

*High average current low emittance beam employing  
CW normal conducting gun*

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# HIGH AVERAGE CURRENT LOW EMITTANCE BEAM EMPLOYING CW NORMAL CONDUCTING GUN\*

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## Abstract

CW normal conducting guns usually do not achieve very high field gradient and waste much RF power at high field gradient compared to superconducting cavities. But they have less trapped modes and wakefields compared to the superconducting cavities due to their low Q. The external bucking coil can also be applied very close to the cathode to improve the beam quality. By using a low frequency gun with a recessed cathode and a carefully designed beam line we can get a high average current and a high quality beam with acceptable RF power loss on the cavity wall. This paper shows that the CW normal conducting gun can be a backup solution for those projects which need high peak and average current, low emittance electron beams such as the Relativistic Heavy Ion Collider (RHIC) e-cooling project and Energy Recovery Linac (ERL) project.

## INTRODUCTION

Many of the advanced scientific research projects such as the RHIC e-cooling [1] and ERL [2] rely on the high peak and average current, low emittance electron beams. The superconducting cavity is the first choice of the injectors for these projects due to its high RF power efficiency and relatively high achievable maximum electric field on axis (more than 40MV/m) at CW mode. But the superconducting cavities need to work at liquid helium temperature and the trapped modes and wakefield issues are serious.

The normal conducting cavities have much less trapped mode and wakefield problems but it's hard to achieve very high Electric Peak Field (EPF) on axis which is important to get low emittance beams. The maximum EPF on axis is limited by the available RF power and the RF power efficiency issues. In this paper we will study the possibility of employing normal conducting cavities working at CW mode as the high peak and average current, low emittance electron beam injectors.

## DESIGN CONSIDERATIONS

One way to increase the RF power efficiency is to lower the RF frequency. The RF frequency for the ELSA project in France [3] [4] is 144.33MHz. We also adopt this low frequency for our CW normal conducting cavity.

Another way to improve the RF power efficiency is to increase the accelerating gap of the cavity (cavity cell length). The increase of the cavity cell length can increase the electron energy at gun exit but reduces the EPF on axis at the same RF heat dissipation level. The cavity cell length for our case is optimized to be about 25cm so that

the electron beam energy at gun exit is high (about 2.7MeV) and the EPF on axis is not too small (about 14.0MV/m). The ELSA injector cavity has an accelerating gap of about 10cm working at pulsed RF mode with EPF of 20MV/m to 30 MV/m.

Another important aspect of designing the CW normal conducting cavity is the emittance compensation issue. It is pointed in reference [5] that a recessed cathode and a closer solenoid to the cathode are required to get the best emittance compensation. The cathode recess again decreases the EPF on cathode but provides strong RF focusing near cathode which is very important for emittance compensation. In our cavity design the cathode recess has been optimized to be such that the EPF on cathode is found to be about  $\frac{1}{2}$  of the EPF on axis.

The RF heat dissipation on the cavity wall is another issue to consider for the CW normal conducting gun. The EPF on axis of our CW normal conducting gun is 14MV/m so that the maximum temperature on the cavity is just below 100 °C with water cooling. The maximum power density on the wall is 14.4 W/cm<sup>2</sup> and the total power loss on the wall is 550 kW. It should be pointed out that these conditions are rather conservative and we have space to push up the peak field.

Fig. 1 shows the geometry and the temperature distribution on the cavity wall. Fig. 2 shows the EPF on axis from the cathode to the gun exit.

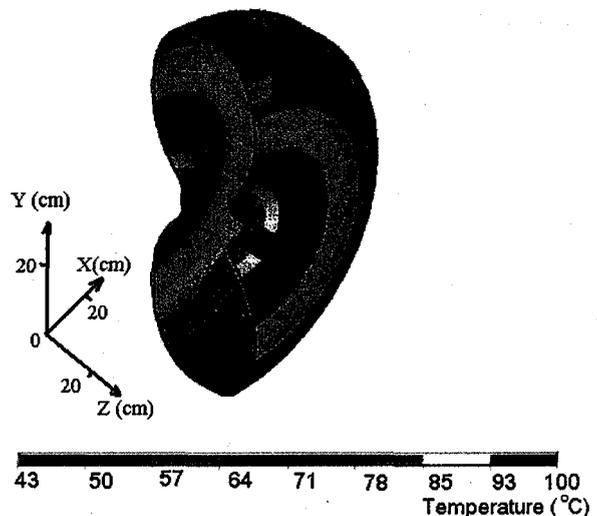


Figure 1: Cavity geometry

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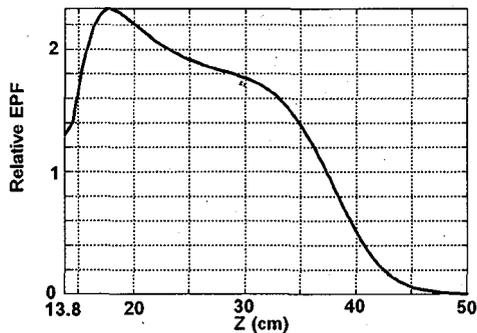


Figure 2: EPF on axis

The system is schematically shown in Fig.3 where the booster linac frequency is assumed to be 433MHz and the solenoid for the gun (bucking coil) is put right after the gun exit.

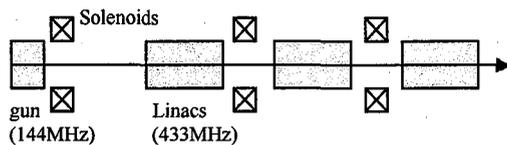


Figure 3: CW normal conducting injector system

### SIMULATION RESULTS

The computer code PARMELA was used for the beam dynamics simulation, using 10000 macro-particles. Fig.4 shows the emittance (100% particles) vs. distance from cathode for the optimized 5nC/bunch case. The emittance is sufficiently compensated.

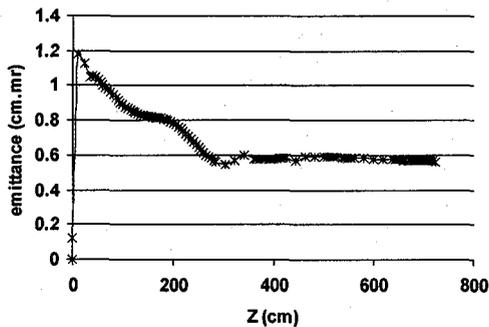


Figure 4: Emittance vs. Z (5nC/bunch)

The curve in Fig.4 is the emittance including all the particles in the beam bunch. The small part of the electrons on the bunch edges (both longitudinally and transversely) contribute greatly to the emittance. These "bad" electrons are not effective in most applications such as the electron cooling. Practically these "bad" electrons are not included in the emittance measurement either. We calculate the emittance including the 90% of the particles with the lowest action. This 90% particle emittance is more practical and useful for many applications.

Fig. 5 shows the emittance at linac exit for various bunch charges. The blue curve represents the emittance including all the particles while the pink curve represents

the emittance including 90% of the particles. With 10% reduction of the "bad" bunch charge the emittance is improved about 40%.

The longitudinal phase space for the 5 nC per bunch example is shown in fig. 6. The emittance is dominated by the large sinusoidal RF distortion. This distortion can be corrected by using the higher order harmonic cavities working at deaccelerating phase to achieve very small energy spread (not included in this study).

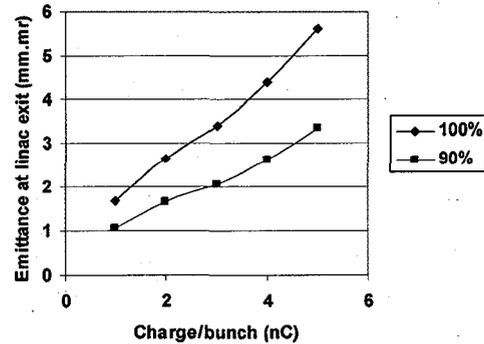


Figure 5: Emittance at linac exit vs. charge/bunch

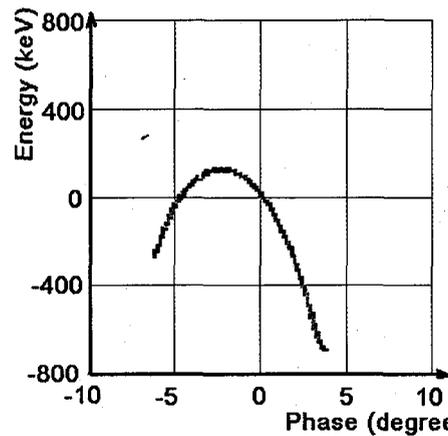


Figure 6: Longitudinal phase space at linac exit (5nC/bunch)

Table 1 lists the optimized parameters for the 5nC charge / beam bunch case.

Table 1: Optimized parameters for 5nC/bunch

Parameters	Results
EPF on cathode	8.1 MV/m
EPF on axis	14.0 MV/m
Drift space from gun exit to linac entrance	2.5 m
Spot size on cathode (Uniform distribution)	4.5 mm ( $R_{Max}$ )
rms bunch length (Gaussian distribution)	40 ps
Launching phase	55 degree
Energy at gun exit	2.7 MeV

Energy at linac exit	19 MeV
Transverse emittance (100% particles)	5.6 mm.mr
Transverse emittance (90% particles)	3.3 mm.mr
Thermal emittance	1.3 mm.mr

## DISCUSSION

In the ELSA experiments in France, the experiment results match the simulation results perfectly. This indicates that as long as one gets a good quality electron beams from simulation based on practical parameters one can get a good quality beams experimentally.

Even with the conservative parameters used in our simulations we got already a good quality beam capable of running the RHIC e-cooling and ERL projects. The EPF on axis can actually be pushed to even higher value which will further improve the emittance.

The final emittance is still dominated by the slice emittance, as we are using a Gaussian charge distribution. When using a top hat shape or ellipsoid shape one can significantly reduce the slice emittance. In other words, there is still room to improve the beam quality.

Another advantage of using this low frequency CW normal conducting cavity is that the optimized launching phase is relatively high. This makes it easy to employ the Diamond Amplified Photo-cathode [6] [7] which prefers a high launching phase and low frequency cavity.

## CONCLUSIONS

Beam dynamics simulations for a normal conducting low frequency (144MHz) cavity working at CW mode were presented. These simulations are based on conservative parameters. The results clearly indicate that although the EPF on axis is relatively small one can still get very good quality electron beams. The transverse emittance of the beam at 5nC/bunch can be as small as 3

$\mu$ . The CW normal conducting cavity can be a backup injector for the RHIC e-cooling, ERL and the other electron accelerators which require high peak and average current, high quality electron beams.

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