

## STAINLESS FLANGE BONDED TO NIOBIUM TUBE AND SIMPLE ALUMINUM SEALING

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### Abstract

We have successfully used indium sealing for superconducting (sc) RF cavities for a long time. Indium sealing has high reliability, but several problems: cavity contamination by indium fragments and too soft to self-standing so on. These problems bring performance degradation of sc cavity to the final horizontal cavity assembly. We need other simpler sealing to establish the degradation free final assembly. As a simple sealing instead of indium, we have developed aluminium sealing, which uses an aluminium ring 1mm wide and 1mm thick. This kind of ring can be easily made cutting by EDM or stamping out of 1mm aluminium sheet. For reliable aluminium sealing, we have developed stainless flange bonded to niobium tube in order to get higher hardness of the flange. We successfully used HIP technology to bond the stainless tube and the niobium tube. We made leak tight tests of the bonding with thermal cycle from 750°C to 1.5K for 3 times, and confirmed leak tightness. The aluminium sealing was also successfully tested with super-leak. In this paper, we will present the R&D and results.

### 1 INTRODUCTION

Indium sealing has been used successfully for a long time in sc RF cavities. Actually it is very reliable even in super-fluid liquid helium. However, it has several problems: 1) flange disassembling is annoying by adhesion of indium fragments, which sometimes contaminates cavities and results in field emission, 2) the cost is rather expensive e.g. 30\$ per one sealing for our L-band cavities, 3) in the final horizontal cavity assembly it needs special fixtures and make the assembly complicate. Therefore other laboratories: DESY, SNS are changing to aluminium Helocflex or aluminium solid ring sealing. We are also developing simple aluminium sealing. We want to keep the stick sealing property of indium but abandon its too softness. Wire or thin ring of aluminium is suitable for such a sealing property.

In the KEK standard preparation, high temperature annealing such as 1400°C is not necessary because electropolishing guarantees high gradient without it. Really electropolishing needs hydrogen degassing but its annealing temperature is 750°C and rather low, which makes possible to use stainless steel material. If we choose aluminium sealing, hardness of metal flanges must be higher. Reactor grade niobium material might be a candidate but still expensive compared with stainless steel.

Stainless steel cannot be welded directly to niobium but stainless steel/niobium clad material can be jointed to niobium beam tubes of cavities. The thermal stress between the different materials is questionable but it is not so pessimistic. One simulation shows a safety margin of factor 4 against stress breaking [1]. If we developed successfully such a clad flange, aluminium sealing become very simple. We can make aluminium thin sealing ring to just cut an aluminium plate.

Here, we report the development of stainless/niobium bonded flange, its thermal cycle test from 750°C to 1.5 K with leak tightness, and aluminium thin sealing ring and its leak tightness at super-fluid liquid helium.

### 2 FLANGE FABRICATIONS FROM STAINLESS/NIOBIUM CLAD TUBE

#### 2.1 HIP bonding

As mentioned above, stainless steel cannot be joined directly to niobium material by EBW or TIG welding. We developed a method, in which a niobium tube is bonded in a thick stainless tube (SUS 316L, JIS) using hot isostatic pressing (HIP) technique. This is a now industrial conventional technology. The bonding principle is sketched in Fig.1. A niobium tube is wrapped with stainless material as a work. Gaps between the niobium and the stainless are sealed in vacuum. We refer the vacuum warping to canning. Then it is exposed to hot (typically 800°C) and highly pressurized argon gas (2000kg/cm<sup>2</sup>), then vacuum spaces of the gaps is crashed

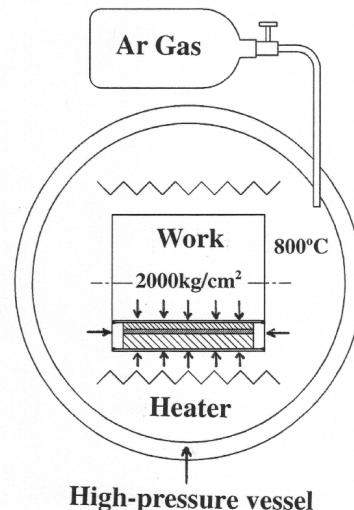


Figure1: Principle of HIP bonding

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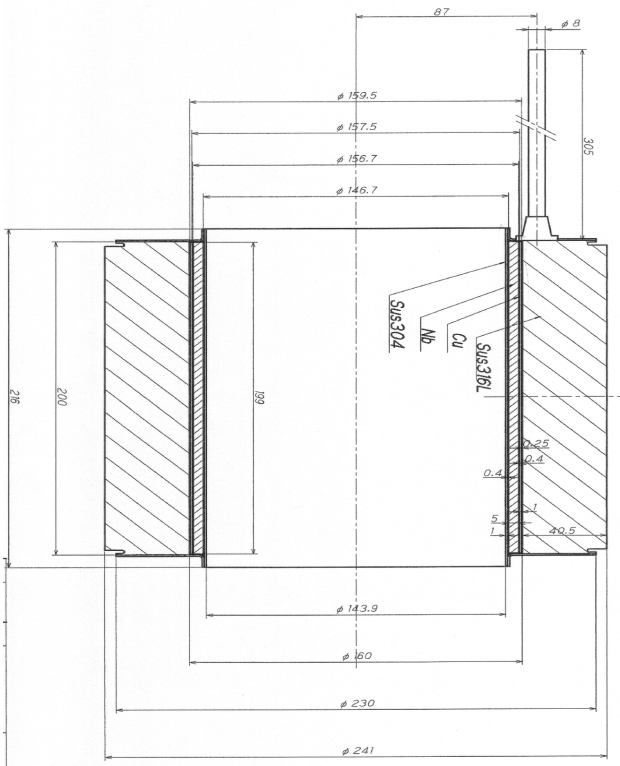


Figure 2: Designed canning tube for helium vessel base plate



Figure 3: HIP bonded tubes and machined stainless/Nb flanges, and aluminium sealing rings

by the high pressure and the hot circumstance. It results in a good bonding between the different materials.

A canning tube is drawn in Fig.2. We prepared 4 tubes: an outer stainless thick tube as flange, a copper tube as an interlayer between outer stainless and niobium, a niobium tube, and an inner thin stainless tube. The outer stainless tube has a size 226mm long x 158 inner diameters x 41.5 mm thick. Copper tube is a 2 mm thick seamless pipe. The niobium tube was an electron beam welded pipe rounded a 5 mm thick plate. The stainless inner tube of 1mm thick also welded by EBW. These four tubes were electron beam welded at the both ends. In a HIP company, bake at 500°C was carried out for degassing. The 8mm diameter tube is for the bake. By recent fabrication, this baking is not always necessary if the work is baked enough around 150°C in EBW chamber during canning process. After the bake, the tube was pinched off and the gas in the work was vacuum-sealed. Then it was processed by HIP at the condition: 800°C, 2000kg/cm<sup>2</sup> for 3 hrs. In Fig. 3, tubes HIP bonded and the cut cross sections are seen.

## 2.2 Machining of flanges

After HIP tubes were cut into a doughnut by lathe, flange ring were machined as shown Fig.3. The inner stainless was mechanically removed off by lathe. A part of outer stainless flange was removed until niobium material appeared. The flange is electron beam welded beam tube of L-band or 972 MHz niobium cavities. The niobium edge is cleaned by a light chemical polishing then welded niobium to niobium. A tube welded the flange is seen in Fig.3.

## 2.3 Copper interlayer

The hardness of the stainless became softer after HIP and 750°C annealing from 230 Hv to 150 Hv, but it is still higher than niobium by factor 2 [2]. We tried the HIP without copper interlayer between stainless and niobium. It was leak tight at super-fluid liquid helium but it was developed by SEM observation that the boundary has a lot of holes with size of about 2x10 μm<sup>2</sup>. On the other hand as an interlayer, a copper plating of 40μm thick, or several-layered copper foil were tested with the bonding but both were not succeeded in.

## 2.4 HIP condition and mechanical property

Mechanical property was measured at room temperature and 4.2K (only for finally fixed condition). The results are summarized in Table1. A is the results at room temperature of the samples bonded niobium between copper materials. This sample is for an evaluation the bonding strength of niobium and the interlayer. The HIP temperature of 600°C is too low to get a good bonding. The bonding boundary has a higher strength than 200Mpa at 800°C. Copper limits the tensile strength. B is the results at 4.2 K of samples bonded copper between niobium materials. The Copper/Nb

bonded boundary has a higher strength than 523 MPa, and is larger of the room temperature than factor 2.5 [3]. C is the directly bonded SUS and niobium. Tensile strength is limited by niobium.

### 3 THERMAL CYCLE LEAK TIGHT TEST OF FLANGES

Thermal cycle test with leak tightness against superfluid liquid helium was carried out for the bounded boundaries of the of flanges, which were used as helium vessel base plate for JAERI 600 MHz  $\beta(=v/c)=0.604$  5-cell structure [4]. The doughnut pieces cut from a HIP tube were removed all of the inner stainless. The ends were machined and niobium tube was partially naked. The tow machined flanges were electron beam welded Nb to Nb at the centre. The outside was welded a stainless cover with a stainless venting port. The structure was annealed at 750°C for 3 hrs to simulate the cavity annealing. After the annealing, it was leak tight checked at room temperature. In addition thermal cycles of 10 times from room temperature to liquid nitrogen temperature were took for it. At the cooled, it was directly dipped in liquid nitrogen intentionally with rough. Then it was TIG welded at the port to the evacuation tube in the vertical cryostat. The structure was fast cooled to 4.2 K in 45 minutes. Liquid helium was collected enough, and then pump cooled to 1.5 K, and held the temperature for about 1 hour. A helium leak detector was continuously operated during the cooling down or exposing to 1.5 K. After warming up to room temperature, leak tight test was carried out and

Table1: HIP condition and bonding

A. Cu/Nb/Cu Samples, at room temperature

HIP Temp. [°C]	Pressure [MPa]	Tensile [MPa]	Breaking location	Preparation
600	196	117	Boundary	CP
800	118	201	Copper	CP
800	196	221	Copper	CP

B. Nb/Cu/Nb Sample. at 4.2K

HIP Temp. [°C]	Pressure [MPa]	Tensile [MPa]	Breaking location	Preparation
800	196	523-548	Copper	Non Annealed
800	196	534-556	Copper	Annealed 750°C, 3hrs

C. SUS/Nb/SUS, at room temperature

HIP Temp. [°C]	Pressure [MPa]	Tensile [MPa]	Breaking location	Preparation
800	118	292	Boundary	Digressed
800	118	284	Niobium	Digressed
800	118	280	Niobium	Digressed

made sure the leak tightness. After the successful test, the port was cut and the structure was annealed again. Other two same heat cycle tests were carried out. No vacuum leak was detected for every test.

### 4 ALMINIUM SEALING

#### 4.1 Fabrication of aluminium sealing rings

The similar SUS/Cu/Nb bonded flanges were really electron beam welded to L-band or 972 MHz niobium cavities. For the vacuum sealing of the cavities, thin aluminium sealing rings were tested, which were cut from stacked 1 mm thin flat aluminium sheets by EDM. The inner diameter is 102mm and the width is 1mm. A great care was taken for the EDM cutting not to happen corrosion on rings. The industrial surface finishing of the aluminium sheets, which was rolled surface, was used as a sealing surface. Not to make scratches on the surface, the aluminium sheet was cover with thin plastic film at deliver to KEK. Rings were chemically polished slightly before the use. The surface roughness before use was  $1.43 \pm 0.19 \mu\text{m}$  in Rim.

#### 4.2 Optimum flange groove

The flanges were machined to have a groove for sealing ring to stand itself in a horizontal position, which is considered horizontal final cavity assembly. The width and depth of the groove was designed from the result in Fig. 6. There the relationships between shrinkage in thickness and elongation in width are measured as a function of torque tightening bolts. The results are for molybdenum coated bolts (M8) and non-coated ones with pure aluminium (JIS 1050). The similar results were obtained for nuts coated sliver. The width of 2 mm and depth of 0.5 mm are used for the flange design.

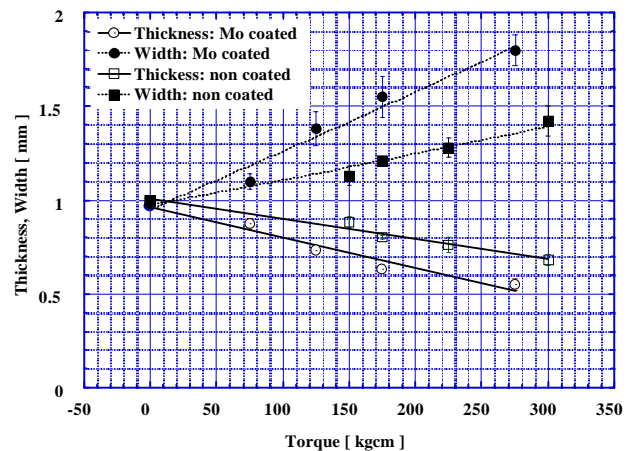


Figure 3: Relationship shrinkage of thickness or elongation of width as a function of bolt tightening torques

### 4.3 Leak tight torque

Optimum torque of bolt tightening is investigated for the aluminium-sealing ring at room temperature. The size of the ring is the same as mentioned above, but the surface finishing is different. This ring was cut by EDM perpendicularly to the axis of a welded tube. Therefore the surface (Rim= $17.00 \pm 0.53\mu\text{m}$ ) is rather rough compared with the directly EDM ring from aluminium sheet. Therefore, rings were mechanically ground with emery papers to get smoother surface. 5 rings were tested. One was leak tight at the torque of 100 kgcm. The others were leak tightened at 125 kgcm. The optimum torque will depend on the surface roughness. In our experiment, the torque higher than 125 kgcm is need for the leak tight aluminium ring searing.

Table 2: Leak tight torque at room temperature

Torque [kick]	50	75	100	125
No. of Ring				
1	×	×	○	
2	×	×	×	○
3			×	○
4			×	○
5			×	○

× : leak, ○ : leak tight

## 5 VACUUM LEAK TIGHT TEST OF CAVITY FLANGES

Aluminium sealing rings described at sections 4.1 and 4.3 were leak tight tested in superfluid liquid helium with 4 rings each using L-band sc niobium cavities, of which beam tube flanges were stainless/niobium clad ones. The cavies were measured performance in superfluid liquid helium in vertical cryostat sealing the cavity vacuum. After the test, they were connected to helium leak detector and the cavity vacuum was opened. For each cavity, the leak detector observed the helium partial pressure as similar as indium sealing. Therefore we can conclude the aluminium ring sealing is as leak tight as indium. The niobium/stainless clad flanges were also reconfirmed the leak tightness with superfluid liquid helium.

## 6 CONCLUSIONS

We have successfully developed stainless/niobium bonded flanges. These flanges were leak tight with superfluid liquid helium. A simple thin aluminium sealing rings were fabricated and successfully tested leak tightness with superfluid liquid helium.

## 7 REFERENCES

- [1] K.Mukugi et al., "Mechanical Evaluation of Nb-SUS HIP bonded Structure", Proc. of the 3<sup>rd</sup> Superconducting Linear Accelerator Meeting in Japan, KEK May 25-26, 2000, pp.55-56, in Japanese.
- [2] K.Saito et al., "R&D of Nb/Cu Clad Seamless Cavities at KEK", in this meeting.
- [3] This measurement was carried by Drs. Y.Tsutchiya and N.Ouchi at JAERI. These results will be presented somewhere.