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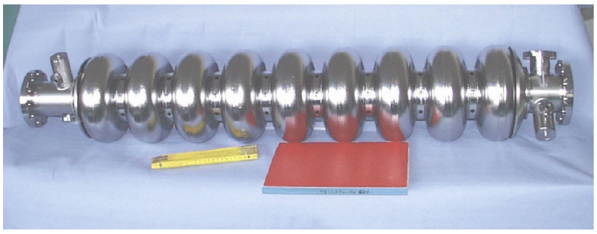

Research and Development on Superconducting Radio-Frequency
Technology for Electron Linear Accelerators

Fabrication of spinning machine
and
Evaluation of spinning parameters

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The spinning of seamless cavities

Spinning is a low-cost 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 rollers acting onto a workpiece clamped against a rotating chuck. It is a characteristic of this process that the movement of tools onto a rotating piece, acts upon a very localized area where plastic flow takes place. 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. At LNL spinning has been applied by the author to the construction of seamless TESLA-shape cavity prototypes:. The technique primarily consists in a rotary-point method of extruding metal pressing it against a mandrel rotated by the headstock of a lathe. A metal disk is firstly spun into truncated-conical shape onto a preform. Subsequently the final shape is obtained spinning the material from the external, onto a mandrel that exactly reproduces the shape of the cavity interior. Hence the truncated cone piece is spun against the mandrel, starting from the basis. The cut-off and the half-shell being closer to the truncated cone basis are the first to be obtained. Subsequently the manufact is spun at the level of the equator looking for the closest fit of the metal to the mandrel. The material after the equator that has still to be spun has conical shape. By the same method the material of such a region is made flowing under the external roller creating the second half shell and the second cut-off. The mandrel is made collapsible so it can be extracted from the cavity after forming. By this process the metal is made flowing under plastic deformations in a bi-dimensional space. In this way, rather high % reduction can be achieved without any buckling or cracking. This method found for the forming of monocells has been successfully applied in iterative way for the construction of seamless multicells. No matter the number of cells, no intermediate annealing is needed.

Spinning a multicell cavity directly from a 3 mm thick 1 meter diameter niobium blank is certainly impressive , but however unpractical for industrial production. Hence the procedure has been engineered by first producing seamless tubes then by subsequently spinning the cavity. When spinning a multicell from a tube indeed, the spinning procedure is the same for every cell. Moreover spinning from a tube, rather than directly from a blank, insures a much better wall thickness uniformity for the spun cavity. Niobium seamless tubes are however not commercial, so we have been simultaneously developing three different methods: forward flowturning and deep-drawing both direct and reversal.

Fabrication of the spinning machine

Fig. 1 shows the spinning lathe used before starting the CARE project. The lathe turret supporting the rollers moved along an axis of about 45 degrees respect to the spinning axis. Since the shear force was applied onto the spun piece by the roller only when this moves forward, the necking process worked only for a half cell.

Fig. 1: The spinning lathe used for the fabrication of seamless cavity prototypes. The lathe had only one turret which hold the rollers.

In other words, the main problem indeed is the following: the revolving turret supporting rollers can move back and forward along a direction that is approximately 45 degrees from the cavity axis. It moves forward in order to have rollers applying a radial force to the tube that must be plastically deformed. It moves backward in order to retract the roller after the deformation in order to shift to one another point to deform. During this latter operation, the pressure is released and there is no any possibility to apply any plastic deformation. Due to the peculiar shape of the cavity in each dumbbell, the actual machine can spin only the half cell that is encountered along the roller rectilinear path. In order to spin the other half-cell, the cavity must be dismounted from the lathe together with the internal mandrel. The whole stuff is turned of 180 degrees, the half-cell that was previously untouched by the roller becomes the part that must be plastically deformed. This operation is at the moment iterated several times up to the moment when the full dumbbell is finished. This operation is rather heavy to do, is time consuming, and it is rather risky. Not only for the piece that can be damaged during the operations of dismount from lathe headstock, piece tournament and remount, but also because the collapsible mandrel can move from the correct position. Further the late is not long enough for the nine-cell spinning and the pressure between headstock and tailstock is not sufficient. Due to this limit, that is normally found on all spinning lathes we know, the cavity needed to be dismounted from the lathe headstock, tilted and remounted several times for each necking operation. This meant wasting time, not only because of the time lost for dismounting the cavity and turning it on the lathe, but mainly because each time the cavity is dismounted and mounted from the lathe headstock, the cavity rotation axis must be aligned every time from the beginning.

The fabrication time will be strongly reduced by adding a second turret working in the opposite direction to the standard one. As shown in Fig.2, the turret has been designed, fabricated and added to the lathe. In this configuration, the cavity remains mounted onto the lathe during the whole spinning operation (apart from when the internal collapsible die is dismounted), while is the operator to move around the lathe depending on the half cell he has to spin. This makes the spinning procedure shorter in time, less expensive and therefore easier to industrialize.

The spinning machine for producing seamless multi-cell resonators starting from a tube has been finished and it is currently working. The research activity about spinning is executed in an external firm that already owns a lathe currently used for spinning resonators.

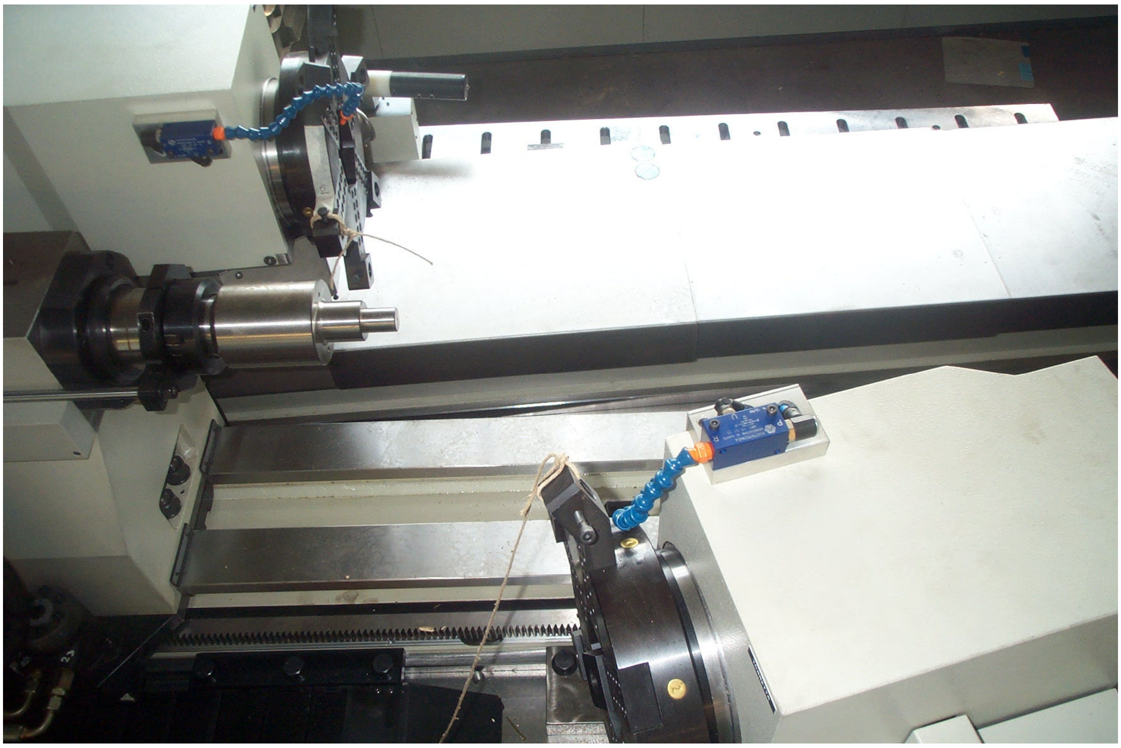

Fig. 2: The new spinning lathe with two turrets which hold the rollers. In this configuration, the rollers can work in opposite direction.

The previous machine however was also not enough powerful for the spinning operation. Therefore we adapted the already existing machine designing some modified parts to add to the existing machine. All the work done is reported in the following, fully respecting the milestone deadline:

- The new turret has been added and it works in opposite direction and on the other side of the already existing one.
- The hydraulic plant was implemented and valves were added, for achieving a pressure of 120 bar.
- Since the increase in pressure was too large for the existing headstock configuration, and since the max rotation speed was 2000 rpm, the bearings supporting the headstock were changed adopting forced lubrication bearings with the related pump and ancillaries.
- The headstock was consequently elongated of 100 mm and it was designed of more robust construction.
- The lathe base and carriage appears more solid in the new design. The lathe-basement was elongated of 200 mm.
- The lathe tailstock was enforced too in order to support the higher pressure applied between headstock and tailstock when spinning the part.
- A new motor of 18 KW power, an output speed of 8000/min and a speed reducer of 1:4 was also mounted.

Evaluation of spinning parameters

In standard operation the material wall thickness at the iris, at the end of the necking operation, could be lower than the initial tube thickness. This is actually possible in the double turret configuration, but it requires a severe control of the roller working pressures, of the spinning angular velocity, of the roller feed speed and finally of the pressure between headstock and tailstock.

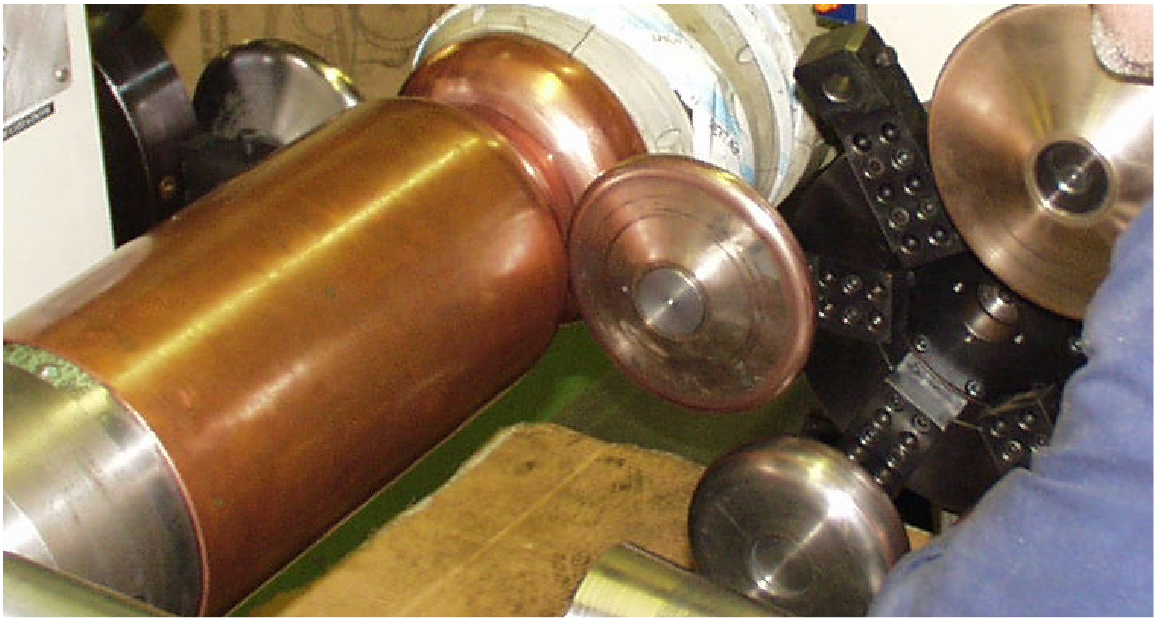

Fig. 3: Phase of the double turret necking process during the spinning parameter definition action.

The definition of spinning parameters must be twofold: first the piece must not crack or wrinkle, then the material must be spun in order to get an uniform wall thickness. Basically the tendency to wrinkle is dependent on the relationship between metal thickness and the area of the blank which, being to be formed, is not clamped. 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 favour wrinkles appearing. For a given material and assigned the cinematic conditions, lowering the angle 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 workpiece at the end of the process when wrinkles removed by continued spinning

The work of settling the parameters is just started on copper tubes for only ending on the niobium tubes due to an obvious problem of the material cost. Many process variables have to be considered when spinning, in order to achieve good trueness of shape, dimensional accuracy, surface finish and wall thickness profile and tolerances. On the basis of our experience, the parameters recognized to govern the final result can be distinguished in Workpiece parameters, Material parameters, Tooling parameters, Machine parameters and Process Parameters. In particular for the Workpiece parameters it is mainly important to control the blank diameter and thickness, the shape and size of the final piece to spin. For the Material parameters it is important to keep under control the material flow curve; the anisotropy; the compressive modulus and the compressive yield strength. For the Tooling parameters it is important to control the shape, size and finishing of the mandrel, diameter, nose radius and shoulder radius of the roller, type and quantity of lubricant; more than the final mandrel however is important all the serial of the pre-mandrels needed for keeping an uniform wall thickness. For the Machine parameter it is important to control the positional accuracy; machine rigidity, operational distance between headstock and tailstock, maximum radius of acceptable blank. For the Process parameters are important the Number of rollers, the roller feed speed the angular speed of the rotation chuck the forming force (tangential, axial and radial components) and the blank support force.

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