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Design of W-band photoinjector

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Abstract

we present a design study on W-Band photocathode RF gun which is capable of generating and accelerating 300pC electron bunch. The design system is made up of 91.392GHz photocathode RF gun and 91.392GHz travelling wave linac cells. Based on the numerical simulation using SUPERFISH and PARMELA and the conventional RF linac scaling law, the design will produce 300pC at 1.74MeV with bunch length 0.72ps and normalized tranverse emittance 0.5mm mrad. We study the beam dynamics in high frequency and high gradient; due to the high gradient, the pondermotive effect plays an important role in beam dynamics; we found the pondermotive effect still exist with only the fundamental space harmonics (synchrotron mode)due to the coupling of the transverse and longitudinal motion.

1.Introduction

Recently, high gradient, high frequency accelerators of mm-scale are of interest in advanced accelerator research [1]. Research on short wavelength, high gradient, RF driven acceleration has concentrated on 90GHz which is in the range of W-Band (75GHz-110GHz), it involes the understanding of millimeter wave power source, high power operation of millimeter wave, and beam dynamics in high frequency and high gradient, and technologies for fabrication and measurement of millimeter accelerator.

The scaling of RF accelerator with respect to RF frequency f is as follow
Shunt impedance $r \sim f^{1/2}$,
Accelerating gradient $G \sim f$,
Peak power required per meter$\sim f^{-1/2}$.

In this paper, we use the above scaling law and codes (SUPERFISH, PARMELA) to design the W-Band photoinjector, and study the beam dynamics in high frequency and high gradient.

2.Design approaches and system

The design system is made up of photocathode RF cavity, emittance compensation drift section, and 60 2π/3 travelling wave cells. We use the conventional RF linac scaling law to scale down the BNL S-Band photocathode RF cavity[2,3] and S-Band SLAC 2π/3 travelling wave cells. The RF cavity length is 0.46cm, the drift length 2.3cm and the linac section length 6.55cm as shown in Fig.1, the drift length is decided in order to make a good match between the photoinjector and linac cells.

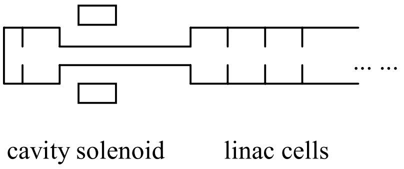

Fig.1 Setup of the design system

Table 1 and Table 2 list the structure parameters of the RF cavity and the linac cells which are calculated using SUPERFISH. The shunt impedance and quality factor show a good agreement with the scaling law.

Table 1 The gun cavity design parameters

Inner radius of the cell(mm)	1.3
Radius of the iris(mm)	0.39
Width of the iris(mm)	0.689
Length of the cavity	4.69
π mode frequency(GHz)	91.392
Shunt impedance(MΩ/m)	269.67
Quality factor	2806

Table 2 The linac cell design parameters

Inner radius of the cell(mm)	1.303
Radius of the iris(mm)	0.409
Width of the iris(mm)	0.182
Length of the cavity	1.092
2π/3 mode frequency(GHz)	91.392
Shunt impedance(MΩ/m)	284.5
Quality factor	2435

3.Simulation result

We use PARMELA to study the beam dynamics of our system. The RF cavity works in π mode, while the Linac cells work in $2\pi/3$ mode. Table 3 gives the typical parameters of the photoinjector.

Table 3 photoinjector parameters

solenoid peak field[T]	5.8
gradient[GV/m]	1
charge[pC]	300
bunch length[ps]	0.72
emittance[mm mrad]	0.5
energy[MeV]	1.74
energy spread	1.7%

Because of the high frequency (small structure), it is difficult to achieve a high charge of electron bunch. the maximum bunch charge in the simulation is 300pC. Above this value, the beam breaks up fast with space charge effects. Fig.2 shows the r.m.s. emittance with bunch charge for the condition B=5.8T, and the average RF cavity gradient=1GV/m. In the W-band linac, the charge of a single bunch charge is constrained by a beam break-up. Zimmermann[6] has estimated the longitudinal and transverse wakefield in a W-Band (91GHz) accelerating structure. The transverse wakefield is almost completely determined by the structure geometry (iris radius). For a 60pC charge, and $a/\lambda \geq 0.18$, the transverse beam break up is negligible. Since PARMELA does not include wake field or beam loading in its calculation, we have studied the 60pC bunch charge extensively .

In order to mininize the beam emittance, we design the emittance compensation solenoid using POISSON, whose peak field is as high as 5.8T. We have simulated the emittance dependance on the solenoid field shown in Fig.3 for the condition Q=60pC, the average gradient=1GV/m.

In our case, the peak electric field in the half and the full cell of the RF cavity is not the same, the electric field amplitude has effect on RF focusing and defocusing which play a role in the emittance evolution of the beam, Fig.4 shows the beam r.m.s emittance dependance on the average field for the condition bunch charge Q=60pC, B=5.8T.

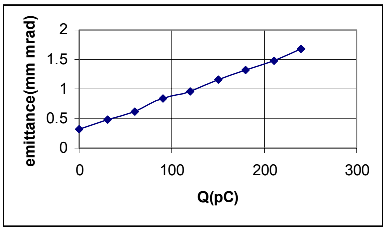

Fig.2 The r.m.s emittance dependance on the bunch charge

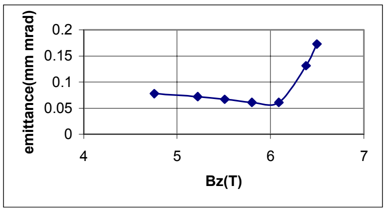

Fig.3 The r.m.s emittance dependance on the peak magnetic field

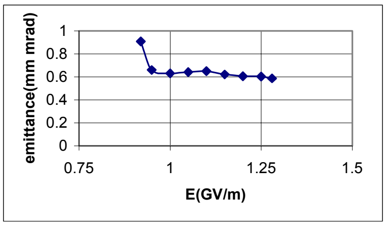

Fig.4 The r.m.s emittance dependance on the gradient

Up to now, there are few works on the beam dynamics in high frequency and high gradient case. Due to high electric field, the RF focusing and defocusing will become more important. We use the 60 linac cells operated at the gradient 1GeV/m to study the beam dynamics in the W-band, the cells operated at the fundamental $2\pi/3$ mode. PARMELA cann't take into account the high space harmonics mode, where the field coefficients are calculated using SUPERFISH. Therefore no high space harmonics exist. However, we can observe the beam envelope osillation, the periodical time of this oscillation approximately scales like the square of the electric field amplitude, and is almost independent of the bunch charge. Hence, we can conclude that there exists the transverse pondermotive effect of the fundamental mode. According to the rf pondermotive focusing theory developed by Hartman and Rosenzweig[4,5], there will be no such effect if only fundamental travelling mode exists. However, if the coupling between the longitudinal and transverse motion is considered, there will exist the pondermotive effect for the case of fundamental travelling mode.

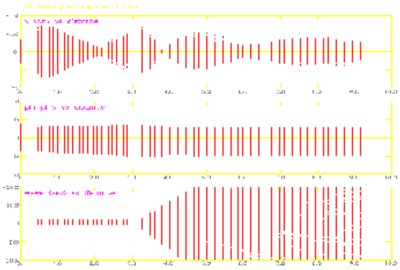

Fig.5 The beam envelope motion

4.Conclusion

The conventional RF linac scaling law works well in the W-band structure. The pondermotive effect becomes obvious due to the high gradient. We conclude that there will exists the pondermotive effect in the case of fundamental travelling mode due to the coupling between the longitudinal and transverse motion.

Acknowledgement

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Reference:

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