DESIGN OF A C-BAND DISK-LOADED TYPE ACCELERATING STRUCTURE FOR A HIGHER PULSE REPETITION RATE IN THE SACLA ACCELERATOR

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Abstract

It is expected that the high pulse-repetition rate of the SACLA accelerator provide a higher rate of X-ray laser pulses to expand ability of user experiments, such as simultaneously providing the laser to several beamlines and reducing a measuring time in the experiment. Therefore, we studied on a C-band accelerating structure for the higher pulse rate above 120 pps than the present rate of 60 pps. Since the higher repetition rate operation is inclined to increase vacuum electrical discharges, it is required to reduce the surface electric fields in the structure without decrease in accelerating voltage. We designed a cross sectional shape of ellipsoidal curvature, which reduces the maximum surface electric or rf field by 20%. The designed structure adopts a TM01-2π/3 mode disk-loaded type with a quasi-constant gradient. Since the high repetition rate also increases the heat load to the structure, in simulation, we optimized cooling channels. As a result of the design, an accelerating gradient of more than 40 MV/m will be expected, when an input RF power of 80 MW is fed into the structure.

INTRODUCTION

The SACLA (SPring-8 Angstrom Compact free electron LAser) facility succeeded to generate of the X-ray free electron laser (XFEL) with a wavelength of 0.12 nm in June, 2011[1]. Since March 2012, the X-ray laser is provided to the user experiments by mainly using one beamline.

To expend user experiment ability, SACLA has a space of five beamlines for the future expansion. The electron beam must be distributed to the beamlines by using a fast switching magnet in order to supply X-ray laser to many experiments users. However, the repetition rate of each beamline decreases inevitably. Therefore, we plan to operate SACLA with a repetition rate up to 120 pps for the upgrade of the beamlines.

Our present C-band (5712 MHz) accelerating structure to adopt multi-bunch operation has a choke-mode cavities [2] and an SiC absorbers outside of each cavity. The present structure generates an accelerator gradient of 37 MV/m to obtain a 8GeV electron beam and has a phase advance per cell of 3π/4 mode in order to machine the choke-mode cavity. Due to the heat dissipation, this complicated structure has distortions of the cavity, which leads large shifts of a resonant frequency and an RF phase. This distortion is a serious problem for 120 pps operation. Therefore, the newly designed accelerating structure does not have complicated choke structures and SiC absorbers. Furthermore, the simple structure gives reduction of the production costs and enable us high precise adjustment of the resonant frequency with the dimpling method after the brazed of the structure.

NEW STRUCTURE DESIGN

The designed disk-loaded structure has a phase advance per cell of 2π/3 for the accelerating TM01-mode and quasi-constant gradient. The highest shunt impedance for a travelling-wave structure occurs in the neighborhood of the phase advance. Therefore, an accelerating gradient of the new structure should be higher than the existing structure. Due to the compatibility of future replacement with the present choke-mode structure for future replacement, a structure length, a filling time and an attenuation parameter of new structure are designed to be the same as those of the choke-mode one.

We used the 3D electromagnetic field simulation codes, ANSYS-HFSS [3], in order to design the structure. By the simulation, the iris diameter (2a) of each cell is linearly changed over 100 cells and a quasi-constant gradient is obtained. The cell diameter (2b) was adjusted so that the resonance frequency for every cell is equal to the operation frequency of 5712 MHz. Table 1 shows the parameters of a new C-band disk-load type accelerating structure. Figure 1 shows variations of the 2a and the accelerating gradient at an input power of 80 MW. The averaged accelerating gradient is expected to be 43 MV/m, when an input RF power of 80 MW is fed into the structure.

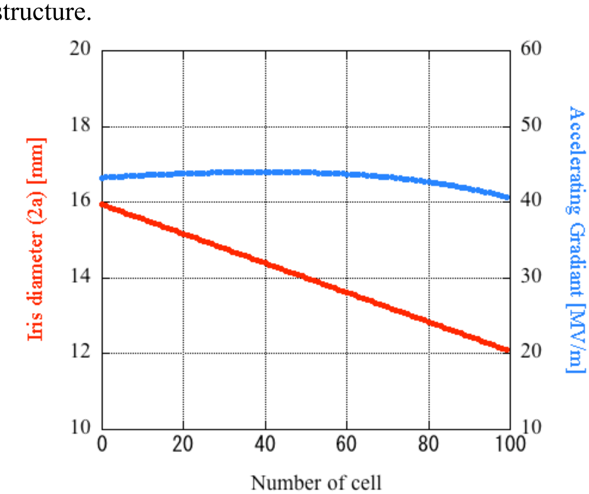

Figure 1: Variation of the iris diameters (red line/left axis) and an accelerating gradient at an input power of 80 MW (blue line/right axis).

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The dipole HEM11 mode is the dominant source of beam wakefield instability [4] and hence the frequency and wakefield of the mode were also calculated. The variation of 2a was so determined that the wakefield of the HEM11 mode falls off in a few nsec and has drops within every bunch interval of 4.2 nsec in the which might be assumed as the minimum bunch-interval of multi-bunch operation in SACLA. Figure 2 shows the calculated envelope of the wakefield. It decreases sufficiently and drops at intervals of 4.2 nsec are less than 2% compare with peak value of the wakefield.

Table 1: Parameter of the new C-band accelerator

Operation frequency [MHz]	f_a	5712
Structure type		Quasi-Constant Gradient (quasi-CG) Disk-load type, Traveling wave structure
Resonant mode		TM01-2π/3
Total cavity length [m]	L	1.862
Unloaded Q factor	Q_0	8800
Group velocity	v_g/c	0.023
Filling time [nsec]	t_F	270
Attenuation parameter	τ	0.59
Average shunt impedance [MV/m]	r	66.0
Number of cell	N	100
Iris diameter [mm]	2a	15.941~12.109
Cell diameter [mm]	2b	43.761~42.451
Disk spacing [mm]	d	17.495
Disk thickness [mm]	t	4
Cross sectional shape of Iris		Ellipsoidal curvature

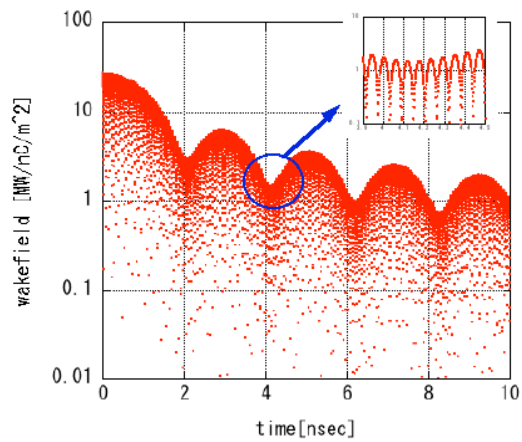

Figure 2: Wakefield envelope of HEM11 mode.

CROSS SECTIONAL SHAPE OF ELLIPSOIDAL CURVATURE

We designed a cross sectional shape of the iris as ellipsoidal curvature, which reduces the strength of surface electrical field. Figure 3 shows the cross sectional view of the ellipsoidal curved iris shape. We estimated the dependence of the maximum surface electrical field dependent on the axis ratio of major and minor axis of an ellipse iris (B/A), by using HFSS and decided the disk thickness (t) is 4.0 mm, as well as to maintain the compatibility to the existing choke-mode type accelerating structure. It is the same as the existing structure parameter in order to replace the choke-mode structure. Therefore, we fix A=2 mm and change the size of B. Figure 4 shows the ratio of the maximum surface electrical field to the on-axis electrical field (E_p /E_{acc}) depending on a ratio of B/A. E_p/E_{acc} becomes minimum at B/A = 2 and is 20% lower than that at B/A=1. Therefore, we adopted the cross sectional shape of the iris as ellipsoidal curvature of B/A = 2.

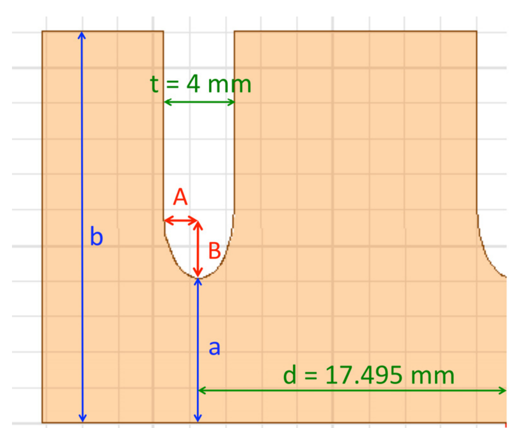

Figure 3: Cross sectional view of the ellipsoidal curved iris shape.

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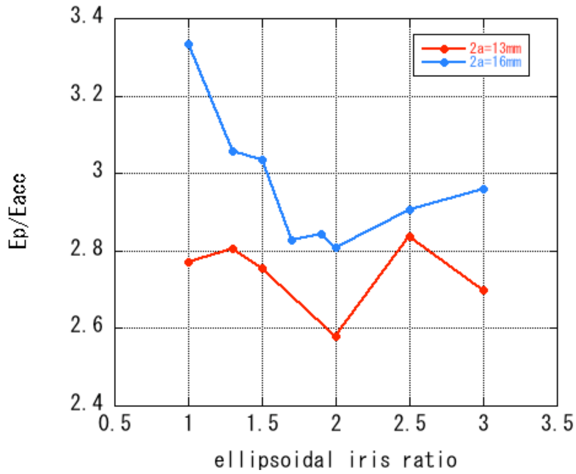

Figure 4: Ratio of maximum surface electrical field to the on-axis electric field (E_p /E_{acc}) depending on the ratio of B/A.

THERMAL EXPANSION EFFECT

The high repetition rate increases the heat load of the accelerating structure, which may causes the thermal expansion and the shift of the resonant frequency. Therefore we carefully optimized the cooling water channels of the accelerating structure. The heat load of the accelerating structure in 120 pps is educed to be 3.8 kW. The initial temperature of the cooling water from a cooling system is 26.5°C. We place eight water flow channels with an 8 mm in diameter as shown in Figure 5. A flow velocity of water is assumed to be 0.8 m/sec. A water flow rate per one channel and the total flow rate are assumed to be 2.5 L/min and 20 L/min, respectively. A counter-flow method is adopted the cooling of accelerating structure in order to make a temperature slope small. We employ a precise temperature-regulation system in order to stabilize the temperature of the accelerating structure by feedback control of the water heater [5]. A required temperature stability should be set at ±0.1°C.

To realize the above-mentioned conditions, we used the ANSYS thermal and structure analysis software to simulate the temperature distribution and expansion of the accelerating structure. Figure 5 shows the estimated temperature distribution of the accelerating structure operated at 120 pps. We designed the resonant frequency of the cavity is set at 5712 MHz with the cavity temperature at 33°C. When the cavity is heated with the heat load of 3.8 kW, 2b is expanded at about 2.8 μm from the original size, and the resonant frequency shifts at 430 kHz. The frequency shifts is compensated by lowering the water temperature by 4.4°C. The rise of the water temperature due to 3.8 kW is 2.7°C. Since we use the counter-flow method, the temperature of the input water temperature should be set at 33°C-4.4°C=28.6°C, which compensates the frequency shift. Since this input temperature is higher than 26.5°C of the initial temperature of the cooling water system, the precise temperature-regulation system can control the temperature by changing the heater power. On the other hand, when the repetition rate is low and the heat load is negligibly small, the temperature of cooling water can be controlled to be 33°C with a heater. Therefore, we can keep the resonant frequency at 5712 MHz for every operation rate by adjusting the heater power.

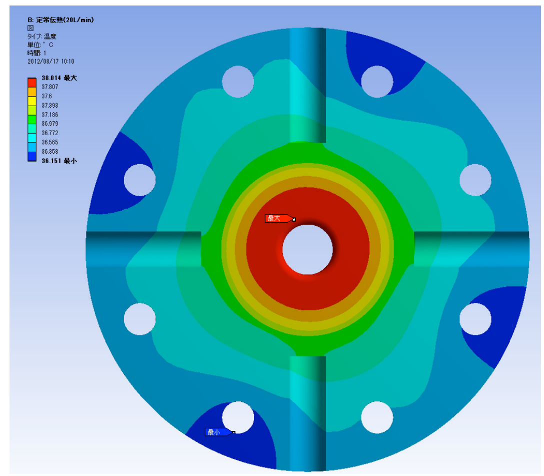

Figure 5: Temperature distribution of the accelerating structure in 120 pps operation

SUMMARY

We designed a new C-band accelerating structure adapted to a pulse repetition rate of 120 pps. The structure is a TM01-2π/3 mode disk-loaded type and has a quasi-constant accelerating gradient of 43 MV/m at an input RF power of 80 MW. Furthermore, the cross sectional shape of an iris having the ellipsoidal curvature decreases a surface electrical field by 20%. We confirmed that the new structure could be operated by 120 pps, by our thermal-expansion analysis. We will manufacture a prototype accelerating structure and perform a high power RF test in 2013.

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