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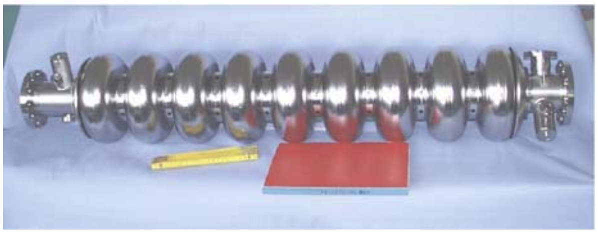

Deliverable 3.1.4.3: "Single cell spinning parameter defined"

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Abstract

Seamless cavities can be spun from either blanks or from tubes according a reliable procedure based on plastic deformation process. The spinning parameters are reviewed and classified in parameters depending on work piece, on material, on tooling, on the machine and on the type of process adopted. Since the number of parameters is about 25, and it would be impossible to investigate them separately, the cross section mutation method has been proposed: holes are intentionally drilled into the blank and their elongation is evaluated as a function of the process. As a function of the forces applied to the work piece by the roller the main causes of failure of the spinning process are identified and understood.

Acknowledgements

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Single cell spinning parameter defined

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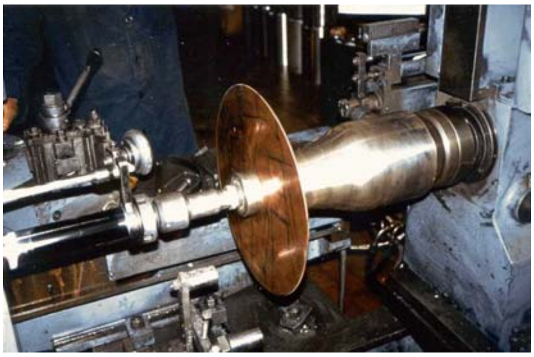
I Introduction



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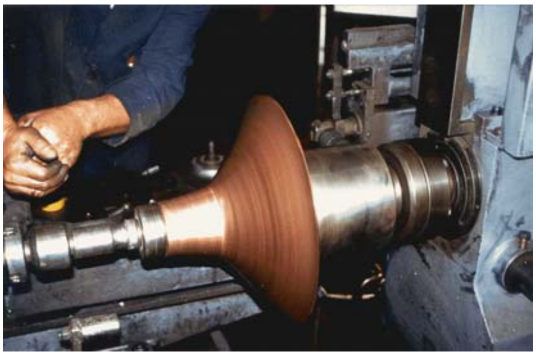

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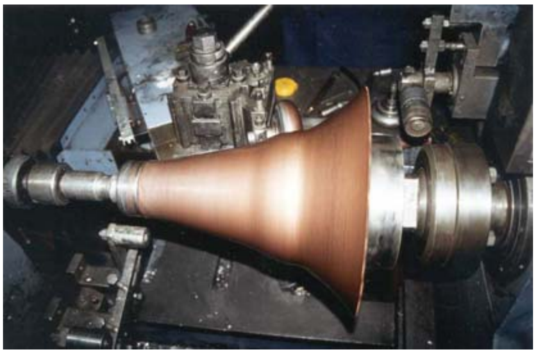

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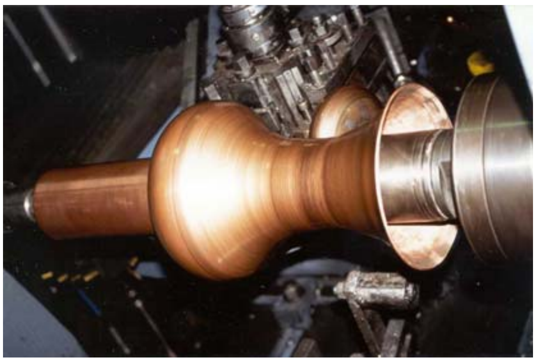

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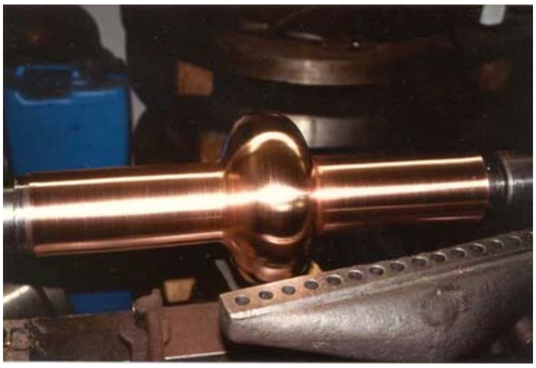

1g

Fig.: 1a – 1f: Different steps of forming a single cell Cu cavity from a circular disc. Please note that in step 1e and 1f an inner collapsible mandrel is in use. This will be pulled out in the next step (Fig. 1g). Niobium forming is done in the same way.

The typical manufacturing process by spinning is shown in figure 1. Spinning belongs to the tension-compression forming process since tangential compressive and radial tensile stresses are generated in the deformation zone just as in deep drawing. Spinning and flow turning are applicable to almost any cold-formable material. After super plasticity, spinning is the only deformation process able to achieve elongations more than 1000% [1, 2]. Surprisingly the elongation limit becomes not important for the classical elongation limits of Nb.

Many process variables have to be considered when spinning from a disk blank, in order to achieve the correct shape, dimensional accuracy, surface finish and wall thickness profile and tolerances.

The shape of the cavities that we spun is shown in figure 2, where a new seamless flange type has been invented and has been tested with success for more than two years. That means that the cavity is totally seamless.

Figure 2: Examples of single cell cavities fabricated by spinning. Please note the integrated flange construction which results in a totally seamless cavity fabrication process.

II Spinning parameters

On the basis of the work done, the following parameters have been recognized to govern the final result.

- Work piece parameters: blank diameter and thickness; shape and size of the final piece to spin.

- Material parameters: flow curve; anisotropy; compressive modulus; compressive yield strength.

- Tooling parameters: Shape, size and finishing of the mandrel; diameter, nose radius and shoulder radius of the roller; type and quantity of lubricant.

- Machine parameter: Positional accuracy; machine rigidity, operational distance between headstock and tailstock, maximum radius of acceptable blank.

- Process parameters: Number of rollers; roller feed speed; angular speed of the rotation chuck; forming force (tangential, axial and radial components); blank support force;

After some spinning practice, the role of each of those parameters can be learned without big difficulties [3, 4]. It is needed only a certain systematic approach in making several tests in which all parameters are kept unchanged and only one parameter is varied.

In this framework, the blank diameter for a mono-cell is fixed to a diameter of 385 mm and a thickness of 3 mm. The material parameters are the standard for 300 RRR Niobium; Niobium from Tokyo Denkai, Wah Chang and Heraeus has been successfully tested.

III The cross section deformation method

In practice there are only a few parameters requiring many tests even from the most skilled spinner. These are the roller path and the number and the direction of forming passes. A simple procedure is to drill a hole into the sheet and observe the deformation of the round cross section into an elliptical cross section. When transforming the blank into a tube in order to spin a cavity, the circular hole in the blank will become more and more elliptical (see figure 3). The elongation of the hole is inversely proportional to the wall thickness of the spun part. Therefore the cross section deformation method is an easy way to find the best spinning procedure without making any thickness measurement of the piece, but just by looking at the cross section mutation directly meanwhile spinning.

During the spinning process the thickness of the material depends on the angle of spinning (see figure 4). Using the cross section mutation method it is a straight forward method to optimize this angle of spinning.

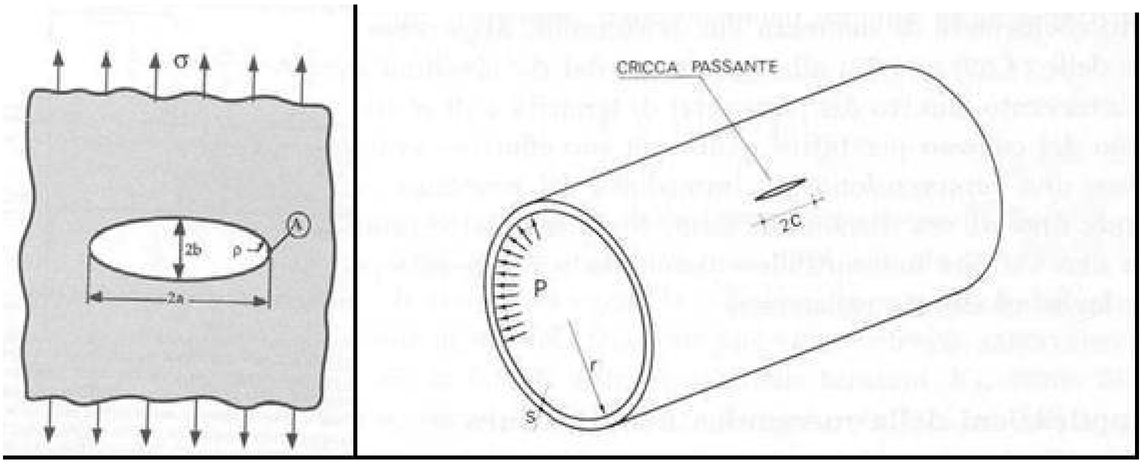

Figure 3: Principle mechanism of the cross section deformation method

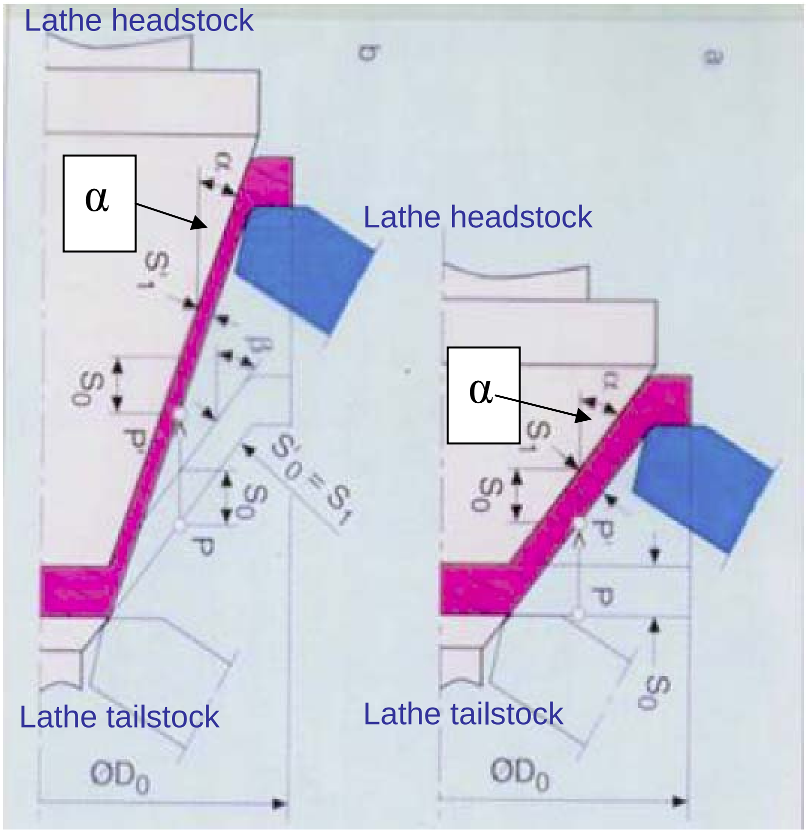

Figure 4: Dependence of the material thickness "S" on the spinning angle α

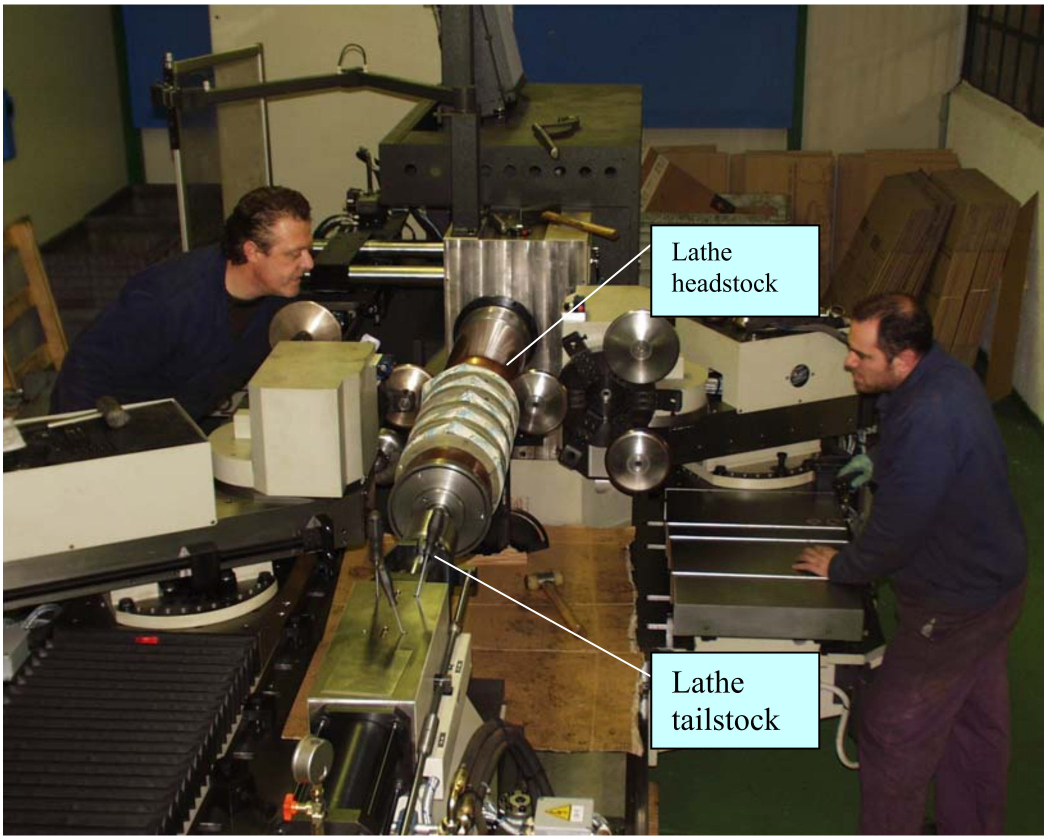

Figure 5: The spinning lathe in the laboratory.

IV Roller parameters

First spinning experience can be gained by using (cheap) Copper instead of the (expensive) Niobium. But there are several specialties when using Niobium. The roller material must be necessarily bronze, when spinning Niobium. Steel tools cannot be used for Niobium, since Steel tends to gall with Niobium. The feeding velocity is lower, due to the fact that Niobium has a tendency to shrink less than Copper. The roughness must be mirror-like, and the shape must be adapted to the cavity shape. The spinning is started with a large diameter roller (when spinning the blank) and must end with a small curvature radius roller (when spinning the iris curvature matching the cell with the cut-off tube. Figure 6 shows different rollers.

Figure 6: Rollers for spinning Niobium cavities: left for the start of the spinning, right for final forming small curvatures at the iris or transition region of cavity to beam pipe.

V Lubricants for spinning

Metal Spun	Spinning at Room Temperature	Spinning at 300-600° F (149-316° C)	Spinning Above 600° F (316° C)
Copper and brass	Soap/wax coating or fatty/mineral oil		
Bronze alloys	Soap/wax or fatty compounds		
Aluminum and alloys	Soap/wax coating, silicone waxes, fatty/mineral oils		
Magnesium and alloys		Soap/wax coating, tallow/graphite, fiberglass	Colloidal graphite, MoS_2, fiberglass
Carbon and low-alloy steels	Mineral/fatty oils, zinc/lithium soap dispersion, MoS_2 paste, dry soap		
Stainless steels*	Mineral/fatty oils, dry soap/borax, wax, glycerin		Solid pigmented coatings, mica, conversion coatings
Titanium and alloys**	Colloidal graphite, MoS_2, phosphate-fluoride conversion coatings, fatty oil/glycerin, silicone bases	Graphite greases, pigmented graphite grease coatings, MoS_2, bentonite clay, powdered mica	Bentonite greases, graphite compounds, MoS_2, MoS_2 greases, powdered mica, metallic coatings
Other refractory metals: Columbium and tantalum	Graphite dispersion, MoS_2, greases, silicone waxes	Not done	Not done
Molybdenum	Not done	Castor oil Beeswax	Graphite and MoS_2, soap
Tungsten	Not done		Copper coatings or pigmented solution

* When formed at temperatures above 1450° F (788° C), on thick sections of 1/4 to 1/2" (6.3 to 12.7 mm), S, Cl, Zn, or MoS_2 lubricants are not used because of surface effects on stainless steel.
** S, Cl, or Zn coatings are not used at elevated temperatures because of surface effects and toxicity.

Table 1: Lubricants for spinning as can be found in standard text books.

The lubricant type is a crucial parameter. The quality of the final result depends on the tenacity and viscosity of the lubricant used and its ability to adhere to the rotating blank. The lubricant is applied to the blank with a swab or a brush before loading it into the lathe. Additional lubricant is added during spinning as judged necessary to avoid the tool from scraping the surface or jamming, and to limit the amount of heat generated. Table 1 lists standard lubricants for various metals. It is the experience of the author that animal fat and soap perform best and produce less contamination.

VI Dynamic spinning parameters

The position accuracy of the piece in the machine of course must be very accurate in order to avoid any undesired texture. The operational distance between headstock and tailstock will be regulated by a tool as shown in figure 7.

Figure 7: Tool to regulate the operational distance between headstock and tailstock

This piece is of fundamental importance for the cavity spinning operation. It is a double concentrically gear mounted onto the lathe tailstock. The internal screw will be fixed onto the die. The external screw ends with a plate which has the dimension of the spun work piece. The plate has a groove that hosts the work piece edge during the spinning. The function of the external screw consists in the transmission of the tailstock pressure directly to the work piece. When we started the project, the tailstock pressure was applied to the work piece through the die. Applying pressure to the work piece directly results now in improved wall thickness uniformity. The work piece indeed slips onto the die during the spinning operations. The separation of the load applied onto the die (through the tailstock) from the load applied onto the work piece gives one more degree of freedom.

As the roller passes on the work piece, the blank gets smaller and smaller in diameter, until the diameter of the spinning chuck is reached. This is possible only by inducing tangential compressive stress in the material. As a consequence, the material is compressed in tangential direction, particularly towards the edge of the blank. There are strict limits, however, to this process. As the load increases, the resistance to buckling is overcome, leading to the formation of wrinkles. The aim is to keep the applied load within limits by progressively forming the blank in a series of steps rather than in one pass.
Figure 8 shows typical shapes at the different stages, whereby a distinction must be drawn between movements towards the blank outer edge, and movements back towards the blank support. The development of work zone and material stress during intermediate stages of spinning is shown. The work piece is shaped with a roller in several increments until the final shape is reached. A material element in the deformation zone is loaded by radial tensile and tangential compressive stresses. We have defined the following quantities:

$+\sigma_t$ = tangential stress,
$-\sigma_r$ = radial tensile stress,
$+\sigma_r$ = radial compressive stress

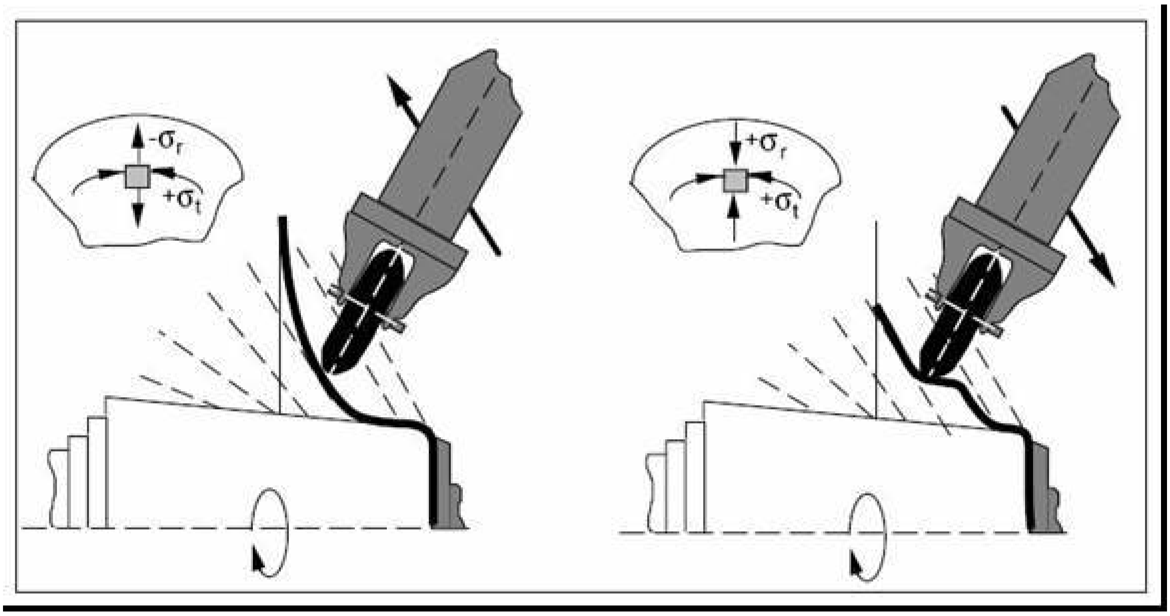

Figure 8: Forming process during moving towards or away from the blank support

Due to the balance of those forces, basically typical failures [5] in spinning are: a) buckling due to tangential compressive strain; b) splitting due to radial tensile strain; c) splitting due to tangential compressive and bending strain; d) splitting due to tangential tensile strain after flipping the edge of the blank over (see figure 9)

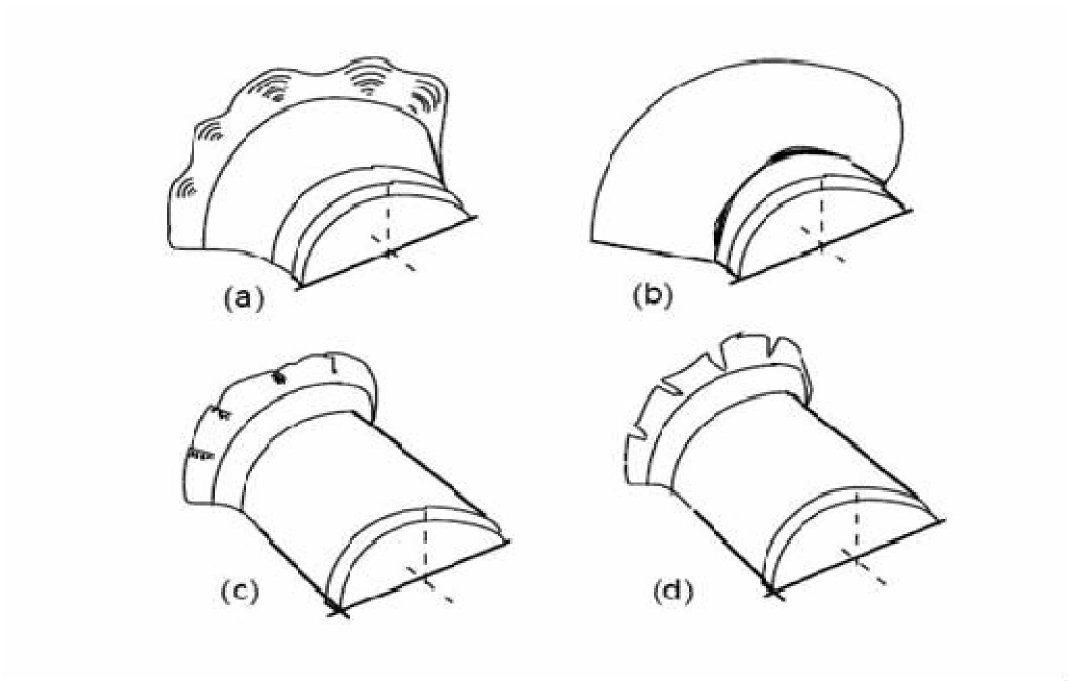

Figure 9: Typical failures in spinning:
a) Buckling due to tangential compressive strain;
b) Splitting due to radial tensile strain;
c) Splitting due to tangential compressive and bending strain;
d) Splitting due to tangential tensile strain after flipping the edge of the blank.

Basically the tendency to wrinkle depends on the relationship between the thickness of the metal and the area of the blank. Also material strength has a direct effect on the limits to tangential loading: a thin large diameter blank will require definitely more intermediate steps than a smaller diameter thick blank. The critical parameter is however the ratio (v/ω) between the feed speed v and the angular speed of the rotating part ω. Increasing v or decreasing ω will favor wrinkles appearing. For a given material and assigned kinematical conditions, lowering the angle a between lathe axis and mandrel surface or increasing the roller nose radius will also provide a higher wrinkles probability. Subsequently radial cracks can form in the outermost portion of the work piece at the end of the process when wrinkles are removed by continued spinning.

Cavities of both frequencies 1.5 GHz and 1.3 GHz can be spun. Just starting from the simple blank, the fabrication time of a mono-cell is of about one hour, while the time needed for a multi-cell is of the order of one hour per cell. Both Copper and Niobium are cold worked. That means that no intermediate annealing is required during forming. The great advantage of spinning consists in the possibility in fabricating one nine cell in only one day. The most evident drawback is that at the moment a manual process is adopted, so the fabrication is subject to the worker skill, concentration and mood. But the spinning process could be automated and the fabrication time can be much more decreased. Spinning is performed in two set-ups and requires the use of two mandrels: a truncated cone pre-form mandrel and the final mandrel in the shape of the finished resonator. The cells of the mandrel are collapsible, consisting in an assembly of sectors held in place by some key-sectors. When the keys are removed, the mandrel collapses and the remaining sectors can be removed from the spun resonator one by one.

VII Summary

Seamless cavities can be formed from a blank or a tube by applying plastic deformations to the material to be shaped. Under an acting stress caused by external forces, the material will deform like plastics without undergoing losses in cohesion. In this respect spinning is a cheap production method of forming axially symmetrical hollow parts of almost any shape. It is a point deformation process by which a metal disc (or a cylindrical preformed hollow component) is plastically deformed by axial or radial motions of a tool or roller. The rollers act onto a work piece which is clamped against a rotating chuck. The mandrel is mounted on the headstock of a lathe. A Copper or a Niobium circular blank is clamped to the mandrel by the follower block. The tool rest and pedestal permit the fulcrum to be moved to various positions by swinging the tool rest and moving the support pin from one hole to another, as needed. Spinning is done by pulling and pushing the tool against the work piece, pivoting around the support pin. At LNL the author has succeeded in cold forming both Copper and Niobium multicells by spinning a simple circular blank onto a collapsible mandrel.

The whole spinning operation does not require any electron beam welding, since also the flanges are seamless. A further advantage of this method lays in the total absence of intermediate annealing. That means that passing from the Niobium blank to a ready-to-electropolish single cell cavity is an operation that takes a time of the order of the tenths of minutes.

The method is relatively simple, once tested and understood. The role of a few key parameters depends on:

- The starting work piece,
- The material to spin,
- The available tooling,
- The adopted spinning machine
- And the process procedure.

No computer code has been adopted for simulating the shape evolution of the cavity. The right procedure has been found by empirically measuring the distortion after spinning of an array of holes drilled on the circular blank before spinning (cross section mutation method) Depending on the roller shape, the elongation of the hole is inversely proportional to the wall thickness of the spun part. The **c**ross section mutation method will be a method for searching the right procedure for spinning a uniform thickness work piece. It avoids unpleasant problems like, wrinkling, thickness weakening, and fracture propagation during and after spinning.

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