NEW PREINJECTOR FOR THE ESRF BOOSTER

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Abstract

A new pre-injector of the 200 MeV linac is under manufacture at the ESRF. Two operation modes are foreseen, a short pulse of 1ns-1nC and a long pulse of 1µs-10nC. The new triode type thermoionic 90 Kev gun has been characterized experimentally. The transverse and longitudinal phase space measurements are compared with simulations. The design and the expected performance of the final set-up which includes vertical deflecting plates, pre-bunching and bunching sections will be presented.

INTRODUCTION

The cathodes currently used for the ESRF electron gun are not produced any more, which triggered the design of a new gun based on the EIMAC Y-845 cathode. For this new design, a few upgrades are foreseen such as the fast chopper used for cleaning purposes. The layout of the new pre-injector is presented in Figure 1. A test bench has been implemented to perform measurements on the beam up to the second lens following the gun. We will present these measurements as well as tracking simulations done using the GPT software [2]. The expected performances for both operation modes will be presented, considering both transverse and longitudinal dynamics. The most challenging feature being the implementation of the fast deflecting plates system, the study of this device will be covered.

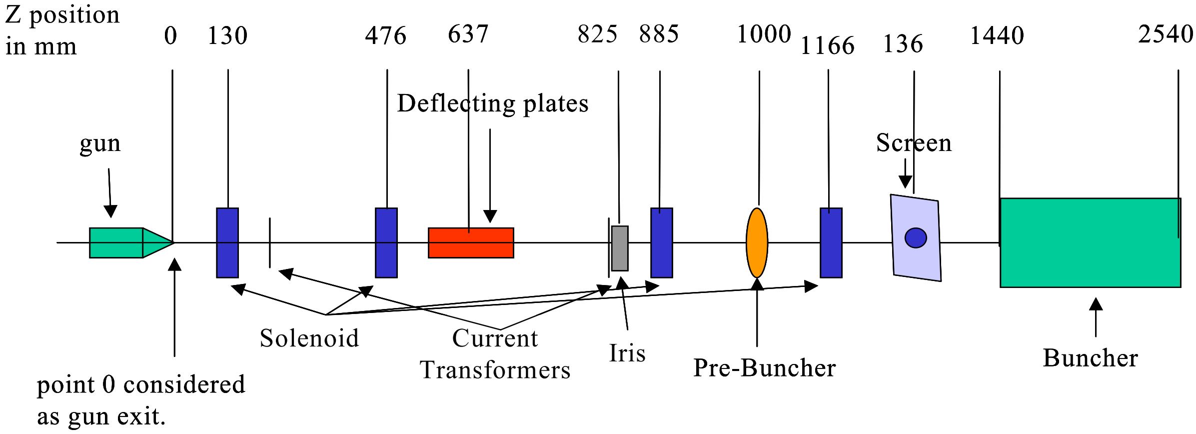

Figure 1: Final layout for the ESRF new pre-injector

TRANSVERSE STUDIES

Measurement set-up

The experimental layout consists of the gun directly followed by a lens, and finally a scintillating screen imaged on a CCD camera. Transverse beam measurements were done using a longitudinally uniform beam of a few µs and varying the gun current from 4 to 400mA. They consist of measuring the beam size versus focussing strength of the lens for a specified beam current. The focussing is changed by acting on the current injected in the solenoid lens. This type of measurement has already been performed a few years ago by the ESRF team [1].

Results and comparison with simulations

Comparison of measured curve and simulation is given in figure 2. The correlation is poor and it became obvious that we will not have a good model of the gun emission without carefully studying the emission process of the cathode. This study would have been complex and costly in terms of time spent. Another option is to use the measurements at different currents to elaborate a model of particle distribution versus current at the gun exit, in order to divert the complex processes of emission and first acceleration. Simulation can then start at the gun exit.

At a specified current, the beam size versus focusing current is recorded on the screen. It then becomes possible, using the Kapchinsky and Vladimirsky (K-V) equation, to derive three parameters defining the transverse distribution at the gun exit: the emittance, envelope divergence and the beam radius [1]. This derivation is valid for a uniform beam and no acceleration sections between the gun exit and the measurement point. The resulting curve of rms normalized emittance versus current at gun exit is given in figure 3 for two different cathodes.

The difference can be explained by the observed different emission patterns of the emitting surfaces. The current dependence is still the same for both cathodes.

Transverse phase space simulation

Simulations were then restricted to a domain where beam dynamics are easier to handle. It was indeed possible to accurately predict the beam size following the second lens validating our simulation model.

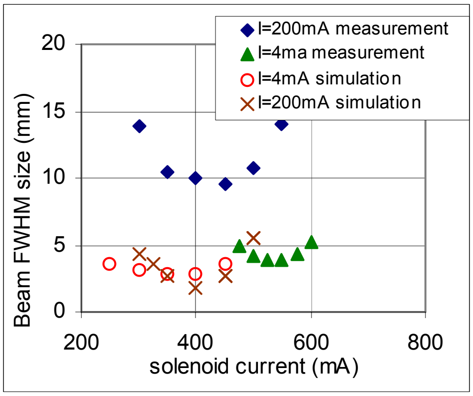

Figure 2: Comparison between simulation and experiment for beam radius versus focussing current at the gun exit. The correlation is very bad showing the irrelevance of the gun emission model used for simulation.

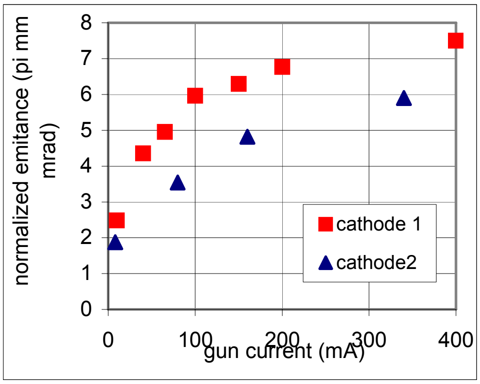

Figure 3: Reconstruction of the emittance versus gun current for two different cathodes. Curves are obtained by fitting Beam size measurements with the K-V equation.

The beam size blow up is compensated along the path by the four focussing coils. The emittance stays constant in this section for the 1µs 10nC beam. Once it enters the buncher, the beam will experience non-linear transverse fields, which will spoil the emittance. This effect is enhanced by the time of flight difference for particles entering the buncher with different longitudinal phases. This emittance growth depends only on the beam size at the buncher entrance. It is well described in the PhD thesis of Mary Beth James on the SLAC injector [3]. For the short pulse mode, because the longitudinal distribution is not uniform, the space charge defocusing effect depends on the longitudinal position, leading to an emittance increase even in the drift sections. This effect is visible on the simulations. It follows that emittance at the buncher exit strongly depends on the beam type. Careful tuning leads to a value of 15 πmm mrad for the long pulse mode and 35 πmm mrad for the short pulse mode. Nevertheless, these values are low enough to allow good capture in the booster

LONGITUDINAL STUDIES

The tracking code allows a description of the longitudinal dynamics. After exiting the gun, a pre-bunching cavity induces an energy modulation of ±10KeV along the 90KeV beam, leading to a velocity modulation and bunching. If the Buncher entrance is located where the bunching is at its maximum, the capture of the buncher will be optimum. Bunching is best if the ratio between natural energy dispersion and pre-buncher modulation is high. It implies strong modulation and short prebuncher-buncher distance. But at some point the capture process in the buncher is no longer limited by the longitudinal phase extension of the beam, but by it's energy dispersion. The best trend between these two effects leads to a prebuncher-buncher spacing of about 30-35cm considering the above modulation and our 22 cells standing wave buncher working in the π/2 mode with a peak field of 25Mv/m. Unfortunately the present design requires us to insert a lens, screen, valve and a bellow in-between the pre-buncher and the buncher, forcing us to lengthen this section up to 44cm.

For the long pulse mode, The percentage of captured particles is then about 70%, 52% being captured within 10Deg of phase.

For the short pulse mode, the space charge force due to high peak current induces some energy dispersion and spoils the pre bunching efficiency. The capture lowers to 55% with only 35% within 10Deg of phase. At the buncher exit, particles have energy of 15MeV. The percentage of particles captured with an energy deviation of less than ±1% is for the long/short pulse mode equal to 62/47%.

Figure 4 is a GPT plot showing the bunching process.

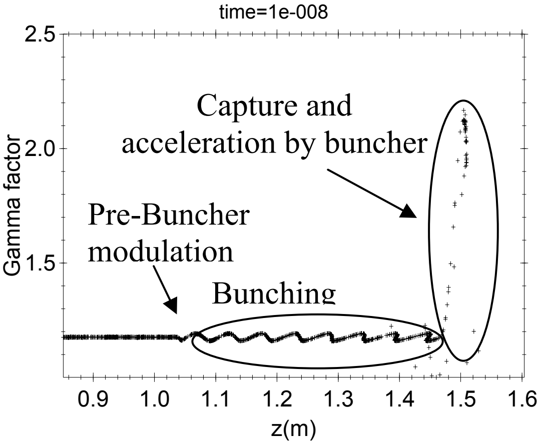

Figure 4: γ-z graph showing the bunching and capture process for a continuous low current beam.

CLEANING SYSTEM

The new pre-injector will be equipped with a cleaning system inserted between the second and third lens. It is composed of fast deflecting plates followed by an iris. Top-up operation is foreseen at the ESRF making it mandatory to clean parasitic bunches before injecting a beam with specified time structure into the storage ring. The purity required is of the order of 10^{-8}. The cleaning process in the booster is at the limit of this performance triggering the necessity for cleaning in the Linac. The system works as follows:

Before and after the main bunch arrives, the parasitic beam is deflected by a DC field and hits the iris. When the 1ns (2σ) main bunch is triggered, the DC deflection is compensated by a pulse propagating between the deflecting electrodes, letting the main bunch pass through the iris. This wave is triggered by a KENTECK pulse generator, which produces a 2.5ns (full width) almost parabolic pulse of 700V maximum amplitude. The plates are 12cm long with a gap of 9mm.

The challenge of such device is to provide good cleaning efficiency without spoiling the main beam. Degradation of the main beam can have two sources:

- To obtain good cleaning efficiency, the Iris should be as small as possible and may interfere with the main bunch.
- The main bunch experiences no deflection on average, nevertheless, because the pulse generator does not produce a flat top, the bunch is transversally distorted resulting in an emittance increase.

Because the parasitic beam is deflected in a given direction it suffices to put in an iris that covers only 1/3 of the beam pipe cross section. The losses induced on the main bunch are then reduced by two thirds. This is only possible if there is no solenoid lens between the iris and the plates.

The study of the cleaning process had to be done in two steps. The simulation was first done up to the middle of the plates, and the final particle distribution recorded. A MATLAB program transforms this distribution by adding the relevant deflection. The new distribution is then the input for the second simulation part, between the middle of the plates and the buncher exit. The deflection is not straightforward to calculate as one has to consider a wave travelling through the plates with the speed of light (c) in the opposite direction to the beam which travels at 0.54*c. The comparison between the shape of the pulse and the deflecting field experienced by particles at different longitudinal positions is given in figure 5 for the plate geometry and pulse described above.

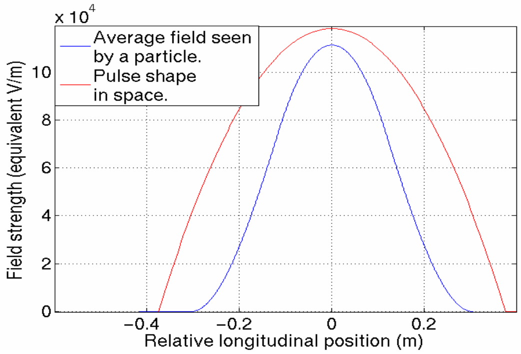

Figure 5: Comparison between the pulse shape in space and the induced average field seen by particles with respect to the bunch centroid.

Results showed a parasitic bunch transmission of less than 1%, for a main bunch (1ns rms 1nC) transmission through the iris of 85% and an emittance at the buncher exit of around 80 πmm mrad. The emittance growth due to cleaning is of more than a factor 2. Nevertheless, transmission to the booster should not be affected.

If experimental tests show strong limitations, cleaning can be optimised using a different pulse generator as is done at Spring 8 [4], with a much sharper rise time and a flat top. One could even think about cleaning only after the passage of the main bunch, where most of the impurities are located. This configuration requires the generation of a single front, much easier to achieve. A new design of electrodes is also foreseen.

CONCLUSION

Longitudinal and transverse beam dynamics have been carefully studied for the new pre-injector foreseen at the ESRF. The implementation of a test bench has been a great tool to elaborate a valid model for the particle distribution used as input in GPT simulations. Regarding the obtained results, the actual layout looks relevant for operation, even if capture for short pulse mode is reduced due to the strong peak current. The cleaning process is feasible and does not induce a too dramatic emittance growth. Nevertheless, the ratio between the main bunch transfer and parasitic bunch transfer could still be optimised if needed.

The results of the computation of all relevant parameters for both modes are given in table 1.

Table 1 : Results summary.

	1ns 1nC	1µs 10nC
Transverse Emittance with cleaning off/on (πmm mrad)	35/80	15
Capture in 10/20 deg of ϕ	35/53%	52/65%
Cleaning efficiency	>99%	
Capture in ±1% of ΔE/E	47%	62%
Transmission through the iris cleaning on.	85%	

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