

Accelerating structure design and fabrication for KIPT and PAL XFEL

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Abstract: ANL (Argonne National Laboratory) and the National Science Center “Kharkov Institute of Physics Technology” (NSC KIPT, Kharkov, Ukraine) jointly propose to design and build a 100 MeV/100 kW linear accelerator which will be used to drive the neutron source subcritical assembly. The linac has almost finished assembly in KIPT by a team from the Institute of High Energy Physics (IHEP, Beijing, China). The design and measurement result of the accelerating system of the linac will be described in this paper.

Key words: S-band, accelerating structure, BBU (beam break-up) effect, neutron source

PACS: 29.20.-c **DOI:** 10.1088/1674-1137/39/5/057006

1 Introduction

A neutron source based on the sub-critical assembly driven by an electron linear accelerator is being constructed [1]. This is a project with the participation of the National Science Center “Kharkov Institute of Physics Technology” (NSC KIPT), Argonne National Laboratory (ANL) and the Institute of High Energy Physics (IHEP) together. For providing a neutron flux of about 10^{13} neutron/s, the design of a linear accelerator with an average electron beam power of the value 100 kW/100 MeV is needed [2]. The main specifications of the accelerator are listed in Table 1.

Table 1. NSC KIPT neutron source parameters.

parameter	values
RF frequency/MHz	2856
beam energy/MeV	100
beam current/A	0.6
beam spread (peak to peak) (%)	4
emittance (1 s)/(m·rad)	5×10^{-7}
beam pulse duration/ms	2.7
RF pulse width/ms	3
RF repetition rate (max)/Hz	625

To satisfy the optimized physical design, the accelerating system of the KIPT linac consists of a 2856 MHz single cavity prebuncher, a 2856 MHz traveling wave buncher and ten 1.34-meters-long 2856 MHz traveling wave accelerating structures. A diagram illustrating the NSC KIPT linac is shown in Fig. 1.

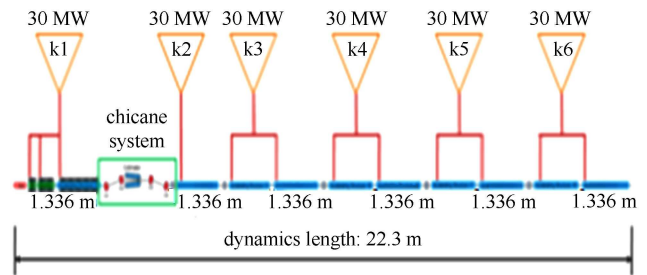


Fig. 1. (color online) System diagram of the NSC KIPT linac.

2 Prebuncher

The prebuncher is a re-entrant resonant standing-wave cavity. A single side coupling mechanism is adopted which is different from the conventional design. As a consequence, an eccentric circle structure is adopted to avoid the asymmetry of the E-field along the transverse direction going through the center of the coupling iris. The model of the prebuncher as well as its cooling water structure is shown in Fig. 2. The main parameters of the prebuncher and the comparison between the simulated and measured results are listed in Table 2 and Table 3 respectively. The designed water flow of the prebuncher is 5 times more than the BEPC one because the drive power of the prebuncher for KIPT is 5 times higher (see Table 2).

Received 23 July 2014, Revised 3 November 2014

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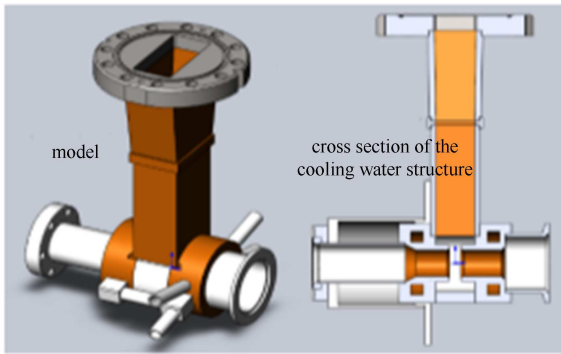


Fig. 2. (color online) Model of the prebuncher and its cooling water structure.

Table 2. Main parameters of the prebuncher.

parameter	BEPC	KIPT
operating frequency/MHz	2856	2856
unloaded Q_0	1000	1446
cavity diameter/mm	50.8	52.62
nose cone diameter/mm	25.4	35
beam aperture/mm	19.05	25
gap distance/mm	8.89	8.89
total length/mm	191	211
β	1.04	1.41
drive power/kW	10	30–50
modulating voltage/kV	50	50

Table 3. Comparison of the simulated and measured results of the prebuncher.

parameter	simulated	measured
operating frequency/MHz	2856.95	2855.94
unloaded Q_0	2002	1446
β	1.33	1.41

A compromise method is adopted in order to decrease the Q factor and limit the wall power loss caused by the low Q value at the same time: two end plates together with their noses are made of oxygen-free-copper while other parts of the prebuncher are made of SUS (Stainless Steel). The layout of the prebuncher is shown in Fig. 3.

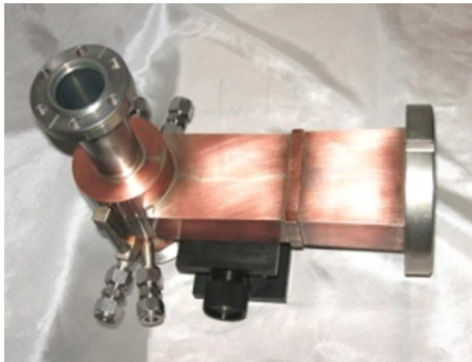


Fig. 3. (color online) Layout of the prebuncher.

3 Buncher

The buncher is a copper disk-loaded structure fabricated by brazing in a hydrogen furnace. It is a traveling-wave structure with only six cavities, including the input and output couplers. It is operated in $2\pi/3$ mode with a phase velocity of $0.75c$. A peak field of 7.1 MV/m in the fundamental space harmonic with the designed driving power of 3.0 MW is achieved. The designed parameters

Table 4. Parameters of the buncher.

parameter	design
operating frequency/MHz	2856
unloaded Q_0	10960
operating mode	$2\pi/3$
length/mm	240.6
cavity diameter ($2b$)/mm	83.292
disk hole diameter ($2a$)/mm	22.615
disk thickness diameter t /mm	5.84
number of cells	6
VSWR (voltage standing wave ratio)	1.06
bandwidth (VSWR<1.2)/MHz	± 2
phase velocity/ c	0.75
shunt impedance/($M\Omega/m$)	36.3
input power/MW	2–4
field gradient/(MV/m)	5.7–8.1

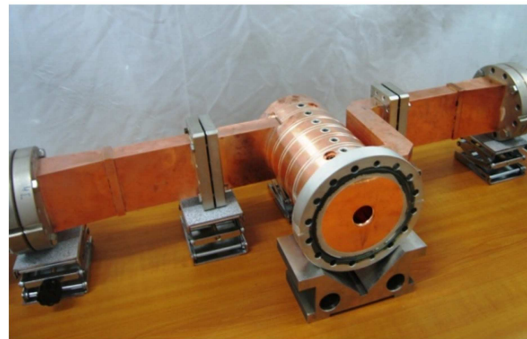


Fig. 4. (color online) Layout of the buncher.

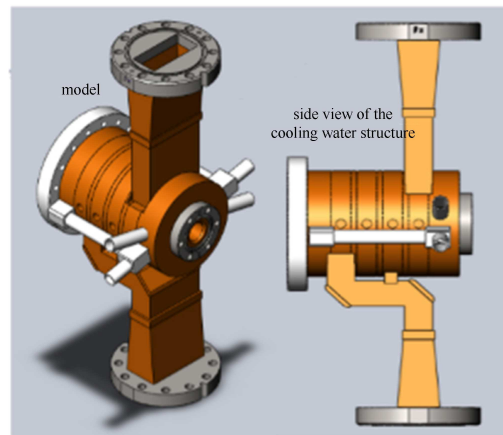


Fig. 5. (color online) Model of the buncher and its cooling water structure.

Table 5. Comparison of the designed and measured results of the buncher.

parameter	designed	measured
operating frequency/MHz	2856	2856
VSWR	1.06	1.02
bandwidth (VSWR<1.2)/MHz	±2	±2.25
attenuation constant/dB	/	-0.56
filling time/ns	/	49.48

and layout of the buncher are shown in detail in Table 4 and Fig. 4 respectively. The model of the buncher as well as its cooling water structure is shown in Fig. 5 (the inner structure of the cooling water system is the same as the prebuncher). The comparison between the designed and measured results of the buncher are listed in Table 5.

4 Accelerating structure

The KIPT linac is composed of 10 constant gradient (C.G.) accelerating structures. The structure has a bigger beam aperture than former designs and the 10 C.G. accelerating tubes (Serial number from A0 to A9) which will be used to boost the beam energy to 100 MeV have already been installed in the accelerator tunnel in KIPT (shown in Fig. 6). The model of the C.G. accelerating tube as well as its cooling water structure is shown in Fig. 7. A water jacket is adopted for better cooling because the average electron beam power is quite high for the project (shown in Fig. 1).

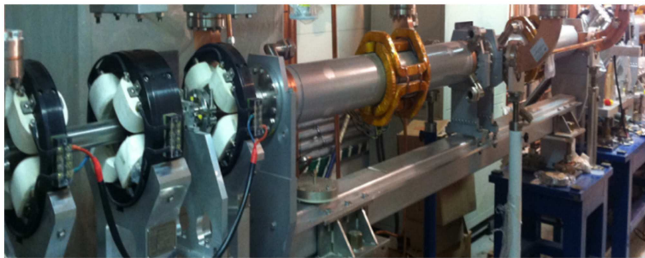


Fig. 6. (color online) Installed accelerating tubes in the accelerating tunnel in KIPT.

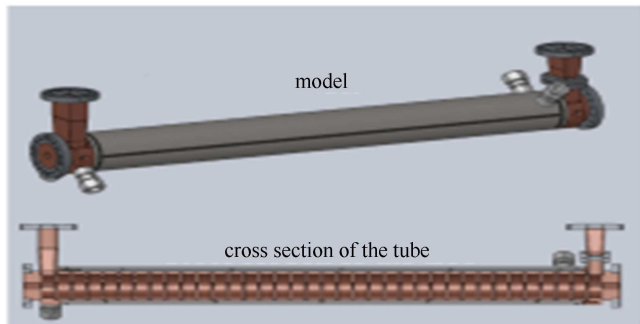


Fig. 7. (color online) Model of the C.G. accelerating tube and its cooling water structure (water jacket).

For high intensity electron linacs, the beam break-up (BBU) effect needs to be considered. To suppress the BBU effect, a bigger aperture and step were adopted in the structure: the disk hole diameter decreases from 27.887 mm to 23.726 mm in a stepwise fashion along the structure (26.22 mm to 19.093 mm for BEPCII 3 m long structure); the average disk hole diameter step increases to ~0.122 mm (~0.085 mm for BEPCII 3 m long structure). To further suppress the BBU effect [3], a method of opening four holes symmetrically distributed on disks is adopted which will benefit the improvement of the BBU threshold current. According to the simulation, when the diameter of the hole equals 9 mm (11 mm, 13 mm), the operating frequency ($2\pi/3$ mode and TM_{01} mode) is still maintained at 2856 MHz but the EM_{11} wave frequency band will move up by about 6 MHz (11 MHz, 18 MHz) with respect to the case without holes in discs.

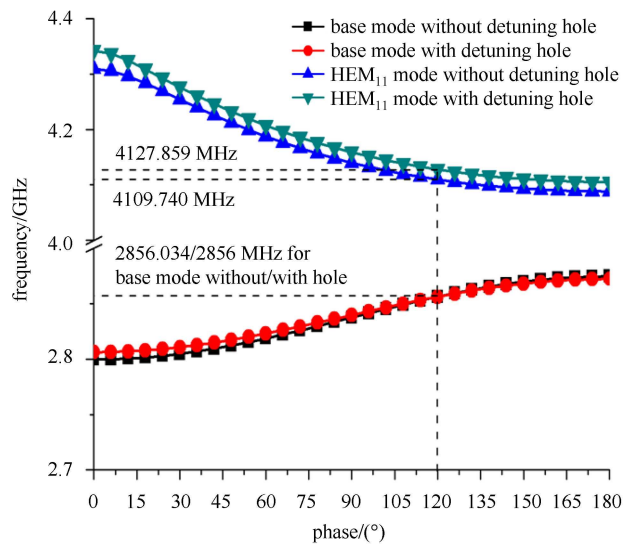


Fig. 8. (color online) Dispersion curves of the base and HEM_{11} waves with and without detuning holes (hole diameter=13 mm).

Table 6. Measured results of accelerating tubes.

serial No.	VSWR (2856 MHz)			attenuation constant/dB	filling time/ns
	f_0	frequency			
		bandwidth/MHz	$VSWR \leq 1.2$		
A0	1.068	5.9	-1.32	221.9	
A1	1.1	5.9	-1.33	221.3	
A2	1.065	5.5	-1.35	221.2	
A3	1.13	5.0	-1.55	222.0	
A4	1.054	6.0	-1.28	217.0	
A5	1.083	6.0	-1.29	224.0	
A6	1.09	5.2	-1.38	222.4	
A7	1.041	5.7	-1.35	220.6	
A8	1.12	5.1	-1.45	221.3	
A9	1.105	5.0	-1.44	223.5	

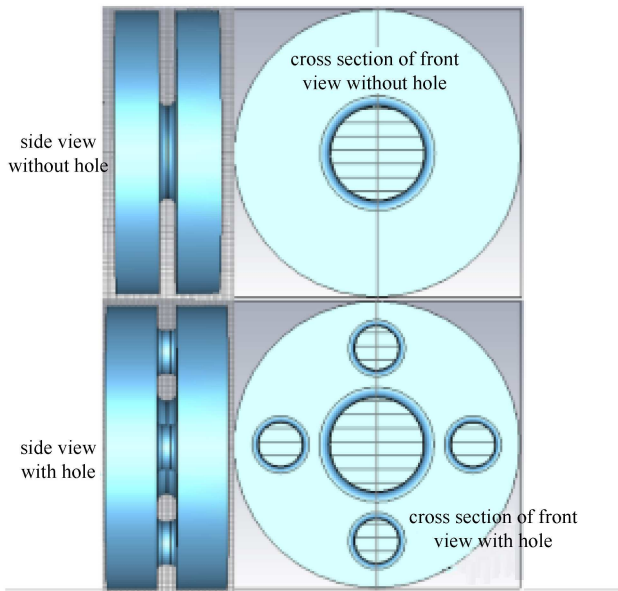


Fig. 9. (color online) Model of the disc with and without detuning holes in Computer Simulation Technology software.

The comparison between the simulated dispersion curves (with and without the detuning holes) of the TM_{01} ($2\pi/3$ base mode) and the EM_{11} (HEM_{11}) wave are shown in Fig. 8 when the hole diameter is set as 13 mm.

For the 10 C.G. accelerating tubes designed for this project, the four holes are opened in each tube as follows:

For the A0 tube, there are no holes.

For the A1 (A2, A3) tube, there are 4 holes from the 3rd to the 6th disks with a diameter of 9 mm (11 mm, 13 mm) and the distance between the center of the hole and the center of the beam aperture is 28 mm. The A4/A7, A5/A8 and A6/A9 tubes are the same as the A1, A2 and A3 tubes respectively. The measured results of the 10 tubes are listed in Table 6. The model of the disc with and without detuning holes in the Computer Simulation Technology are shown in Fig. 9.

The methods adopted above for suppressing the BBU effect are feasible theoretically, however, the results of the mentioned methods will be observed in future testing and commissioning in the accelerating tunnel in KIPT, and we will discuss it in future papers.

5 Conclusion

The work of the accelerating structure design and fabrication for a project with the participation of NSC KIPT, ANL and IHEP together are described in this paper. All of the prebuncher, buncher as well as the C.G. accelerating tubes have given satisfactory measurement results. The methods for suppressing the BBU effect are considered and adopted because of the high intensity of this electron linac. Now two-thirds of the assembling work of the linac has already been finished at NSC KIPT, and all the accelerating structures will be tested in the future commissioning stage.

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