KEK Preprint 95-219
March 1996
A

Status of the Seamless L-band Cavity Fabrication at KEK

T. FUJINO, H. INOUE, K. SAITO, S. NOGUCHI, M. ONO, E. KAKO,
T. SHISHIDO, A. KUBOTA and S. KOIDE

*Submitted to the 7th Workshop on RF Superconductivity,
CEA-Saclay, Gif-sur-Yvette, France, October 17 - 20, 1995.*

KEK Reports are available from:

Technical Information & Library
National Laboratory for High Energy Physics
1-1 Oho, Tsukuba-shi
Ibaraki-ken, 305
JAPAN

Phone:	0298-64-5136	
Telex:	3652-534	(Domestic)
	(0)3652-534	(International)
Fax:	0298-64-4604	
Cable:	KEK OHO	
E-mail:	Library@kekvax.kek.jp	(Internet Address)

Status of The Seamless L-band Cavity Fabrication at KEK

Takeo FUJINO, Hitoshi INOUE, Kenji SAITO, Shuichi NOGUCHI, Masaaki ONO, Eiji KAKO, Toshio SHISHIDO, *Akira KUBOTA and **Shigeyuki KOIDE

National Laboratory for High Energy Physics (KEK)
1-1, Oho, Tsukuba-shi, Ibaraki-ken, 305, Japan.

*Advanced Technology Consulting Co. Ltd..
1-10, Senkawa-cho, Chofu-shi, Tokyo-to, 182, Japan.

**San Planing Co. Ltd..
210, Fukuizumi, Minami Ashigara-shi, Kanagawa-ken, 250-01, Japan.

Abstract

For the future superconducting RF cavity project like TESLA, reduction of the fabrication cost is a great concern. Elimination of electron beam welding in the present fabrication process is one way to do so. Spinning[1], explosive forming or hydro-bulge forming is a candidate to fabricate such a seamless cavity. As a feasibility study, explosive forming was tried for the L-band three cell copper structures and could successfully expand copper tubes by 60 % of the final cell shape. The study of hydro-bulge forming has also started to get enough thickness at the equator section of cavities. Both method need intermediate annealing to form the final cell shape. If one applies these methods to the Nb/Cu clad cavities, large merits are expected on not material cost reduction but also cavity performance.

1. Introduction

The fabrication cost reduction of the superconducting RF cavities is a great issue for a big project like TESLA. The elimination of electron beam welding is a cure for this issue. Generally speaking, such a fast deformation like explosive forming can be helpful to get a higher elongation so that one could make seamless cavities. Explosive forming is very simple and looks a cheaper method. We have considered this method for seamless multi-cell L-band superconducting RF cavities, and started the feasibility test on the 3-cell copper structure. As the result of the first experiment, it was developed that the thickness around equator was not guaranteed enough by this method, and multi-step explosive forming with intermediate annealing was required to complete the final shape. On the other hand, the hydro-bulge forming forces the material into the work and supplies mass during forming. To obtain the enough thickness around equator area, this method is more suitable. If one uses this method as the first step, the sufficient thickness could be obtained even one uses explosive forming as the second step. We have started newly to develop this method. In this paper, we present the results of these

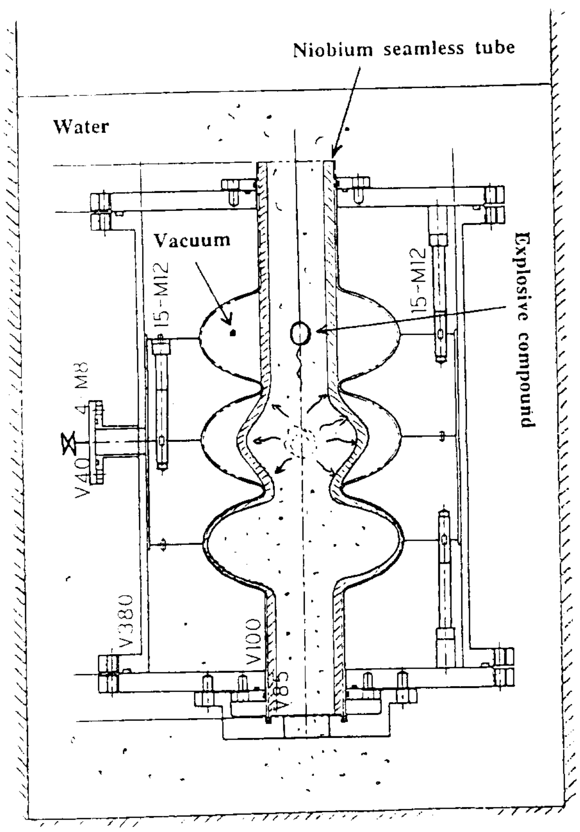

Fig. 1. Idea of the explosive forming method for seamless multi-cell cavities.

experiments.

2. Feasibility study with explosive forming

2-1. Explosive forming

Fig.1 shows the schematic drawing of our explosive forming for seamless cavities. It has a fixture in which the work (tube) is set with explosive compound (blasting fuses; 5.4 mmØ and 330 - 360 mm long). Blasting itself takes place in the water to make shock waves. The whole fixture is immersed about one meter under the water level. We have chosen the L-band (1.3 GHz) 3-cell structure so that the experimental result is a good simulation for the final 9-cell cavities. We designed and fabricated the fixture including a set of dies with the final cell shape. The components of the fixture are shown in Fig. 2. The dies consist of 4 sections, and each section is dividable into half to take out the cavity after blasting. After mounting a tube in the fixture, the spaces between dies and the tube are evacuated and kept under vacuum during forming process (see Fig. 1). We prepared two kind of seamless copper tubes 4 or 6 mm thick and 600 mm long with 60% elongation from Hitachi Cable Co. Ltd.. The outer diameter of tubes was fixed to 85 mm which was the same as our L-band niobium cavity's one.

2-2. Expansion limit in the explosive forming

To complete the final shaped structure, we have to expand tubes by 250 % in the outer diameter at the equator area where needs the maximum elongation. Our first interest in the experiment is how much is the expansion limit by this method and how much power is

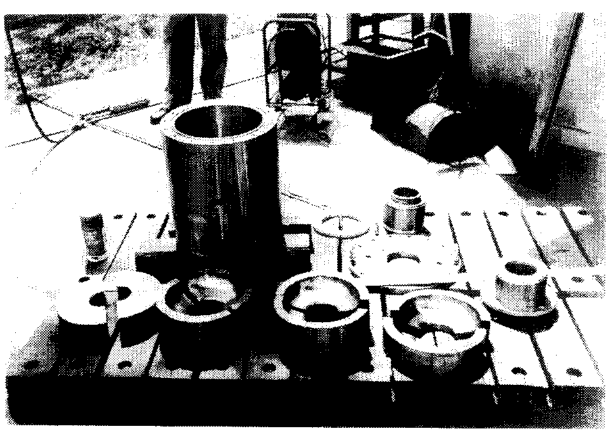

Fig. 2. Photograph of the components included in the explosive forming fixture.

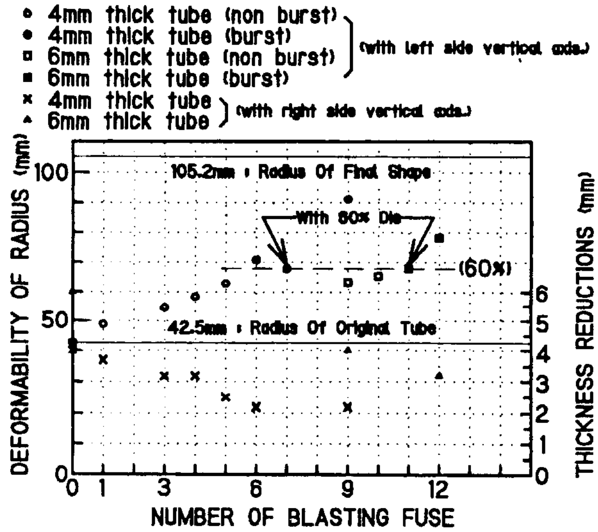

Fig. 3. Relationship between the number of blasting fuse and the expansion in the outer radius of copper tubes.

needed in the blasting. These depend on the diameter size and thickness of tubes. We have explosively formed tubes using the dies with full cavity shape. The experimental results are shown in Fig. 3. Here, the horizontal axis is the number of the blasting fuse and the vertical axis (left) is the expanded outer radius at the equator by the blasting. For the 4 mm thick copper tubes, bursts took place at the iris or the equator. The burst at iris was out of considerations because that was due to the steep slope of the cavity wall around iris. The burst at equator with more than 60% expansion in outer radius needed more than 6 blasting fuses made from PENT of 10.7 g/m. Here, the expansion ratio (E) is defined as the following equation;

$$E[\%] = 100 \cdot (R_1 - R_0) / R_0 \qquad (1).$$

Here, R_0 is the outer radius of the tube before explosive forming, and R_1 is the maximum outer radius after forming. For the 6 mm thick tubes, the elongation limit is not clear because data point is not enough. Anyway by this experiment, one can conclude that the expansion limit is around 60% so that completing by one step is impossible by this method.

In the explosive forming, the large thickness reduction appears due to that tubes are only expanded. This is a large difference from the hydro-bulge forming mentioned later. Thickness reduction is presented in Fig. 3 (mark; x). For 4 mm thick tubes, the wall thickness of the equator area is reduced from the initial 4 mm to 2.5 mm by 60 % expansion.

2-3. Succeeded the 60 % intermediate shaped structures

We have to give up the one step forming of completely shaped structures by the explosive forming. However, if the 60 % expansion is repeated twice, we get 256 % expansion which is enough to complete the final shape. Then, 60 % limit still opens the two step completing included intermediate annealing. We fabricated the intermediate dies with 60 % expansion and tried explosive forming. We chose 6 mm thick tubes for this experiment because for 4 mm thick tube the equatorial thickness becomes too thin after the second blasting. The experiment successed and we made six intermediate structures. One of them is shown in Fig 4. They are waiting for the annealing.

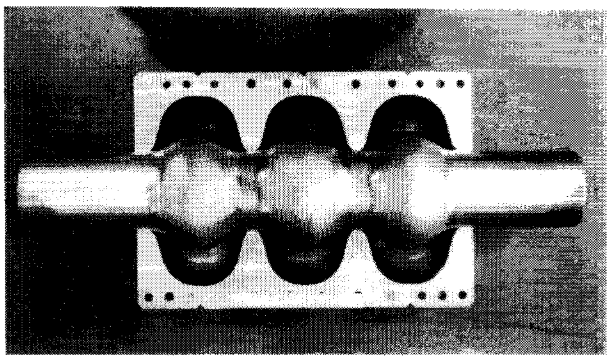

Fig. 4. An intermediate shaped sturucture with 60 % expansion from the tube by successively explosive formed.

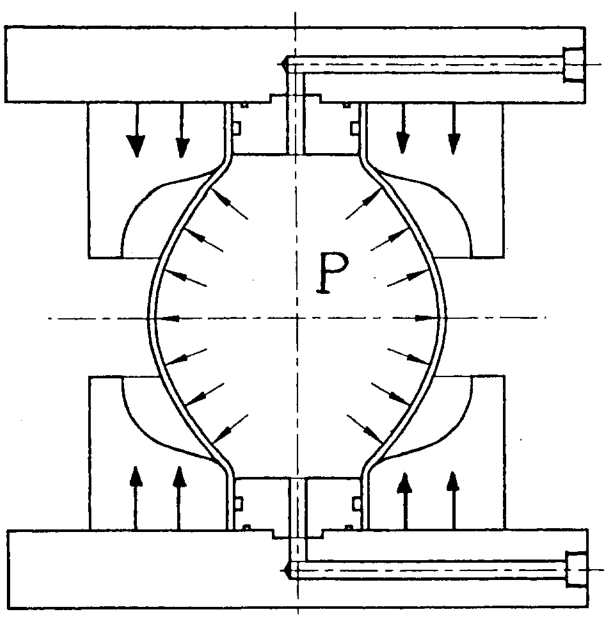

Fig. 5. Principle of the hydro-bulge forming.

3. Investigation of hydro-bulge forming

Even if one uses thicker tubes for explosive forming, the large thickness reduction is inevitable around equator area of cells. As shown the principle in Fig. 5, hydro-bulge forming which expands tubes by inner pressure and supplies mass by forcing the tubes from the either side can avoid this problem. CERN people has already succeeded to make multi-cell structures over wide radio frequency range by this method [2]. We have started the investigation of this method in order to use it as the intermediate forming before the final explosive forming. However, this method itself has a worth to be studied well as the other method for seamless cavities.

3-1. Bursting limit

We have to know bursting limit by the inner pressure in order to pressurize safely. We have done the experiment using 4 mm thick and 300 mm long copper tubes made out of the same quality used in the experiment of explosive forming. Bursting took place at 190 - 200 kgf/cm^2 and the crack in longitudinal direction of the tube was made. This experimental bursting pressure is explaineu well by the following formula of the tensile stress and by the ultimate tensile strength of copper (2091 kg/cm^2).

$$\sigma[kg/cm^2] = p \cdot d / 2 \cdot t \qquad (2)$$

Here, $p[kg/cm^2]$ is the inner pressure, d[cm] inner diameter, t[cm] thickness of the tubes.

3-2. Optimum bulge pressure and forcing tube pressure

Hereafter inner pressure of the tube is called as bulge pressure. If the bulge pressure is not high enough, forcing tube pressure is above it so that buckling in longitudinal direction of the tube is made. The buckling depends on the tube length, forcing pressure and bulge pressure. To see this relationship among these parameters, we have carried out the experiment for L-band copper single cell cavities, using intermediate die with 65% expansion on the tube. The result is shown in Table 1. When the forcing pressure was 23 Tonf and the bulge pressure was 80 kgf/cm^2, the buckling appeared but that did not occur in other cases which the former was over than 29 Tonf and the later was more than 150 kgf/cm^2. When the forcing pressure was less than 30 Tonf, the thickness at the equator section was scattered and there are thinner (3.0

- 3.05 mm) locations. Fig.6 shows the relationship between the forced tube length and the maximum expansion in outer diameter. One can see a clear liner correlation. Here, the forced tube length is defined as the following equation;

$$\Delta L[mm] = L_0 - L_1 \qquad (3).$$

L_0 is the initial tube length and L_1 is one after the hydro-bulge forming. The maximum expansion in the outer diameter is ;

$$\Delta D[mm] = D_1(max) - D_0 \qquad (4).$$

To make a large expansion, it is most important to forcing the tube in the longitudinal direction and to supply mass not to produce the large thickness reduction.

3-3. Multi-step forming included annealing

For the single cell structure, we have investigated the expansion limit by hydro-bulge forming using three kinds of die which has respectively 48, 65 and 100 % expansion to tubes at the equator area. We have failed in 100 % expansion and understood this method also needs the multi-step forming included intermediate annealing.

We made successfully six intermediate structures by the 65 % expansion die. They were annealed for one hour. The annealing temperature was 500°C for three of them and

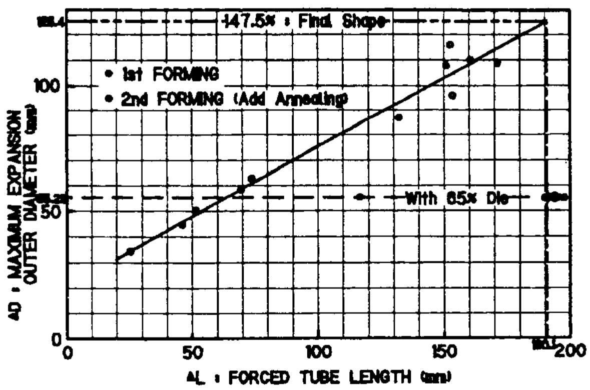

Fig. 6. Relationship between the forced tube length and the expansion in the maximum outer diameter.

Fig. 7. Nearly full shaped structure with hydro-bulge forming by two step included annealing.

Table 1. Experimental results by hydro-bulge forming with 65 %.

Cavity No.	1	2	3	4	5	6	7	8
Length[mm] L0 : before L1 : after ΔL=L0-L1	 261 207 54	 261 207 54	 261 207 54	 300 229.5 70.5	 300 232 68	 339 272 67	 339 272 67	 339 271 68
Thickness[mm] T0[end of tube] T1[center]	 3.8 - 4.2 -	 3.8 - 4.1 3.6 - 4.0	 3.8 - 4.2 3.3 - 3.8	 3.8 - 4.2 3.4 - 3.8	 3.7 - 4.3 3.05- 3.9	 3.7 - 4.3 3.05- 4.0	 3.7 - 4.4 3.0 - 4.0	 3.9 - 4.2 3.3 - 3.6
Forming condition Forcing[Tonf] Bulge pressure[kgf/cm^2]	 23 80	 33 150	 33 170	 33 170	 30 170	 30 170	 29 170	 36 170
Outer diameter[mm] D0 : before D1 : after	 85 Buckling	 85 125	 85 126	 85 139	 85 137	 85 137	 85 137	 85 140
Deformation rate[%] 100•(D1-D0)/D0	-	46	48	64	61	61	61	65

750°C for the rest. By the second hydro-bulge forming, the nearly full shape was formed, however, the orange skin appeared in the 750°C annealed structures. This experimental result is included in Fig.6 (mark; o). We have not yet formed the final shape by this method, but it will be made soon by improving the forming process.

4. Future plan

In the first of all for the future plan, we will make three cell structures by explosive forming itself with intermediate annealing. The full shaped single cell cavities will also fabricated soon by multi-step hydro-bulge forming. Then we will make three cell seamless cavities by the combined method of hydro-bulge forming and explosive forming.

We have a light prospect for the copper seamless cavities by these methods, however, for niobium cavities it will be more difficult than copper cavities. It might be a better policy that we aim at the Nb/Cu clad cavity rather than niobium one, in which a niobium sheet is bonded on the copper wall. This kind of cavity has been realized for the heavy ion superconducting accelerator at JAERI [3]. However, electron welding was one difficulty. If one could make seamless cavities from Nb/Cu clad tubes, this problem is eliminated. The difference in the mechanical property between copper and niobium would be resolved by explosive bonding the thin niobium tubes in the thick copper tubes so that the copper determines the main material property. The Nb/Cu clad cavity brings two additional merits ; one is the material cost reduction and the other is the upgrade the thermal conductivity of the cavity wall. The use of thicker copper walls might could relax the detuning problem by the Lorentz force at high field gradients [4].

5. Conclusion

We have following conclusions from these experiments on fabrication method of seamless cavities;

1) Explosive forming is a very simple method but the expansion is limited by 60% from tube to cell shape.

2) To make a large expansion, mass flow during forming process is very important. Hydro-bulge forming is superior to explosive one in this point. However, this method also has the expansion limit around 65%.

3) Starting from the size of beam pipes, multi-step forming included intermediate annealing is required for either explosive forming or hydro-bulge forming.

Acknowledgment

The experiments of explosive forming were carried out at Chugoku Kayaku Co. Ltd.. Authors would like to Mr. Nakagawa for his useful advice. Hydro-bulge forming took place at Kohoshin Giken Co. Ltd.. We are grateful to Mr. S.Shiokawa, Mr. T.Suzuki and Mr. C. Kubota for their helps and the valuable discussions.

References

[1] V.Palmieri et al., "Seamless 1.5 GHz Cavities Obtained by Spinning a Circular", Proc. of the 6th workshop on RF superconductivity, Oct. 4-8, CEBAF, 1993, U.S.A., P.857-867.

[2] S.Dujardin et al., "Hydroforming Monolithic cavities in the 300 MHz Range", Proc. of the 2nd EPAC, Nice, June 12-16, 1990, P.1100-1102.

[3] S.Takeuchi et al., "Progress in RF-Superconductivity for Heavy - Ion Accelerator at JAERI", Proc. of the 4th workshop on RF superconductivity, Aug. 14-18, 1989, KEK,Tsukuba, Japan, P.469-475.

[4] H.Kaiser, "Mechanical Characteristics of the RF Cavity for the TESLA TEST FACILITY", Proc. of the 6th workshop on RF suprconductivity, Oct. 4-8, 1993, CEBAF, U.S.A., P.398-405.