STUDIES FOR STABLE HIGH-FIELD OPERATION OF X-BAND ACCELERATOR STRUCTURE

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Abstract

The accelerating structures for linear collider main linac operates at an unloaded gradient of 72MV/m. Those designed with a large group velocity (starting at 12% of light velocity) showed intolerable amount of erosion of copper material in the operation above 50MV/m. Recently those with the smaller group velocity (starting at 5% or less) showed less damage even at 70MV/m. In addition to the small group velocity, those recent structures were fabricated by adding more sophisticated treatments on copper surface than before. We briefly review the present status of these high field studies. Then we present ongoing surface studies toward improving the high field and breakdown performance.

1 INTRODUCTION

The main motive force of adopting X-band travelling-wave structures for the main linac of the linear collider is to make the system highly efficient in energy transfer to beam and short linac-length point of view. This view is based on a high shunt impedance and a feasibility estimation of high gradient performance of high frequency structures. To overcome the big wake field due to its small size, the beam hole aperture is designed to be as large as possible. In the original design $a/\lambda = 0.18$. In addition, the structure length was thought better to be long in reducing number of RF feeds to save cost of whole linac. These two requirements made the group velocity of the original design as large as 0.12c[1].

The structures based on this design showed an intolerable speed of copper material erosion during the conditioning[2] and even during running at a fixed field over 50MV/m[3]. The erosion changes the phase advance along the structure, which we can measure electrically. The area of the group velocity higher than 5% exhibited a significant phase change comparing to the lower group-velocity area. Considering these, low group velocity structures (less than 5%) were made and their high-field performances were examined. Typical performances of these structures are presented in the present paper.

These recently studied structures were treated in various new processes which were not applied to the previous structures. The surface behaviour should play an essential role in triggering the breakdown and may cause the erosion of copper surface. These recent structures were found to behave better, especially those made through a heavy chemical etching process of a few micron level in an acid bath, comparing to those made of diamond turned parts followed by a light etching[4]. Studies to examine the characteristics of copper surface on various machining processes and surface treatments started and some representative activities to show the present situation are also described in the paper.

2 TEST STRUCTUER GEOMETRIES

There are two recent structures designed focusing on the wake field suppression, DDS3 and RDDS1 and these served as the reference structures for the linear collider purpose[1]. These structures are both 1.8m long and start at a high group velocity, 12% of light velocity. The latter structure is more realistic because of optimised shunt impedance by introducing rounded shape of the cell comparing to the former composed of a flat disk and a cylinder. However, the ratio of the surface field to the accelerating field for both structures are almost the same so that it is reasonable to study the high field performance by using the structures composed of cells with flat disks and cylinders, just as the former so that rather tedious design and fabrication works will be minimized.

In order to study the structure with reduced group velocity, it is most effective to realize by reducing the beam hole aperture. The line (A) of 1.8m structure shown in Fig. 1 is the beam hole radius of the reference structure as a function of group velocity along the structure. The dotted line (B) overlapping the above and that (C) extending to the lower group velocity side are those with reduced group velocities by reducing the beam hole aperture. The left two lines (D and E) are for the structures with low group velocities but keeping the beam hole aperture size the same as those of reference structures by adopting a higher phase advance per cell, $5\pi/6$ mode. All these parameters are designed to make the structures detuned in the first dipole mode frequencies to simulate the realistic parameter change along the structure. The structure length naturally decreased from 1.8m to 0.5-1m range due to the less group velocity.

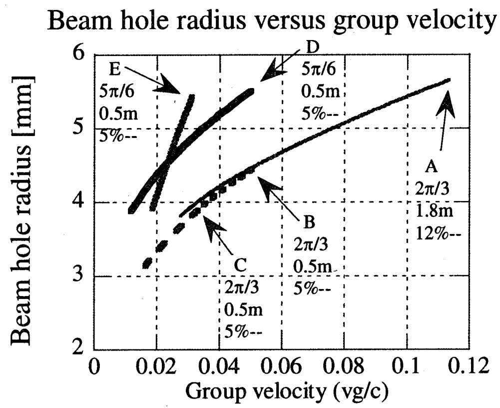


Figure 1: Beam hole radius as function of group velocity.

3 LESS DAMAGE AT LOW GROUP VELOCITY

In Fig. 2 are shown two typical high-field performances of the structures [2,5]. The left figure is for the structure (M2, 1.3m, vg/c starts at 10%) with the similar parameters as A in Fig. 1 but starting group velocity is 10%, while the right for the structure (DS2S, 0.5m, vg/c starts at 5%) with very similar parameters to that of B in Fig. 1.

The conditioning of M2 showed severe phase change, 0.4 degrees/cell, due to the conditioning for 400 hours from zero to the maximum accelerating gradient of 85MV/m, though most of the high field conditioning period was 200 hours at 75MV/m level. Multiple structures with the parameter A in Fig. 1 showed roughly the same amount of erosion rate in a conditioning and operation at 50 MV/m level for thousand hours. On the other hand, the conditioning of DS2S lasted over 5 months, for 2400 hours, with a maximum accelerating gradient of more than 70MV/m. Several thousand breakdowns occurred but resulted in only a small phase change of 0.25 degree/cell.

The phase change pattern tells that the frequency change near input coupler is most significant, meaning that the more group velocity the more severe erosion occurs. The difference in the frequency shift, 1MHz for DS2S and 4MHz for M2, indicates the preference of a lower group velocity of 5% for DS2S compared to 10% of M2.

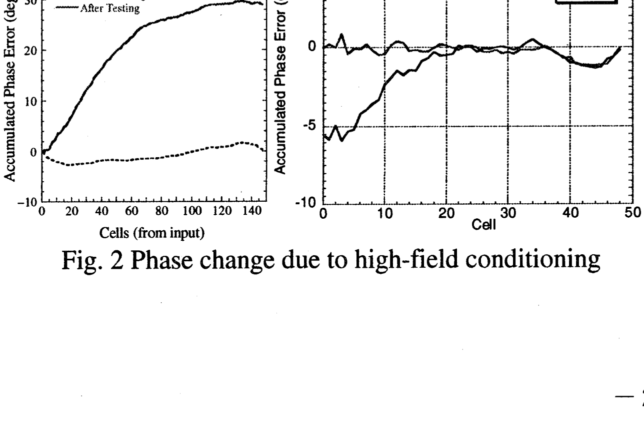


Fig. 2 Phase change due to high-field conditioning

of two structures.

It was also observed that most of the remaining breakdowns after reaching the maximum field occurred near input coupler area. This is one of the issues to be solved, probably modifying the geometry near the input coupler.

4 FABRICATION PROCESSES

The high-field performances should largely depend on the quality of copper surface reflecting the actual fabrication processes and treatments of the structures. Three typical fabrication flows of recent tested structures are listed in Table 1.

Table 1: Typical fabrication flows of recent structures.

Type	F	N	R
Machining	Diamond	Diamond	Usual lathe
Rinsing	O_3 PW rinsing	Light chemical	Heavy chemical
Bonding	VAC DB	H_2 DB	H_2 DB
Brazing	Au Brazing	Au Brazing	Au Brazing
Treatment	H_2 + VAC	H_2 + VAC	H_2 + VAC

Note:

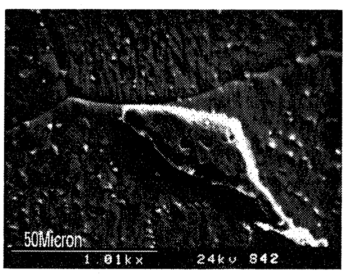
O_3 PW =Ozone-gas included pure-water rinsing.
Chemical =Rinsing in some combination of acid.
VAC, H_2 = Vacuum furnace and hydrogen furnace.
DB = Diffusion bonding at 900 – 1000C.
H_2 + VAC=Surface treatment at high temperature in hydrogen atmosphere and in vacuum.

The first column called F-type in the table, is listed in more detail below; 1-rough machining of class 1 OFC, 2-annealing at 500C, 3-diamond turning with Kerosene mist and cutting by about 40 μm in total with a final cut of 2 μm, 4-rinsing in acetone ultra-sonic bath, 5-storage in air, 6-ozone-gas included pure-water rinsing, 7-storage in air, 8-stacking in a clean room, 9-pre-bonding in a vacuum furnace at about 180C for one day, 10-diffusion bonding at 890C for a few hours in a vacuum furnace, 11-brazing in a hydrogen furnace around 1000C, 12-RF tuning and finally 13-hydrogen furnace treatment and vacuum baking. The second column called N-type is the same as the F-type except for the main bonding stage, where all the bonding processes are made in the hydrogen furnaces. The third column called R-type starts with the parts machined with the conventional lathe but with a thicker chemical etching process. The surface treatment comprises of wet hydrogen treatment followed by a dry hydrogen treatment and vacuum baking at 650C for ten days or so.

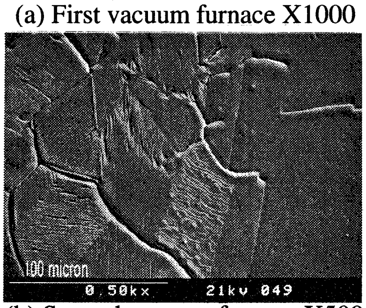
When we compare the conditioning performance of N-type structures to the later R-type ones, that of the latter seems better [4]. This example makes us study the copper surface processes including thick etching.

5 POSSIBLE SURFACE CHANGES

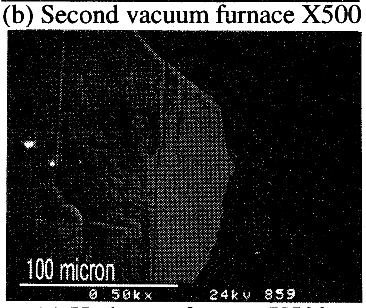
The structures experience many surface treatments during the fabrication. First of all, the machined parts are rinsed in some liquid solution. Then, they are bonded in vacuum or hydrogen furnace, both at a high temperature, 900-1000C, for an hour or more. This process changes the copper surface fairly a lot[6]. Some examples are shown in Fig. 3.



(a) First vacuum furnace X1000



(b) Second vacuum furnace X500



(c) Hydrogen furnace X500

Fig. 3 SEM views of copper surfaces after high temperature treatment; (a) and (b) in vacuum furnace and (c) in hydrogen furnace.

During a high temperature process in a vacuum furnace with its vacuum level of 10^{-5} Torr, the copper surface loses its original cut surface and exhibits a complicated evaporation pattern depending on the crystal-axis directions as shown in (b). It should be noted that even in the same temperature process, the surface appearance may change a lot. The example shown in (a) is the sample prepared and processes in exactly the same manner as (b). We speculate some change as for the furnace occurred between (a) and (b). The surface treated in a high temperature furnace filled with gas, such as hydrogen shown in (c), becomes very smooth with only the grain boundaries stressed. No other material than copper in case (b) and (c) were observed but the high field performance on these surfaces should be studied. Studies under this direction are being planned.

6 IMPULSE DC BREAKDOWN EXPERIMENT

A series of impulse DC high voltage breakdown experiments were performed on the copper surfaces to evaluate the surface quality evaluation [7]. The study indicated the importance of usage of class1 material compared to class 3 or 5. It also showed various aspects of the surface treatment effect.

We decided to pursue the same experiment on the electrodes made through the processes connected to the accelerating structure fabrication. To start with, two pairs of electrodes were tested, which were made by a diamond turning with Kerosene oil mist as a lubricant followed by an acetone ultrasonic bath rinsing. The conditioning speed to reach the saturated surface gradient of 300MV/m level and the reached field level are similar to those of the well-behaved diamond-turned electrodes experienced before[7,8]. We will make the electrodes through hydrogen furnace cycle, vacuum furnace cycle, vacuum baking cycle, etc., to evaluate the effect on breakdown and conditioning performance in near future.

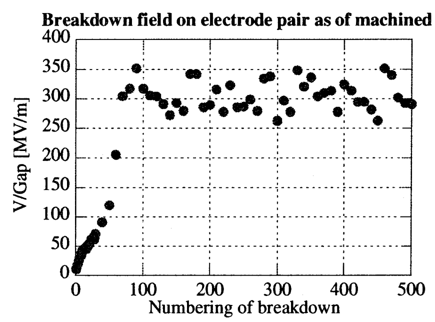


Fig. 4 Breakdown experiment an example

6 ACKNOWLEGMENTS

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