IEEE Transactions on Nuclear Science, Vol. NS-30, No. 4, August 1983

FABRICATION OF SUPERCONDUCTING NIOBIUM RADIO FREQUENCY STRUCTURES*

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Summary

During the last several years a variety of superconducting radio frequency structures have been designed, fabricated and tested. The diverse structures and fabrication techniques will be described. For much of the work described, no claim is made as to the original conception having taken place in our laboratory. This paper is a description of our experiences in this field.

Introduction

The early superconducting RF devices at Cornell were structures machined from solid Niobium. Most of these early structures were of the "Muffin Tin" type and operated at 2.8 GHz or 8.5 GHz. Such a device is shown in figure 1.[1,2] In order to decrease material cost, fabrication cost, and thermal resistance we developed the deep drawing of the individual muffin cups which were then welded into accelerating structures. These deep drawn cups are shown in figure 1. This work was done at 8.5 GHz, 2.8 GHz and 1.5 GHz. In the process of designing complex structures for accelerator beam tests[2,3,4], we also learned how to make a large variety of Nb wave guide components including wave guide bellows as shown in figure 2 and 3.

In this effort swaging was employed in forming the higher order mode coupling irises and electrical discharge machining was used to groove the bottom of each cell in order to inhibit multipactoring. At this time TIG welding as well as electron beam welding was used in the fabrication of many of the wave guide components. Metal spinning was employed in the componets for a "Cross Bar" structure at 2.8 GHz and for cylindrical cup halves at 1.5 GHz.

Deep drawing was used for producing the cup halves for cylindrical structures at 1.5 GHz and 8.5 GHz as shown in figures 4 and 5.

In light of our experience which indicated that one should minimize both machining and welding, we have developed the cold hydroforming technique of making resonant structures by expanding seamless tubing in a periodic manner. Single cell niobium cavities have been made at 3 GHz and 4 GHz.[5] Multiple cell copper prototypes exist and we expect soon to complete niobium multiple cell structures manufactured by this method. Figure 6 shows the essentials of the technique and figure 7 shows some structures manufactured by this method.

The problem of multiple wave guide transitions from 2°K to room temperature has been encountered and several devices have been built using ceramic or Kapton windows and 2°K to 77°K heat exchangers.

Machining

Most of our niobium machining experience has been with numerically controlled milling machines. The flood coolant system is used with 1,1,1 trichlorethane. Other coolants have been tested but none work nearly as well for a smooth clean cut. Tool surfaces speeds of 80 SFPM are generally used with a chip load of 0.002 in. per tooth. High speed steel end mills with a steep back rake (aluminum cutting) give the best results and show the least tool wear.

Lathe turning is done in a similar manner. In this case the extreme back rake is even more important in order to "peel" the material and allow the chip to slide freely from the tool. Conventionally ground cutters work very poorly and tend to smear the surface.

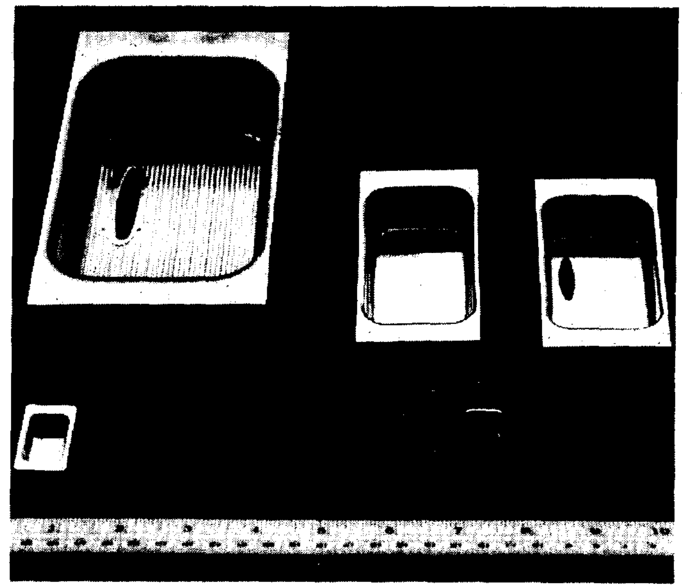

Figure 1

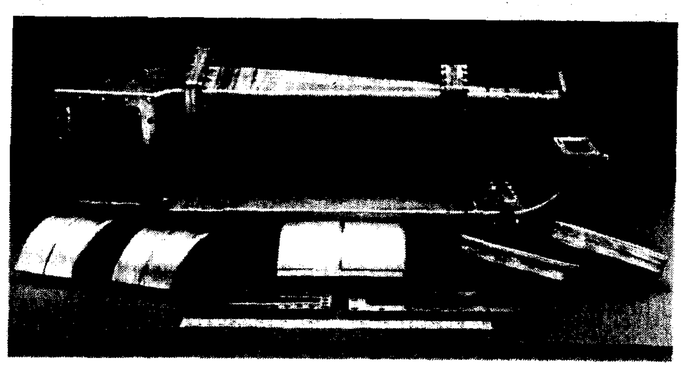

Figure 2

Deep Drawing

We have done deep drawing of both round and muffin tin half cells as well as a variety of wave guide components. The earliest muffin tin dies were made of steel and galled very badly. Since then, muffin tin cells have been drawn using aluminum bronze die material (35 KPSI yield). All other parts have been made using dies of 7075-T651 aluminum (73 KPSI yield). Neither of these materials show any tendency to gall, but the aluminum is cheaper, more available, and easier to machine. A variety of drawing lubricants have been used and while all seem satisfactory, including motor

0018-9499/83/0800-3351$01.00

oil, "Never Seez" seems to perform the best. The formability of Niobium is quite good in that it does not readily work harden, but the grain size of the material should be as small as possible (ASTM 5 or smaller) to prevent severe "orange peeling". Most drawing processes have been proofed with annealed copper. While the Niobium parts will require greater force, the formability of the two materials, both in an annealed state, are nearly equal.

Spinning

Our experience in this area is not very extensive. We have made a few parts and find that thin small parts lend themselves more to this technique. Thicker parts require extreme forces and the necessity of interstage anneals is obvious.

Swaging

Swaging has been done with 7075-T651 aluminum dies and has been very similar in its characteristics to deep drawing.

Electrical Discharge Machining (EDM)

In order to prevent multipactoring in the muffin tin structure, a series of grooves (0.06" wide, 0.06" deep, 0.125" spacing) were machined in the bottom of each cup as shown in figure 1. Ordinary EDM machines were used with highly filtered oil and copper electrodes. Currents of 10 amps average were used and a material removal rate of 0.025 cu in per hour were experienced.

Welding

The preferred method of welding Niobium is Electron Beam Welding (EBW) because of uniformity and minimum weld shrinkage. Due to the fact that our EBW machine is not numerically controlled, some complex shapes have been TIG welded. After unsuccessfully attempting local gas shielding, we have achieved satisfactory welds in an evacuable glove box which is pumped to 10 m torr vaccum before back filling with argon. It seems that adsorbed moisture is a major contaminant which must be controlled. EBW welds with a smooth underbead have been achieved in Niobium thickness up to 0.08". This technique seems to require a very low welding speed, 20 in/min as opposed to a more normal 60 in/min. High field breakdown frequently occurs at welds and mechanical polishing is often used.

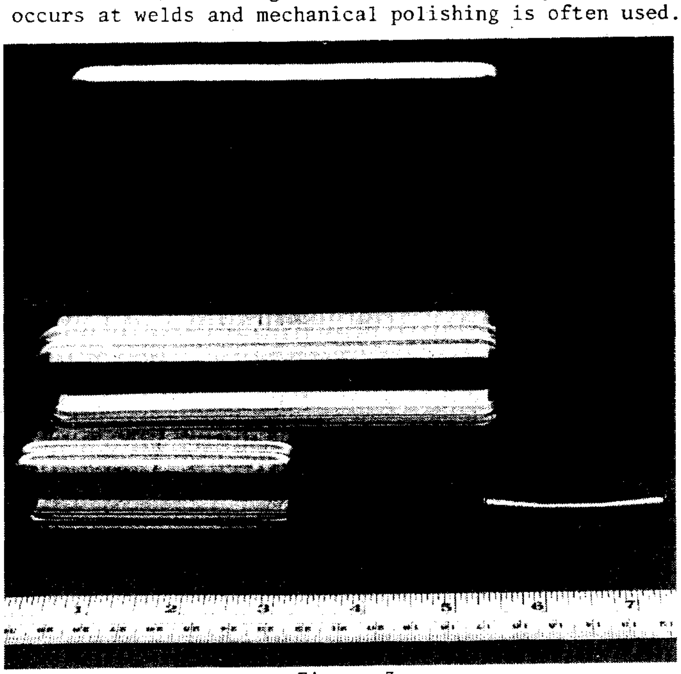

Figure 3

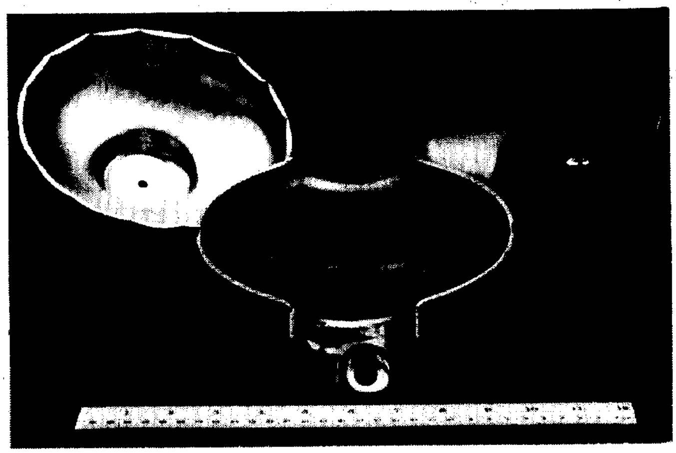

Figure 4

Figure 5

Hydroforming

In order to avoid any welds in the high field regions of the niobium resonant structure, we have pursued a technique of hydroforming a complete multi-cell cavity from a seamless tube. We have formed such shapes with an ID:OD ratio of 1:3. The essentials of the technique are shown in figure 7. Multiple stages are required in order to avoid lateral instability of the tube as axial force is applied. We find six stages to be satisfactory with an interstage anneal at every other stage. The technique chosen forms one cell complete at a time and has no limitations on the number of multiple cells which may be formed. While complete computer modeling of the process has not been done, calculations have been made which allow us to predict the thinning and buckling at each stage. Approximately 3% thinning per stage is our usual design goal. The development of a device to measure hydraulic fluid flow at 10 KPSI was necessary in order to monitor the process.

Some tests have been made with explosive forming but indicate a complete lack of stress rate advantage. Hot forming shows no advantage up to 800°C, but shows promise above 1200°C. We may pursue this effort in the future in spite of the difficulty of working at this temperature without contamination.

RF Windows

In the construction of the 1.5 GHz, 10 cell muffin tin structure[4] several R.F. windows were required. One window was required in the higher order mode wave guides to separate the accelerator vacuum from the dewar insulation vacuum at 2°K. Such a window was made from 0.005" Kapton film which was sandwiched with Indium seals between wave guide flanges. The window held one atmosphere and had RF losses below 5 mw.

The high power feed window as made of a 0.2" thick alumina disc edge cooled at 77°K. The transition from 2°K to 77°K was constructed of 0.015" stainless, copper plated on the inside 10^{-4} in thick. On the outside were copper fins with a stainless tube spiralling the length of the wave guide. This tube has typically a 10 mg/sec input of 4.2°K helium. Such a transition has a heat leak of 100 mw conduction and 100 mw RF loss to the 2°K liquid bath at a transmitted power level of 6 KW. Such a window/heat exchanger unit is shown in figure 8.

Conclusion

Superconducting Radio Frequency structures of Niobium can be manufactured using most of the normal metal fabricating techniques. The emphasis in the future must be on cost savings and better RF performance.

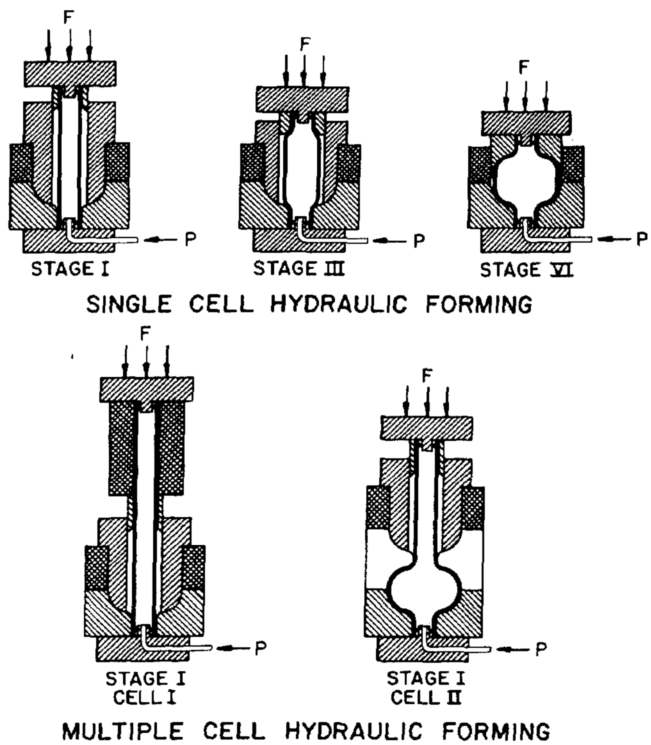

Figure 6

Acknowledgements

We wish to thank R. Mitstifer, C. Firenze, and C. Henderson for continued contributions to our efforts as well as the staff at most of the R.F. Superconducting laboratories around the world for a wealth of valuable information and communication.

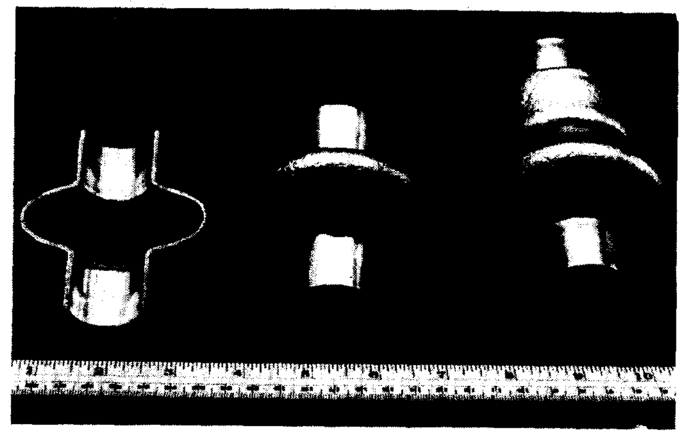

Figure 7

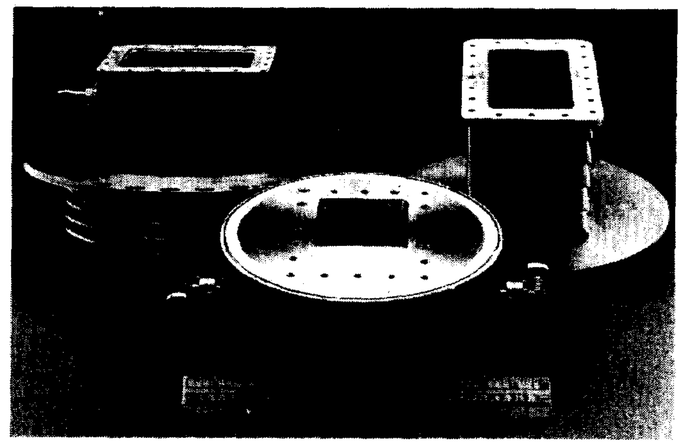

Figure 8

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*Work supported by the National Science Foundation.