A Magnetic compressor for a 5 MeV Electron Beam

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Abstract

The efficiency of an undulator to produce a coherent electromagnetic beam depends strongly on the quality of the electron beam and of its density. The desired charge per bunch requires a rather long emission at the photocathode, typically 200 ps for charges of tens of nC.

This paper deals with a magnetic compressor working in the 4-5 MeV range with the objective to compress a 200 ps long bunch into 70 ps long or less. A second compression can be made at 20 MeV.

The optical system is a 4-magnet/α-type system, but with a 360° total deviation. In fact, the first and the forth magnets are the same. The crossing point is in the center of it.

As in all transport systems, it is extremely important to have a very good correction of geometric but also of chromatic aberrations with a large bandwidth capacity. Then, the second problem is space charge because of the relatively low energy of operation.

The TRANSPORT and TRACE 3-D codes are used for optimization up to the second order and comparison is made with the results of a step by step integration code with evaluation of the space charge effect.

I - INTRODUCTION

To get good quality and high charge bunches for FEL operation, two approaches are available, either with short pulses high gradient and high frequency, or with longer pulses at lower frequency. In this last case, it is necessary to compress the bunches before entering the wiggler.

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The most efficient compression scheme seems to be two stages reducing the length of the bunch by a factor of three at each time, the first one at 5 MeV, the second at 20 MeV. Such a scheme is presented in the context of the free-electron laser ELSA.

The beam is accelerated from a photocathode in two cavities at 144 MHz. The bunch is compressed from 200 ps to 60 ps long in a 360 degrees loop, then accelerated to 20 MeV in cavities at 433 MHz before a second compression to 20 ps long in a 180 degree-turn.

II - FITTING PROCEDURE

Once the general feature has been chosen by geometric considerations and the step by step computation code without space charge, the fine adjustment has been realised by the fitting procedure of the program TRANSPORT [1] up to the second order terms included. It is not possible in such an optical device to eliminate all the second order terms contributing to the emittance growth. So the result of the second order optimization depends on the choice of the beam ellipses at the entry of the turn.

III - SPACE-CHARGE EFFECT

Along the turn, a monoenergetic parallel beam is strongly distorded, and presents singular points.

Still in order to take into account the space-charge forces we use the following simplification : we suppose that the beam at the entrance of the turn is an uniformly charged ellipsoid, and remains so around the whole turn ; however its aspect ratio can change in great proportion. With such an assumption, and neglecting the relative motion of the electrons the components of the field at a point in the rest frame of the bunch is proportional to its coordinates, once the coordinates axes are the ellipsoid axes [2]. The field is evaluated and applied in this frame taking into account the boost between the laboratory frame and the rest frame of the beam. Such a computation is valid at least for the first order terms.

Taking the result of the fit obtained by the program TRANSPORT, we evaluate the space charge effect with the help of the TRACE 3-D code [3].

In the step by step code -AIMANT 45-, space charge is introduced through a different assumption : the bunch is supposed to be parallelipipedic at the entrance, then at each step, a parallelepiped envelope is adjusted to the bunch although with the space charge forces are computed along the central line of each face as if the charge density was remaining uniform in the bunch.

To reduce the emittance growth and to keep the beam envelop inside the vacuum pipe, gradients are foreseen for the two central magnets of the 360 degrees loop and two small quadrupoles are installed in the 180 degrees turn. A set of three quadrupoles before each compression loop adjusts the beam ellipses according to the bunch charge.

The general result is that the blow-up of the beam due to space charge can be corrected by adding a gradient in the magnets 2 and 3 : a negative gradient index in magnet 2 and a positive one of almost the same magnitude in magnet 3. This introduces some chromatism defects. Still the growth of the horizontal emittance is strongly reduced.

We consider a bunch at 5 MeV, 200 µs, 8 mm in diameter and transverse emittances of 2 π.mm.mrad at the entry. With 20 nC charge the horizontal emittance is increased by a factor 4 without gradient and by 1,25 with two gradients indices respectively -0,061 and 0,056 for magnets 2 and 3. In that case, the vertical beam envelope increases by a factor 3 between the entrace and the middle of the loop, which requires a magnet gap of the order of 30 mm.

It is likely that the effect of the wake field due to the narrow beam pipe is negligeable in this case. That has still to be confirmed with the help of a program like TBCI-SF in three dimensions.

IV - REFERENCES

[1] K.L. Brown et al., Transport : a computer program for designing charged particle beam transport systems, CERN 80 - 04, March 1980.

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[3] K.R. Crandall and R.S. Mills, Trace 3-D documentation, L.A.N.L., September 13, 1985.

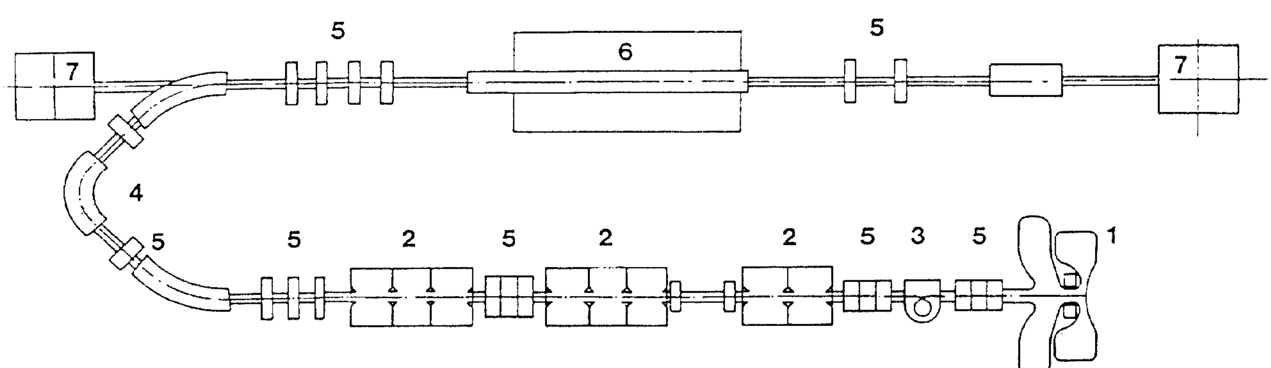

Fig. 1. Layout of the future ELSA experiment, showing the location of the two compression stages.

1 - 144 MHz cavities
2 - 433 MHz cavity
3 - 360° - loop
4 - 180° - turn
5 - quadrupoles
6 - ondulator
7 - mirror

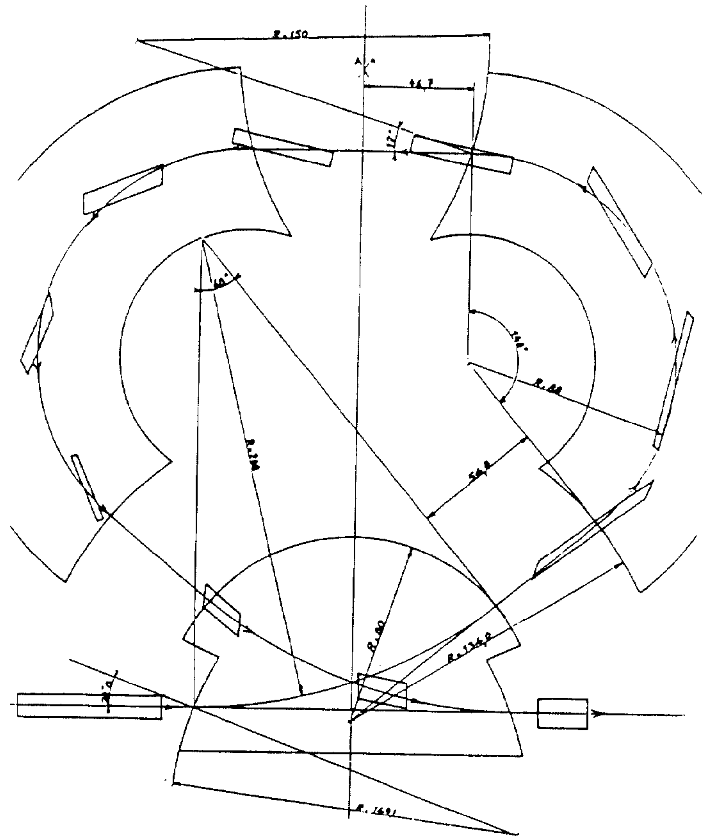

Fig.2. Magnetic compression of the bunch in a 360° turn. This figure shows the drastic change in shape of the bunch as it proceeds through the magnets.

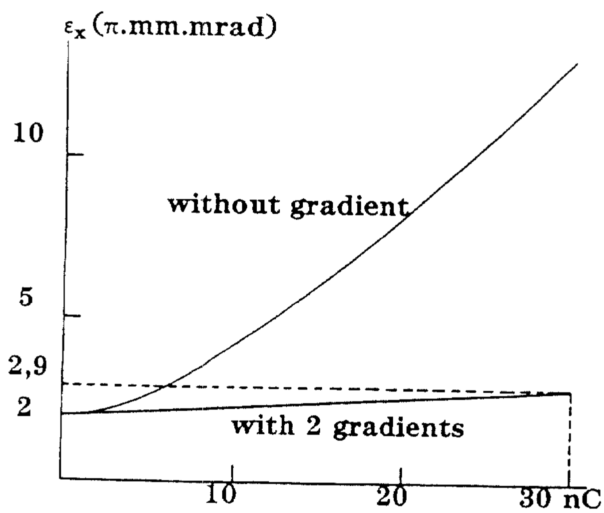

Fig. 3. Horizontal emittance as a function of the bunch charge.

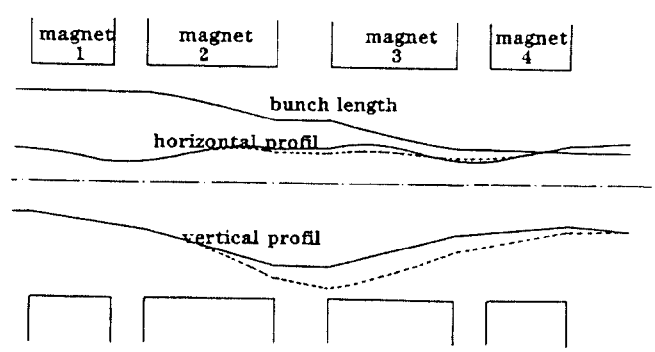

Fig. 4. Beam profiles for a 20 nC bunch. The continuous lines are without gradient, the dashed lines are with two gradients

This figure shows that with a very careful choice of the gradients in magnets 2 and 3, the apparent emittance blow-up due to space charge, can be reduced down to acceptable values, up to more than 30 nanocoulombs total charge (within the limits of linear approximation of space charge forces).