Precise Fabrication of X-band Accelerating Structure

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Abstract

An accelerating structure with $a/\lambda=0.16$ is being fabricated to study a precise fabrication method. A frequency control of each cell better than 10^{-4} level is required to realize a detuned structure. The present machining level is nearly 1MHz/11.4GHz in relative frequency error, which just satisfies the above requirement. To keep this machining precision, the diffusion bonding technique is found preferable to join the cells. Various diffusion conditions were tried. The frequency change can be less than 1MHz/11.4GHz and it can be controlled well better than that.

I. INTRODUCTION

In the Japan Linear Collider (JLC)[1], a train of 90 bunches are designed to be accelerated in an RF pulse. In order to suppress the multi-bunch emittance growth due to the wake fields excited by the preceding bunches, the wake fields should be reduced by two order of magnitude at the following bunch. Various damped structures have been discussed up to date. Some of them showed satisfactory damping characteristics, though accompanied by a severe degradation of the accelerating mode[2,3]. A detuned structure is an alternative candidate for reducing the wake field effect by carefully tuning the higher order mode frequencies of all cells in the structure[4,5]. To suffice the requirement of the JLC, it is necessary to tune the frequency of each cell within 10^{-4} level(5]. In addition to the frequency control, each cell should be aligned better than a few μm level[6].

In order to study how to actually fabricate such a structure, a prototype structure with constant impedance type is being fabricated. The fabrication should be proceeded in such a way that it makes possible to judge whether such a structure is feasible or not standing on the present status of the fabrication technique.

The present paper describes some basic experimental studies and a brief perspective for the structure R&D's in near future.

II. GEOMETRY

The present structure is a disk-loaded structure of constant impedance type with $a/\lambda=0.16$. A schematic drawing to describe a cell is shown in Fig. 1. The basic parameters are listed in Table.1. Four small holes are the channels for cooling water. Left most figure includes the waveguide port in coupler cell superimposed to the cross sectional view of the regular cell. This arrangement of the waveguide port makes the outer diameter (OD) of coupler cell 80mm. In order to make each cell aligned within a micrometer using outer surface of each cell, the OD of the regular cell was decided to be the same as that of the coupler cell.

In order to keep the phase slip of the beam compared to the accelerating mode within 2 degrees along the structure with 150 cells, the random variation of the frequency of each cell should be less than ±0.59MHz. Since the full width of this tolerance is about the same as the requirement for the HOM frequency, we decided at a moment to refer this number as a criteria of HOM frequency controllability. The tolerance to keep this criteria against the independent change of each dimension is listed in Table 1. Various calculated parameters for the structure are listed in Table 2.

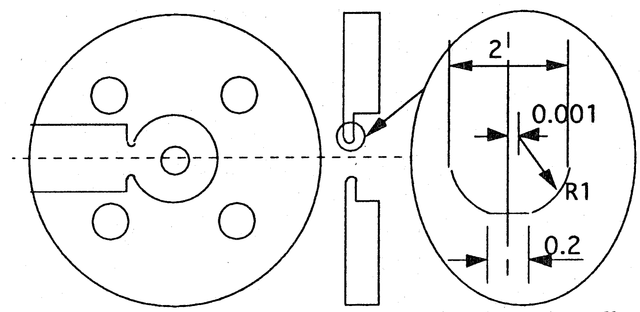

Fig. 1. Schematic drawing of a regular cell and coupler cell.

Table 1. Dimensions, sensitivities and tolerances.

parameter	value [mm]	sensitivity [MHz/μm]	tolerance [± μm]
2b	21.6682	-0.60	1.0
2a	8.3974	+0.25	2.5
t	2.0	+0.13	4.6
g	6.7474	-0.090	6.6
OD	80.000		0.2

Table 2. Parameters of the structure of Table 1.

freq.	11.424	GHz
φ	2π/3	radian/cell
κ	4.2618	%
vg/c	3.8245	%
r/Q	12.218	kΩ/m
Q	6657	

III. MACHINING

Each cell was machined from OFHC copper after an annealing at 500°C in one hour between the medium machining and the last one. For the medium and last machining, a single crystal diamond tool of 0.4R is used to cut 20μm in depth in several passes. The very last cutting is about 1μm in depth. The beam hole, accelerating cell itself and the outer circumference are cut without re-chucking the cell to make sure that the concentricity among them to be better than 0.1μm. Typical flatness at present is 0.3μm in 80mm in diameter. The cell length were controlled better than 1μm by cutting the vacuum chucking surface before each setting of the cell. The OD's were controlled at present better than 1μm with a moderate feedback from a cell machining to the followings. The surface roughness is 50nm.

To check the reproducibility of the machining, each cell frequency was measured in a resonant mode with half dummy cells stacked at both sides with compression pressure of 150kg. The frequencies of zero mode and π mode in TM010 passband are good measures for the dimensions of 2b and 2a. Those are plotted in Fig. 2. Though the period of machining was more than a week, the frequencies are controlled within ± 0.6MHz.

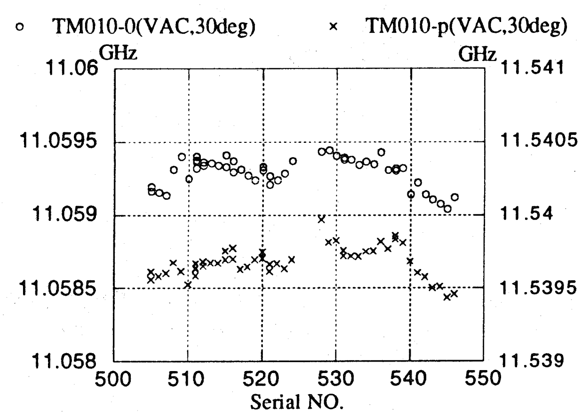

Fig. 2. Frequencies of zero and π mode for each machined cell.

IV. BRAZING

Because the brazing technique was most popular for the authors at the early stage of the present study, the characteristics of the brazing of two cells were first studied. The cells have a gap of 70μm for a brazing sheet between two contact planes in addition to the geometries of Fig. 1. These two contact planes are varied between 2mm and 10mm in width and they were located at the average diameter of about 22mm for inner contact and about 70mm in outer contact area. There is in addition a 2×2 groove for a brazing wire at the inner side of the above gap. The detail of the dimensions are described in ref. [7].

Surface flatness became several μm level after brazing, though it was well better than 1μm before brazing and the pressure was transferred via a thick graphite block with surface flatness of better than 1μm. Though this surface flatness change is huge, the lengths at some points in 80mm diameter were measured before and after brazing to check the dimensional change in axial direction. The results are shown in Fig. 3. It is seen from the figure that the cell length change is proportional to the pressure for a same kind of brazing structure, though the amount and even the sign are dependent on the brazing structure. It can be noted that the pressure difference along the structue gives rise to substantial mechanical changes varied from top to bottom in vertical brazing case.

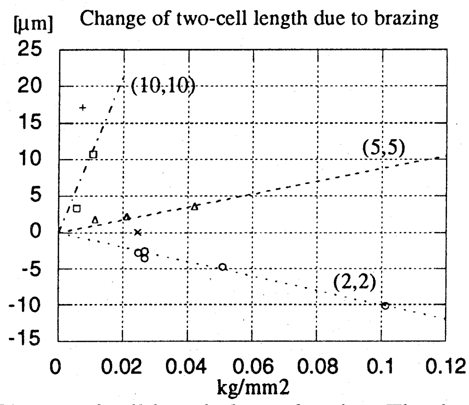

Fig. 3. Change of cell length due to brazing. The data for 10-cell and 5-cell brazing are included with being divided by 5 and 2.5, respectively, to normalize to 2-cell case.

Frequency changes were measured and plotted in Fig. 4 versus the pressure during the brazing. From this figure, one can see again that it is favorable to reduce the total pressure to make the change small.

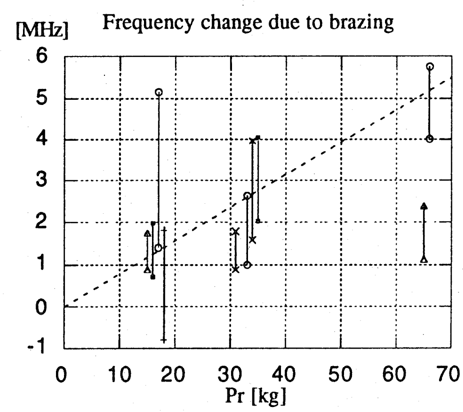

Fig. 4. Frequency change due to brazing two cells versus pressure during brazing. Each top and bottom points correspond to the maximum and minimum among nπ/3 modes.

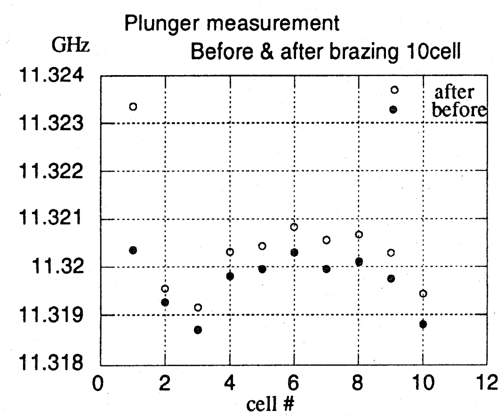

Fig. 5. Change of each cell frequency due to brazing ten cells. The load for pressure was 16kg and the pressure was 0.025kg/mm^2.

The frequency of each cell in ten cells was measured before and after brazing using two plungers inserted from both ends and measured $\pi/2$ mode frequency. It was found that even though the end cell were deformed much, the cells inside were rather stable or at least the same change among each other as shown in Fig. 5.

V. DIFFUSION BONDING

Since the frequency change and mechanical deformation seems rather uncontrollable and sensitive to the brazing structure, it seems preferable to pursue a more stable bonding structure than brazing. The flat surface such as shown in Fig. 1 is a natural result of this and the diffusion bonding can be one of the candidates.

If the flat surfaces are exposed in vacuum at high temperature more than several hundred degrees, the oxygen in the surface can be dissociated. This process can be performed at lower temperature if copper surface is covered by such material as gold or silver. The resulting active surface can be joined with each other with rather small pressure to make the plastic deformation in actually non-flat surface.

Various cases as the following were examined in the present two-cell joining experiments; gold or silver to be coated on copper, thickness of the coating from 1 to 10μm, the coating on one sided or both sided, joining temperature from 700 to 890°C, period of maximum temperature from 10 minutes to 1 hour, contact pressure from 0.1 to 12g/mm^2, which correspond to the loading weight from self weight to 53kg.

No vacuum leaks were encountered in more than 20 cases including multi-cell ones more than two, though some voids of a few μm size were detected. The coated material was found to be diffused toward both direction into the copper body to form a symmetrical gaussian distribution. In the case of 890°C in gold coating case, even the liquidization is also expected at some places in the bonding surface, which helps to fill the gap between the non-ideal surfaces. Typical surface flatness after bonding was found about 1μm level for the case of 700°C with a pressure up to several g/mm^2 using a jigging with flatness better than 1μm. The two-cell length did not severely depend on the pressure .

The frequency changes due to these diffusion bondings were measured for the two-cell configuration and plotted in Fig. 6. As can be seen in the figure, almost all the data were fallen in ±1MHz. We suspect a bad surface flatness of the jigging for the case in bins from 10 to 12. All the data from 1 to 3 and 13 to 17 are those using the jigging with flatness better than 1μm. In Table 3, some typical results of two-cell diffusion bonding are listed.

Table 3. Typical results of diffusion bonding of two cells.

temp °C	period min	pressure g/mm^2	δf MHz	δd μm
700	60	0.5	1	-1
800	10	3.4	0.3	
890	30	10	0.5	-3

If the top example of a low temperature and a low pressure bonding is compared to the bottom of a high temperature and a high pressure one, it was found that the diffusion bonding is rather stable against deformation. Then, it is a good candidate for precise fabricaton of the accelerating structure. Further detailed studies including the analysis of the cases with more cells or the effect of the precision of the jigging are needed to definately discuss the feasibility of this diffusion bonding technique to precise fabrication of the actual structure.

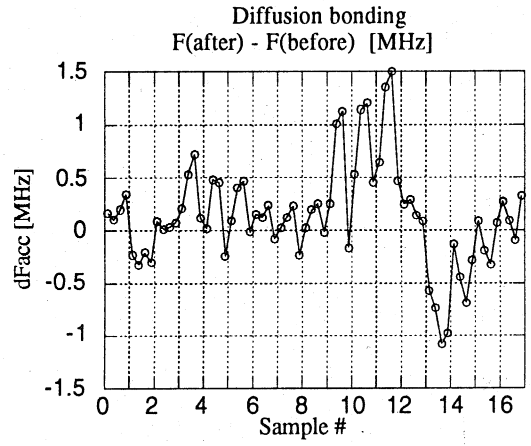

Fig. 6. Frequency change due to the diffusion bonding of two cells. In each bin, the changes of $n\pi/3$ mode are plotted from left (n=0) to right (n=3).

VI. CONCLUSION

The brazed cells are deformed in several μm order and suffer from the frequency change as large as several MHz, especially for the end cells. These are largely depend on the pressure and the brazing structure. Therefore, it is not easy to apply this bonding method to precise fabrication of such a structure as a detuned structure. On the other hand, the diffusion bonding was found good for keeping the machined precision in mechanical and frequency point of view. Therefore, a 30cm-long accelerating structure of constant impedance type is being fabricated to study the whole process of the fabricatin using this bonding method.

VII. REFERENCES

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