RESEARCH AND DEVELOPMENT OF 1.3 GHZ LOW LOSS CAVITIES MADE OF CHINA LARGE GRAIN AT IHEP*

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Abstract

Institute of High Energy Physics, IHEP, has studied superconducting RF cavities since Oct. 2000. To contribute to International Linear Collider (ILC) for which superconducting RF cavity was chosen, research and development of 1.3 GHz low loss cavities using China large grain niobium was carried out recently at IHEP. The study is based on the latest research direction in the material and the shape of the cavity and involves the design of low loss shape for higher gradient and fabrication using large grain niobium material. The shape and some parameters of the cavity will be presented in this paper and be compared with alternative structure (low loss cavity) design data. In the manufacture the cavity was formed by standard procedures, such as deep drawing, trimming and welding by electron beam. To prepare the RF surface for vertically cryogenic test, centrifugal barrel polishing, barrel chemical polishing, annealing, high pressure rinsing and baking were employed. This paper introduces the features of the fabrication and surface treatments on the large grain cavity and presents the preliminary results of the research.

INTRODUCTION

The accelerating gradient in the ILC main linac is supplied by over 16,000 9-cell superconducting RF cavities, grouped into approximately 12.6 m long cryomodules. The baseline cavities use the TESLA design developed at DESY over the past 10 years and are fabricated from polycrystalline high purity niobium [1]. Some scientists believe that the limit could actually be given by the high surface current on the surface of the niobium, which is determined by the surface magnetic field. Based on this belief, recent studies on cavity shapes at DESY, Cornell University and KEK have proposed some low loss shapes [2]. By slightly changing the shape of the cavity cell walls, it is possible to reduce the peak magnetic flux on the walls and allow the cavity to reach higher accelerating gradients before reaching a critical field limit on the niobium surface and starting to quench. New cavity shapes have been successfully tested as single cell structures up to gradients of 50 MV/m at both Cornell University and KEK. On the other hand, single cells have been produced at Jlab, KEK(Cooperating with IHEP) and DESY from large grain ingot material or from single crystal, cut directly from the billet by either wire or saw cutting [3,4,5]. This new development has opened the new potentials to simplify the production sequence and consequently the cost. Initial experience indicates that very smooth surfaces can be obtained with large grain material using the chemical polishing etch process only, thus avoiding the necessity for the more complex electro-polishing process. This is attributed to fewer defects, a reduced intrinsic strain and significantly reduced grain boundaries in the large grain material. As a relatively new but exciting development, little experience exists at present. Different vendors have developed the technology to provide large grain materials. By testing cavities using their materials, it should be possible to investigate the performance.

The study on the issues above has been going at IHEP to contribute to the ILC project. A new kind of low loss shape cavity had been designed and some large grain niobium sheets from OTIC, Ningxia, China and fine grain niobium sheets from Tokyo Denkai, Japan were purchased. Two large grain and three fine grain single-cell cavities were fabricated by standard technologies. Some programs of surface treatments have been proposed and carried out on the two large grain cavities. The preliminary results of the research will be presented in this paper.

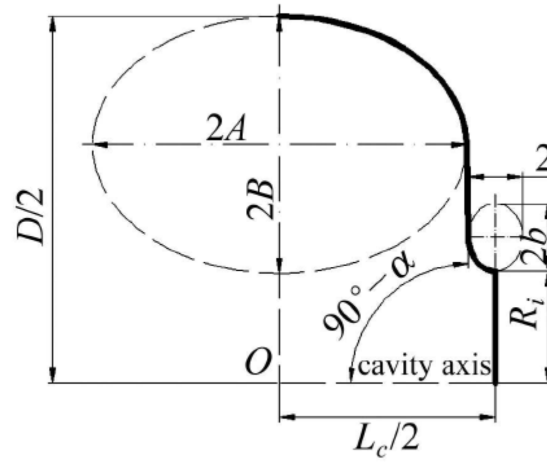

Figure 1: Elliptical half-cell geometry. 1/4 part is shown.

DESIGN OF THE LOW LOSS CAVITY

In order to determine a cavity geometry that has the necessary electromagnetic performances for the 1.3 GHz 9-cell superconducting RF cavities linac, we have used a geometry parameterization that allows easily balancing peak electric and magnetic field. The cavity geometry is elliptical both at the equator and at the iris, and is shown in Figure 1.

Although the cell parameterization described above is convenient for the analysis of the cavity behaviour as a

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Table 1: Main cavity parameters.

Cavity parameters	Midcup for multi-cell	Mono-cell with tube
Working Mode	π	0
L_c/mm	115.38	
α/(°)	1.00	
R_i/mm	30.00	
D/mm	196.66	
a/mm	7.25	
b/mm	9.05	
A/mm	50.00	
B/mm	34.50	
Length of tube/mm	-	110.00
f_0/MHz	1300.00	1289.34
$G=R_s*Q$/Ohm	285.00	283.00
(R/Q)/Ohm	133.10	138.20
E_p/E_{acc}	2.30	2.10
$(H_p/E_{acc})/(O_e/(MV/m))$	36.06	35.47
K_{cc}(Coupling)/(%)	1.54	-

function of its shape, it is rather cumbersome to use in the standard RF code as SUPERFISH for the cavity geometry definition, especially for tuning, where several iterations on the cavity parameters are needed in order to obtain the design frequency. For this reason, a program based on Microsoft Visual Basic was developed to execute the field solver iteratively for tuning purposes and gather the solution data.

Making an elliptical cavity design we restricted ourselves by the optimisation of two characteristics, which limit in principle the achievable value of accelerating field in cavity E_{acc}: the peak surface electric field (E_{pk}) and the peak surface magnetic field (H_{pk}). The results are summarised in Table 1. In Table 2, some parameters of the cavity are compared with some kinds of cavities proposed at other labs (TESLA-800, Cornell RESCC, KEK/DESY LLSCC). From the comparison, the design of low loss cavity indicates more similarities with DESY/KEK low loss cavity.

Table 2: Some parameters to compare low loss cavities.

	TESLA (DESY)	RESCC (COR.)	LLSCC (IHEP)	LLSCC (KEK)
f_0/MHz	1300	1300	1300	1300
$G=R_s*Q$ /Ohm	271	278	285	284
(R/Q)/Ohm	113.8	126.8	133.1	134
(H_p/E_{acc})/ Oe/(MV/m)	42.60	37.80	36.06	36.10
E_p/E_{acc}	2.00	2.20	2.30	2.36
K_{cc}/%	1.89	2.38	1.54	1.52
$((R/Q)*G)$/ Ohm^2	30840	35250	37934	37970

CAVITY FABRICATION

Niobium properties

The large grain niobium sheets of 2.8 mm thick were produced by OTIC, Ningxia, China. Standard procedures convert the ore to niobium ingots after multiple electron beam melting of aluminothermically reduced niobium oxide. Sheets of 2.8 mm thickness are sliced from the ingots by saw machine. *RRR*, the most important value for superconducting RF cavities, is more than 300. Tantalum with a concentration of 50 ppm is the maximum metallic impurity. Among the interstitially dissolved impurities, oxygen whose content is 28 ppm in these sheets is dominant due to the high affinity of niobium for oxygen above 200 °C. The size of the large grains in the sheets is not uniform. Even two sides of one sheet have different grain numbers. Care had been taken to ensure that sheets are thoroughly defect-free and no scratch. Seamless beam tubes of fine grain niobium have been manufactured by the vendor and adopted for the large grain cavities. As for the flange which would be in region of low magnetic field, niobium with low *RRR* of about 50 was chosen instead of the high purity material needed for the cells to reduce the cost.

Deep drawing and electron-beam welding

The dies for deep drawing were made from high yield strength aluminium alloy. To achieve the ideal curvature of half-cells, precise three dimensional geometrical measurements and fine polishing on the contour of the dies were performed by a process of iteration. The deep drawing process was simulated in a preliminary exercise with copper sheets to check the performance of the dies and choose the proper size of sheets.

Half-cells of the large grains cavities were produced by two-step deep-drawing. Clean motor oil was painted onto the niobium for lubrication. As shown in Figure 2, tearing

Figure 2: Half-cells after deep-drawing and trimming.

at the iris, strong earring and grain steps at equator region occurred due to the non-uniform grain sizes of the sheets.

To get the curvature required at the iris, the nose of the cup was then coined with a coining ring and the male die. The half-cells were trimmed to final size for electron beam welding on a lathe. When trimming well cooling with lubricants was provided in consideration of the high reactivity with oxygen.

All of the parts were electron beam welded together in a vacuum chamber. The half-cells were thoroughly cleaned by ultrasonic degreasing, 10 μm chemical etching and ultra-pure water rinsing. As the experience was short for the technical staffs to operate the machine welding niobium material a complete cavity of fine grain material was especially arranged to fumble for the parameters of the machine to weld different parts of the cavity. Since niobium is a strong getter material for oxygen it is important to carry out the welding in a sufficiently good vacuum. The pressure in the chamber was less than 10^{-3} Pa. To achieve full penetration in the 2.8-mm-thick niobium, a set of electron-beam welding parameters were generally V=60 kV and I=125 mA at a 1200 mm/min weld speed. The strategy for the different welding seams was a little adjustment of beam current. The equator welds were done first and the iris welds were done last. By using the defocused electron beam outside, the weld spatter was not significant and the underbead looked smooth by a CCD (charge coupled device). Finally the six cavities were welded successfully as shown in Figure 3.

Figure 3: Six low loss cavities welded in Beijing. Three cavities made of fine grain niobium material from Tokyo Denkai. Tow cavities made of large grain niobium material from OTIC, Ningxia. Another one made of fine grain material from OTIC, Ningxia and just for electron beam welding test.

Figure 4: Machine for centrifugal barrel polishing at IHEP.

CAVITY TREATMENTS

In order to propose surface treatment recipe for the cavities, the following aspects were taken into consideration. For the ILC project, fine grain cavities treated by chemical polishing have adequately been investigated. Large grain cavities by electro polishing (EP) have also achieved good results. Our priority would be given to the large grain cavities. The process of chemical polishing etch would only be applied to avoid the more complex EP. Two large grain cavities have both been objected to some surface treatments. The brief introductions of these processes are the following.

Grinding

To ensure a smooth inner surface in this high electric field region and to avoid geometric field enhancement, the extra step of grinding the iris weld was performed. As the flange welds were liable to grind, they were done.

Centrifugal Barrel Polishing

Referring to the machine for centrifugal barrel polishing at KEK [6], we developed a machine in Beijing as shown in Figure 4. The machine can accommodate a 1.3 GHz three-cell cavity. Three kinds of stones were used for polishing. The roughest stone have the surface roughness of 100 Mesh and can efficiently smooth the welding underbead and remove the small spatters. If there were no visible defect in the image from the CCD, two fine stones of 200 Mesh and 600 Mesh would be employed to smooth inner surface. The mass of the cavities almost did not decrease but the surface turned evidently smooth with the fine stones.

Chemical Polishing

The acids for chemical etching were the mixture of HF (48%), HNO_3 (60%), and H_3PO_4 (85%) in the volume ratio 1:1:1. The temperature of the cavity during chemical polishing (CP) could be controlled by the outside rinsing of the water supply. The material removal speed of the

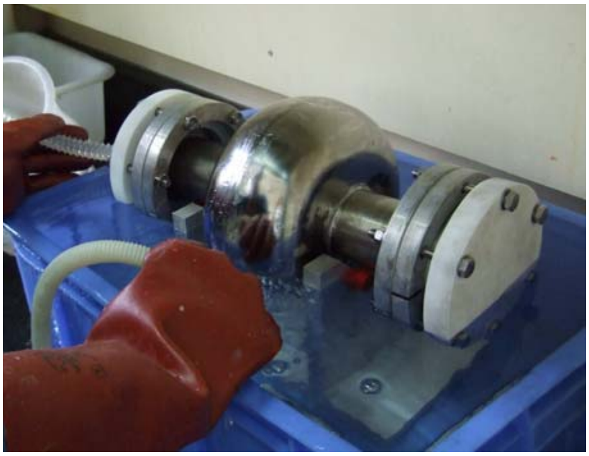

Figure 5: Horizontal chemical polishing on the large grain cavity of low loss shape at IHEP.

vertical process was 4 μm/min and correspondingly 2 μm/min for the horizontal according to the tests in advance. For the cavity, each head was dealt with vertical CP for 7 minutes. And a horizontal CP of 20 minutes was also applied as shown in Figure 5.

High Pressure Rinsing and Annealing

Immediately after CP, the cavity was placed in a loop of ultra pure water system for 2 hours. The specification of the water includes the resistance of more than 18 MΩ/cm and the total organic carbon (TOC) of 17 μg/l. To eliminate the particles larger than 0.22 μm, a filter is equipped before the nozzle from which ultra-pure water spurts to remove any chemical and particulate residues from the niobium surface.

Annealing/degassing was performed at 750 °C for 3 hours in the vacuum furnace at a pressure of 10^{-4}~10^{-5} Pa, which serves to relieve mechanical stress of the cavity and remove the hydrogen in the material. The cavities were placed in a titanium box to prevent the niobium from the contamination by the residual oxygen in the vacuum chamber. The process of heating was controlled slowly enough for the cavities to release the thermal stress. Before and after 350 °C, both take 2 hours and about 350 °C, a stay of 30 minutes was used to homogenize the temperature of the cavities. The cooling down was natural and lasted 10 hours.

Baking

After annealing, the inner surface of the two large grain cavities was compared with each other by the CCD. Large Grain Cavity 2 (LGC2) had the better surface and was chosen to prepare for RF test. The cavity was treated with a fine CP of 10 μm and high pressure rinsing of 2 hours. The still wet surface from ultrapure water was exposed to the filtered air in the Class 10 clean room and was dried. In the clean room, the cavity was assembled with an RF input-coupler and pick-up antenna on ends of cavity, respectively, with the indium wire seals. In the vacuum station, the vacuum leaking of flange connections was strictly checked. When the cavity was evacuated to about 10^{-5}~10^{-6} Pa, the ion pump was switch on and then the 125 °C baking of 48 hours was started. During baking, the vacuum ranged from 10^{-5} to 10^{-7} Pa obtained by ion pump.

The vertical RF test was postponed due to the shortage of liquid helium.

SUMMARY

A new cavity with low loss shape was proposed at IHEP for ILC. According to the design the dies for deep drawing was manufactured in Beijing. The fabrication of the low loss cavities using large and fine grain niobium by standard recipes was successfully completed in Beijing. Surface treatments, such as grinding, centrifugal barrel polishing, chemical polishing, annealing, high pressure rinsing and baking was carried out at IHEP although the vertical RF test was limited by the shortage of liquid helium.

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