STATUS OF THE ELSA-2 PROJECT

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Abstract

The ELSA facility [1] was designed in the 80's as a test bench for high-power FEL physics and technology. It is now mainly used as a high brightness 1-20 MeV electron source or as a picosecond hard X-ray source. In response to this change in the user's needs, dedicated beamlines are under construction in a new experimental area. The main features of the project will be reviewed: the linac energy upgrade up to 40 MeV, a new design for the magnetic buncher using two alpha magnets (with a unit field index), and plans for a Thomson source. This source in the 1-50 keV range will use the intrinsically synchronous drive laser of the photoinjector.

1 OVERVIEW OF THE BEAMLINES

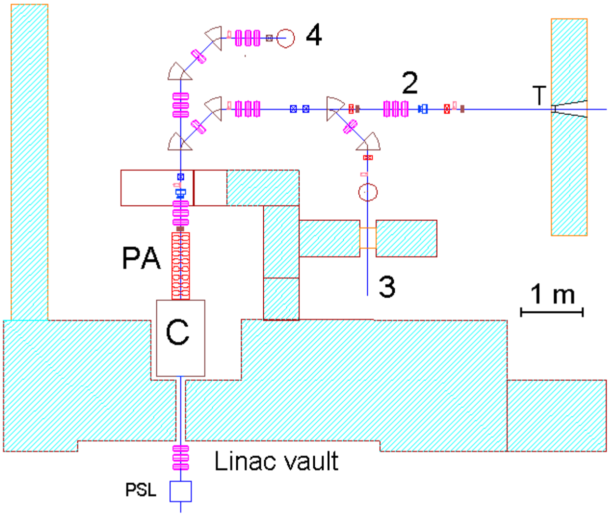

Figure 1: design of the three beamlines under construction. The ELSA beam comes from the bottom of the figure (accelerator vault).
C=bunch compressor (see fig.2), PA=1300 MHz Post-Accelerator, PSL=phase space linearizer, T=target

The ELSA accelerator vault was originally designed to house the linac and the FEL resonator, in a compact setup, which leaves only a few square meters for the present core application of the beam: the generation of picosecond hard or soft X-rays. In response to this demand, we decided to build a new 80 m^2 experimental area with dedicated beamlines (fig. 1). The new building is now almost ready and we plan to begin the installation of the beamlines this fall.

A hole, bored in the accelerator vault, will bring the electron beam into the new building. The first component of the new lines is a magnetic buncher (C on fig. 1, zoomed on fig. 2 and detailed in next section). Its momentum compaction term is 3 ns. We took advantage of the 600 mm lower floor level of the new building to put the deviation in a vertical plane. This configuration saves space at the cost of a slightly more complicated holder.

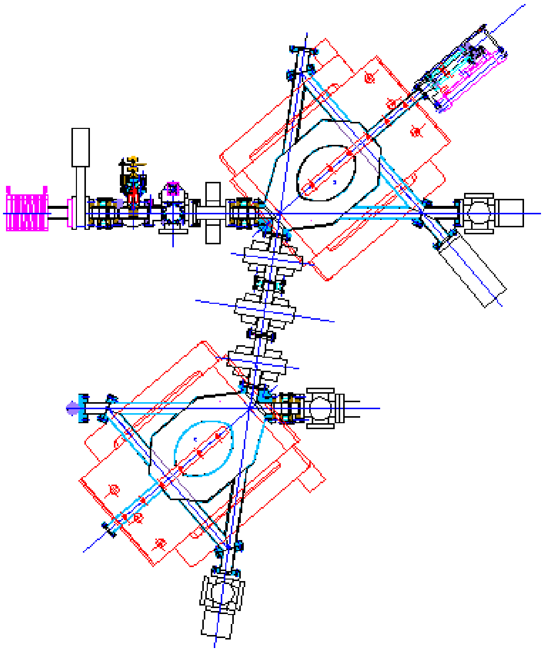

Fig. 2: Side view of the compressor with the 2 alpha dipoles, the 3 quadrupoles and the associated diagnostics (BPM, current monitor, OTR screens, Faraday cups and alignment mirrors).

The compressed bunches will be 10 to 20 ps long. This duration is suitable for injection into a 1 m long 1300 MHz accelerating section (PA on fig. 1). The rf source will be taken from a recently decommissioned linac. The expected energy gain is 20 MeV.

This energy upgrade has a strong impact on the intensity of secondary beams (for example, photoneutron or positron production). But its main interest is the enhanced brightness and energy range of the envisioned X sources: for example, the brightness of an X Transition Radiation (XTR) source will be increased by about two decades. Moreover, the XTR spectrum is hardened (cutoff proportional to γ), so the losses by auto-absorption in the target will be lower.

The three planned beamlines have specific features:

Line “2” (on fig. 1) will be mainly used for hard X-ray production by bremsstrahlung on a thick target “T”, with

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enough room behind the target to house X-ray imaging experiments.

Line “3” will be dedicated to low background or high average intensity experiments

Line “4” is the Thomson source project.

The Thomson Source

Several groups recently demonstrated proof-of-principle generation of soft X-rays in the keV range by interaction of a ps or fs laser with a MeV electron beam in a collinear [2,3] or orthogonal configuration [4]. To achieve our Thomson source, we will take profit of the low-emittance of the ELSA electron beam and of the intrinsically synchronous drive laser with a final amplification at a few 100 mJ level. The first experiments will use the 20 MeV beam. In a second step, the energy upgrade to 40 MeV is expected to enhance the performances of the source:

— Brightness should be one order of magnitude higher (smaller focus point and increased directivity)

— Maximum X energy will be boosted from 10 keV to 50 keV.

2 THE DOUBLE ALPHA COMPRESSOR

2.1 Conceptual design

The constraints for the ELSA-2 magnetic buncher are:

- A momentum compaction term R_{56} = 3 ns,
- Compact and optically equivalent to a 800 mm translation in the vertical plane,
- An energy acceptance from 5 to 20 MeV,
- A low transverse emittance degradation.

The last point is of primary concern for magnetic bunchers on high-current low-emittance beams, such as the beams required for SASE FELs projects. Coherent Synchrotron Radiation (CSR) plays an important role in emittance growth of intense short pulses. See for example the LEUTL compressor experiment at the Argonne APS [5] or the study of a S-chicane for the TTF-FEL [6].

The final design of the ELSA-2 buncher involves 2 alpha dipoles and a quadrupole triplet between them (see fig. 2). Alpha dipoles were proposed by H.A. Enge in 1963 for ion beams [7].

Ideally, an Alpha-dipole field structure is a constant gradient field in a half space. More precisely :

For $z>0$, $B_x = G\,z$, $B_y = 0$ and $B_z = G\,x$

For $z<0$, $B = 0$.

This is a quadrupolar field and an alpha-dipole can be thought of as a half quadrupole used off axis.

Compared to ordinary dipoles, Alphas have two specific qualities:

– For an injection angle of 40.71° with respect to the z-axis, the entry and exit points in the z=0 plane are the same: the dipole is perfectly achromatic and the trajectories for different energies are homothetic, with a scale factor $\gamma^{1/2}$ (cf. fig.3).

– Because of the continuity of the field at z=0, it is possible to build near-ideal alphas with almost no fringe field.

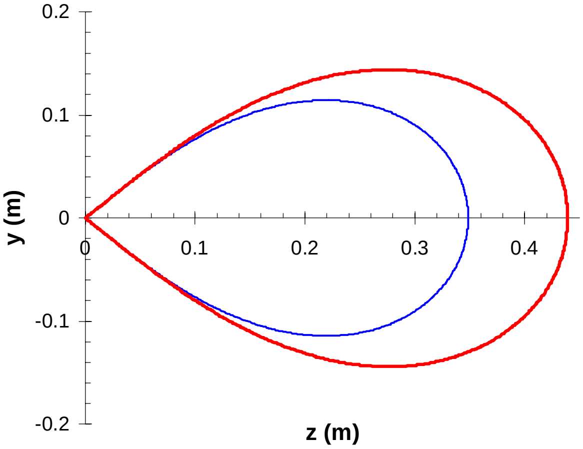

Fig. 3: Electronic trajectories at 10 and 17 MeV for a constant gradient of 1 T/m. The entry and exit angles are 40.71° for perfect achromatism.

To our knowledge, Alpha dipoles have only been used at low energy, for the rf thermo-ionic gun of the SSRL’s Mark III injector at Stanford [8] and of the Beijing FEL project. For that reason, we paid a great attention to their magnetic design.

2.2 Magnetic simulations and mechanical design

Extensive POISSON simulations (fig. 4) were the basis of the mechanical design (fig. 5):

— the precise shape of the entry shunt is critical for a rapid transition between the null field and a constant gradient field

— a movable part on top of the entry shunt gives the necessary tuning to cancel the integral of the field in the z<0 region. Because the simulations are not reliable enough, this tuning will be done experimentally after measurement of the actual field. We took special care to obtain an adjustment as independent as possible of the actual gradient.

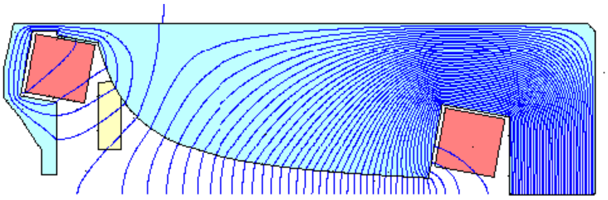

Fig. 4: POISSON simulation of an (halved) alpha-dipole. The shape of the entry shunt (on left) must be carefully designed in order to cancel the integral of the fringe field. The residual magnetism of the 316L (yellow) spacer (see also fig. 5) was taken into account in the calculations.

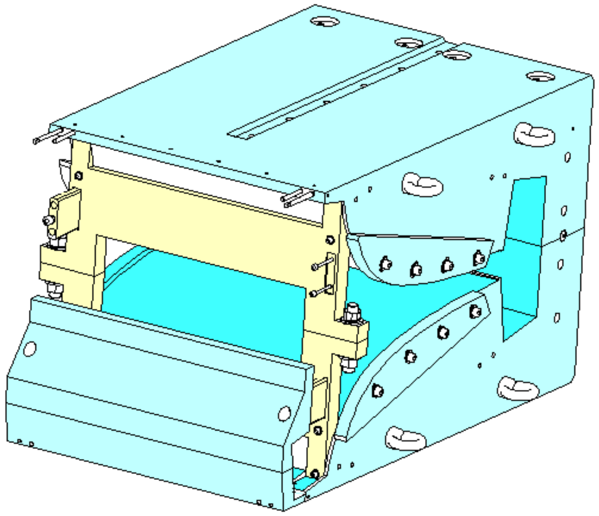

Fig. 5: mechanical design of an alpha magnet. The coils are not represented. The yokes are in soft iron (XC06), except the (yellow) spacer in amagnetic stainless steel 316L (the so-called "stick in crocodile's mouth").

3 THE RF LINEARIZER

Emittance studies on ELSA showed that the current in the photoinjector should be kept under 100 A to get close-to-best performances. Therefore, acceleration of high bunch charges (5 nC and over) requires long drive laser pulses. 60 ps is an optimum for ELSA operation. Without rf linearizer, this precludes compressing the beam under 20 ps.

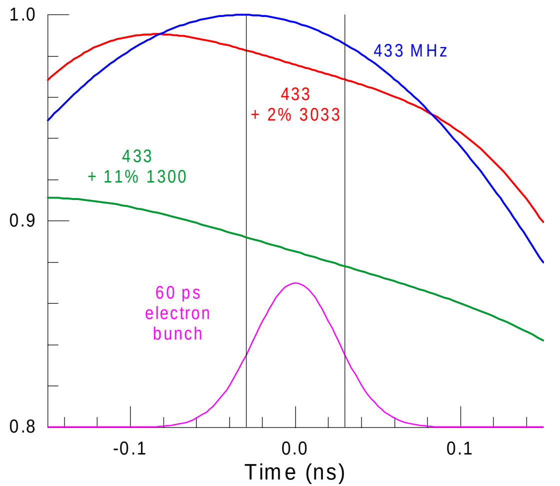

Fig. 6: linearization of the rf energy chirp with 1.3 GHz (3rd harmonic) or 3.03 GHz (7th) deceleration before bunching.

Indeed, magnetic bunching of an electron beam requires an energy chirp in the beam. Due to the nonlinearity in the energy chirp created by phase shifting the rf field, the maximum compression factor of a magnetic buncher is of the order of 3. To go beyond this value, one should linearize the chirp by a slight deceleration in an harmonic cavity between the linac exit and the buncher [9].

The higher the harmonic H, the less power and deceleration are needed ($\propto H^4$ and $\propto H^2$ respectively).

Figure 6 compares 3f (1.30 GHz) and 7f (3.03 GHz) linearization.

Though 3 GHz linearization appears as the ideal solution, we are still considering the 1300 MHz option because, as previously mentioned, the sources are available for use. The 3 GHz one should be bought and the requested power (10-20 kW peak, 0.3% duty cycle) is an embarrassing intermediate between high-power klystrons and solid-state amplifiers, because of the lack of offer in this domain on the market.

The benefits of a better compression are important for the applications of the beam. Whatever the X conversion principle, a shorter electron beam means a higher peak brightness X beam. Moreover, for the Thomson source, shorter electron pulses mean also a better overlap of the electron and laser beams, and hence a more intense X beam.

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