A Constant Gradient Planar Accelerating Structure for Linac Use*

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Abstract

Planar accelerating millimeter-wave structures have been studied during the last few years at Argonne National Laboratory in collaboration with Technical University of Berlin. The cavity structures are intended to be manufactured by using x-ray lithography microfabrication technology. A complete structure consists of two identical planar half structures put together face-to-face. Since microfabrication technology can make a single-depth indentation on a planar substrate, realizing the constant impedance structure was possible but a constant gradient structure was difficult; changing the group velocity along the structure while maintaining the gap and the depth of the indentation constant was difficult. A constant gradient structure has been devised by introducing a cut between the adjacent cavity cells along the beam axis of each half structure. The width of the cut is varied along the longitudinal axis of the structure to have proper coupling between the cells. The result of the computer simulation on such structures is shown.

I. INTRODUCTION

Previously, a planar constant impedance cavity structure was investigated [1,2] and its linac application was investigated [3,4]. The constant impedance structure may be simple and easy to fabricate but may not be the best for accelerator applications, especially this type of microstructure operating at a mm-wave frequency, due to difficulty in heat removal. The heat loading in the constant impedance structure was shown [5]. In a constant impedance structure, the concentration of heat at the structure input can limit the high power rf operation of the structure. In order to have higher shunt impedance of the structure, the thickness of the irises between the cells must be small (say $<0.1\lambda$). However, heating imposes a limit in this case; heating at the center of the irises limits the maximum input power. Successful heat removal and uniform heat loading throughout the structure are important for optimum performance of the mm-wave accelerating structure.

The constant gradient linear accelerating structure has been used in many practical accelerators due to its higher energy gain and better frequency characteristic. The constant gradient structure has higher shunt impedance and more uniform power dissipation, and is less sensitive to frequency deviations and beam break-up when compared to the constant impedance structure [6].

Unlike the circular cylindrical cavity structure, the planar structure at the mm-wave frequency must be manufactured by micromachining technology such as the Lithography, Galvanoformung, Abformung (LIGA, a German Term) process. Since the process can provide the precision required for the accelerator, the structure can be simple without having tuning mechanisms for the individual cavities. However, the one limiting factor in this precision manufactured structure is that it has to have uniform indentations on a planar wafer.

To have a planar constant gradient structure, the cell-to-cell coupling must be controlled. Since the structure needs be manufactured as a single piece on a wafer, this can be done by adjusting the cell width and length with a constant depth within the structure. The control of cell-to-cell coupling in a periodic structure can be made in two different ways for the constant gradient planar structure: 1) with no cut in the irises, the cell dimensions *w* and *g* can be varied while the cell-to-cell distance *(g+t)* and the cell depth *d* are fixed constant, 2) one or more posts can be used instead of the iris between cells. However, with 1) the cavity Q and the shunt impedance become lower and the maximum voltage limit will be lower; and with 2) heating on the posts will limit the power level.

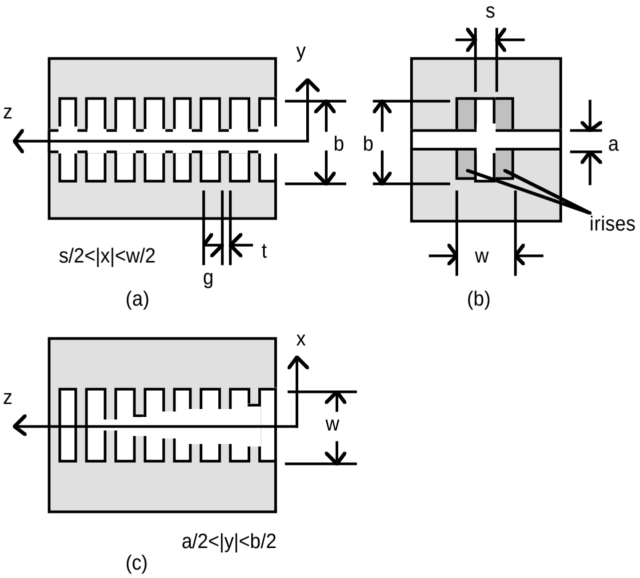

Figure 1: A constant gradient structure with cuts in irises

Figure 1 shows a structure that can be used as a constant gradient structure. The irises between the cells have vertical cuts with a controlled width along the axis. The cutwidth is

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greatest at the input side and becomes smaller toward the output.

II. SIMULATION

A 2π/3 traveling wave has been chosen as the accelerating mode. Assuming the shunt impedances and Q-facto are constants throughout the structure, the group velocity of a constant gradient accelerating structure can be shown to be

$$v_g = \frac{\omega l}{Q} \frac{(1-(1-P_l/P_o)z/l)}{(1-P_l/P_o)}, \qquad (1)$$

where Q is the cavity quality factor, ω is the angular frequency, *l* is the length of the section, P_o is the structure input power and P_l is the leftover power at the structure output. For a leftover power $P_l / P_o = 0.15$ at the output of a 7cm-long accelerating structure, the average attenuation constant α=13.6 nepers/m. The number of cells is 84 and the shunt impedance is 300MΩ/m. The required group velocity normalized to the speed of light along the structure is in the range of 0.94 to 0.14.

In the constant impedance structure design [1] the aperture height was chosen to be 0.6mm. In constructing the constant gradient structure, the aperture height needs to be smaller for low cell-to-cell coupling at the end of the structure. It has been found that 0.5mm aperture height can be used for the minimum coupling with a=0.5mm, b=2.2mm, g=0.633mm, and t=0.2mm. The slight reduction in the aperture height may not reduce the effective aperture size, since the vertical cuts are made in most irises.

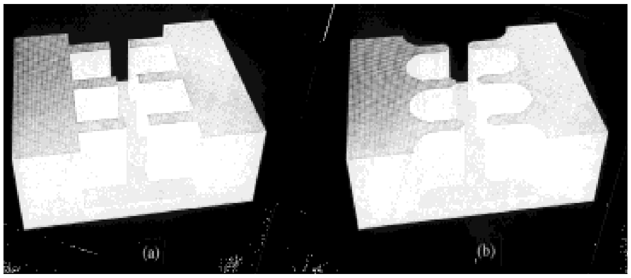

Figure 2: Two types of constant gradient planar structures used in the simulation

Using the MAFIA code [7], the structure was simulated to find the frequencies, field distribution, and shunt impedance. Two different cell shapes were used for comparison: a shape with right angle corners and a shape with half circles. Figures 2(a) and 2(b) show the bottom half of the 3-cell unit structures for the simulation. The structure in Figure 2(b) has rounded corners at the cuts in the irises. For unit structures with various cutwidth *s*, the group velocity was found. The group velocity vs. the cutwidth with an aperture height of 2a=0.5mm is shown in Figure 3.

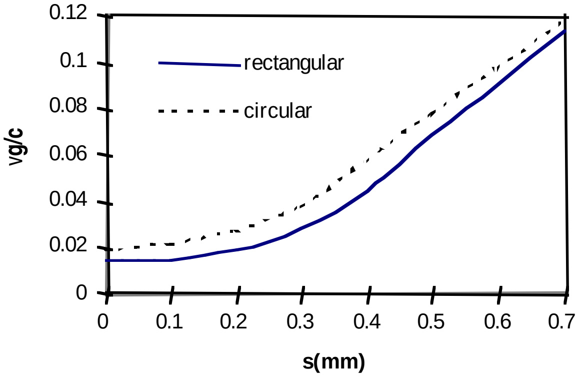

Figure 3: Group velocity vs. cutwidth *s* in irises

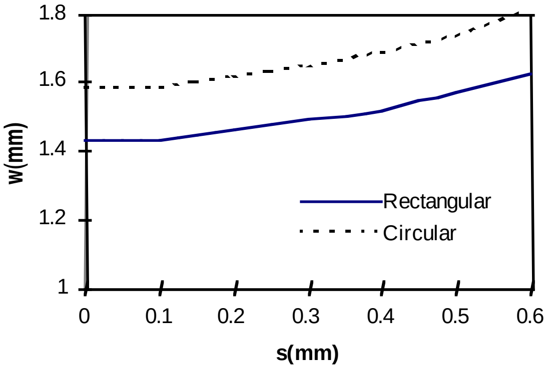

Figure 4: Cell width *w* vs. cutwidth *s* in irises

Figure 4 shows the cell width *w* for different cutwidths for the two differently shaped cases. The Q-factors and the shunt impedances of the structures are shown in Figures 5 and 6, respectively. Note that the cavity with greater cutwidth in the iris has a higher Q-factor but a lower shunt impedance (s>0.1mm) than the cavity with smaller cutwidth in the iris.

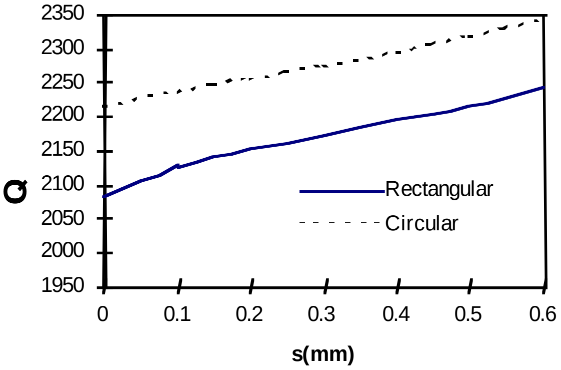

Figure 5: Cavity Q-factor vs. cutwidth *s* in irises

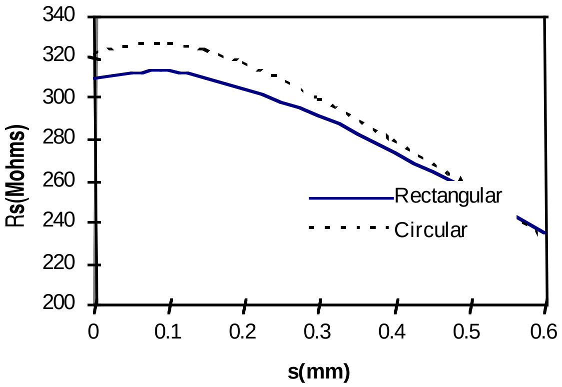

Figure 6: Shunt impedance of $2\pi/3$ mode vs. cutwidth in irises

III. HEAT LOADING

Figure 7 shows the temperature distribution in a rectangular cell with a cut in the iris due to rf power dissipation. An input power of 29kW and 1% duty cycle were assumed at the input of the structure. For the same input power, that is for a similar energy gain, the heat loadings in the first cell of the constant gradient structure and the constant impedance structure were 34W/cm^2 and 80W/cm^2, respectively and their temperatures at the hottest point were 34°C and 45°C, respectively. The area near the beam axis is the hottest area as in the cylindrical cavity. To compare the result with the constant impedance case, the same heat flux of 80W/cm^2 is used [5]. For the same amount of heat loading, the constant gradient and the constant impedance structures have 47°C and 45°C, respectively, at the tip of the iris. With the same power dissipation at the first cell, the constant gradient structure has 55% more energy gain.

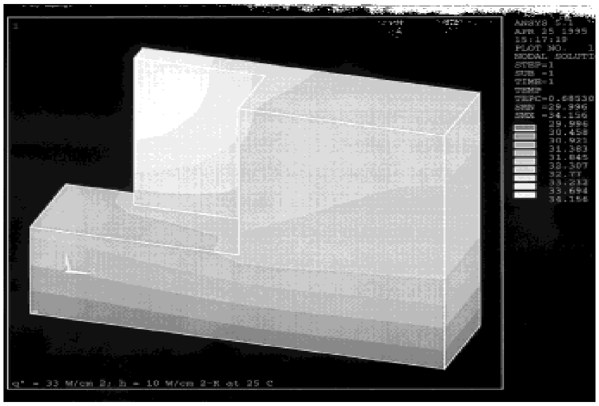

Figure 7: Temperature distribution of a cell with a cut in the iris

IV. DISCUSSION

Previously a planar structure with the aperture only in the x-direction was discussed as the quadrupole-like characteristic [1,3,8]. With additional cuts in the y-direction, the coupling apertures look like cross slots. When the vertical slots are much narrower than the horizontal slots, the focusing characteristic of the structure would be close to the quadrupole characteristic. If the vertical slot width *s* is comparable to the horizontal aperture height *a*, the focusing characteristic will become different. At the four corners of the irises facing each other, the electric field concentration is greatest. Thus, the electric and magnetic fields may not be assumed to be rotationally symmetric at near the beam axis; the electric and magnetic forces can not be rotationally symmetric.

With the cross-like aperture, $E_x = 0$ on the *y-axis* and $E_y = 0$ on the *x-axis*. For a particle traveling with the velocity of light at small offsets in x and y, the magnetic forces can be stronger near the iris corners. For small offsets in x and y in the transverse plane, the electric forces due to the electric fields, will be stronger toward the corners of the irises. These forces can be similar to the force in an octupole magnet field.

V. CONCLUSION

Constant gradient accelerating cavity structures have been computer simulated. It was found that a structure with cuts in the irises can be made with a microfabrication process and used for building a linac system. The calculations shown in the previous sections can provide the physical dimensions of the constant gradient linac structure. The heat concentration at the center of the dividing wall between the cells can be lowered; the input power to the structure can be increased for higher energy gain. Using a pair of half structures in parallel, a precision alignment is a must and is expected to be possible. The input/output couplers of the constant gradient structure can be designed as shown in [9].

VI. REFERENCES

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