

## DEVELOPMENT OF A NIOBIUM BELLOWS FOR BEAMLINE CONNECTIONS\*

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### Abstract

Superconducting cavities in an accelerator assembly are usually connected at the beampipes by stainless steel bellows. The bellows operate at an intermediate temperature, compensating for alignment tolerances on the cavity beamlines and for thermal contraction during cooldown to cryogenic temperatures. This transition from one cavity to the next in a cavity string is typically of the order of  $3/2$  wavelength long with approximately half a wavelength taken up by the bellows. If one could incorporate a niobium bellows in the beam pipe, this distance could be reduced by half a wave length. In the case of a big accelerator such as TESLA the overall cavity length for the accelerator could be reduced by roughly 10 % or 2000 m. In terms of cost savings this would amount to several million dollars.

Motivated by this we have begun to develop a niobium bellows to be used on a 2.75" diameter beamline. It is made from 0.3 mm thick niobium sheet, rolled into a tube and secured by a longitudinal full penetration electron beam weld. The weld is made at high speed with a narrow, focused beam reducing the heat affected zone, thus limiting the grain growth, which could affect the formability. Subsequently, two convolutions are pressed into this tube in a 2-stage process, using an external die and a polyurethane internal expander. Niobium cuffs and flanges are electron beam welded to the formed bellows, which facilitates leak testing and allows some measurements of compression/expansion and bending.

In this contribution the fabrication process and the subsequent mechanical and vacuum tests with the bellows will be described.

### INTRODUCTION

In modern superconducting accelerators such as linear colliders or energy recovery linacs there is a need to increase the "real estate" accelerating gradient to as high a value as possible, because this directly affects the length and therefore the cost of an accelerating system. Typically accelerating sections are connected at the beam pipes with stainless steel bellows to provide sufficient flexibility to compensate for alignment tolerances and for thermal contractions during cooldown from room temperature to cryogenic temperatures. Additional space between cavities is taken up by higher order mode damping devices, fixturing for mechanical and/or piezo tuners and for gate valves. In total the space between the end cells of cavities in a cavity string, which is not contributing to acceleration of particles, is in the order of 3 half

wavelengths. At an accelerator operating frequency of 1300 MHz this is  $\sim 35$  cm and in the case of the Spallation Neutron Source (SNS) cavity strings, which operate at 805 MHz, the space between end cells is  $\sim 50$  cm, reducing the effective accelerating length to  $\sim 57\%$  of the total length of a module. If one could shorten a portion of the space between cavities by eliminating e.g. the SS bellows and replacing it by a niobium bellows as part of the beam pipe, one would realize some cost savings, avoid a transition from superconducting beam pipe to normal conducting beam pipe and implement a more compact design.

### DIE DESIGN

It became clear after initial tests that for the forming of the convolutions in the thin material – we chose a material thickness equal to the thickness of the stainless steel bellows (0.012" ) – the niobium could not be stretched to form the convolutions but rather had to be formed into the convolution without thinning of the material. This requirement influenced the design of the forming die in such a way that the convolutions could not be formed simultaneously and that during the forming the end of the niobium tube had to be free to move towards the convolution, which was being formed. A sketch of the die is shown in Fig. 1:

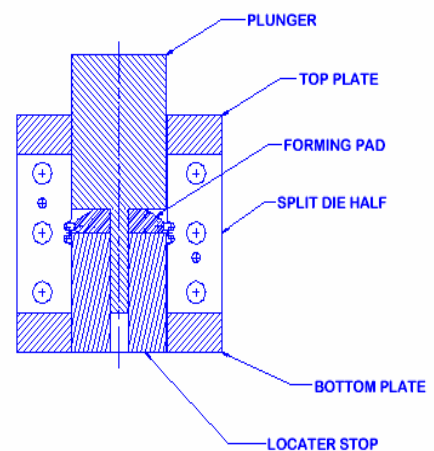


Figure 1: Die Design.

The die consists of several subcomponents as shown in Fig. 2: a plunger and a locator stop shown on the left side, a split die with the machined convolutions and a top and bottom plate. The die material is Al 7075. The forming pads are made from polyurethane and are shown at the bottom.

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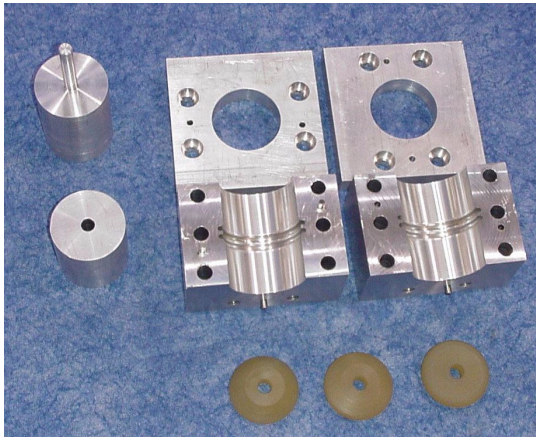


Figure 2: Subcomponents of the bellows forming die.

We believe that the shape of the polyurethane forming pad is crucial for a successful shaping of the bellows convolutions after the first one has been shaped. As can be vaguely seen from Fig. 1, the forming pad is holding the first convolution in place and prevents a stretching of the material of this convolution while the plunger is compressing the niobium for the second convolution in place.

### ELECTRON BEAM WELDING OF NIOBIUM TUBE

The bellows may be made from thin-walled seamless tubing or rolled and electron beam welded from thin sheet. It is crucial that the tube fits snugly into the forming die. In the case of a rolled, welded sheet as applied here, the heat affected zone near the electron beam weld must be minimized. The latter has been accomplished by a high welding speed, providing a full penetration, smooth underbead weld seam. Fig. 3 shows the welded tube and Fig. 4 is a micrograph of the weld seam.



Figure 3: Welded thin wall niobium tube.

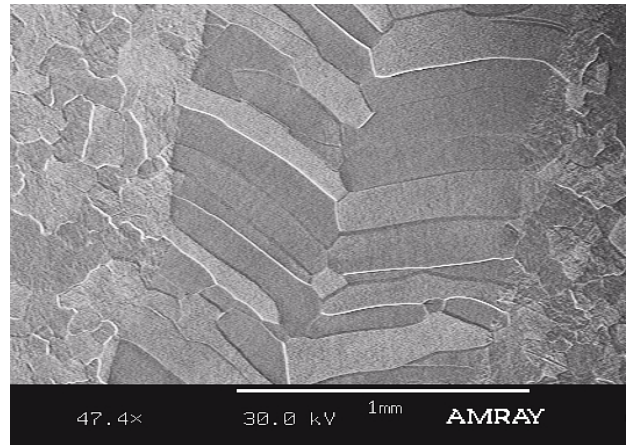


Figure 4: Micrograph of weld seam.

### FORMING OF BELLOWS

The bellows was formed with a maximum pressure of 20 tons in the following steps:

- Generous lubrication of welded tube and Al7075 die components with motor oil.
- Assembly of tube into die.
- Pushing of top plunger with 10 tons, 1 min of resting and increasing the pressure to 20 tons.
- Disassembly of die, moving of formed convolution into bottom groove in die and re-assembly of die after additional lubrication.
- Forming of second convolution as described above.

The formed bellows is shown in Fig. 5, still placed in the forming die.

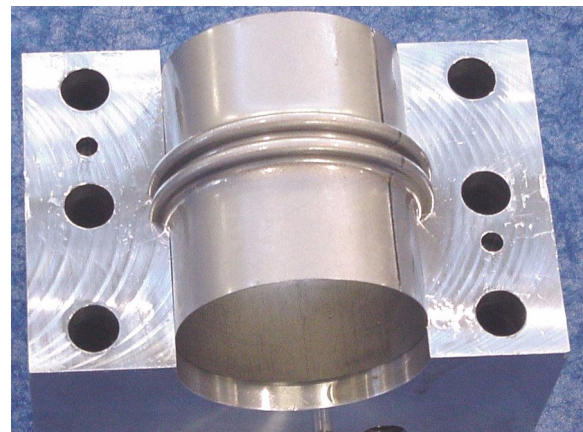


Figure 5: Formed bellows still placed in forming die.

A rather crucial area of the process is the deformation of the weld seam during forming of the convolutions. Because of the thin material we were worried about ripping of the weld area with its enlarged grains (see Fig. 4). As can be seen in Fig. 6, the area of the weld shows some “caving in” of the material and some stretching of the grains, but subsequent as thermal cycling tests and

leak checking showed, the integrity of the weld area was not compromised.

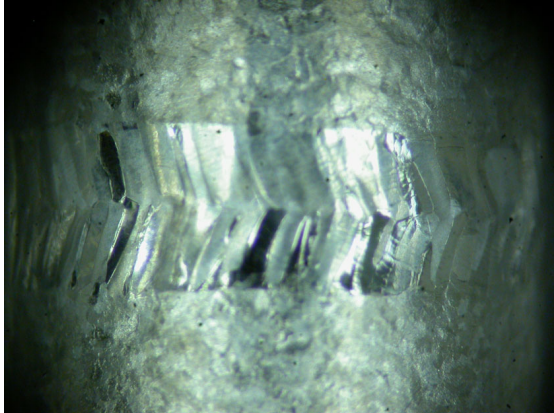


Figure 6: Deformed area of the weld seam in the convolution.

### MEASUREMENTS ON THE BELLOWS

The bellows was completed by electron beam welding flanges on both ends of the formed tube. The results of tests of the assembly shown in Fig. 7 are given below with specifics of the tests:

- a. thermal cycling to liquid nitrogen temperature (3 x) and leak checking: **leak tight**
- b. measurement of angular flange deformation: **3 degrees**
- c. measurement of axial stretching: **+/- 3 mm**
- d. measurement of spring constant: **1.6 mm/kN**



Figure 7: Bellows with welded on Nb55Ti flanges.

### SUMMARY

We have successfully developed a procedure to form a bellows from thin (0.012") niobium sheet, which was welded into a tube. Important steps in our opinion are: an electron beam weld with essentially no heat affected zone beyond the weld; a die design, which allows the free movement of the niobium tube into a groove in the die, thus avoiding stretching and therefore thinning of the material; and an appropriate shaping of the polyurethane forming pad, which captures the first convolution in the groove during the forming of a subsequent convolution thus preventing stretching of the material.

We believe that even a bellows with only two convolutions can provide sufficient flexibility to compensate for alignment tolerances on a cavity string of niobium cavities. Nevertheless we are interested in increasing the number of convolutions in our future developments.

If the bellows will become a part of the cavity beam tubes as anticipated, the problem of shielding the bellows from chemical attack during buffered chemical polishing or electropolishing needs to be addressed.