DETUNED ACCELERATING STRUCTURE FOR LINEAR COLLIDER

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Abstract

The effect of the short- and long-range wake field excited in the accelerating structures for the main linac of the linear collider should be largely suppressed to realize a beam acceleration without a severe emittance growth. In order to realize this suppression, two performances are essentially important; proper frequency distributions of the higher modes in the structure and a good cell alignment along the structure. In order to realize these performances, we have been studying a high-precision machining and fabrication technologies of detuned structure. Through reviewing recent fabrication studies, we describe our fine fabrication technology and relevant measurement methods of frequencies and alignments of cells.

1 INTRODUCTION

In a main linac of linear collider using a high frequency linear accelerating structures, the suppression of the deterioration of the beam emittance due to single-bunch or multi-bunch wake field is one of the key issues to obtain a high luminosity.

Single-bunch wake field almost depends upon the average misalignment of the accelerating cells in a whole structure. On the other hand, multi-bunch wake field due to higher modes in the structure depends on the distribution of modal frequencies and kick factors of higher modes in addition to the cell misalignment. In the multi-bunch case, the stored energy of the modes is well localized and the misalignment spreading over 20 cells or so is very important.

We have been developing detuned structures to establish X-band accelerating structure to meet the above requirements. The controlled characteristics of higher modes is obtained by applying an ultra-precision machining technology of recent years for the cell fabrication and keeping the precision through the following processes such as bonding. In addition, good alignment is obtained by aligning such cells by pushing them against a precise V block, because the concentricity among outer diameter, beam hole aperture and cell inner surface is well realized automatically by the present method without re-chucking while cutting the relevant parts.

Two 1.3m-long detuned structures have been fabricated so far. A few dummy-cell stackings were also performed to study from mechanical view point. Results based on these experimental studies are described in the present paper.

2 REQUIREMENTS

Design and requirements for the linear collider, JLC, are described in the reference [1]. The mode spacing of the higher modes with largest kick factors is about 10MHz. Therefore, the frequency of those modes should be controlled with a precision of 1 MHz, though this precision should be satisfied only for relative from a mode to another. The tolerance of cell misalignment is estimated assuming that a given number of cells are offset by the same amount and such groups of cells are randomly distributed along the whole linac. The severest number for the alignment tolerance is about 9μm for the range with number of cells from 1 to 20. Table 1 below summarizes some target values for our study on detuned structure.

Table.1 Requirements and parameters of tested detuned structures.

number of cells	150
length	1.3m
outer diameter	80mm
beam hole diameter	7~11mm
frequency controllability	1MHz
cell alignment tolerance	5 μm

3 CELL FREQUENCY MEASUREMENT

The cell frequency was firstly measured by a plunger method[2]. From the study, it was concluded that the frequency change due to such process as bonding could be measured with a precision of 0.2 MHz. However, the position of plunger to represent the right frequency of a cell is not well determined as shown in Fig. 2. In the figure, the non-linearity of dwelling point is plotted as function of cell number. The beam hole aperture increases from lower numbering cell to higher. The difference changes rapidly especially near low-numbered cells because the power leakage through the coaxial space between plunger and beam hole is fairly large there. This situation is confirmed in a calculation based on a scattering matrix formalism[3]. This large difference in diameter between plunger and beam hole is inevitable for the case of detuned structure because the aperture size in such structures naturally changes significantly. For example, the beam hole aperture of the tested detuned structure ranges from 7 to 11 mm, while in this case we used a plunger with diameter 5mm.

In order to escape from this systematic deviation of measurement values from the nominal value, a bead perturbation method should be introduced. Fig. 2 shows a measurement result for one of the detuned structure using metallic bead by S. Hanna[4].

In addition to the capability to measure such accelerating mode, there is a possibility to apply a special bead offering a possibility to measure higher modes[5].

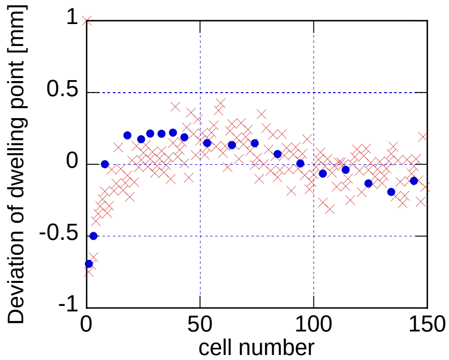

Figure: 1 Deviation of dwelling point from the mechanical center of cells for a detuned structure.

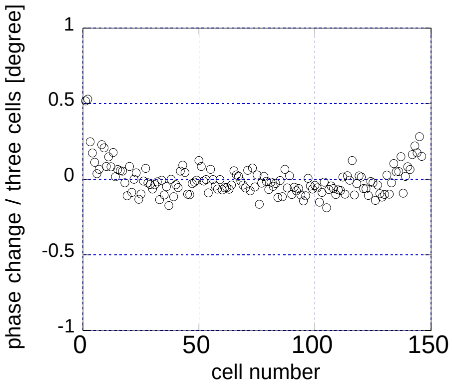

Figure: 2 Bead pull measurement for the same structure as the previous figure.

3 CELL ALIGNMENT

Since the structure is made through a high temperature process of diffusion bonding, the structure can easily be straightened after bonding if we have a good measurement method of cell alignment. However, misalignment of cells within a short length is difficult to correct by a small external bending force without perturbing the electrical characteristics of cells. Therefore, the structure should be made without such a short-length misalignment of cells.

The outer diameter of cells can easily be machined using ultra-precise lathe within an accuracy better than 0.5µm by keeping a good concentricity with respect to axis of the cell and the beam hole. Then, we can align the cells by pushing the cells against a good reference line, such as a precise V-block. The following processes should be performed without disturbing the alignment. We cite a diffusion bonding process at a high temperature in a vacuum furnace for such a cell bonding method. The outer diameter of the cells is 80mm and the number of cells is 150 so that the total length of the structure is 1.3m. The cells are stacked on a V-block set at some angle and then pushing with an axial pressure. We carefully measured the alignment of cells in each fabrication stage to study the mechanism to deteriorate the cell alignment.

3.1 Method of cell alignment measurement

One of the configurations we took for the measurement of the cell alignment is shown in Fig. 3. Two capacitive sensors are sitting on a linear guide mechanism and are facing to the outer diameter of each cell with a gap of about 0.1mm in between. This gap is measured with a resolution of 0.2µm. The relative movement of this gap is the measure of the misalignment of the cell. The transverse motion of the sensor can be checked by measuring the movement of Wollaston prism[6] which is sitting in the same girder as the capacitive sensor.

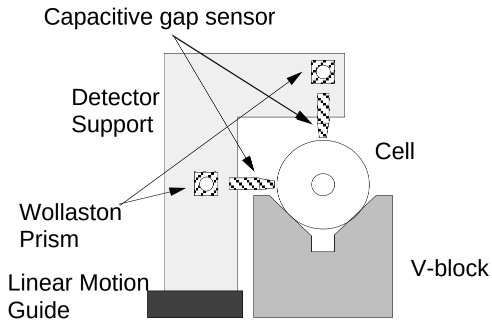

Figure: 3 Cells are stacked on a V-block. The alignment of the cells are measured using the capacitive sensor at top and side of a cell. The position of each capacitive sensor are calibrated by measuring the position of Wollaston prism located on the axis of the relevant sensor. The capacitive sensors and prisms are set on a single girder running parallel to the V-block guided by a linear-motion guide rail.

The lines in Fig. 4 shows the V-block straightness by measuring one cylinder block sitting on the V-block and shifting along it. Open circles and triangles are those of cells stacked against V-block at 60˚ from horizontal position. It was found that the cells can be aligned within 5µm or less with respect to V-block. It is also noted that the cell-to-cell misalignment is well less than 1µm.

The bonding we applied is a diffusion bonding in a vacuum furnace. The cells are stacked, compressed with an axial force of 40kg, rotated to vertical and suspended in a furnace. The variation of cell alignment due to rotation from the stacked angle to near vertical was measured. The result is shown in Fig. 5. As can be seen in the figure, the stacked cells are fairly unstable against such rotational movement when the angle is larger than 80˚. Though this movement is almost reversible, the mechanism should be studied to confirm a reliable bonding.

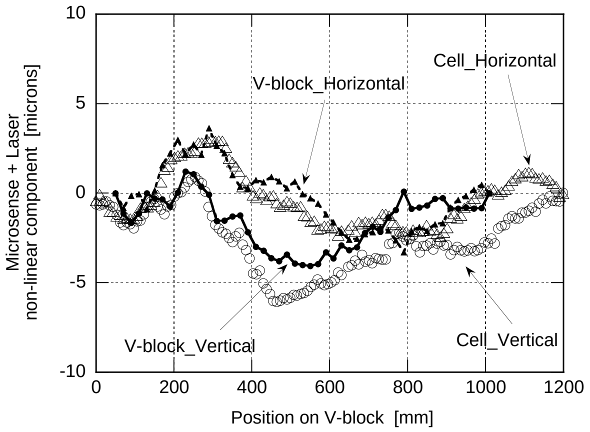

Figure: 4 Lines are the straightness of V-block. Open symbols are position of cells after stacked on it which is slanted at 60 deg.

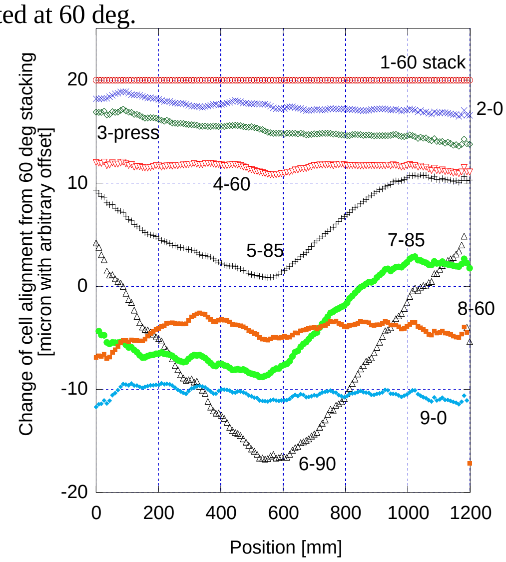

Figure: 5 Change of cell alignment due to rotation of the stacked cell from horizontal towards vertical position. First numbers are the order in the study and the second number following hyphone are the angle of the V-block.

After hanging in a vertical position, the cell alignment was checked with a vertically suspended wire. This wire system has much room to modify to obtain the straightness but it showed no slippage between cells more than a few µm. After diffusion bonding, the cell alignment was measured with sustaining the structure at two positions to make the sagging minimum resulting in an estimated sag of less than 1 µm. Measured alignment is shown in Fig. 6. It is found that the cells slippage between cells was less than 2 µm. A smooth bending was of the order of 30 µm which can be corrected easily down to less than 5 µm level.

4 DISCUSSION

The measurement system accuracy over 1.3m is 1 µm if air turbulence is well reduced. This can be judged from Fig. 6, for example. In the present system, this requirement is satisfied by covering the system with a hood. However, such an circumference easily contradicts to various fabrication processes and it might be better to introduce a system which is not perturbed much with the circumference, as is proposed by Kiyono[7].

Recently, the authors are trying to assemble and bond 206 cells in the same way as the present one. The outer diameter is 60mm in diameter and the length is 1.8m, meaning thinner and longer than the previous ones. It seems that the stability of alignment of cells are fairly unstable comparing to the present one. Though this situation depends on the cell quality, it indicates the difficulties to realize the same technology for a longer and thinner structure. The detailed study on how the stacked cells are positioned in a vertical position and how the bonding result reflects the characteristics due to previous processes is an issue to be studied seriously from now to judge reasonable dimensions of the structure from mechanical fabrication point of view.

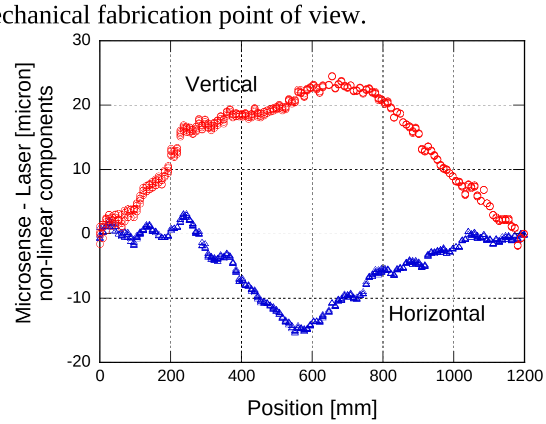

Figure: 6 Alignment measurement after diffusion bonding. Five successive measurements were superimposed.

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