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PRIMARY DESIGN OF 4 A S-BAND LINAC USING SLOTTED IRIS STRUCTURE FOR HOM DAMPING*

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Abstract

A S-band LINAC with the operating frequency of 2856MHz and beam current of 4 A was designed for flash X-ray radiography for hydrodynamic test. The optimization of the parameters of the LINAC was processed to achieve the minimum beam radius and the proper energy efficiency. For the purpose of reducing the beam orbits offset at the exit of LINAC, a slotted iris accelerating structure would be employed to suppress the transverse Higher Order Modes (HOMs) by cutting four radial slots in the iris to couple the HOMs to SiC loads. In this paper, we present the design of the LINAC and the results of beam dynamic analysis.

INTRODUCTION

Linear induction accelerators were used in large-size or full-size radiographic hydrodynamic test with dose of hundreds of Rad by accelerating several-kA electron beam to tens of MeV. In addition, small machine, such as pulsed X-ray machine with several hundreds kV and anode-pinch diode, was used in small-size hydrodynamic subdivision experiments for dynamic material characteristic study, micro jetting diagnosis, et al.

In the past twenty years, intense-beam normal conducting RF accelerator has been developed with great achievement due to the development of large collider technology. The CLIC Test Facility, CTF3, has accelerated the beam with current of up to 5A to150MeV with full beam loading [1-2]. The HOM was damped by using slotted iris constant aperture (SICA) accelerating structures. The 100MeV/100kW linac, constructed by IHEP and used as a driver of a neutron source in KIPT, Ukraine, has accelerated a beam of 2A to 100MeV by using detuning accelerating tubes [3-5].

The great progress in intense-beam linac motivates the compact radiographic facility driven by a 4A 30MeV linac, which might be utilized for multi-pulse radiographic with the material planar density of several to tens g/cm^2. The most considered parameter, FWHM of transverse distribution of electron beam, should be limited less than 1 mm. A radiographic system has been discussed before [6]. The Monte Carlo codes, Geant4, has been used to simulate bremsstrahlung characteristic, such as exposure dose, energy deposit in target and increment of X-ray spot size by electron scatter, with 30 MeV electron beams bombarding tantalum target with various thickness in a certain radiography layout. Simulation results showed that the exposure dose 1 m away from the target right ahead was about 9.1 R and the X-ray spot sizes were not increased with the increment of the thickness of target material. The results also shown that pulse number was limited by temperature rise in target, which was increased intensely with a very tiny beam transverse size.

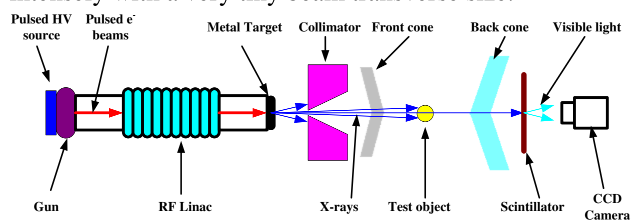

Figure 1: Layout of a typical flash X-ray radiography system using RF accelerator.

In this paper, the design of accelerator was described. A beam dynamic analysis was carried out with the primary design of the accelerating structure. BBU effect calculation was also carried out.

GENERAL DESCRIPTION OF THE ACCELERATOR

Layout of the accelerator, which consists of a DC gun, 3 accelerating tube, a chicane and matching beam line, was shown in Fig. 2. The total length is about 14m and could be reduced by farther optimization. Table 1 lists main parameters.

Table 1: Main Linac Parameters

Parameter	Value
RF frequency	2856MHz
Energy	>30MeV
Beam current (max)	4A
Energy spread (FWHM)	<1%
Emittance (RMS)	<50mm mrad
Beam pulse length	100ns
Number of pulses in a train	4-8
RF pulse duration	10μs
Pulse repetition rate	10Hz
Klystron power	65MW
Number of klystron	3
Number of ACC. structure	3
Gun voltage	~120 kV
Gun beam current	10A

ACCELERATING STRUCTURE

The goal of the design of accelerating structure is to achieve a high RF-beam power efficiency with short length as much as possible. Two type of structure was considered: the conventional disk-load structure and

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constant-aperture structure. Both of them should be slotted on the iris to suppress the HOM modes, which would be introduced by the beam. The input power, limited by klystron power and transmission efficiency, was determined as 45MW. There were 3 rules to determine cell arrangements for constant gradient along the axis when there is no beamloading:

1. The structure is solvable. The group velocity of all accelerating cells should not be negative and smaller than the maximum one when the length of nose cone is 0;
2. The unloaded gradient should be chosen carefully making the surface electric field as small as possible;
3. The acceleration structure should be as short as possible to make microwave - beam conversion efficiency as high as possible. We determine the conversion efficiency to be 0.95 times the maximum conversion efficiency by abandoning part of the acceleration cells to improve the average loading gradient.

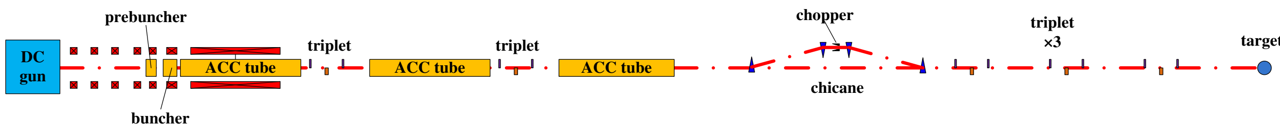

Figure 2: Layout of the accelerator.

The arrangement of disk-load structure has only a unique solution in the case of certain input power and average unload gradient. Some results with unloaded gradient of 12MV/m with the different input power calculation are shown in Figure 3. With a certain beam load and unloaded gradient, the number of cells required to achieve specific microwave-beam efficiency (90% for example) increased linearly with input power, and the loaded gradient satisfying the above requirements did not change.

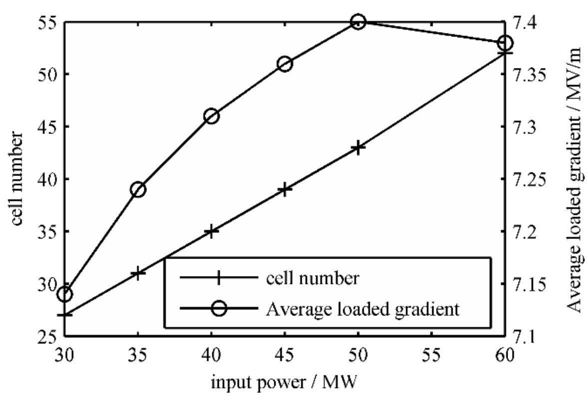

Figure 3: Calculation results of disk-load structure with a certain unloaded gradient of 12MV/m with various input power.

With the employee of nose cone to achieve constant-aperture, the arrangement is also determined by the iris diameter. With a certain input power, there will be an appropriate value of iris diameter resulting minimum surface electric field as shown in Fig. 4.

The design of two types of structure for 45MW input power is list in Table 2. The average loaded gradient is larger to CTF3 2998MHz structure (6.5 MV/m for beam current of 3.5A [1]), but more critical to the RF breakdown threshold with about 6 times larger RF pulse length. The uniform un-loaded gradient design will bring a lower surface electric field of whole accelerating structure. The results are shown in Fig. 5.

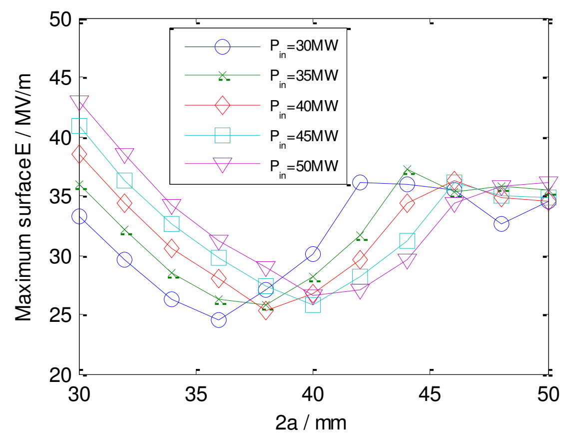

Figure 4: Maximum surface electric field of different structure design.

Table 2: Design of Two Type Accelerating Structures

Parameter	Unit	Disk-load	Constant-aperture
Input power	MW	45	45
E_{acc} (no beamloading)	MV/m	12.0	12.1
E_{acc} (max beamloading)	MV/m	7.36	7.38
E_{max} on surface	MV/m	27.66	29.70
Phase advance per cell		2π/3 - mode	
RF-beam effeciency		0.893	0.895
Number of cells		39	39
Iris diameter (2a)	mm	36.010-35.051	36
Length of nose cones	mm	-	0.031-0.706
Ratio of v_g to c		0.05576-0.05151	0.0550-0.0504
Energy gain	MeV	9.95	9.98

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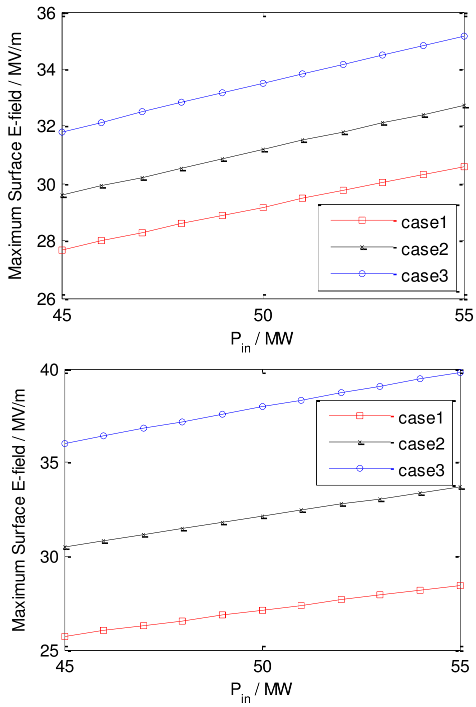

Figure 5: The maximum surface electric field with different unloaded gradient arrangements. Upper: disk-load structure; lower: constant-aperture structure. Case 1: uniform unloaded gradient; case 2: unloaded gradient linearly changed within ±10%; case 3: unloaded gradient linearly changed within ±20%.

BEAM DYNAMIC

Beam dynamic analysis was carried out using PARMELA code without consideration of BBU. The FWHM of beam horizontal distribution at the end of the accelerator can be controlled less than 1 mm in the case of the 4A beam load. Fig. 6 shows the beam envelop along z axis. Fig. 7 and Fig. 8 shows beam transverse distribution, energy spectrum and longitudinal distribution, respectively. If the BBU effect is taken into account, the beam lateral size jitter will be in the order of mm, and after preliminary calculation, it can be known that when the Q of dipole modes were reduced less than 20, the beam position jitter can be controlled less than 0.1mm, shown in Fig. 9.

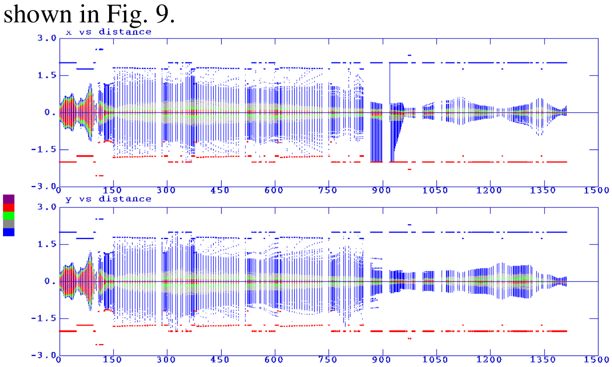

Figure 6: Beam envelope calculation result.

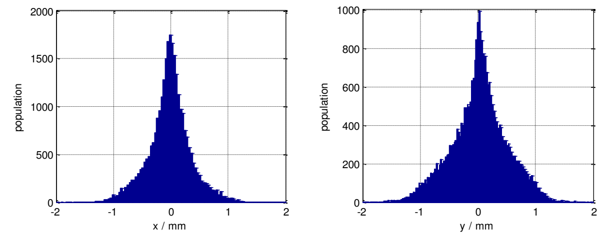

Figure 7: Beam transverse distribution at the exit

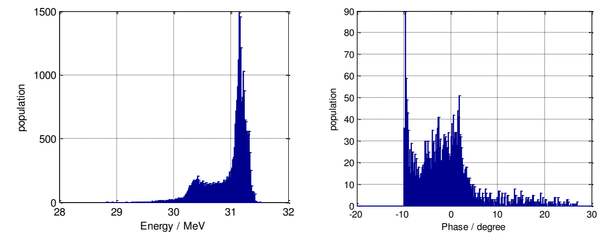

Figure 8: Beam energy spectrum and longitudinal distribution at the exit.

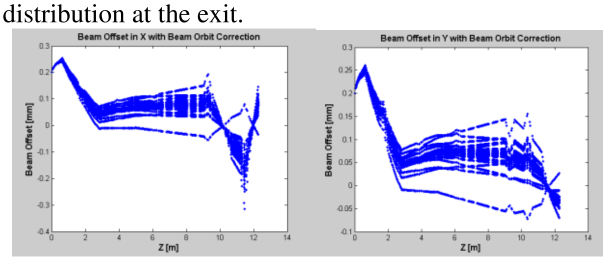

Figure 9: Beam offset calculation with a 100ns RF duration considering long-range wakefield.

We will use the uniform-gradient disk-load structure. The accelerating structure will be designed carefully to suppress Q of most dipole modes less than 20.

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