INTEGRATION OF THE PHIN RF GUN INTO THE CLIC TEST FACILITY

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Abstract

CERN is a collaborator within the European PHIN project, a joint research activity for Photo injectors within the CARE program. A deliverable of this project is an rf Gun equipped with high quantum efficiency Cs_2Te cathodes and a laser to produce the nominal beam for the CLIC Test Facility (CTF3). The nominal beam for CTF3 has an average current of 3.5 A, 1.5 GHz bunch repetition frequency and a pulse length of 1.5 μs (2332 bunches) with quite tight stability requirements. In addition a phase shift of 180 deg is needed after each train of 140 ns for the special CLIC combination scheme. This rf Gun will be tested at CERN in fall 2006 and shall be integrated as a new injector into the CTF3 linac, replacing the existing injector consisting of a thermionic gun and a subharmonic bunching system.

The paper studies the optimal integration into the machine trying to optimize transverse and longitudinal phase space of the beam while respecting the numerous constraints of the existing accelerator. The presented scheme uses emittance compensation and velocity bunching to fulfil the requirements.

INTRODUCTION

One goal of the Joint Research Activity PHIN within the CARE project [1] is the demonstration of an rf photo-injector capable of delivering the nominal beam parameters for the CLIC Test Facility (CTF3 [2]). The photo-injector has to provide 2332 bunches at 1.5 GHz with 2.33 nC each. In addition the 1.4 μs long bunch train will be divided into ten 140 ns long sub-trains which have to be shifted by one 3 GHz period with respect to each other in order to be able to seperate this sub-trains with a 1.5 GHz rf deflector later on in CTF3. The photo-injector consists of a 3 GHz, 2.5 cell rf gun provided by LAL, Orsay equipped with high quantum efficiency Cs_2Te cathodes from CERN and a high power laser system developed by CCLRC, Rutherford. Details about the design and status of the photo-injector which will be tested at CERN at the end of 2006 can be found in [3, 4]. After successful testing and full characterization of the beam quality, it is envisaged to replace the existing CTF3 injector with the new photo-injector. The present injector consists of a thermionic gun, a 3 GHz buncher and a broadband sub-harmonic bunching system at 1.5 GHz which is also used to switch the phase by 180 deg for the sub-trains. The present injector provides a beam emittance of 50 μm and a bunch length of 12 ps FWHM. Satellite bunches are created in the wrong 3 GHz bucket with this sub-harmonic bunching system. The satellites have less than 10 % of the nominal bunch charge.

The photo-injector promises a better emittance, below 20μm, shorter bunches and no satellites which should improve significantly the beam quality and transmission of CTF3.

INTEGRATION CONSTRAINTS

The integration of the new photo-injector into CTF3 has to respect several constraints. The installation should change as little as possible from the existing machine to maximize the availability of the test facility. The existing tunnel is too narrow to install the rf-gun directly in front of the first accelerating structure. The rf-gun together with the large cathode loading system has to be installed at the location of the present thermionic gun. This leads to a space of about 2 m between the cathode and the first accelerating structure. This is of course a concern for the emittance preservation of the rf-gun.

Additional accelerating structures are available and could be used to fill the space and accelerate earlier but only one 3 GHz klystron and modulator unit is available to power the rf-gun and these structures. The klystron can provide 40 MW output power and the rf-gun needs 30 MW to reach its nominal gradient of 85 MV/m under full beam loading. The fully loaded CTF3 accelerating structure needs also about 30 MW to accelerate a 3.5 A beam with a gradient of 7 MV/m, therefore an rf pulse compression system with a gain of 1.5 would be needed to power the gun and an accelerating structure with only one klystron. This kind of pulse compression is already obtained using a barrel open cavity for the energy storage [5] in main LINAC of CTF3 and spares are available. The disadvantage of the pulse compression is a phase variation of up to ±10 deg over the compressed rf pulse.

Simulations have been done for two scenarios: The rf-gun only and a drift of more than 2 m to the entrance of the first accelerating structure and secondly the rf-gun with one meter drift and one more accelerating structure having a length of one meter.

RF-GUN ONLY

The rf-gun designed by LAL [4] consists of 2.5 cells at 3 GHz, with strong coupling (β = 2.9) to cope with the strong beam loading. The beam will start after 500 ns filling time so that the loaded gradient is 85 MV/m and flat over the 1.4 μs beam duration. The gun is equipped with a solenoid for emittance compensation and a backing coil to insure a vanishing magnetic field on the cathode. All simulations performed with PARMELA assume a round laser spot with σ_r =1.4 mm and a laser pulse length of σ_t =4 ps. The nominal beam current of 3.5 A was assumed for the space charge calculations. Optimizing the beam parameters after about one meter drift space resulted in a beam energy of 5.45 MeV, a bunch length of 6 ps FWHM, a well compensated emittance of 15.4 μm and a beam size of σ_r =1.2 mm, confirming the initial optimization done by LAL during the design of the rf-gun.

It was clear that these beam properties could be nicely preserved if not improved further if the first acceleration section would start after one meter of drift space. In addition this drift space could be used for diagnostics.

Adding another meter of drift space turned out to be uncritical. Without an additional focusing coil the emittance compensation is still further improved resulting in an even smaller emittance after 2 meters of 12µm as shown in figure 1. The beam size increases somewhat because of a weaker focusing. Adding additional solenoids reduces the beam size but disturbs the emittance compensation.

Therefore installing the rf-gun even with 2 meters of drift space between the gun exit and the first accelerating structure seems to be possible and does not spoil the beam quality.

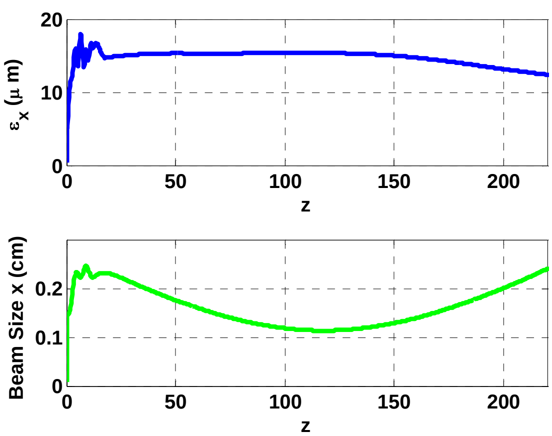

Figure 1: Horizontal emittance and beam size for the rf-gun with 2 m drift space.

RF-GUN AND ADDITIONAL ACCELERATION

An additional accelerating structure is now inserted into the simulated beam line starting 90 cm after the cathode. It is assumed that we can power this standard CTF3 accelerator with 30 MW which results in a gradient of 7 MV/m for the nominal beam [6]. The phase is tuned to be on crest for the arriving bunches. A solenoid with a field of 0.15 T is placed over the entrance of the accelerating structure. The beam is accelerated to 13.3 MeV, the energy spread resulting from the off crest operated rf-gun improved accordingly and all beam parameters are essentially preserved. The emittance increases to 14 µm compared to the case without accelerating structure as shown in figure 2. In order to provide the necessary rf power for the rf-gun and the accelerating structure a compressed rf pulse has to be used. The rf-gun needs a flat top of 2 µs to provide the 1.4 µs long bunch train. Simulations showed that the present pulse compression systems used in CTF3 can compress the nominal 5.5 µs rf pulse out of the klystron to 2 µs with a power gain of 1.5. Since the compression is done by a phase variation of the

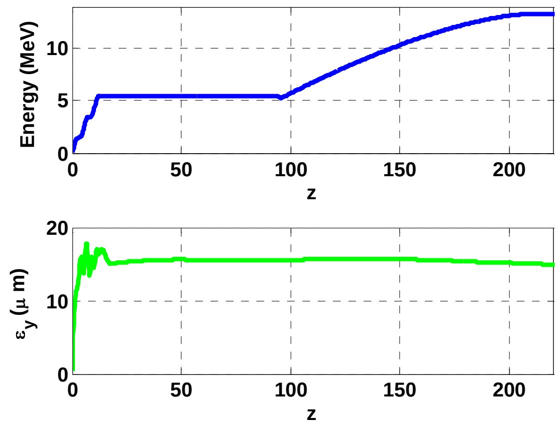

Figure 2: Beam Energy and vertical emittance for the scenario, rf-gun and one accelerating structure.

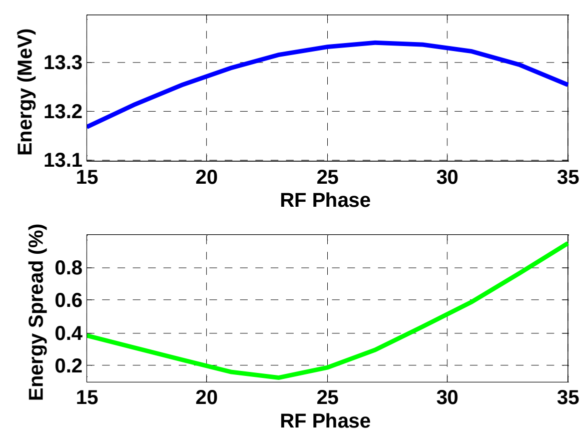

Figure 3: Variation of energy and energy spread at the end of the injector as a function of input phase.

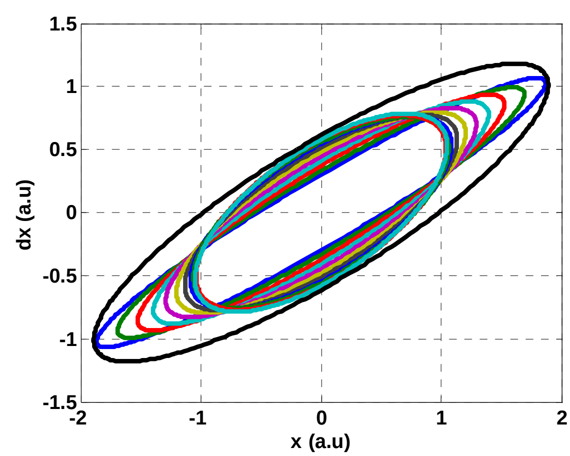

Figure 4: Phase Space ellipse for bunches at different beam phases (coloured curves) and the envelope for the whole train (black curve).

input pulse to the klystron, the compressed pulse has also a phase variation of up to ± 10 deg. The influence of this phase variation on the beam was simulated with PARMELA with a series of single bunch simulations at different phases. The variation in energy and energy spread can be seen in figure 3. Figure 4 shows phase space ellipses at the exit of the accelerating structure for the different phases. The result is a 1.8 times bigger phase space (black curve) for a bunch train with such a phase variation.

With an additional accelerating section the CTF3 beam could profit from a higher energy and a reduced energy spread from the injector at the expense of an increased emittance.

RF-GUN AND VELOCITY BUNCHING

CTF3 is used to demonstrate the CLIC drive beam feasibility but also as a source for 30 GHz power production. In this mode the bunch repetition rate is 3 GHz and the beam gets decelerated in a 30 GHz power extraction structure in the middle of the LINAC to produce 30 GHz rf power for CLIC accelerating structure testing. For this mode of operation very short bunches are needed to insure a form factor close to one at 30 GHz. In the present machine a magnetic bunch compressor after the injector is used to shorten bunches to 2 ps FWHM. This bunch compressor introduces a large energy spread and leads to an emittance growth of about 50%.

Therefore it would be attractive to use an additional accelerating structure for velocity bunching [7] to compress bunches in a smoother way. A number of simulations have been performed to study this case and it turns out that one can optimize single parameters like bunch length, energy spread or emittance growth but in general a compromise has to be found. For example as shown in figure 5 a good compromise is to phase the rf-gun 25 deg off crest and the accelerating structure at zero crossing. The emittance is preserved at this working point, with a bunch length of 2 ps FWHM but the energy spread rises to 2.8 %, which will however be reduced after further acceleration. Going

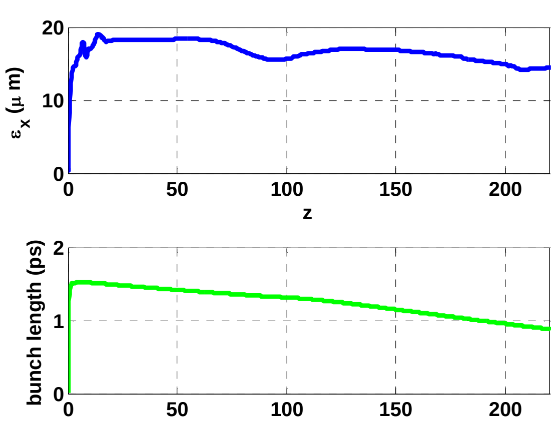

Figure 5: Horizontal emittance and bunch length (rms) for the velocity bunching case.

further off-crest in the rf-gun results in even shorter bunches, for example 1.7 ps at 30 deg but with 40 % emittance growth. By increasing the phase in the accelerating structure towards more acceleration one can trade off energy gain and improved energy spread against the bunch length. In general there is a lot of freedom to optimize individual beam parameters by changing the phases of the rf-gun and the accelerator which adds a lot of operational flexibility to CTF3. This mode offers short bunches directly from the injector, the same energy as for the present set up and the magnetic bunch compression could be suppressed which should reduce the emittance growth down stream of the injector.

CONCLUSIONS

The integration of the PHIN photo injector into CTF3 has been studied with PARMELA simulations taking into account the constraints imposed by the existing building and available hardware. It turns out that installing the rf-gun even 2 meters in front of the first accelerating structure will not result in a degradation of the beam properties and would be a straightforward implementation.

Adding one more accelerating structure would add a very attractive flexibility to the machine with the option of using this structure to bunch the beam. However this flexibility has to be paid for by a rather complex rf-system with pulse compressor and a phase variation over the pulse. This will clearly degrade somewhat the beam quality but would be still an improvement compared to the present system.

Simulations with a current of 5 A as used for the power production mode show a 20-30% higher emittance due to the higher space charge already at the exit of the rf-gun. Since the space charge is not extremely high for these beams the emittance is already pretty stable at the exit of the rf-gun at 5.4 MeV.

It seems rational to start with the installation of the rf-gun only to gain experience first and keeping the additional accelerating structure as a future upgrade path. The influence of the phase variation could then be studied experimentally with the rf-gun.

REFERENCES

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