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RECENT EXPERIENCE WITH THE SPINNING OF 1.5 GHz SEAMLESS COPPER MONOCELLS

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Abstract - *The paper reports technical considerations to take into account, whenever spinning a seamless monocell from an OFHC copper circular blank. The formation of buckling, the anomalous thinning of the cavity wall or the appearing of cracks can be kept under control, depending on forming parameters such as the rotation speed, feed rate and roller shape. The thickness uniformity of the resonator is strictly related to the shape of the breakdown mandrel (chuck) used for preforming the blank. No intermediate anneals are needed during forming. Hardness measurements and metallographic analyses locate the regions of the cavity where spinning parameters are the most critical.*

Introduction

Strong interest around new forming techniques has arisen throughout the superconducting accelerators community, since the Tesla Test Facility (TTF) construction was started [1].

Some of the authors have proposed a new technique for cold forming seamless multicell resonators based on the idea of spinning a single circular blank on the outside of a particular mandrel [2-3]. In the following text we report some technical considerations on how to avoid forming failures whenever spinning 1.5 GHz copper monocells. The aim of the work was the understanding of the forming technique on a simplified model of convenient size such as a monocell resonator. We consider this as a compulsory step before moving to the problem of multicell forming.

The forming process

Fig. 1 shows the workpiece and the breakdown mandrel for preforming and the collapsible mandrel set-up for the final forming, together with an alluminum and a copper workpiece in diferent stages of the process. The preforming operation was performed on a hydraulic machine, while the spinning of the final resonator was made on a hand-spinning lathe, using a scissors-like tooling (a roller lever paired to a compound lever pivoting on a pedestal).

If starting from an annealed slab, intermediate anneals are not necessary. At temperatures higher than 200°C, copper starts to become softer (fig. 2). After a vacuum annealing for two hours at 250°C, the Vickers hardness of our copper blank was equal to 48 HV. Annealing at higher temperatures improves ductility slightly, but promotes grain grow. This is responsible for the appearance of an "orange peel" surface in the cavity interior.

Obviously the resonator could be directly spun onto the final mandrel. However the use of a breakdown mandrel minimizes the risk of getting anomalous thinning of material, since it helps in driving the progressive plastic deformations in a way to avoid anomalous material stretch, that otherwise would propagate in an uncontrolled way. It is the shape of the preforming chuck (in particular the height of the frustum part) that determines the wall thickness ratio between the two irises. An initial value of 4 : 1 of such a ratio obtained by means of a naive design pre-mandrel, could be promptly improved to almost 1 : 1 by means of a more accurate sizing of the chuck frustum cone. Fig. 3 shows the thickness and the hardness distribution profile after both steps.

Risk of breaking the piece

Spinning is a forming process in which the sheet thickness remains unchanged. Spinning belongs to the tensile-compression forming processes since tangential compressive and radial stresses are generated in the deformation zone just as in deep drawing. Flowturning, also known as shear forming or rotoforming is similar to spinning, but it intentionally thins the metal by shear forces. In contrast to spinning, flow turning is a compressive forming process like rolling.

Usually spinning is done on curved surfaces, but the achieved elongation is seldom very large being saved the original workpiece thickness. On the other hand with flowturning it is possible to elongate the material to a reduction unobtainable by any other plastic deformation technique. The flowturning of a curved contour piece is often so complex that the geometry of the piece is often limited to the one of simple cones or a cylinders.

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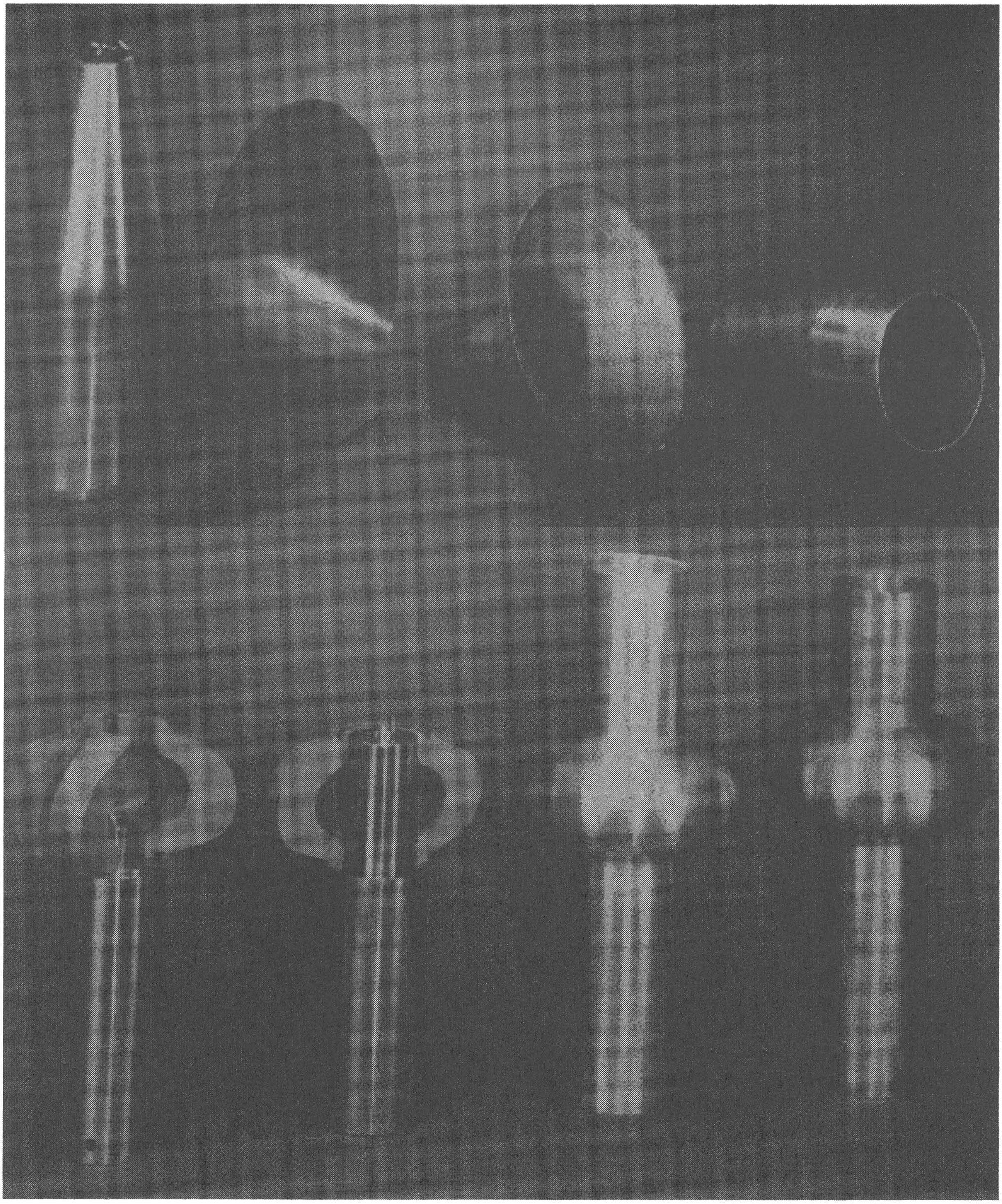

Fig. 1. Mandrels set-up for spinning monocells resonators and progressive steps of forming.

It must be noted that our forming process calls for a hybrid technique between spinning and flowturning. That makes quantitative treatment of the process dynamics even more dificult. However in this context we will report on general concepts that are common to both techniques.

The forming process cannot be carried out in a single step, but the workpiece is shaped with the roller or a forming bar in several increments. Forming does not take place along the entire circumference at once, but it is limited to the small region near the roller. The roller geometry influences the forces acting on the piece during the process. At a given instant the force applied by the roller onto the piece can be broken down into three components, as sketched in fig. 4: an axial component **Fa**, a radial component **Fr**, and a tangential component **Ft.**

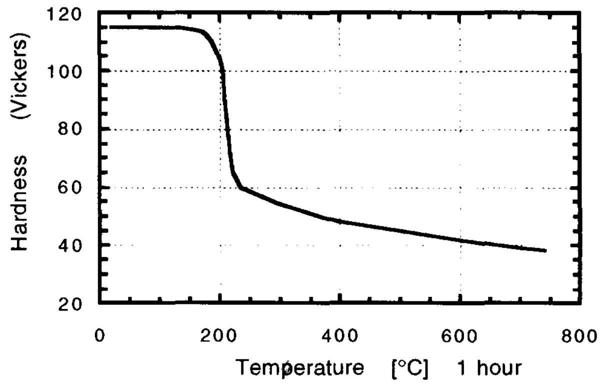

Fig. 2. Hardness of OFHC-Cu versus temperature for 1 hour annealing.

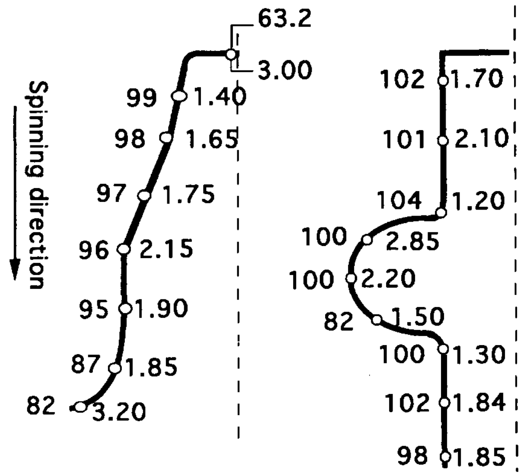

Fig. 3 Averaged hardness and thickness distribution profile along a meridian for a copper workpiece after preforming and after forming . For each profile hardness (Vickers) is reported on the left, while thickness (mm) is on the right. Almost no difference is found instead across azimuth.

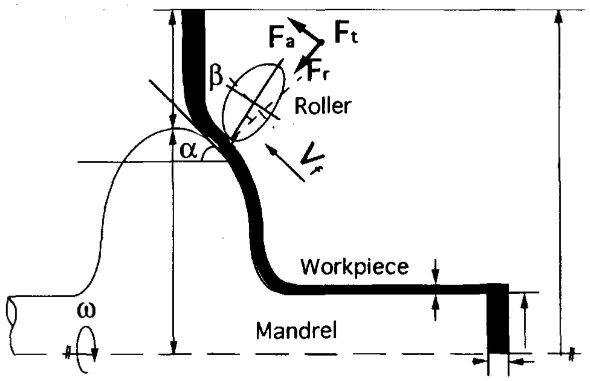

Fig. 4. Schematic representation for the forces applied by the roller to the workpiece during the spinning operation. F_a and F_r are displayed in the section plain, while F_t is orthogonal to the plain.

A material element in the deformation zone is loaded by radial tensile and tangential compressive stress. In the wall of the workpiece there are axial tensile stresses. Analogous to the drawing ratio, the ratio between initial and final diameter is called "Spinning ratio". The largest spinning ratio that can be achieved in a single step is limited by three failures modes.

Irreversible wrinkle formation due to tangential Compressive stresses - Due to the compressive tangential stress the piece edge tries to buckle rather than shrink. During spinning the flange is supported only in the region of the tool and it is free over the remainder of the circumference. Hence, unless a back-up roller or wooden lever is used to accompany the workpiece edge, the tendency to buckle and to form wrinkles is greater in spinning than in deep drawing.

Wrinkles formation is determined by at least five factors: the mandrel geometry, the roller geometry, the blank characteristics (material, diameter and thickness), the rotation speed of the chuck ω and the feed rate v_f of the roller. Buckling can be broken down into two different plastic deformations, one in the radial direction and the other in the circumferential direction. Keeping constant the angle between mandrel and roller, the roller diameter and the edge radius of the roller, the appearance of wrinkles is a threshold phenomenon starting when the feed per turn v_f/ω passes a given value. The increase of the feed rate v_f or the decrease of the rotation speed ω favours buckling (fig. 5a). Fixing instead the kinematic parameters, for a given material, buckling is favoured by decreasing the piece thickness, by having a large diameter of the starting blank and by a too small α, where α is the angle of the mandrel tangent with the axis.

Circumferential cracks due to radial tensile stresses. If the spinning ratio is very large or if the edge radius of the roller is small, then the axial thrust force of the roller can generate very high tensile stresses in the wall which cannot be transmitted by the corresponding portion of the cup cross section. In this case tangential cracks will appear in the transition from the flange to the wall.

These are the main parameters determining whether such failures will occur, the feed rate and the angle α. In general the smaller this angle is, the higher the probability will be to reduce the thickness up to the breaking limit given by the striction coefficient (fig.5b). There also is a threshold for the feed rate over which the piece will break.

Radial cracks due to tangential compressive stresses and bending stresses. Radial cracks can form in the outermost portion of the flange at the end of the process when wrinkles are removed by an excessive reworking of the material. The resulting alternating bending stress can cause cracks. The defect of pict. 5c is a classical example. Having not yet reached the limiting spinning ratio, light wrinkles

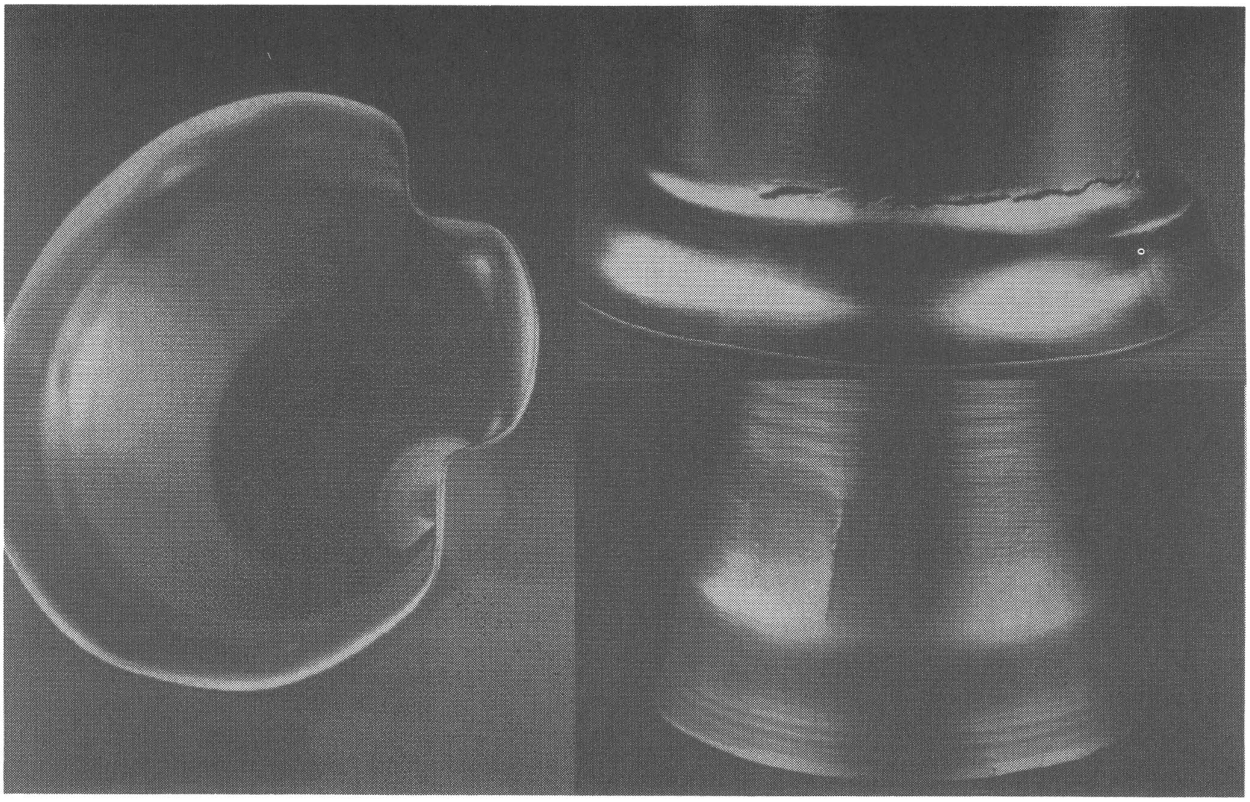

Fig. 5 Three common failure modes when spinning a monocell resonator from a circular blank

can be initially removed by subsequent passes of the roller. The material however keeps memory of its deformations. Further passes of the roller will indeed cause the appearing of longitudinal cracks.

Less dangerous however are edges cracks due to the tensile stresses acting in certain locations and stretch the material under its forming limit. Therefore one of the most important operations during the forming process is the almost continuous trimming of the workpiece edge in order to remove chipped edges. The foil must be perfectly circular and the system composed of the workpiece, mandrel, lathe headstock and tailstock should be perfectly balanced during rotation. The appearance of any misaligned angular momentum, will jeopardize the result causing thickness disuniformity along the azimuth or by longitudinal cracks propagating along the piece.

Conclusions

Spinning could be a valid approach to the problem of seamless resonators. The control of working parameters such as spinning feed, rotation speed and roller-piece contact angle is necessary in order to avoid fractures, buckling or other types of failures. No intermediate anneal is needed. Nevertheless copper hardness distributions suggest that a final annealing should be carried out to restore the low temperature high thermal conductivity of OFHC copper. Workpiece hardening however, could be strongly decreased if instead of spinning the simple copper blank, at least for preforming, it is spun as a sandwich made from the copper blank and a thinner iron blank. If the surface in between is properly lubricated, the iron in contact with the roller will absorb all the stress otherwise released to the copper. In such a way the copper workpiece will be also subject to a much smaller thickness reduction.

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