STUDY OF A MAGNETIC CHICANE AT THE FNAL/NICADD PHOTO-INJECTOR USING REMOTE OPERATION FROM DESY

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Abstract

A magnetic chicane is installed at the FNAL/NICADD photo-injector. It enables the compression of 1 to 8 nC bunches with a total energy of 16-18 MeV. The energy-phase correlation at the entrance of the chicane is set up by adjusting the phase of a 9-cell superconducting cavity located upstream of the chicane. This paper will report measurements of beam emittance and energy spread as a function of the 9-cell phase.

1 INTRODUCTION

The FNAL/NICADD photo-injector is operated at the A0 hall of Fermilab. This photo-injector is nearly identical to the TESLA Test Facility photo-injector installed at DESY. Since January 2002, the FNAL/NICADD photo-injector can be operated remotely. This paper reports the first results obtained using a remote operation from DESY. These studies concern the beam dynamics in the magnetic chicane. The experimental results are compared with the simulation codes TraFiC^4 [1] and HOMDYN [2].

2 EXPERIMENTAL LAYOUT

The FNAL/NICADD photo-injector consists of a 1.625 cell RF gun resonating in the $TM_{010,\pi}$ mode at 1.3 GHz. The gun contains a high quantum efficiency Cs_2Te photo-cathode that is triggered by the UV light of a Nd:YLF laser. To confine the space charge dominated beam, three coils (primary, secondary, and bucking to zero the magnetic field on the cathode) installed around the gun produce a solenoidal field, and a TESLA type 9-cell superconducting cavity accelerates the beam after the gun. A magnetic chicane composed of four dipoles is installed after the 9-cell cavity to produce longitudinal compression of the beam. A quadrupole doublet and three quadrupole triplets are used to transport the beam to a spectrometer at the end of the beam line ($z\cong$11.2 m). The beam line contains several flags (mainly OTR screens) and diagnostics (bunch charge, transverse emittance, etc.). A detailed description of the photo-injector is presented in [3].

Three PC's and one web cam are used at DESY to operate the photo-injector [4] remotely. One PC controls, via ssh, the low level RF and the aquisition of beam images, which are stored at DESY. A second PC controls the elements of the beam line (magnet currents, motor positions, etc.). A third PC operates the web cam and displays an image of the beam and of the oscilloscope via a web browser.

3 CHICANE MODEL

The chicane is composed of four dipoles, which bend the beam in the vertical plane. The four dipoles are of equal strength, but they differ by the shape of their pole-tips: the two outer dipoles have trapezoid-like pole-tips and the two inner dipoles have parallelogram-like poles. A 3-D model of the chicane was made using OPERA [5]. The field predicted by OPERA is in excellent agreement with the measurements and is linear up to 5 A. OPERA predicts B_y^{max}=339 G for 1 A.

Figure 1 shows the trajectory of a 16.5 MeV electron through the chicane. With all dipoles at 2 A, the electron exits the last dipole with a large angle; upon increasing the inner dipoles to -2.25 A, the electron exits parallel. This effect is observed experimentally, and the chicane is operated with the inner dipole currents higher by 5 to 10 % than the outer ones. We think that there is a cross-talk in the inner magnets that was not taken into account in the original design.

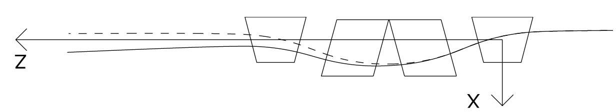

Figure 1: OPERA-3D particle tracking in the bunch compressor for 2 A in the outer dipoles and -2 A (solid line) or -2.25 A (dashed line) in the inner dipoles.

The pole-tips of the chicane were designed to partially compensate the horizontal focussing of the chicane. The transverse focussing of the chicane is shown in Figure 2, which gives the measured transverse size of a 1 nC beam at z=6.52 m as a function of the current in the inner dipoles of the chicane. At the entrance of the chicane, the beam spot was symmetric with a size of $\sim$1mm RMS.

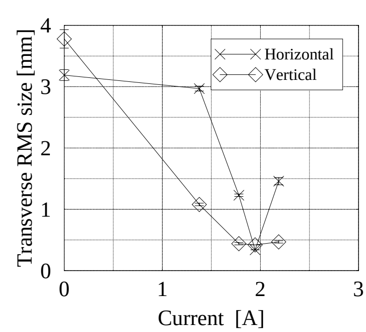

Figure 2: Chicane transverse focussing for a 1 nC beam.

4 EXPERIMENTAL RESULTS

For all the measurements presented in this section, the transverse size of the laser pulse was measured at σ=0.85 mm and the longitudinal distribution at 10 ps FWHM. The 9-cell cavity was operated with a useful pulse length of 100 μs and an accelerating field of 12 MV/m. The RF gun pulse length was between 30 to 50 μs, the repetition rate was 1 Hz and a train of 10 to 30 bunches was used. In the following, Q is the charge per bunch, E_0 is the peak RF field at the cathode, ϕ_0 is the launch phase and B_z^{max} is the maximum axial field of the solenoids.

4.1 Energy and Energy Spread

Figures 3 shows the evolution of the energy and energy spread as a function of the 9-cell cavity phase for a compressed and uncompressed beam. For these measurements: Q=1 nC, E_0=35 MV/m, ϕ_0=40° and B_z^{max}=1175.7 G. For the uncompressed measurements, the chicane was turned off and degaussed. For the compressed case, the current in the chicane was 1.387 A for the outer dipoles and -1.49 A for the inner ones.

We can see in Figure 3a that the energy of a compressed beam is slightly lower than the energy of an uncompressed one. The measurement with the uncompressed beam was done one week later than the measurement with the compressed one. We think that the difference in energy is due to a lower setting of the field of the RF gun and/or 9-cell cavity for the uncompressed beam. As expected, HOMDYN does not predict any change in the energy of a compressed beam, but it predicts an energy ~0.5 MeV lower than measured. We suspect the calibration of the spectrometer magnet to be responsible for this disagreement. A new calibration of the spectrometer is currently being done at Fermilab.

While decreasing the 9-cell cavity phase, the 1 nC compressed beam showed an energy modulation. Figure 4a shows the case of 35° off-crest (close to the maximum compression) with E_0=40 MV/m. We believe this energy modulation is a signature of the bunch self-interaction via Coherente Synchrotron Radiation (CSR) [6] as the beam travels through the chicane. Because of the curved trajectory in the chicane, radiation emitted from the tail of

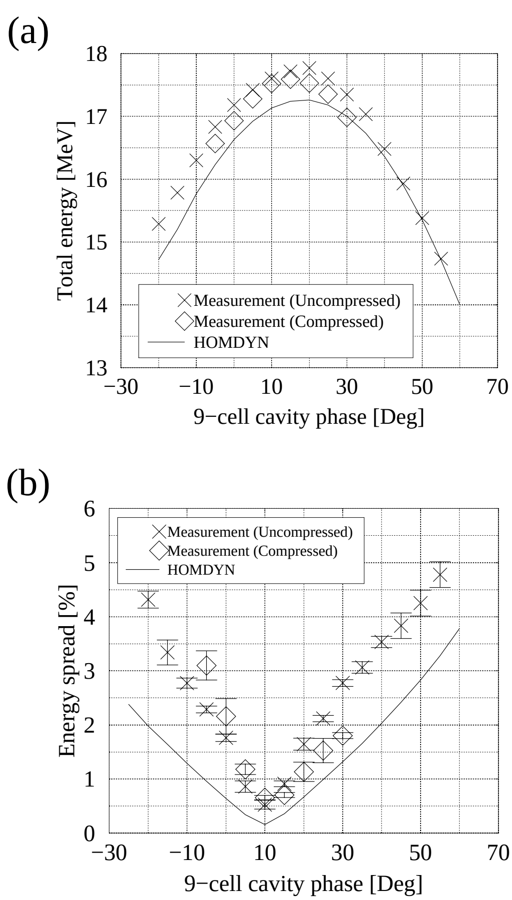

Figure 3: (a) Energy and (b) Energy spread of a compressed and uncompressed 1 nC beam.

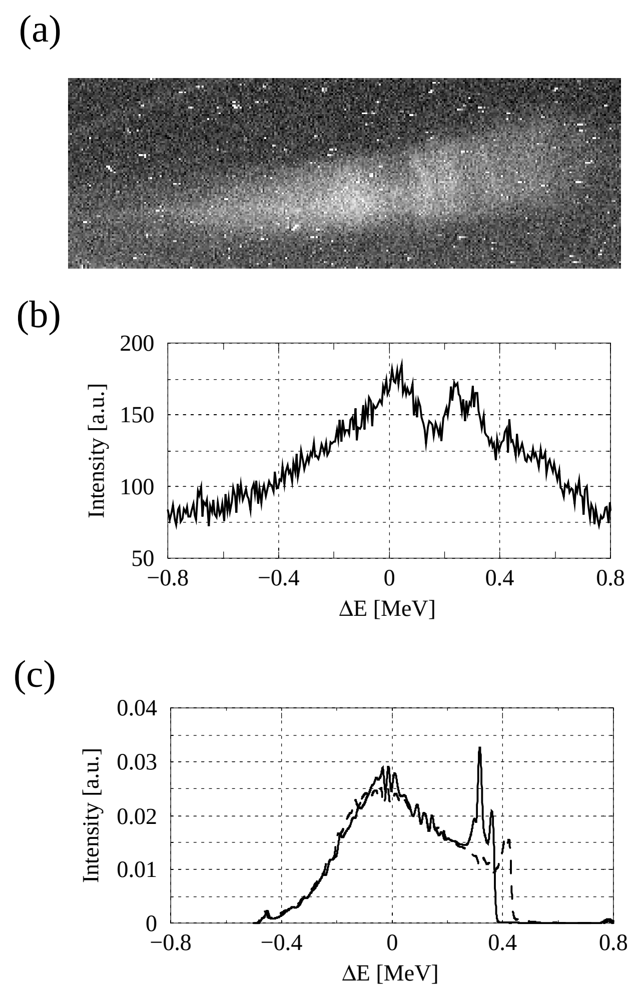

Figure 4: (a) Energy profile of a 1 nC compressed beam, (b) projection and (c) TraFiC[4] simulation for a chicane bending angle of 20° (solid line) and 18° (dashed line).

the bunch at a retarded time catches up with the head of the bunch thereby, producing a position-dependent energy modulation along the bunch. The energy modulation can be seen in Figures 4a and 4b where three peaks are visible: one peak close to the tail of the bunch, and two close to the head. The corresponding TraFiC^4 simulation shown in Figure 4c supports our observation: for a bending angle in the chicane of 20°, three peaks are visible one close to the tail and two close to the head. Figure 4c shows also that the energy modulation is sensitive to the bending angle of the chicane, since TraFiC^4 predicts that a decrease of 2° in this parameter does not allow to observe the energy modulation anymore. The differences between Figures 4b and 4c may also be due to emittance-induced smoothing because of the betatron function at the screen. The profile generated by TraFiC^4 is an energy projection only, i.e it does not include transverse effects. The TraFiC^4 simulation shows also a loss in the total bunch energy of 8 keV due to CSR effects. Thus the CSR effects cannot be responsible for the difference of energy that appears in Figure 3a between the compressed and uncompressed beam.

Figure 3b shows a variation of the energy spread for the compressed and uncompressed beam while dephasing the 9-cell cavity. The energy spread is mainly correlated to the RF. It is interesting to notice that for the compressed beam when the 9-cell cavity phase is lower than the one giving the minimum energy spread then the length of the beam decreases (see Fig. 5) implying an increase of the charge density and space charge which leads to an increase of the energy spread. HOMDYN predicts values of the energy-spread lower than those measured. This is probably due to the fact that the beta function was not minimized at the point of measurement of the energy spread. Detailed descriptions of the measurement of the energy and energy spread at the FNAL/NICADD photo-injector can be found in [3].

4.2 Bunch Length

Figure 5 shows the compression of a 2 nC beam. For this experiment we used E_0=40 MV/m, ϕ_0=40° and B_z^{max}= 1320.8 G. The bunch length was measured at z=6.52 m using a 2 ps Hamamatsu streak camera. HOMDYN shows a good agreement with the experimental results. The current in the outer dipoles of the chicane was 1.271 A.

4.3 Transverse emittance

The emittance measurements were done at z=9.63 m using an emittance slits probe. The beamlets passing through the slits are viewed with an OTR screen located at a distance d=380 mm from the slits. A description of the slits probe and details about the data reduction technique can be found in [3]. The charge was set to Q=1 nC and the other parameters to E_0=40 MV/m, ϕ_0=40° and B_z^{max}= 1320.8 G. For the chicane turned off and degaussed, we measured ϵ_x=10.8±1.7 mm·mrad and ϵ_y=10.4±1.8 mm·mrad. For a compressed beam (outer dipoles of the chicane set at 1.271 A and 9-cell phase decreased by 25° w.r.t the minimum energy spread) we measured ϵ_x=9.3±0.9 mm·mrad and ϵ_y=12.5±1.4 mm·mrad. Thus, there is a small increase in the emittance in the plane of deflection of the chicane. HOMDYN predicts a transverse emittance of ∼1 mm·mrad for an uncompressed beam and twice larger for a compressed one. The disagreement in the emittance between HOMDYN and the experiment for a low charge beam was already observed in [3]. Work is in progress to understand the reasons for this disagreement. No TraFiC^4 simulation have been done for these measurements.

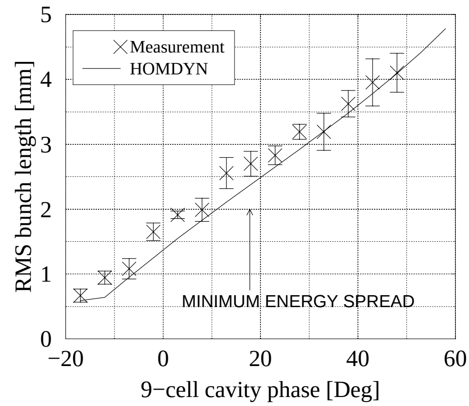

Figure 5: Compression of a 2 nC beam.

5 CONCLUSION

The chicane presented in this paper compresses the beam by a factor of 5 to 6. Energy-modulation of a compressed beam has been observed and we believe this modulation is due to CSR effects. The emittance of a compressed beam has been measured and did not present a significant increase compared to the emittance of an uncompressed beam. More measurements of the emittance of a compressed beam must be done to confirm this result.

The remote operation of the FNAL/NICADD photo-injector works very well. The photo-injector is also operated from LBNL for flat beam studies [7].

6 REFERENCES

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