BEAM OPTICS DESIGN FOR DC HIGH-VOLTAGE ACCELERATOR OF MW LEVEL

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Abstract

Here, we report on the working group "beam optics design" of MW levels dc high-voltage accelerator, that will be used in radiation technologies in large-scale industrial production (flue gas treatment, metallurgy, waste water treatment, etc.). This workshop also had working groups on "Electron Guns Designs and Beam control device", "MW level high-voltage power supply designs and fabrication", and "Beam scanning and extraction devices designs and fabrication". Comparing with existent high-voltage accelerators, our facility have higher average power of >500mA dc, which resulting in some technological challenges on beam production, power supply, and beam extraction. Here, we are concerned with several proposals that other laboratories have been working on. Subjects of concern are optics, accelerator design and modeling, stability requirements that connects the conventional DC high-voltage accelerators for round-the-clock operation. We describe the design, the projected performance and the status of our facility.

INTRODUCTION

We developed a series of RF accelerator whose electron beam is small in size, and they have been the driver of high energy industrial CT. To satisfy the requirement of radiation technologies in large-scale industrial production (flue gas treatment, metallurgy, waste water treatment, etc.), we have started the developmental program of MW level's dc high-voltage accelerator.

This accelerator is designed with unified systems and units enabling them to be adapted to the specific requirements by varying the main parameters such as energy range, beam power, etc. The design is suitable to transmit high intensity current and realize the cathode of long lifetime, and can provide long term and round-the-clock operation of accelerators under the conditions of industrial production processes.

ACCELERATING TUBE STRUCTURE CHARACTERISTICS

A picture of the accelerating tube is shown in Fig 1. The cathode is single crystal LaB_6 and its best operating vacuum is less than 10^{-4}Pa. The channel aperture is 120 mm. This provides good vacuum conditions in the cathode region and consequently long time. The outer diameter of the insulator is 150 mm, its inner diameter is 130mm. A distance between the electrodes is 14mm. The ratio of the electrode's thickness to the insulator's height is 1/7. The 95 Al_2O_3 ceramic rings are connected to the 1Cr18Ni9Ti electrodes by thermodiffusion welding.

An accelerating tube is made up of seven sections, and a section includes ten electrodes, eleven insulators and two mounting flanges. Its rated voltage is 1.2 MeV, and the mean operation gradient in the tube is 11.13kV/cm. Operating experience indicates the tube can be safely running as high gradient as 20kV/cm in a steady state.

DESIGN OF POTENTIAL DISTRIBUTION

We introduce the paraxial movement track equation in electrostatic field:

$$r'' + \frac{V'(z)}{2V(z)} r' + \frac{1}{4V(z)} \left(V''(z) - \frac{I}{\pi \varepsilon_0 r_b^2 v} \right) r = 0 \qquad (1)$$

the quantity V the generalized potential of charged particles, v equals to $\sqrt{\frac{2eV}{m}}$,r is the radial position of charged particle, and the prime symbol denotes a derivative taken with respect to z. The third term on the left hand side of Eq.1 represents the electrostatic focusing and defocusing progress of space charge force. Apparently, if want to have a beam form requisite, we must acquire some field gradient to counterbalance space charge force. Therefore ,we have to adjust the potential difference between adjacent electrodes. Now, for 0.5 ampere beam size of ϕ6, the required field gradient varies with generalized potential can be displayed in table 1.

Table 1: V & V'' for 0.5 ampere beam size of ϕ6

V (kV)	5	10	15	20	25
V''(kV/cm^2)	4.77	3.37	2.75	2.38	2.13

Cathode immerses in electrostatic field of accelerating tube. The beam current value is controlled by the cathode temperature, i.e. the gun is operated in a regime of full emission current take-off. Hence, the field on the cathode must be sufficiently strong, or it maybe in a space-charge-limited flow region. Considering the feasibility of beam current control, the quantity of field should be more than 7kV/cm on the surface of a ϕ6 cathode for 0.5 ampere. Table 2 lists the corresponding field for different current intensity of different size cathode.

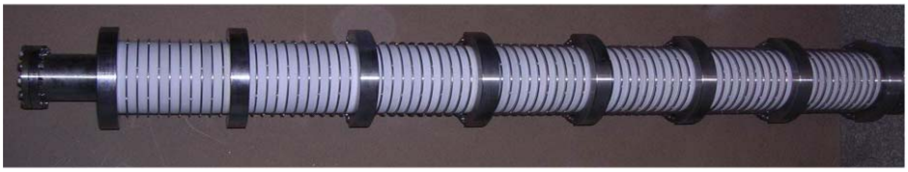

Figure 1: A picture of the accelerating tube.

Table 2: Extraction current and field intensity and cathode size.

Diameter of cathode(mm)	6	6	6	6	10	10	10	15	15
Surface field (V/cm)	8943	7336	5677	5262	6508	4555	3257	5063	2531
Extraction current (mA)	1106	765.3	523.2	469.0	1398	819.4	494.8	1669	590.8

If we try acquiring enough field gradient to balance space charge force by adjusting the difference between next electrodes, as a result, the field on some insulator-vacuum interface would approach or exceed 20 kV/cm, and this state must never be chosen for round-the-clock operation. So our design is the voltage distribution is homogeneous, but the voltage between cathode and anode is raised up to 45's kV.

ELECTRON GUN LAYOUT AND BEAM DYNAMICS SIMULATION

Figure 2 shows the electron gun layout. The slanted electrode adjacent to the source is pierce electrode and the cone angle is 20 degrees. This surface bends electric fields to generate focusing forces near the source. The electric force counteracts the defocusing beam-generated forces on the edge of the beam.

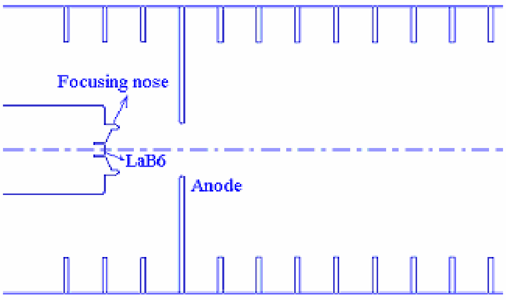

Figure 2: The layout of electron gun.

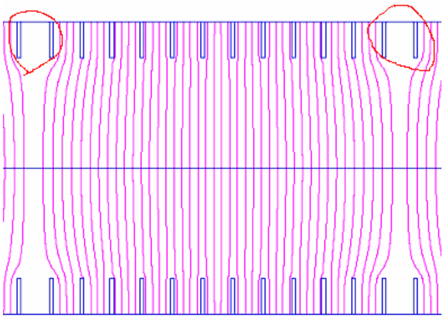

Figure 3: The equipotential lines distribution.

For the accelerating tube is made up of seven sections, the connecting flange region results in a large descent of axial field. Fig 3 shows the distortion of equipotential lines in or near the connecting flange region. The electrical field distribution was calculated using the computer program Poisson. Fig 4 displays the electric field distribution along axis from cathode to the accelerating tube exit. It clearly indicates the wide fluctuations of electric amplitude due to the effect of a connecting flange.

Beam dynamics studies were carried out from the cathode to the end of the accelerating tube using GPT code developed by Bas van der Geer and Marieke de Loos. Fig 5 displays the beam size at the end of the accelerating tube. The size is Φ30 including 86 percent of 5000 macro particles, and fig 6, which histogram represents radial distribution at the end of the accelerating tube, do approve that result. The envelope of 5000 macro particles can match the later beam propagation system, that is to say, our design can meet the requirement of customer.

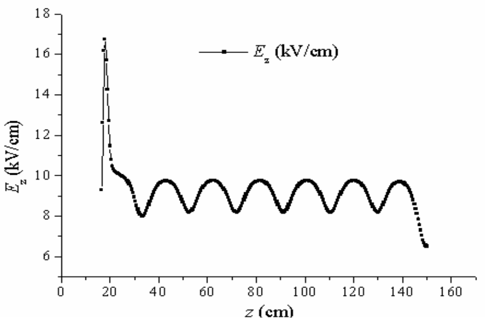

Figure 4: The axial electric field distribution.

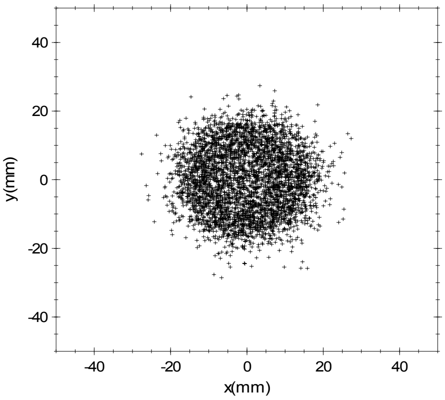

Figure 5: The beam size at the end of accelerating tube.

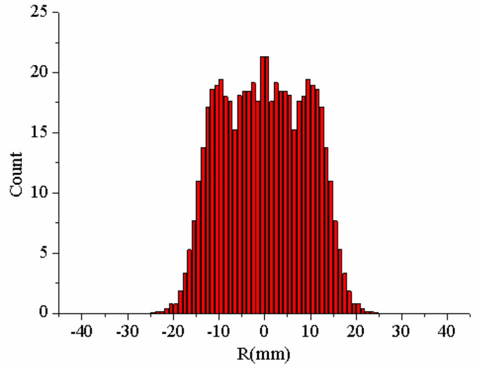

Figure 6: The radial distribution of particles at end of accelerating tube.

THE PRESENT CONDITION AND A WORK SCHEDULE

Based on the simulation we have conducted, we have performed the fabrication of the accelerating tube and accomplished the voltage hold-off capability test that voltages to 240 kV were applied to per section.

Now, we are ready to extracting beam from low to rated current step by step, at the same time, considering improvement of the measurement system to conduct a more complete exploration of all beam parameters, which are the constraint on the performance of this accelerator, relevant to the application.

REFERENCES

[1] H.B.Wang, et al. *High Power Laser and Particle Beams*, 2005, 17(6):930-934.

[2] X.J.Yin, *et al. High Power Laser and Particle Beams*, 2004, 16(2):246-250.

[3] S.F. Chen, et al. *High Power Laser and Particle Beams*, 2001, 13(4):513-516