PRODUCTION OF C-BAND DISK-LOADED TYPE CG ACCELERATING STRUCTURES

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Abstract

Mitsubishi Heavy Industries, Ltd. manufactured six C-band disk-loaded type and quasi-constant gradient (CG) accelerating structures for the XFEL facility, SACLA (SPring-8 Angstrom Compact free electron LAser). These structures were newly designed by RIKEN for operation at an acceleration gradient of over 45 MeV/m and a repetition rate of 120 pps. We report the production and low-power RF properties of these accelerating structures.

INTRODUCTION

In April 2013, Mitsubishi Heavy Industries, Ltd. contracted with RIKEN to manufacture six C-band disk-loaded type and CG accelerating structures for the XFEL facility, SACLA. The first structure was delivered in August 2013 to RIKEN and the other five were delivered in March 2014.

Devices of the accelerator system operable at a high repetition rate are being developed by RIKEN, as one of the possibilities to grow in the performance of SACLA. The C-band disk-loaded type structures were designed to enable us operation at a high repetition rate of more than 120 pps and a highly acceleration gradient of more than 50 MV/m. We paid attention to reduction in manufacturing cost and compatibility with the C-band choke-mode type accelerating structures in use as the main accelerators of the SACLA [1, 2].

We will report the results of the production and low-power RF test of these newly manufactured six accelerating structures in this paper.

FEATURES OF THE ACCELERATING STRUCTURES

The disk-loaded accelerating structure is a quasi-constant gradient (Quasi-CG) type. Its resonant frequency is 5712 MHz (30 deg. C in vacuum) and its total length is 1.8 m. Figure 1 shows the outline view of the accelerating structure. Table 1 shows required specifications.

The resonant frequency, total cavity length, attenuation constant τ, filling time t_F, and position of cooling pipe are designed to be compatible with the present choke-mode type structure [3, 4] for SACLA. There are two major modifications from the choke-mode type structures. One is that the regular accelerating cells have no choke structure but tuning holes and the other is that the accelerating mode was changed from $3\pi/4$ to $2\pi/3$. As a result of the former, the phase shift can be tuned after the

Table 1: Requirements Specifications of the C-band Disk-Loaded Type Accelerating Structure

Items	**Requirements Specifications**
Resonance frequency	5172 MHz +/- 0.2 MHz
	30 deg. C in vacuum
Coupler type	J-type double-feed coupler
Number of cells	100 + 2 coupler cell
Total cavity length	1.8 m
Structure type	Quasi-constant gradient
Phase shift	$2\pi/3$
Integrated phase error	≤ +/- 3deg.
VSWR	≤ 1.1
Q factor	8000 ≤
Average shunt impedance	55 MΩ/m ≤
Attenuation constant τ	0.56
Filling time t_F	270 ns
Material of cells	OFC-CLASS1 HIP
Brazing process	Vacuum brazing

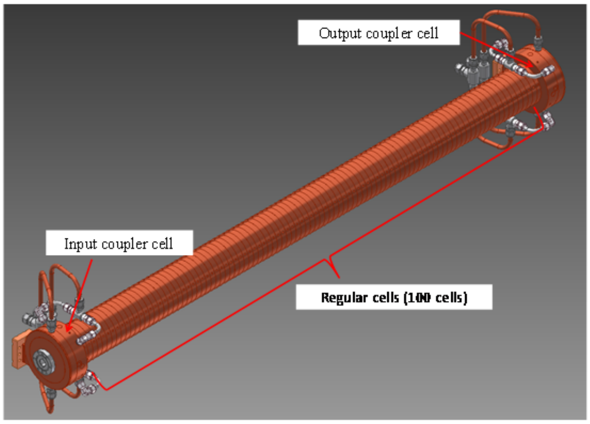

Figure 1: C-band disk-loaded type accelerating structure.

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ISBN 978-3-95450-133-5

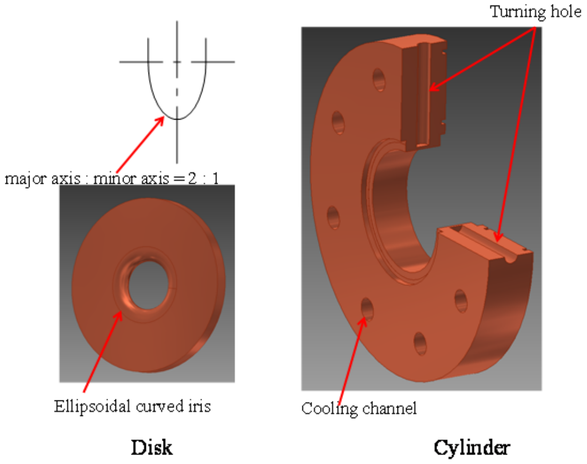
resonance frequency shift of each accelerating cell due to brazing process cannot be compensated by tuning, because of accelerating cells cannot equip tuning hole due to the choke structure surrounding the accelerating cell. As a result of the latter, the shunt impedance and the axial electric field can increase so the break down probability seemed to increase due to increase of the surface electric field. To reduce the risk of breakdown, the beam-hole edge, where the maximal surface electric field takes place, has ellipsoidal shape shown in Figure 2 to reduce the strength of the surface electric field.

PRODUCTION

Regular Accelerating Cell

Regular accelerating cells consist of disks and cylinders to simplify the geometry of them and improve workability. The beam-hole edge of each disk was ellipsoidally filleted, as noted in the preceding section. The place around each cylinder has eight holes arranged axisymmetrically to form cooling pipes and four holes for tuning by dimpling. The inner surfaces of the cells were mirror finished by using an ultraprecision lathe. The surface roughness is below 0.1 μm except the beam-hole edge with a roughness of 0.3 μm. Figure 2 and Figure 3 show schematic views and pictures of the disk and the cylinder, respectively.

The inner diameter of the cylinder was oversized so that the frequency of the regular cells was tuned by approximately 2 MHz lower than an operating frequency of 5712 MHz, since the frequency was shifted high by the final brazing process.



Disk **Cylinder**

Figure 2: Schematic views of the disk and the cylinder.

Coupler Cell

The J-type double-feed coupler is integrated with the structure as with the choke-mode type structure. The coupler consists of a coupler cell, a square flange, a waveguide (WR-184), and a beam flange. Figure 4 and Figure 5 show a schematic view and a picture of the coupler cell, respectively.

The frequency and the phase shift of the coupler temporally assembled were measured by the nodal shift method and adjusted by modifying the internal diameter of the coupler cavity cell and the size of irises connecting the cell to the J-feeder. Figure 6 shows the measurement layout for the coupler cell. The coupler was brazed in a vacuum furnace after the RF adjustment.

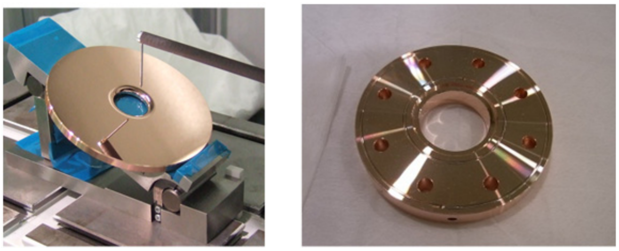


Figure 3: Disk and cylinder.

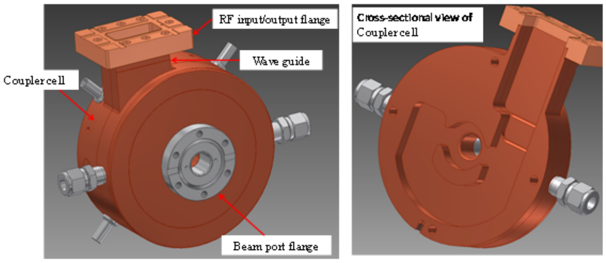


Figure 4: Schematic view of the coupler cell.

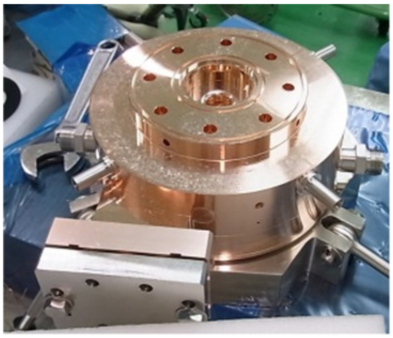


Figure 5: Coupler cell.

Brazing and Tuning

The couplers, disks and cylinders were stacked vertically with upstream side up and were brazed in the same position in a vacuum furnace. Figure 7 shows vacuum brazing layout for the accelerating structure. After the brazing, a phase shift of the each cell was measured by the nodal shift method and was tuned to a 120 deg. phase advance among the cells. by dimpling as mentioned above. We conducted the RF tuning for the structures in a condition of a temperature stabilized within +/- 0.5 K in order to improve accuracy of the RF measurement. In addition, temperature deviation of the accelerating structure during the tuning was controlled within +/- 0.05 K in the entire length of the structure by running temperature-stabilized water to the cooling channels of the accelerating structure.

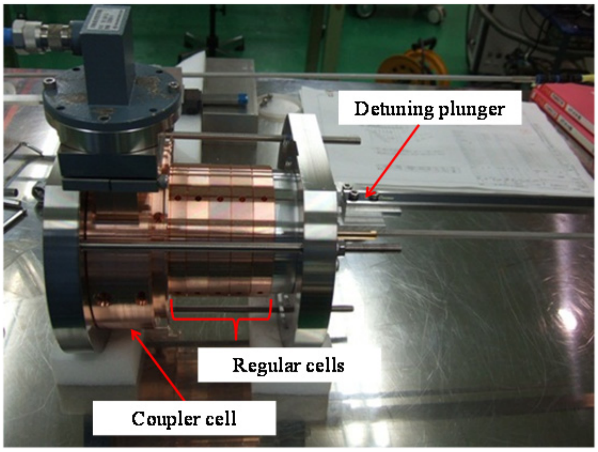


Figure 6: Measurement layout of the coupler cell.

After the tuning, a phase shift of each cell was measured by using the bead-pulling method [5] and the tuning was conducted again as necessary.

In the brazing process, cells are vertically stacked as already mentioned, so the cells on the downstream side of the structure were subjected to the higher load than that of the upstream side. In addition, material strength of the copper greatly decreases at the brazing temperature. As a result, the cells on the downstream side were slightly deformed after the brazing and their resonant frequency shifted high beyond our original expectations. Therefore, an integrated phase error was seemed to exceed the range of +/- 3 deg. as required even after the tuning by the nodal shift method. To fix this problem, tuning of the cells by the bead-pulling method was conducted so that the integrated phase error was improved and reflections from the cells were reduced.

Results of the Low-power RF Test

Table 2 shows the measured RF properties of the accelerating mode of the structures after tuning.

In the case of the first structure labelled with #001, its integrated phase error of 3.2 deg. did not slightly meet the required specification. In the case of #003-#006, the further oversized diameter was given to the cells on the downstream side against their large phase shift by the brazing, and tuning accuracy was improved so the integrated phase error was below 2.8 deg. and the VSWR was below 1.05. Figure 8 shows the results of the integrated phase error of #003 by way of example.

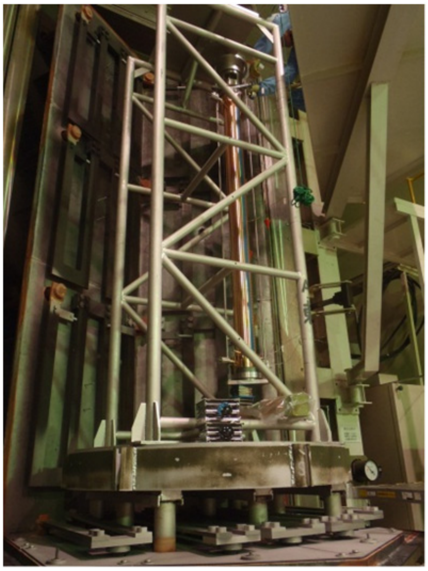


Figure 7: Vacuum brazing layout of the accelerating structure.

RESULTS OF THE HIGH-POWER RF TEST

A high-power RF test for #001 has already been conducted by RIKEN in the test bench of SACLA. An acceleration gradient of 50.1 MeV/m was achieved for 0.5 μs in RF pulse width and at 60 pps in repetition rate. The operation with 42MV/m at 120 pps was possible for 24 hours or more without stopping due to the electric discharge etc. It was also verified that no thermal side effect was observed during operation at 120 pps. The detailed discussions on the results of the high-power RF test are described in the proceeding written by T. Sakurai et al.[6].

CONCLUSION

Six C-band disk-loaded type and CG accelerating structures were manufactured and the low-power RF tests of the accelerating structures were conducted. As a result, the first structure has a slight deviation in integrated phase-shift error but the others are fulfilled the required specifications. Consequently, the manufacturing method of the C-band disk-loaded type accelerating structures was established.

Table 2: Results of the Low-power RF Test for Each Product

	#001	#002	#003	#004	#005	#006
Resonance frequency [MHz]	**5712**	5712.02	5712	5712	5712	5712
Integrated phase error [deg.]	3.2	2.8	2.7	2.8	2.8	2.8
Input VSWR	1.02	1.09	1.01	1.04	1.03	1.05
Attenuation constant τ	0.54	0.54	0.54	0.54	0.54	0.55
Filling time t_F [ns]	273	271	273	269	272	272
Q factor	**8981**	**8969**	**9023**	**8944**	**8979**	**8950**

ISBN 978-3-95450-133-5

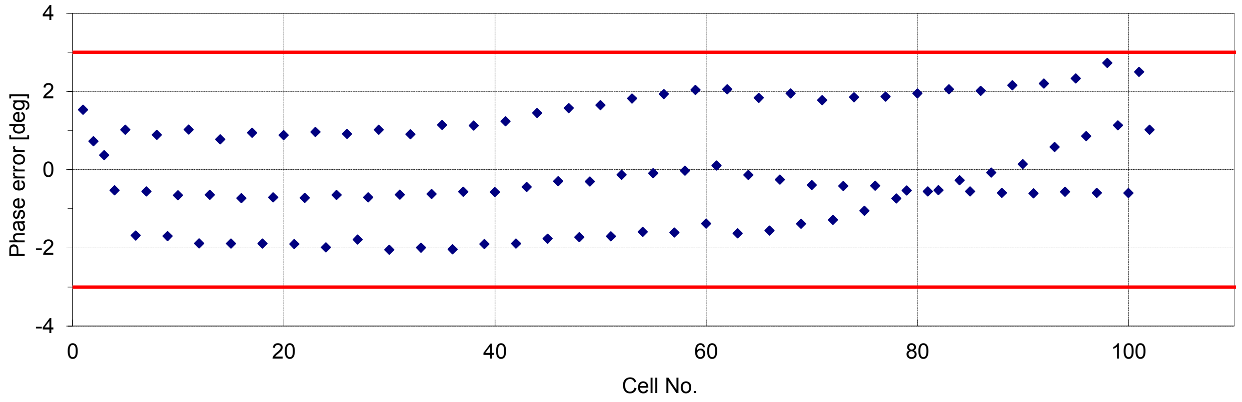


Figure 8: Results of the integrated phase error of #003.

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ISBN 978-3-95450-133-5