INITIAL DESIGN OF A SUPERCONDUCTING RF PHOTOINJECTOR OPTION FOR THE UK'S NEW LIGHT SOURCE PROJECT

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Abstract

The injector for the UK's New Light Source project is required to deliver low emittance 200 pC electron bunches at a repetition rate of up to 1 MHz. Initial design of a photoinjector based around a 1½ cell L-band superconducting RF gun able to meet these requirements is presented, including beam dynamic simulations of the injector up to the end of the first linac module.

INTRODUCTION

Low emittance electron beams delivered at a high repetition rate are desired for several future FEL-based light source projects including the UK's New Light Source (NLS) [1]. Currently operational linac-based FELs such as LCLS [2] and FLASH [3] use 1½ cell pulsed normal conducting RF guns operating at the frequency of the main linac but only in single or train pulsed modes. The LCLS S-band gun has experimentally demonstrated beams with emittance values down to 0.3 mm mrad [2], however, its performance is limited in repetition rate due to cavity heating. The first stage of NLS will use an L-band RF photoinjector utilising a modified PITZ gun [1] which, according to simulations, is able deliver 200 pC bunches with emittance in the range of 0.3 mm mrad. However, this gun is also unable to operate at 1 MHz CW as desired by the science case for the project. Use of a superconducting (SRF) gun cavity would potentially allow for resolving the problem of operation in CW mode.

Four injector options were considered as potentials to deliver 1 MHz CW. Thermionic cathode based injectors were ruled out, as despite recent advances at SCSS [4], they have so far been unable to provide short bunches, low emittance, and high repetition rate simultaneously. High voltage DC photocathode guns were ruled out because they are unable to deliver the low emittance required since the maximum achievable field strength available on the photocathode is limited to less than 5 MV/m, due to parasitic field emission from high voltage electrodes. The two remaining options are a low frequency, normal-conducting RF gun based injector, as described elsewhere [5] and an L-band superconducting RF gun, as described here.

INJECTOR DESIGN

Previous studies [1] concentrated on a two cavity L-band gun with a 1½-cell launch cavity largely adopting the TESLA cavity shape, and an adapted Cornell 2-cell booster cavity. To reduce complexity of the gun, we focus here on a single cavity, 1½ TESLA cell design, as seen in Fig. 1. Recently a of 1½ cell cavity prototype was vertically tested at TJNAF to a peak electric field of 40 MV/m [6] and a gun with a field of 50 MV/m is potentially feasible. However, as this is pushing the state-of-the-art, simulations below have been carried out at both 40 and 50 MV/m peak fields. Fig. 2 shows the on-axis electric field for the gun at 50 MV/m.

At 1 MHz CW repetition rate, existing UV laser systems are not able to drive metallic photocathodes so alkali photocathodes have to be considered. A 3½ cell SRF gun operating with Cs_2Te photocathodes is under commissioning at FZD [7] with a goal to deliver 1 mA average current, and a SRF gun using K_2CsSb photocathodes is under development at BNL [8] to operate in CW mode with an average current of 50 mA.

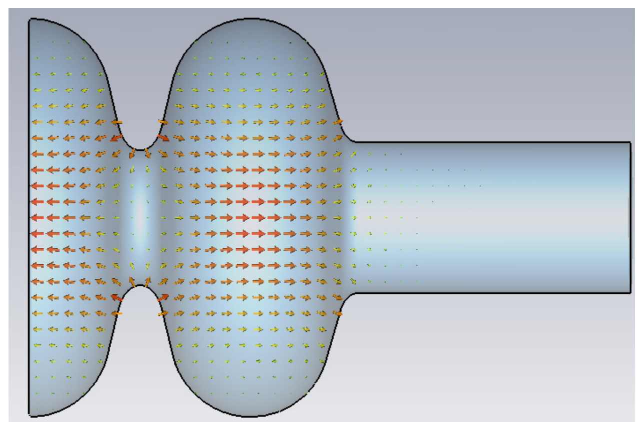

Figure 1: A 1½ TESLA cell SRF gun cavity with the fields shown for the accelerating mode as simulated in CST Studio.

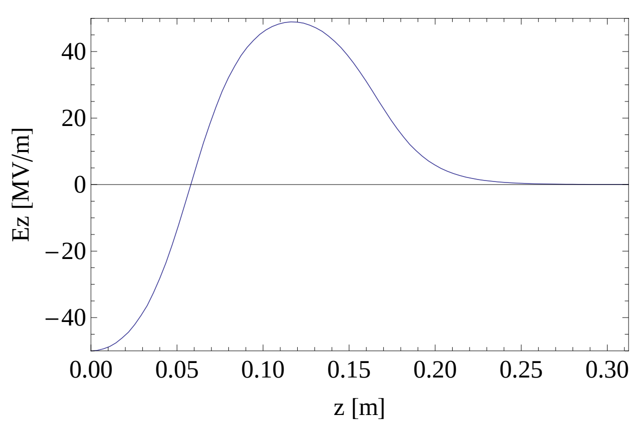

Figure 2: On-axis electric field in the gun cavity.

Since the high acceleration field in the SRF gun prevents bunch expansion and keeps it length close to that of the initial laser pulse, a separate buncher is not required. ASTRA [9] simulations have been carried out

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with a laser pulse with a 1 mm diameter flat-top transverse profile and a 30 ps flat-top temporal profile with rise and fall times of 2 ps. Initial thermal energy of 0.7 eV was included – this assumes a Cs_2Te photocathode will be used. Following the gun cavity is an emittance compensation solenoid which may be superconducting in order to be contained within the gun cryostat. An alternative is to have a second cavity operating in a TE mode which provides a field profile similar to that of a solenoid. This would require additional cavity design and a dedicated RF power supply, mode locked to the gun RF, due to the different frequency to the TM accelerating mode.

At 50 MV/m peak field the gun accelerates the electron beam to 4.5 MeV. Operating at 40 MV/m this energy is reduced to 3.6 MeV. The gun is operated at a phase of +3° from crest for 50 MV/m and +1° for 40 MV/m. These phases were chosen for optimal emittance. Following the solenoid, the beam is then injected into the first module of the main linac where it is further accelerated to 130 MeV. The linac module contains eight 9-cell TESLA cavities at a frequency of 1.3 GHz. These are operated at an average accelerating gradient of 15 MV/m. The first cavity is operated at a phase of -40°. The remaining cavities are then operated at +4.5° in order to compensate the energy chirp.

SIMULATION RESULTS

Fig. 3 shows the evolution of beam parameters along the injector with the gun operated at a field of both 40 and 50 MV/m. Fig. 4 shows the final distribution of the 200 pC bunch at the exit of the first linac module for ASTRA simulations of 100,000 macroparticles, again at both 40 and 50 MV/m. The flat current profile has a duration of 35 ps and the slice emittance remains low, around 0.3 - 0.35 mm mrad, throughout the bunch for the 50 MV/m case. For the 40 MV/m case slice emittance increases up to an average of 0.39 mm mrad whilst other beam properties remain unchanged. The average energy of the bunch at the first module exit slightly drops from 129.7 to 129.0 MeV. The full beam parameters are summarised in Table 1. It is possible to get a smoother evolution of transverse beam size through the linac, however, this comes at the expense of a rise in slice emittance across the bunch from 0.3 mm mrad at the head to 0.4 mm mrad at the tail. Therefore the injector setup with a slightly divergent beam but flat slice emittance profile was chosen.

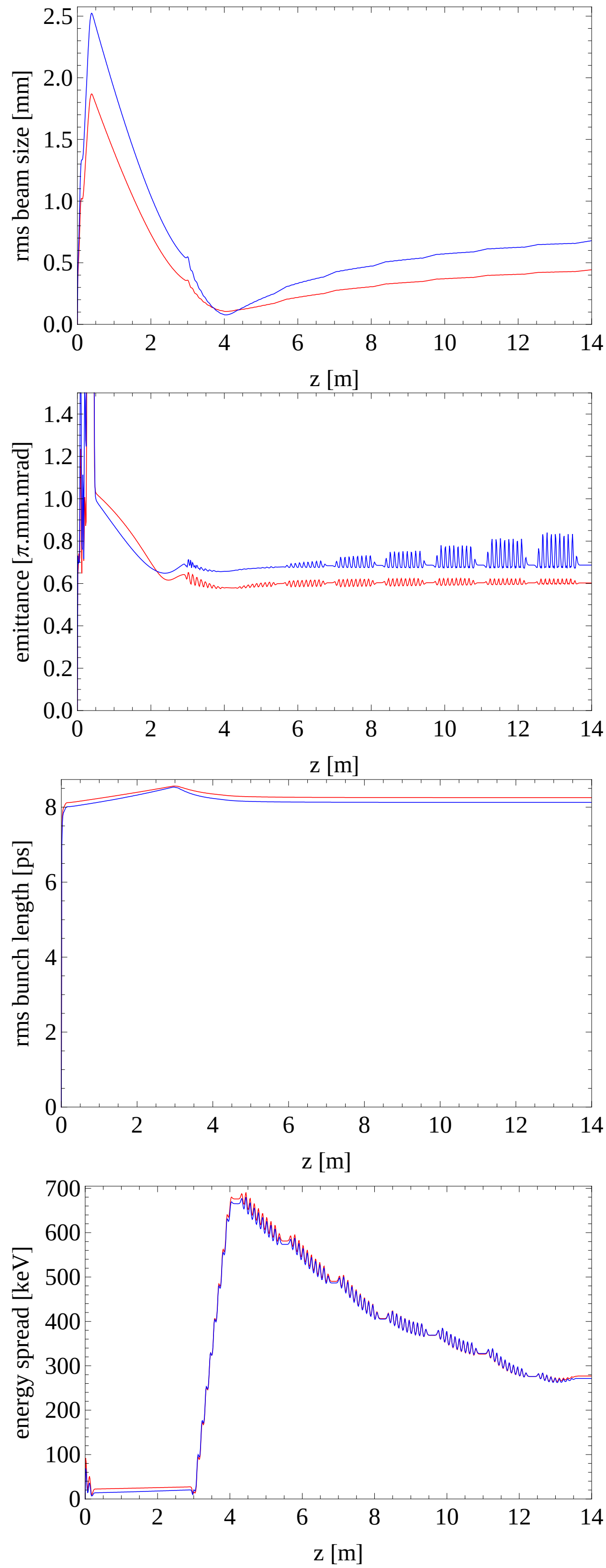

Figure 3: Evolution of beam parameters in the injector with gun peak fields of 50 MV/m (red) and 40 MV/m (blue).

Table 1: Beam Parameters at the Exit of the Injector for Gun Peak Fields of (A) 50 MV/m and (B) 40 MV/m

Parameter	Units	A	B
RMS projected emit	mm mrad	0.602	0.687
Average slice emit.	mm mrad	0.302	0.387
Full bunch length	ps	35.2	33.7
RMS bunch length	ps	8.26	8.13
RMS longitudinal emit.	keV mm	686	662
RMS energy spread	keV	277	272
Average kinetic energy	MeV	129.7	129.0

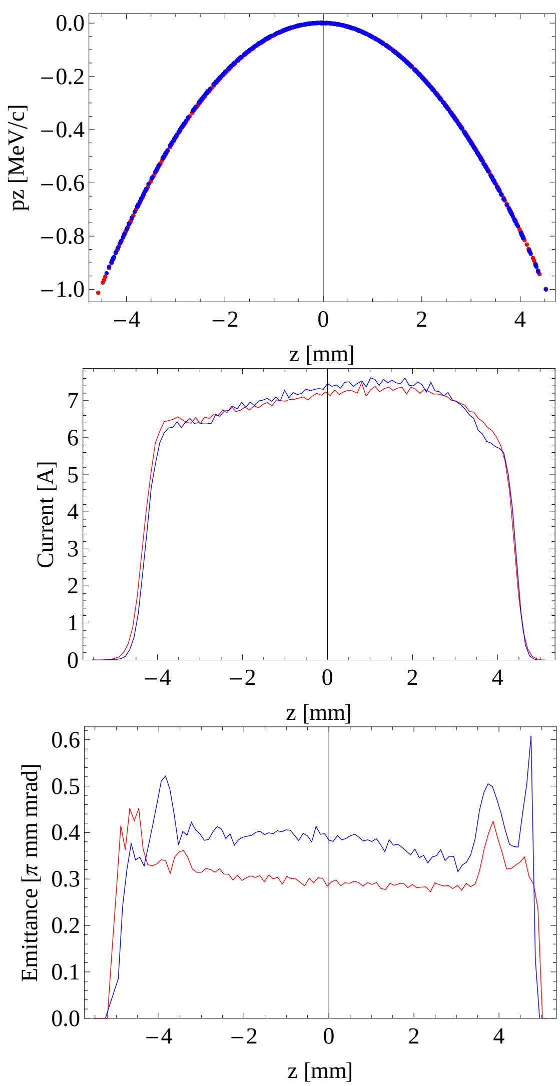

Figure 4: Bunch properties for the injector at the exit of the first linac module, with gun peak fields of 50 MV/m (red) and 40 MV/m (blue).

SUMMARY

A 1½-cell superconducting L-band gun, based on TESLA shape cavities, is capable of producing a beam suitable for NLS, at a high repetition rate, and with slice emittance similar to that of the normal-conducting low repetition rate design. To keep the emittance this low, the bunch length has to be longer, over 8 ps rms. If the gun would not be able to operate at the high peak fields of 50 MV/m, reduced operation at 40 MV/m results in a bunch with similar properties but an increase in slice emittance from 0.3 to 0.39 mm mrad. Further tracking through the NLS single-pass linac design and both SASE and seeded FEL simulations has been carried out for the 50 MV/m case, and has shown similar performance to the normal conducting L-band injector [10].

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