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Beam Transport of Ultra-Short Electron Bunches

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ABSTRACT: Focussing of ultra-short electron bunches from a wakefield accelerator into an undulator requires particular attention to be paid to the emittance, electron bunch duration and energy spread. We present a design of a focussing system for the ALPHA-X transport section, which consists of a triplet of permanent magnet quadrupoles. The design has been carried out using the GPT (General Particle Tracer) code [1], which considers the space charge effects and allows us to obtain a realistic estimate of the electron beam properties inside the undulator and therefore the properties of synchrotron emission and self-amplified spontaneous free-electron laser action.

The first design

The primary transport section is the segment between the end of the plasma channel and the start of the undulator. This section transports electron bunches produced by a plasma wakefield accelerator usually using magnetic devices. A synchrotron radiation source or free-electron laser requires the electron bunches to be focused into an undulator for a wide range of energies. In particular, the energies expected range is from 50MeV to 1GeV.

The primary transport section of the ALPHA-X beam line has been modeled using the GPT (General Particle Tracer) code [1]. GPT is a software package developed to study 3D charged particle dynamics in electromagnetic fields. Using this code, it is possible to create an electron bunch and propagate it through all kind of devices and structures.

In the first stage, the transport section was assumed to be 1 m and an initial design was achieved using a triplet of permanent quadrupole magnets placed after the plasma channel [2]. All the quadrupoles were assumed to have a strength S of 500 T/m, while the lengths of the quads were assumed to be L for the side quads and L' ≈ 2L for the central quad. This type of triplet focuses the beam to a specific point, acting as a zoom lens.

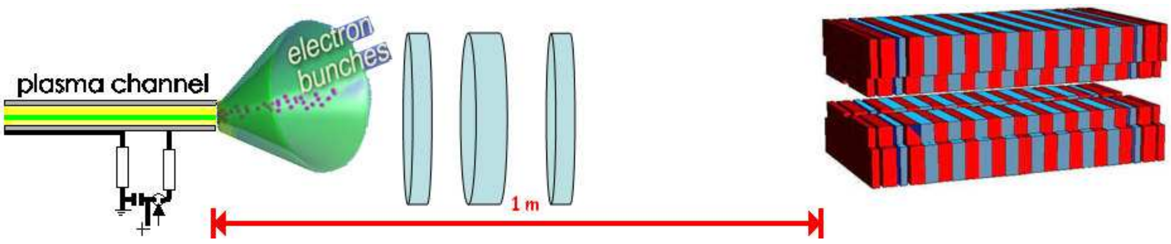

Figure 1: a schematic of the primary transport section

The quadrupoles have been modeled using the CST Studio Suite by splitting a cylinder into 12 sectors magnetized with a magnetic field of 1.2 T. The results show that it is possible to produce a focal point at the centre of the undulator.

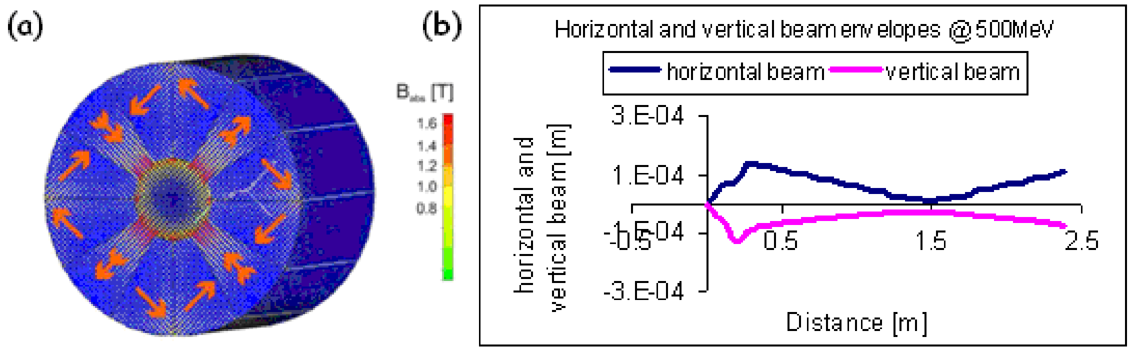

Figure 2: (a) Magnetization of a quadrupole and (b) development of the horizontal and vertical beam at 500MeV

One of the main goals is to focus the beam at the centre of the undulator for a wide range of energies in the range of 50 - 1000 MeV.

Since the beam energy divergence after the plasma channel strongly depends on the energy, the quadrupole magnets should move to provide matched transport for every energy. To achieve this, many simulations have been carried out using the GPT code to find the best position of the magnets in the transport section while producing a focus at the centre of the undulator. For these simulations, three different triplets of quadrupoles are used and the emittance has been assumed to be fixed at $\varepsilon_n = 1\pi$ mm mrad.

The final design

In this stage, we considered the real ALPHA-X beam transport section, including the dynamic quadrupole magnets already installed in the beam line. For this reason, the beam transport section is assumed to be 3 m in this segment, consistent with the ALPHA-X transport section. This implies that the focal point should be at 4 m.

For this design, the goal is to use the electro-magnetic devices in addition to the permanent magnet to reduce the permanent magnet lens movements. Moreover, the new design increases the bunch length slightly (fig.3).

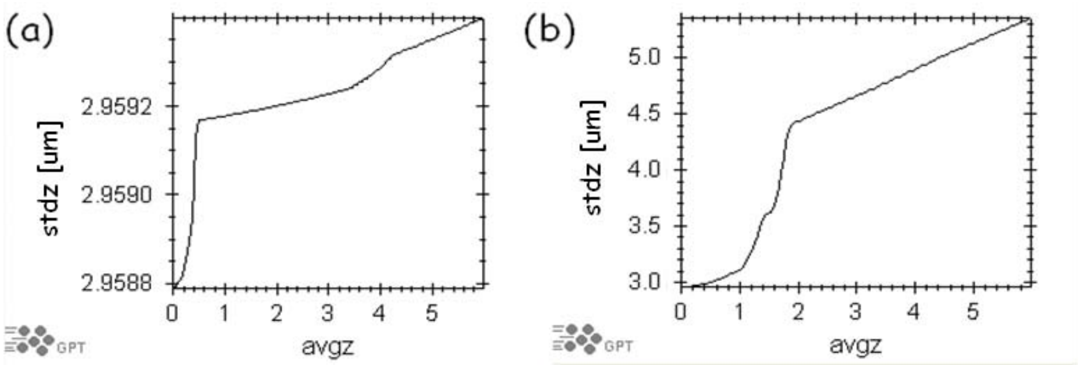

Figure 3: Bunch length using (a) permanent magnets and (b) permanent and electro-magnetic magnets

The last step is to consider also the undulator as a real component, because the ALPHA-X slotted pole undulator, which is part of the amplifying medium, focuses and guides the electron bunches, particularly at low energies.

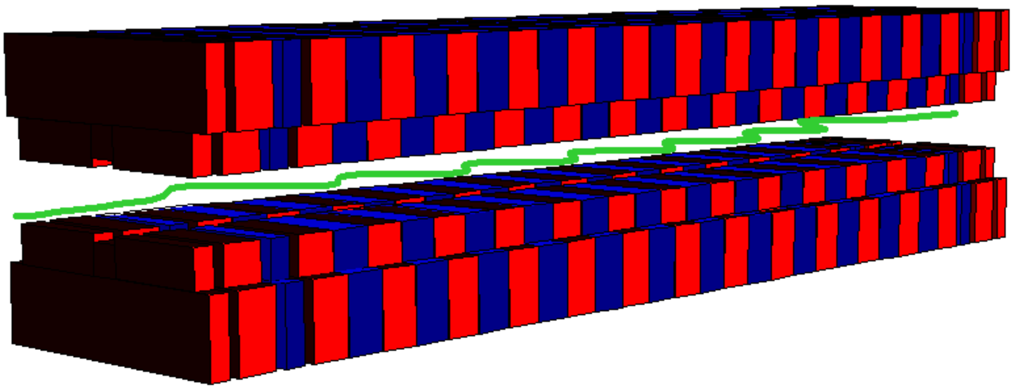

Fig. 4: the ALPHA-X undulator

In the case of the permanent magnet quadrupoles, the actual magnetic field of the undulator was given as input to the GPT code. Many simulations have been carried out to demonstrate the effectiveness of the design. The results from the GPT code are shown in fig. 5. It can be seen that the undulator focuses the beam at low energies, while at medium and high energy, it has little effect on the beam.

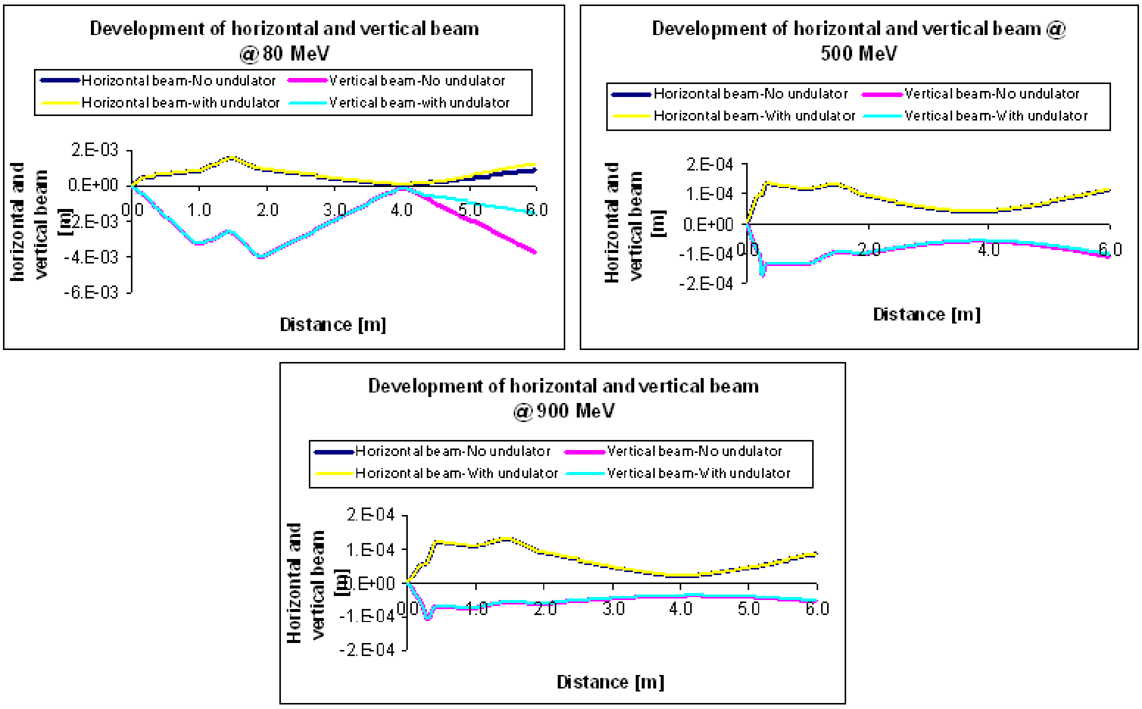

Fig. 5: Development of horizontal and vertical beam envelopes at low (80 MeV), medium (500 MeV) and high (900 MeV) energies, respectively.

Latest result and future developments

Using the magnetic fields of all the magnetic devices that will make up the ALPHA-X beam transport system, we have achieved a focal spot at the centre of the undulator of a few microns.

In the future, the magnet positions will be iterated to obtain the best solid angle for matching the beam entering the undulator.

References

[1]. S. B. van der Geer and M. J. de Loos, General Particle Tracer code: design, implementation and application (2001)

[2]. T. Eichner, F. Grüner, S. Becker, M. Funchs, D. Habs, R. Weingartner, U. Shramm, H. Backe, P. Kunz and W. Lauth, Physical Review Special Topics – Accelerators and Beams 10, 082401 (2007)