

PRECISE FABRICATION OF 1.3M-LONG X-BAND ACCELERATING STRUCTURE

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Abstract

Precisely controlled frequency distributions of the higher modes in each cell and the good straightness of the cells along the structure are the key issues on the detuned structure for the main linac of the Japan Linear Collider. The fabrication studies of a few full-size accelerating structures have been performed based on the technique of the ultra-precise machining of the cells and the diffusion bonding to join them. As of today, the frequency controllability of each cell was found to be better than 1Mhz in the standard deviation of the accelerating mode and the alignment of the cells along the structure was found to be better than 10 μm .

Introduction

The preservation of the multi-bunch emittance is one of the key issues to reach a required high luminosity for the most of the present-day linear colliders[1]. One of the source of the emittance growth is the dipole wake field due to the accelerating structure. Three methods have been proposed so far, heavily damping, detuning with a medium damping and purely detuning. In the present paper was studied the last approach, "purely detuned structure".

In order to realize this approach, the control of the frequency distribution of the dipole modes and the transverse positions of those modes with respect to the beam is essential to realize the designed cancellation of the wake field. In the Japan Linear Collider, JLC[1], each structure consists of 150 cells and four structures are interleaved in dipole mode frequency. In this case, the frequency spacing between nearest neighbor is about 1Mhz. Because the stored energy of most of the modes are spreading in more than 20 cells, it is enough to control the random error in each cell frequency better than 1Mhz. The tolerance of the alignment of those modes along the structure is assumed as 5 μm from the simulation results for NLC[2], where most of the parameters are similar to those of the JLC.

To meet the tight tolerance of the frequency control, the cells which consist of the structure are firstly machined with an ultra-precise lathe and a milling machine. Secondly they are bonded through a diffusion process between the flat surfaces of the cells. No tuning is performed after bonding.

From the previous fabrication studies of 30cm-long constant-impedance structures, the bonding at a temperature above 800°C was found reliable to obtain the vacuum tight junction for the present quality of the machined cells[3]. The change of the accelerating mode frequency is less than 1MHz out of 11.4GHz. It is necessary to study the applicability of the present fabrication technique to the 1.3m detuned structure.

Electrical design parameters

In order to make the detuning of the dipole modes, the beam hole radius and the disk thickness are varied so that the unperturbed dipole modes are distributed in a truncated Gaussian. The actual parameters are shown in Fig. 1. The cell inner radius "b" was determined to make the $2/3$ mode to be the operating frequency. Practically, the frequencies at three points along the structure were studied experimentally by measuring the frequencies of the resonant $2/3$ modes in varied number of regular cells with half end cells at both ends to estimate the frequencies in the periodic structure. Using these three points as a correction to the precise numerical estimation of the frequencies at the other points in the structure, all the dimensions "b" were determined[4].

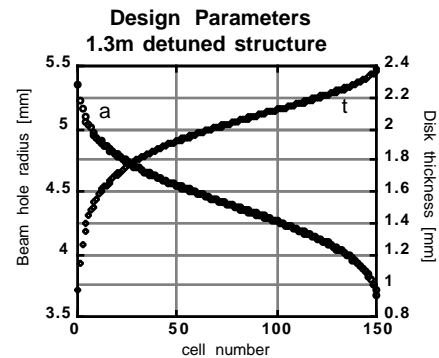


Fig. 1 Cell parameters (a,t) along the detuned structure.

Structure description

Three 1.3m structures were fabricated. The first one, called "M1", came out with severe vacuum leakage after the first diffusion bonding at 800°C. We speculate that this failure is largely due to the complex shape of the cells where four slots are sitting on the bonding surface so that there might be many burrs which make the reliable bonding difficult. In the following two structures, "M2" and "IH1", the slots on the bonding surface were removed. The rather large diameter of 80mm is for stabilizing the stacking and bonding processes in addition to integrate the water cooling channels to make the fabrication as simple as possible for mass production purpose. The coupler cells are firstly milled to make the two symmetrical wave guide ports with a precision of 1 μm and then the cell inner surface and bonding surface are cut by the ultra-precise lathe. In Table 1 are listed various fabrication informations of the two structures.

All the cells are machined using a ultra-precise lathe to make the bonding surface to be as flat as possible, typically 0.3 μm or better, with a surface roughness of 50nm. These cells were chemically rinsed in a series of weak acid, pure water and acetone bath. The cells are stacked along a Vee block and compressed in the axial direction. Keeping the

compression force and hanging vertically in a vacuum furnace, the stack is diffusion bonded to join all the important part of the structure. The symmetrical wave guide ports, which are coated with 10 μm thickness of silver were brazed in the next furnace operation with a wire brazing alloy as a backup.

Table 1
Fabrication process informations.

Structure		M2	IH1
temperature	$^{\circ}\text{C}$	850	890
period	hours	4	0.2
pressure at top	kg	16	40
stacking		hor. V	ver. V
furnace		vacuum	vacuum

Frequency control

The first step to realize the good frequency control is of course to cut the cells in a good precision. In the case of M2, the standard deviation of 2b is $0.41\mu\text{m}$ while maximum deviation is ± 2 , which is precise enough to satisfy the tolerance of 1Mhz.

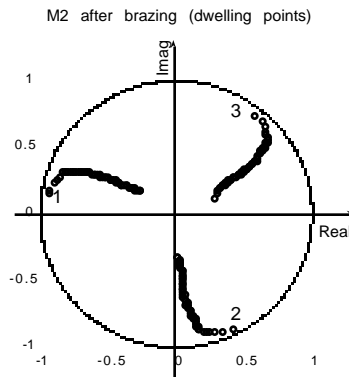


Fig. 2. Dwelling points in nodal shift measurement of M2.

To check the frequency change due to the bonding process, the reflection phase seeing from the input wave guide were measured by shifting the plunger of 5mm in diameter inserting from the output coupler side. This nodal shift measurement were performed just after stacking and just after bonding. An example is shown in Fig. 2. The plunger was moved in 0.2mm step and the dwelling points were deduced by finding the point of a minimum movement in the reflection phase. Due to the large difference of diameter between the plunger and the beam hole, especially near the input side, the dwelling points were shifted by more than 0.5mm from a nominal position along the structure. This behavior appeared in the reflection phase shifting from a simple line of $240^{\circ}/\text{cell}$ near the input coupler.

From the nodal shift measurement, the phase difference due to the movement of the plunger through three cells were used to estimate the frequency shift of the cells. This analysis removes such effects as the mismatch at the input and becomes more precise than the direct comparison of those between the adjacent cells. In Fig. 3 are plotted the frequency changes due to the whole bonding processes of M2. The

standard deviation of the frequency change was found 0.66Mhz while almost all the cells are within ± 1.5 . It is to be noted that the standard deviation of the frequency change in the first diffusion bonding of IH1 case was as large as 1.1Mhz while that through the additional diffusion bonding and the final brazing only 0.4Mhz. The larger value in the first bonding than that of M2 case might be due to the poor surface flatness or a higher temperature of bonding comparing to the M2 case. The frequency shift in M2 is tolerable but the characteristics of the frequency change on the bonding parameters should be studied further.

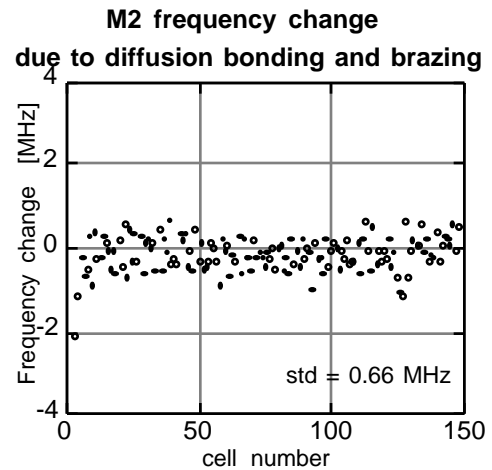


Fig. 3. Frequency shift due to bonding of M2.

Alignment

The cell alignment was measured just after stacking the cells but before removing from the vee block. The measurement was performed by capacitive sensor, microsense. In Fig. 4 are shown the case of IH1. The cells were found to follow the vee block within $8\mu\text{m}$ by a simple stacking in a horizontal vee. Because of the miscut of some of the cells in their outer diameter, OD, the alignment data were corrected by using measured OD's. Some data points which deviate much from the smooth line are speculated to be due to the mismeasure of the OD of the particular cell. The alignment change due to the bonding was found less than $10\mu\text{m}$. A similar characteristics but a little worse alignment of the order of $20\mu\text{m}$ was found in the case of M2 than that of IH1. It should be noted that the cell to cell movement was very small in M2 case, where almost $1\mu\text{m}$. There are a few different points between the fabrication process of IH1 and M2, such as vertical stacking or horizontal, and there is a room to further study and refine the alignment of the cells to meet the required tolerance of several μm reliably.

Shrinkage

In order to proceed the plastic deformation to fill the gap between the cells during the diffusion bonding process, the pressure was applied ranging from 3 to $20\text{g}/\text{mm}^2$. Rather long period of diffusion bonding process under this pressure at

high temperature makes the cells shrink. In Fig. 5 is shown the case of IH1. The measurement was performed by measuring the distance from the end of the structure to the cell position. The shrinkages of both first and second diffusion bonding at 890°C were about 1μm per cell. That of the final brazing at 800°C was found only 0.3μm. The shrinkage was found 0.87 μm in the M2 through a diffusion process and a final brazing in total.

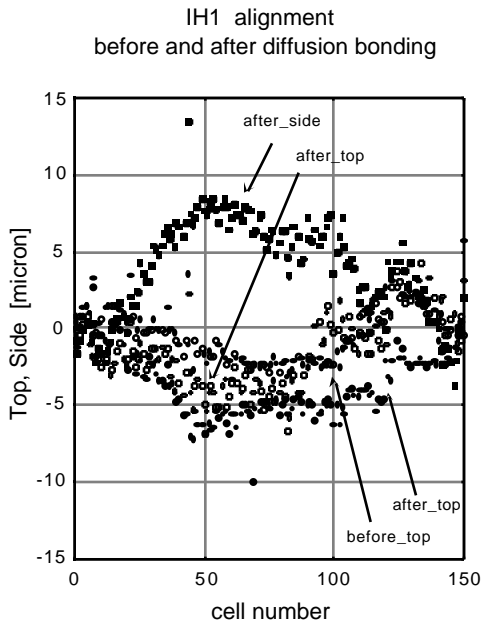


Fig. 4 Alignment of cells of IH1.

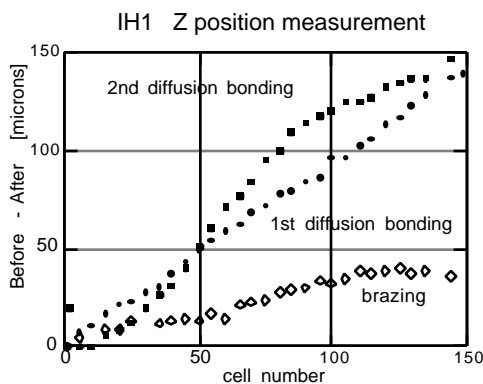


Fig. 5. Shrinkage of cells in IH1.

Summary and discussion

Three structures were fabricated to study the precise fabrication method of 1.3m accelerating structure. The last two structures came out to be vacuum tight and various characteristics were discussed.

The accelerating-mode frequency of each cell can be controlled with the standard deviation of 0.41Mhz in cell machining while that due to bonding 0.66Mhz. The relative frequency error of the TM110 mode is estimated to be almost the same as that of the accelerating mode. Therefore, the standard deviation of the random frequency error of the TM110 mode in each cell is about 1Mhz.

The alignment of the cells along the structure were better than 10 μm. The present simple stacking method should be refined to make the alignment better by a factor of 2. Each cells were found to be shrunked by about 1μm.

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