ADVANCEMENTS ON SPINNING OF SEAMLESS MULTICELL REENTRANT CAVITIES

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Abstract

Seamless nine-cell cavities, in either Niobium or Copper, can be fabricated with uniform thickness, by spinning seamless tubes. Seamless tubes are cold formed starting from circular blanks. In this paper we will outline the advantages of the technique and we will report technical considerations in perspective of an eventual mass production.

INTRODUCTION

New generation colliders ask for large numbers of cavities. Reduction of fabrication costs then becomes mandatory. The standard fabrication technique of n-cell reentrant cavities foresees the forming of 2n half-cells and their consequent EB-welding at the equator and at the iris.

This technology is perfect for prototyping, but in the author opinion, it is not the most convenient for a mass production. The EB-welding indeed has several drawbacks:

- Ultra high vacuum is required inside the welding machine meanwhile processing. The RRR values of Niobium at the weld indeed drastically depend on the quantity of residual impurities.
- Welds are not free from defects: micro-cracks can be detected into the weld due to an imperceptible misalignment of the two halves to weld, an imperfect cleaning of the half-cell rim that has to be welded, or a not perfect control of beam power and path, stresses induced in the material due to anisotropic rolling and to anisotropic thermal expansion of the Heat Affected Zone (HAZ). Moreover the surface can be affected by material protrusions and micro-bubbles located deep into the weld. After a surface removal by chemical or electrochemical etching, micro-bubbles become craters and are difficult to be purged by chemical residuals.
- Niobium swarf is not negligible. Half-cells are either spun or deep-drawn by disks cut from rolled sheets, generally squared slabs. The contour material and also the iris disk (cut at the base of all the 2n half cell cups) must be re-melted and refined. The money saved however from swarf recovery is of very little significance, since it will be re-bought from Nb suppliers at almost the price of Steel. It goes underlined that the high price of Niobium material is essentially due to the purification process. Raw material has a relatively low cost. It is indeed not generally well-known that Niobium abundance in nature is even higher that that of Copper.
- Time of manufacture is also a parameter that has to be considered, since it directly affects cost. Up to the present moment, none has done simultaneously the 18 or more welds of a nine-cell of the TESLA-type. Welds are done subsequently one by one, and in the same way it is done also the charging of parts to be welded into the machine. The possible automation of the EB-based fabrication technique must still be demonstrated.

Seamless cavities certainly represent the way to large scale production, since both manufacturing time and costs can be kept minimal. Spinning, in particular is a forming technique as simple as powerful. Nine-cell-cavities can be spun both directly from disk and from a seamless tube. Tubes can be easily formed both from planar disks (by spinning or deep-drawing) and from a billet (by extruding).

THE SPINNING TECHNIQUE

The spinning process [1,2] of a copper mono-cell from blank is displayed in fig. 1. The process is mainly divided in four steps. A circular disk of 400 mm diameter and 3 mm thickness is first preformed onto a frustum shaped mandrel, then the first half-cell is formed and a cylindrical shape is given to the remaining part of the piece, by means of a second pre-mandrel. The third step consists in spinning the obtained manufact onto a collapsible mandrel that has exactly the same shape of the cavity interior, up to when the roller overcomes the equator and fixes the piece to spin onto the mandrel. Then the fourth and last step consists in inserting a further frustum-shaped collapsible mandrel in order to guide the material when spinning the second half-cell. Both collapsible mandrels are then removed.

Generally the most part of the working time is spent in order to set-up the machine. The whole forming operation takes less than 10 minutes, a time absolutely competitive in comparison with the standard half-cell drawing, edge trimming, positioning into the EB- Chamber, vacuum pumping and welding. The dismounting operation of the mandrel takes a few minute time. In order to reduce fabrication times, mandrels made of low melting alloys or dissolvable compounds have been tried successfully and are under study at the present for a future industrialization of the techniques. The presence of an internal mandrel insures the high respect of tolerances on internal dimensions and as a consequence of the resonant frequency.

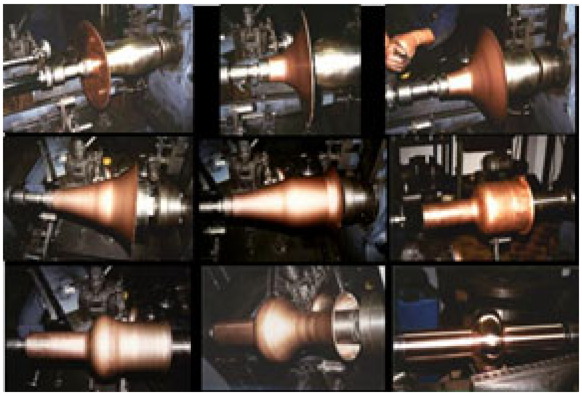

Figure 1: Spinning of a 1,5 GHz Copper cavity.

Copper, Niobium, Niobium clad Copper, Aluminium and even Niobium sputtered Copper blanks, have been successfully spun in a range of frequencies ranging from 6 GHz to 500 MHz, as shown in fig. 2.

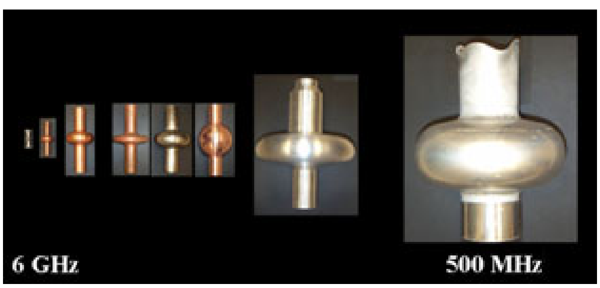

Figure 2: The spinning technique is successfully applied at low cost to cavities of 6 GHz, 3 GHz, 1,5 GHz of different beta, 700 MHz and 500 MHz.

Cavities after spinning must be internally tumbled or mechanically grinded, then simply electropolished. Low temperature radiofrequency tests have proofed that the seamless approach and in particular spinning is a solution worthwhile to pursue. Q-values over 1e+10 and accelerating fields over 40 MV/m have been reproduced on all the last spun prototypes spun at LNL of the INFN, treated and measured in different laboratories. In fig. 3, it is reported the most significant and representative result obtained by K. Saito at KEK at 1,6 K onto a bulk Niobium 1,3 GHz monocell, spun at LNL of the INFN.

One another point in favour of the spinning technique is given by the CERN results on Niobium sputtered Copper cavities. Although the Q-slope versus accelerating field that is an usual problem for thin film cavities, Q-values up to 1e+11 have been achieved at low power. In this framework it goes underlined that the Niobium sputtering technology works only onto spun substrates.

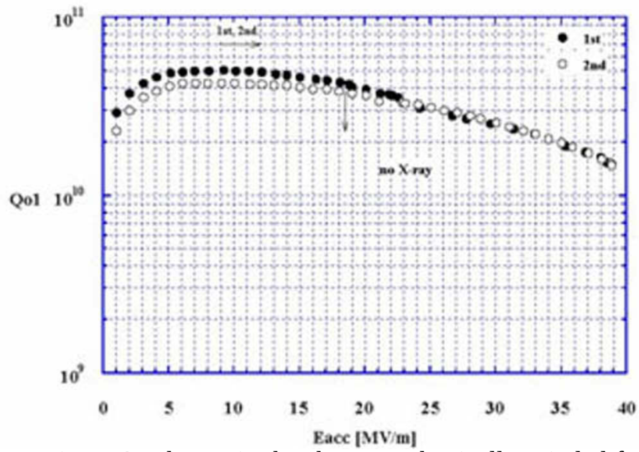

Figure 3: The cavity has been mechanically grinded for 100 microns, then barrel finished for 84 hours, vacuum annealed at 750 C for 3 hours, electropolished for 50 microns and then high pressure rinsed.

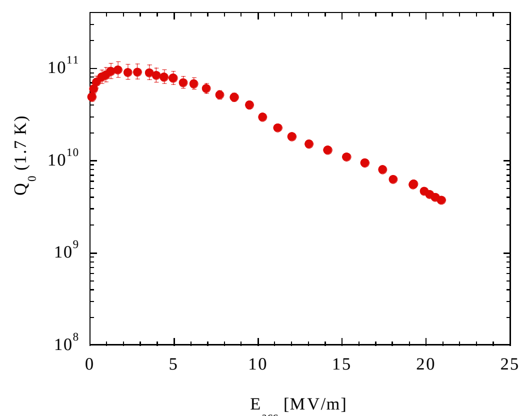

Figure 4: Niobium film 1.5 GHz resonator; the film has been sputtered onto a spun Copper resonator.

EB-welded or hydroformed substrates are not suitable for Niobium sputtering: Q-values are in the range of only 1e+9. In the author opinion, the reason is due to the getter properties of niobium. It is well-known that diffusion of gaseous impurities across grain boundaries (inter-grain diffusion) is two or three order of magnitude higher than that inside grains (intra-grain diffusion). Spinning is compressing the material onto a an internal steel die, while hydroforming is expanding the copper tube onto an external die. Keeping that into account, spinning "closes" the spaces between grain boundaries, blocking diffusion. Hydroforming instead opens those spaces, enhancing diffusion of impurities from substrate that go straight into the Niobium film.

MULTI-CELL SPINNING

Multi-cell cavities either in Niobium or Copper can be formed both directly from circular blanks and from tubes. In fig. 5 it is shown the spinning procedure of a ten-cell 1.5 GHz cavity from a 1 meter diameter disk. Spinning a cavity directly from a disk is more immediate process than that from a tube, but of course it is more difficult to industrialize. The reason is that after the forming operation of each cell, the remaining material to be formed is shaped in form of a frustum. That frustum becomes shorter and thinner, the more cells we spin. As a direct consequence, each cell is spun from a different dimension frustum, and the force applied then to the material is different from cell to cell. The spinning of a 9-cell resonator, therefore, is based on a 9-step procedure, where each cell forming step is different from the subsequent. When forming a cavity from a tube instead, each cell is formed exactly in the same way. This, of course, is a procedure much more industrial. If ever 20,000 cavities will be built, one should only repeat 180,000 times the same operation. In reality, if the spinning of the resonator is performed onto a non-annealed seamless tube, cells are not formed applying rigorously the same forces to the forming of each cell. The tube hardening indeed grows progressively along the tube axis depending on the tube forming solution we choose. This however is a problem of minor importance: The spinning procedure remains unchanged from cell to cell, if the cavity is spun under high pressure between lathe headstock and tailstock; in alternative it is always possible to anneal the tube before spinning.

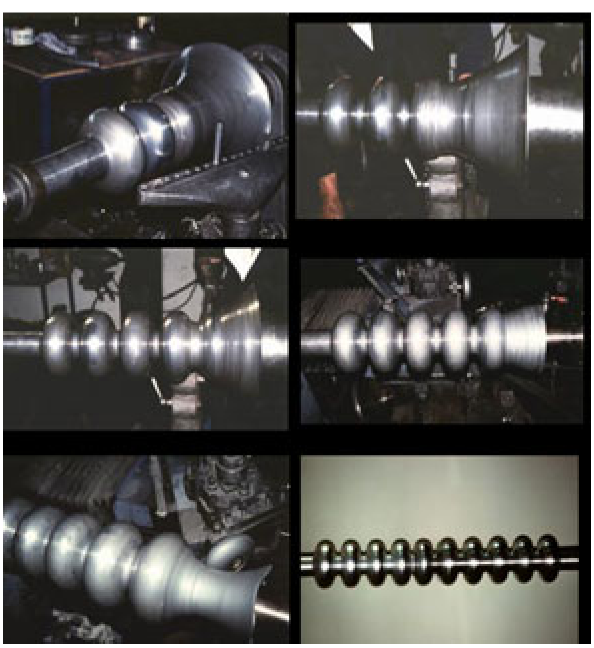

Figure 5: Spinning of a multicell cavity from disk.

SEAMLESS TUBE FORMING

Niobium seamless tubes however are not commercial and the R&D of such tubes is mandatory whenever planning the construction of large number of resonators. In order to get seamless tubes suitable for the further spinning process, we are simultaneously developing three different methods: forward flowturning and deep-drawing both direct and reversal.

Figure 6: Flowturning of seamless Cu tubes.

Both Niobium and Niobium clad Copper have been successfully formed by flowturning (fig. 6-7). Tubes 1400 mm long are normally formed without any intermediate annealing from either disks of 8 mm thickness and 780 mm diameter or disks of 12 mm thickness and 550 mm diameter.

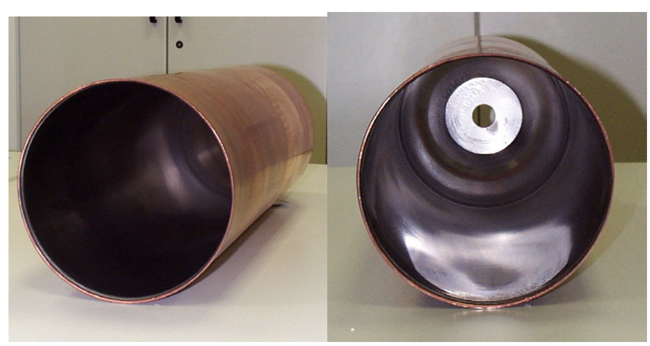

Figure 7: Niobium clad Copper seamless tubes.

Bi-metal tubes can be successfully formed both by flowturning and by deep-drawing. Of course, by deep-drawing the Nb and Cu original thickness of the slab is maintained in the tube. By flowturning instead the original thickness is reduced, but it is maintained the thickness ratio between the two metals. In the author opinion indeed flowturning is a more suitable technique for composed materials, both because for the better control that one has on tolerances, and for the reduced Niobium thickness one can achieve. Starting for instance from a Nb clad copper slab 10 mm thick (9 mm Copper, 1 mm Niobium) one can easily produce tubes 3,3 mm thick (3 mm Copper, 330 microns Niobium). At that point the Niobium cost saving become very important. Crucial attention however must be paid to the mechanical grinding, barrel finishing and to electropolishing: the quantity of Niobium that is removed should be dramatically controlled.

Deep drawing gives poorer tolerances if compared with flowturning, but it is advisable for a mass scale production because of low costs and of reduced manufacture time. A circular blank is first drawn into a cup then redrawn into smaller diameter parts as sketched in figure 8.

Seamless Niobium tubes (208 mm in diameter and up to 700 mm in height) were successfully deep drawn from 3 mm disks of 800 mm diameter. In the case of direct deep-drawing four steps were needed and again no intermediate annealing was required (Fig. 8).

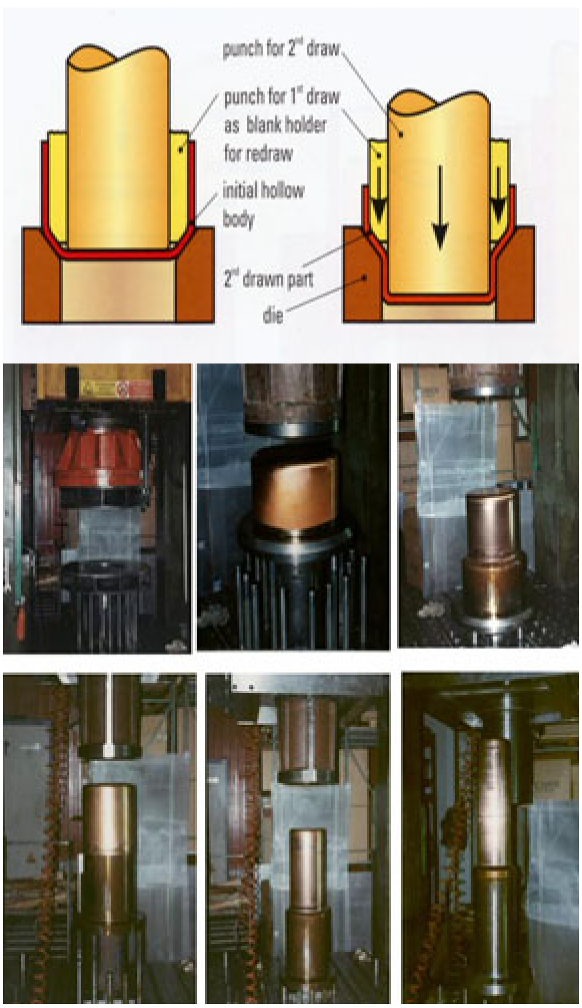

Figure 8: Direct deep drawing of seamless tubes. The techniques works successfully for Copper, Niobium, and Niobium clad Copper.

Reversal deep drawing instead gives an internal surface with a submicrometric roughness. As understandable from fig. 9, the first operation in reversal deepdrawing is just the same than in the direct deepdrawing. The difference is in the redrawing steps: the punch pushes the tube bottom, with the difference that it is plugged externally to the tube rather than internally. In such a way, after each redrawn, what was the external surface becomes the internal, and viceversa. All the procedure does not require any intermediate annealing as well.

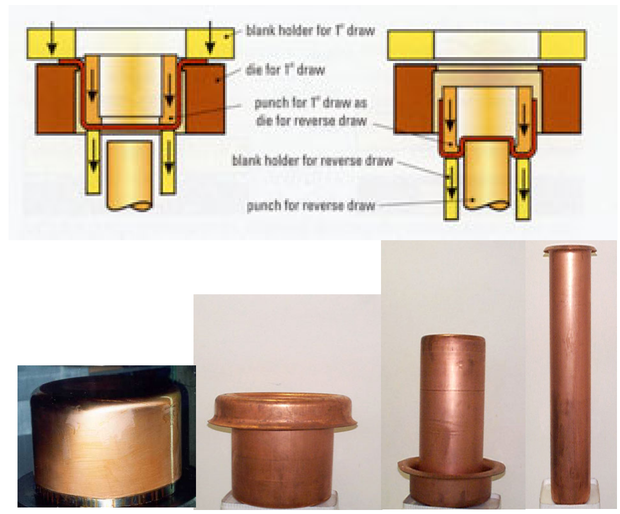

Figure 9: Reversal deep-drawing of seamless tubes.

THE NINE-CELL SPINNING

Spinning of seamless Niobium nine-cell cavities is not a problem. We have started from a circular Nb blank 550 mm in diameter, 12 mm thick. A seamless tube has been flowturned and from it, the cavity has been spun following the usual procedure. The cavity is displayed in fig. 10, and the thickness distribution is plotted in fig. 11. The thickness is in average 2.8 mm, and the two points where the thickness is 2 mm and 1.8 mm are due to mistakes in roller position. Such mistakes are exclusively due to the fact that the one produced is still a prototype. The procedure indeed is still manual and it has been not yet automatized. The whole spinning process has taken around 30 hours of manwork. However the main part of the time is due for machine setting up, for the internal die extraction and for other operations due to the fact that the roller can be pushed only forward and not also backward. This indeed obliges us in extracting the cavity from lathe after the spinning of each half cell, turning the cavity on a specular position along the axis in order to make the successive half cell and so on 18 times. After building a suitable spinning machine, that pushes the roller both forward than backward, and then that can work on both halfcells, the cavity will be spun without the current delay times. The time dedicated to spinning indeed is of the order of less than two hours for a nine-cell.

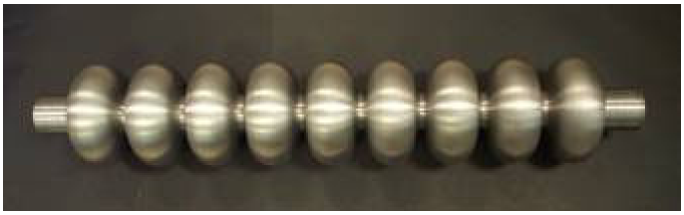

Figure 10: The first Niobium seamless 9-cell cavity ever fabricated.

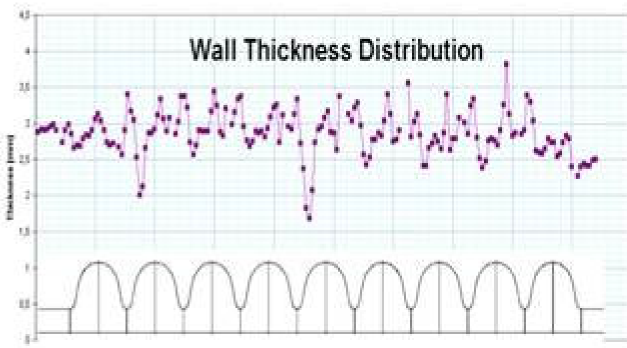

Figure 11: Wall thickness distribution for the nine-cell cavity.

The advantages of the spinning technique can be resumed in the following slogan:

- Short fabrication times;
- No welds;
- No intermediate annealing;
- Almost no swarf;
- Machine adaptability to almost any cavity shape and size without further investments in equipment.
- Low fabrication costs

REFERENCES

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