achieve high accelerating gradients. Barrel polishing can partly replace the expensive and environmentally critical chemical or electrochemical polishing. In addition a rather smooth surface as result of barrel polishing gives a good starting condition for subsequent electropolishing EP allowing achievement of better EP quality (see for example /1/).

A new machine, especially designed for centrifugal barrel polishing, was built at DESY. Further improvement of the construction and parameter optimization allowed working out the technological process of CBP. The machine improves the treatment of the inside surface of RF cavities (removal of the damage layer and smoothing the welding area) using grinding chips, compound and water. High efficiency of the process was achieved thanks to centrifugal forces appearing during rotation of the cavity around the machine axis, which press the chips onto the cavity inside surface. Removing of the metal takes place by movement of the cavity wall concerning the chips during rotation of the cavity around its axis.

MACHINE AND TECHNOLOGY OF CBP

The machine (Fig. 1) is designed for CBP of single, two and three cell cavities in horizontal and vertical positions /2/. The machine has two pedestals (10) connected by stands (12). The frame is rotating in the bearings of the pedestals. The frame consists of a supporting slab (11), two arms of the frame (6) and of the rod with counterweights (5). The cavity is fixed in the supporting slab. The frame is rotating by the main motor (7) equipped with the controller allowing change of the rotating speed between 0-140 rot/min. The cavity rotates around its axis opposite to the frame direction. Changeable gear wheels (9) allow choice of the rotating speed of the cavity depending on the treatment procedure (preliminary grinding or final polishing).

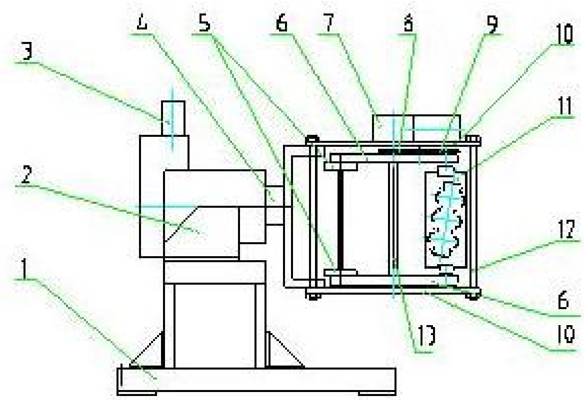

Figure 1: Schema of the machine for centrifugal barrel polishing.
1- support plate; 2- carcass; 3- motor of the rotating system;4- horizontal spindle; 5- counterweight; 6- arms of the frame; 7- main motor; 8- not movable pinion; 9- changeable gear wheel; 10- pedestal; 11- supporting slab; 12- stand; 13- machine axis.

The design of the machine allows to turn it by motor (3) around the horizontal spindle (4) located in the carcass (2).

CBP takes place in two stages. During the first stage the surface is preliminarily grinded. The cavity is filled with 600 g of grinding chips with plastic binding adding 400g of water and 5-10 g of compound. Then one closes the cavity tightly and fixes it in the lodgements of the machine. The CBP happens in the vertical position with flipping in order to remove the material more uniformly.

One applies the following parameters for the first step of CBP: - preliminary grinding. The rotating speed of the cavity around the machine axis is 120-140 rot/min; the rotating speed of the cavity around the own axis is 360-400 rot/min. A layer of 140-150 µm can be removed by CBP with this machine in 5-6 hours. This is sufficient for complete smoothing of the welding areas. In addition one achieves complete removal of all protrusions, scratches and another surface defects.

The second stage of CBP (final polishing) is curried out with chips of plastic or ceramic binding by rotating the cavity around the machine axis with a rotating speed of 70-100 rot/min. The rotating speed of the cavity around the own axis is 100-120 rot/min. Duration of the treatment is 1-2 hours

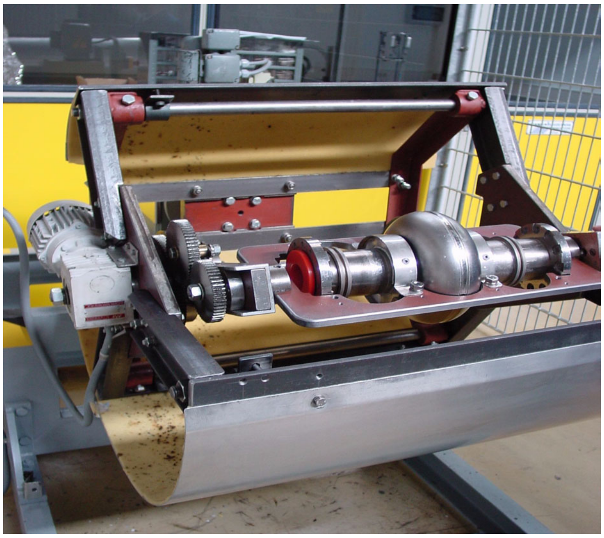

Figure 2: Photo of the machine for cavity CBP.

INFLUENCE OF THE TECHNOLOGICAL PARAMETERS ON THE CBP EFFICIENCY

For optimization of the rotating speed and of the type of grinding chips tests on 14 chip types and 4 types of compound were carried out. A special procedure was developed that allows observation of chips movement on the cavity wall.

Table 1: Influence of the chips type and the CBP parameters on the removal rate.

Area	R_a/R_r	$(\omega_r/\omega_a)^2$	ω_a, rot/min	Removal rate µm/h Chips with plastic binding	Removal rate µm/h Chips with ceramic binding
Overcritical area	2.3	9,8	140	30	8*
		9	120	17	8*
			100	10	5.5*
Under critical area		1.44	120	5.3	4
			100	3	2.5
			80	2.5	1

* The surface is very rough and damaged by flying chips.

It turned out (see Table 1) that the CBP is most efficient when applying chips with plastic binding that are working at overcritical regime. The overcritical regime can be characterized by the formula:

$$(\omega_r/\omega_a)^2 > R_a/R_r$$

ω_r -angular velocity of the resonator rotation around the own axis
R_r – cavity radius
ω_a - angular velocity of the resonator rotation around the machine axis
R_a = A+ R_r – radius of the cavity wall rotating around machine axis
A -distance between cavity and machine axis

The overcritical regime has a high rotating speed of the cavity around the own axis. A thin layer of abrasive particles appeared close to the cavity wall, thus supporting material removal.
Chips with ceramic binding are heavier and more stable than those with plastic binding. Therefore ceramic chips have a bigger friction on a viscose niobium surface at high velocities. The abrasion rate of them is low. Such chips can be applied only for the fine grinding operation, that takes place in the under critical regime defined by formula $(\omega_r/\omega_a)^2 < R_a/R_r$.
The highest efficiency was achieved by using chips with pyramidal shape and plastic binding (type RKS - 10P). These chips were used in most experiments. It turned out that the treatment duration with one load of chips should not exceed three hours (Fig. 3) because of the chip abrasion. The removal rate is 30 µm in the first hour of treatment, 19 µm in the second one and 13 µm in the third one, respectively.

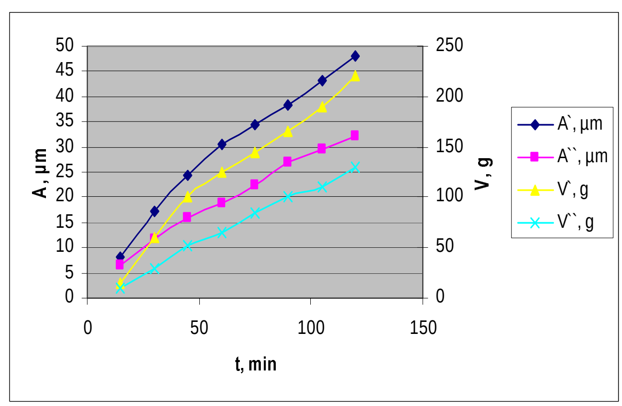

Figure 3: Removal rate A and grinding chips losses V versus time of the treatment t. A` and V` represent the rotation speed n=140 rot /min, A`` and V`` represent the rotation speed n=120 rot /min, (amount of grinding chips 600 g, $(\omega_r/\omega_a)^2$ = 9.8).

Increasing of the chip mass allows enhancement of the removal rate of Nb layer (Fig. 4). However, if the chips dose is more than 600-700 g they do not have enough space. Parts of the chips fly through the centre and damage the surface on opposite side of the cavity.

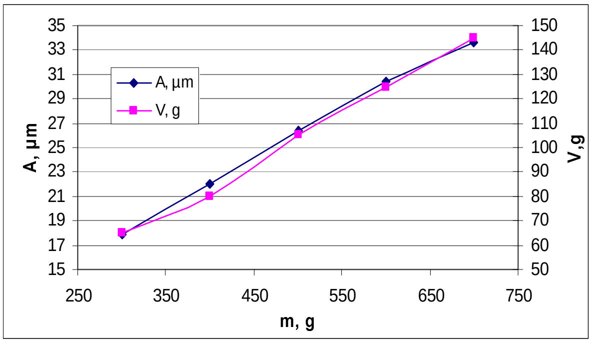

Figure 4: Removal rate A and chip losses V versus amount of grinding chips m (treatment time t=60 min, rotation speed n=140 rot/min, $(\omega_r/\omega_a)^2 = 9.8$).

Increasing of the rotating speed of the machine increases the chip pressure on the cavity wall which results in an enhancement of the removal rate (Fig. 5).

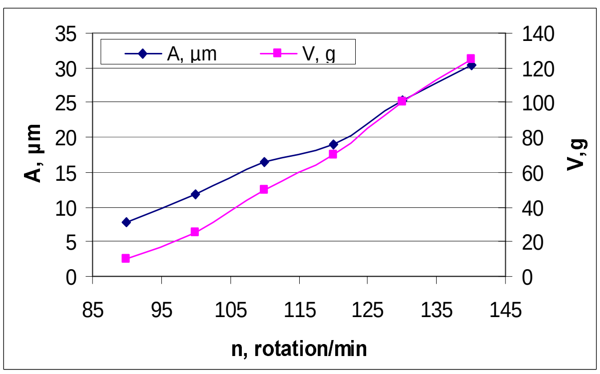

Figure 5: Removal rate A and grinding chip losses V versus rotation speed n (amount of grinding chips 600 g, treatment time 60 min, $(\omega_r/\omega_a)^2 = 9.8$).

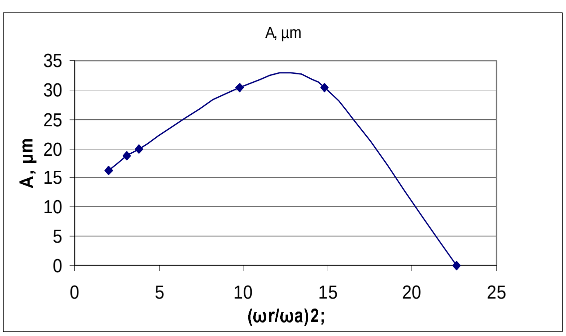

Fig. 6: Removal rate A versus of the parameter $(\omega_r/\omega_a)^2$; ω_r -angular velocity of the resonator, ω_a - angular velocity of the machine (treatment time t=60 min, rotation speed n=140 rot/min, amount of grinding chips m=600g).

The ratio between the ω_r -angular velocity of the resonator, ω_a - angular velocity of the machine is very important. It should be chosen correctly. Otherwise either the removal rate is rather low or the chip adherence on cavity walls and the material removing is close to zero (Fig.6).

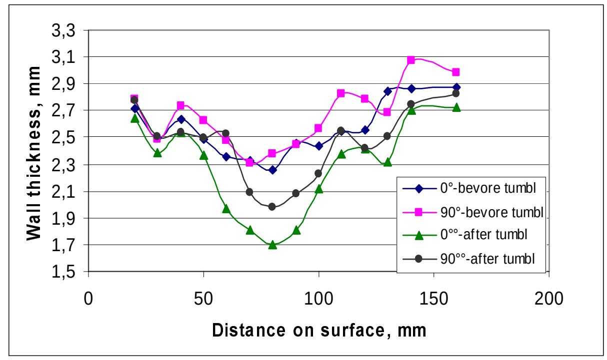

Fig. 7: Wall thickness distribution in the hydroformed single cell cavity before and after CBP.

The removal rate of CBP in the equator region is higher than in the iris area. This can be seen for example on the seamless single cell cavity represented in Figure 7.

CONTAMINATION CAUSED BY ABRASIVE PARTICLES AND HYDROGEN

The CBP treated surface of the cavity was checked by light microscope and scanning electron microscope SEM. Rest of abrasive particles imbedded in the surface was found. The particles penetrate into Nb for example at the EB welding area up to the depth of about 40...50 µm (Fig. 8). Such particles completely disappear after removing a layer of ca. 60 µm.

The thickness of the contaminated layer can be reduced to 20-30 µm by using chips with a finer structure and by applying a lower rotating speed of CBP for the last 30-40 µm. The surface becomes smoother in this case and under considering of the supplementary BCP or EP treatment the second step of CBP (fine polishing) can be cancelled. The duration of the CBP remains the same.

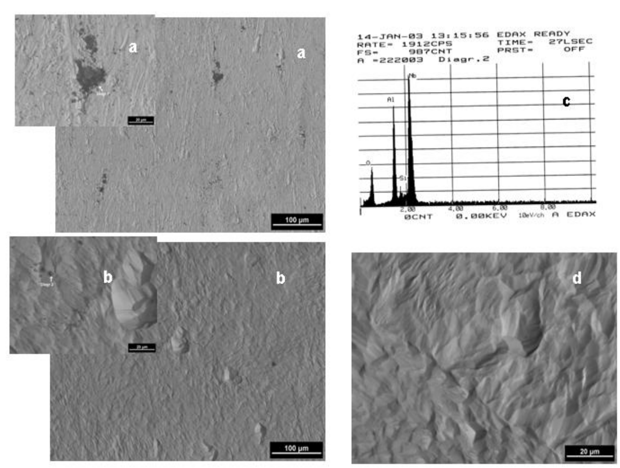

Fig. 8: Inside surface of the cavity after 120-140 µm tumbling, not etched (a). Abrasive particles can easily be detected. EDX –diagram of one of the observed inclusions (c). The same surface after 40 µm BCP (b). Abrasive particles can still be seen. The same surface after 60 µm BCP. Abrasive particles disappeared (d).

The cavity surface of the equator region before and after CBP can be seen in figure 9. After CBP the EB welding seam becomes completely invisible.

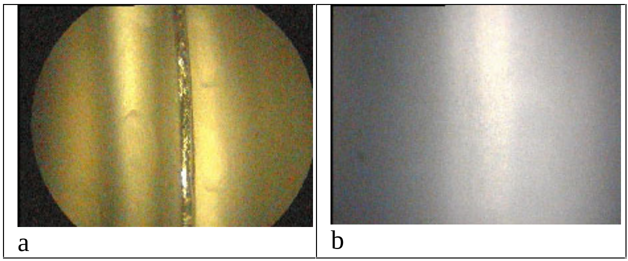

Fig. 9: Equator area of a single cell cavity before (a) and after (b) CBP.

It is well known that hydrogen contamination takes place during grinding of high purity niobium in a water containing medium. As expected the hydrogen contamination was observed in the CBP treated cavities. The hydrogen distribution in the single cell cavity can be seen in figure 10. The hydrogen content is higher at the equator region where a thicker Nb layer is removed. There are two ways of fighting against hydrogen contamination. One way is the annealing at ca. 800°C which very efficiently eliminates hydrogen in Nb. As Fig. 10 shows outgassing of a rather high content of hydrogen in high purity Nb works quite well. The second way is, as proposed in /3/, to use hydrogen free liquids for CBP. In this case the hydrogen contamination at CBP can be reduced significantly. For example the hydrogen content is ca. 5 wt. ppm after removal of 20 µm by CBP in the FC-77 liquid (C_8F_{18} and $C_8F_{16}O$).

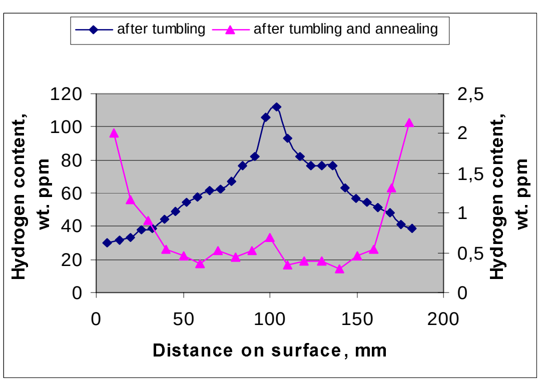

Fig. 10: Hydrogen distribution along the cavity axis in the hydroformed single cell cavity 1K1 after CBP (rectangles, left scale) and after annealing at 800°C for 1 hour (triangles, right scale).

The developed technique was tested on two single cell cavities. The RF test results of these two CBP treated cavities 1AC1 and 1AC2 are shown in Fig. 11. Very high accelerating gradients were achieved: Eacc = 32 – 39 MV/m with a quality factor up to Q = 1.4 x 10^{10}. This proves that the developed CBP technique works efficiently.

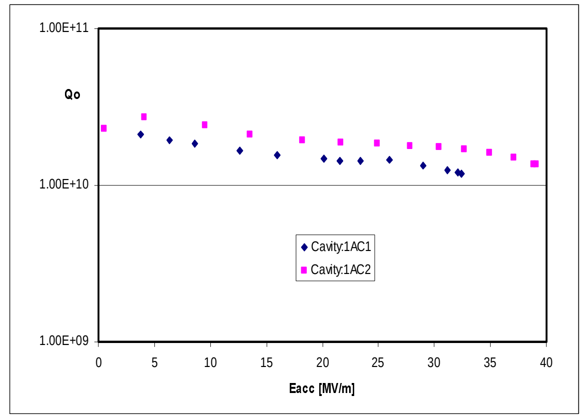

Fig. 11: RF test results of two CBP treated cavities.
Cavity 1AC2: RRR=240 , CBP - 162µm, BCP -40µm, annealing at 800°C, 2h, EP(CERN) - 80µm, Baking 126°C, 48h,
Cavity 1AC1: RRR=290, CBP - 142µm, BCP - 40µm, annealing at 800°C, 2h, EP(CERN) - 80µm, Baking 126°C, 48h.

CONCLUSIONS

The technological process and a machine for centrifugal barrel polishing (CBP) of the RF surface of single cell, two- and three cell cavities of TESLA shape were developed.

Influence of technological parameters on the removal rate and surface quality is investigated. Maximal removal rate of Nb layer is > 25 µm/h. The complete cycle can be carried out in 8 hours by removing of 140-150 µm and achieving the total smoothing of welded areas.

Removal of ca. 50 µm Nb layer by BCP or EP is necessary in order to get the surface released from abrasive particle contamination. The thickness of the contaminated layer can be further reduced by parameter optimization.

The observed hydrogen contamination after CBP can be cured by annealing at ca. 800°C for 1-2 hours.

The high accelerating gradient was achieved on single cell cavities after CBP, electropolishing and baking; Eacc = 32 - 39 MV/m with a quality factor up to Q= 1.4 x 10^{10} at highest gradient.

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