CONCEPT FOR ELENA EXTRACTION AND BEAM TRANSFER ELEMENTS

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Abstract

In 2011 the ELENA decelerator was approved as a CERN project. Initially one extraction was foreseen, which should use a kicker and a magnetic septum which can be recuperated from an earlier installation. Since then a second extraction has been approved and a new solution was studied using only electric fields to extract the beam. This will be achieved by fast pulsing a separator, allowing single-bunch but also a full single-turn extraction from ELENA towards the experiments. The extraction and transfer requirements of ELENA are described, followed by the principal differences between the magnetic and electric field concepts. The design of electrostatic focussing and bending devices for the transfer lines will be presented. Finally the field quality which can be achieved with the separator and the concept of its power supply will be discussed.

MAGNETIC EXTRACTION CONCEPT

When the ELENA accelerator was approved in 2011, the baseline design used a fast magnetic kicker recovered from the former Anti-proton Accumulator (AA) at CERN, which could have been followed by an outside vacuum magnetic septum (re-used form the former LEIR machine) to steer the beam into the extraction channel. Sufficient hardware and required spares are available to build and operate reliably a single extraction.

The required kicker performance was determined by the apparent septum thickness and the space available for the extraction in the ELENA ring.

Table 1: Principal Septum and Kicker Magnet Parameters

	Injection Septum	Extraction Septum	Extraction kicker
Deflection angle [mrad]	340	392	383
Beam energy [MeV]	5.3	0.1	0.1
$\int$B.dl [mT.m]	113	18	18
Septum thickness [mm]	22.8	22.8	n.a.
# turns	20	20	1
Current [A]	1120	178	1492
Rise/fall time (2 – 98)% [ns]	DC	DC	200
Flat top length [ns]	DC	DC	0-600

Magnetic Kicker

The principal kicker parameters are shown in Table 1. The kicker is a transmission line type magnet made of C-core ferrites, interleaved high voltage and earth "mirror finish" aluminium magnesium alloy plates, alumina insulation and an outer stainless steel support frame. It is placed in a vacuum vessel and the whole is bakeable at 300 °C to reach the required vacuum pressure. The high voltage power converter is also recuperated from the AA era. It consists of a SF_6 filled 15 Ω Pulse Forming Line (PFL) charged up to 80 kV and discharged by fast thyratron switches. The magnet is terminated by a matched resistor. The pulse length can be adjusted by the use of a dump thyratron. Due to the limited length of the PFL, this system only allows single-bunch extraction at a maximum repetition rate of 1 Hz.

Magnetic Septum

The extraction septum is identical to the magnetic septum used for injection, but running at a lower current. These devices are recovered from the former LEIR accelerator and two complete magnets (SM12) plus spare coil are available (Fig. 1). The principal magnetic extraction septum parameters are also shown in Table 1.

Figure 1: SM12 magnetic septum magnet.

SM12 will be used with a magnetic screen adjacent to the septum and yoke to minimise the leak field as seen by the orbiting beam. It is expected that the leak field will be less than 1 ‰ of the main field, but this will be measured and its effect on the circulating beam simulated before installation.

ELECTRIC FIELD EXTRACTION

Since the approval of a second extraction for Gbar and further new experiments, the cost for building an additional magnetic septum and the preparation of a second kicker magnet (available) into a vacuum tank needed to be taken into account [1]. To optimise the required resources, an alternative solution was studied using a fast deflector to replace the magnetic extraction elements. The electrode layout of this device resembles a separator, but with an adapted electrode angle and shape. The required fast pulsed power supply is based on a pulse generator developed for the LINAC4 chopper.

Fast Deflector

The principal fast deflector parameters are shown in Table 2. The aim is to deflect the extracted beam by 180 mrad and with a field homogeneity of ± 1 %.

The electric field was calculated [2] and the trajectories of single particles were tracked to determine the exit angle. The electrode shape and location were chosen such that the exit angle in the horizontal plane of the incoming beam was within ± 1 % of the nominal deflection angle.

The resulting geometry of the electrodes is non-parallel to the orbiting beam, to minimise the maximum required voltage, and the electrodes themselves are non-flat (Fig. 2) to achieve the field homogeneity requirement. The length of the electrodes is a trade-off to allow a relatively small vacuum vessel diameter (Ø 260 mm so that standard vacuum flanges can be used) and the required voltage on the electrodes to obtain the field.

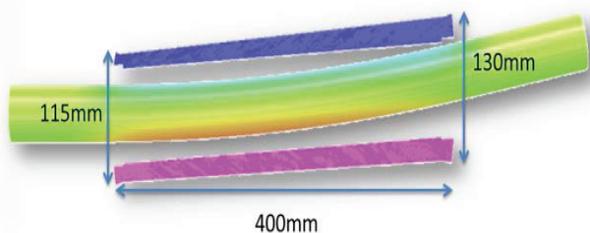Figure 2: Fast deflector electrodes (pink and blue) with the particle tracking results for Ø 52 mm beam (top view).

Subsequently the deflection of the beam in the vertical plane was determined for this geometry. The vertical deflection was less than ± 3.9 mrad, within the acceptance of the device (defined as Ø = 52 mm).

Finally the maximum particle deflection was studied. By increasing the field the limit of the geometry was determined to be 240 mrad. With this angle an incoming beam (Ø 52 mm) just does not touch the electrodes or vacuum vessel. Although the homogeneity in the horizontal plane remains better than ± 1 %, the vertical deflection is increased to ± 5.69 mrad.

Latest integration studies have shown that the nominal beam deflection angle should be increased to 200 mrad. The deflection uniformity and the field homogeneity of

the present design for this deflection angle are still to be determined.

Table 2: Principal Fast Deflector Extraction Parameters

Good field region	Ø 52	mm
Deflection angle	180	mrad
Physical device length	700	mm
Electrode length	400	mm
Electrode height	130	mm
Electrode gap	115 - 130	mm
Voltage	± 5.1	kV
Deflection angle homogeneity (H)	± 1	%

Pulse Generator

The electrodes of the fast deflector will be energized by a bipolar high voltage modulator capable of supplying a maximum of ± 6 kV. The basic circuit of the modulator (Fig. 3) consists of a positive and a negative section which charge the positive and negative electrodes, represented schematically as +C_el and –C_el, respectively. Considering the positive section, a buffer capacitor, +C_buffer, is charged to a predetermined voltage by a high voltage DC power supply, +HV. A fast high voltage switch push-pull circuit comprising +SW_on and +SW_off allows control of the electrode voltage. In the non-energized state the electrode is held at zero voltage with +SW_off closed and +SW_on open. To charge the electrode +SW_off is opened and +SW_on is then closed; the electrode capacitance is charged via +R_on. Voltage stability is maintained on the electrode by virtue of the large storage capacitor +C_buffer. To de-energize the electrode the reverse action is taken: +SW_on is opened and +SW_off is then closed and the electrode capacitance discharges through +R_off.
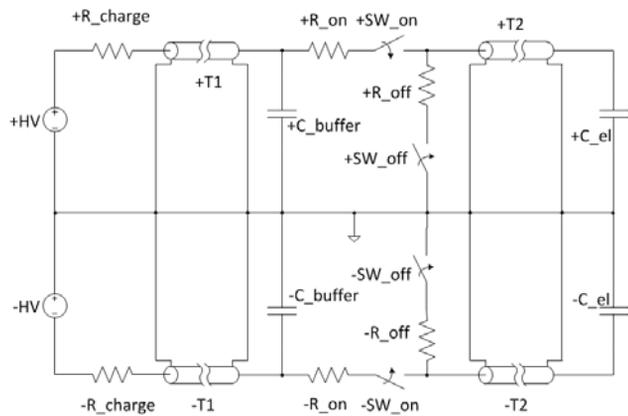

Figure 3: Simplified circuit showing the positive and negative sections of the modulator.

The modulator will be capable of allowing extraction of single or multiple bunches. To ensure good extraction the

flat top of the voltage pulse applied to the electrodes must be less than 0.1%. Equally, in the case of extraction of less than four bunches the post-pulse ripple must be less than 0.1% of the previously applied pulse voltage to avoid perturbation of the remaining beam. Circuit simulation shows that there is a strong dependency of rise and fall time on the length of the connecting cable T2. To ensure that the rise and fall time to 0.1 % of the nominal applied voltage pulse is less than 1 µs it is required that T2 cable lengths are less than 15 m.

TRANSFER LINES

In the transfer lines [3], switching between the different experiments is foreseen on a bunch-to-bunch basis. It is being investigated to extract a single bunch only every turn from the ring thus allowing to increase the rise and fall time for the deflectors in the line.

Use of Fast Deflector

The required fast deflector (switching time 1 µs) is planned to be realized as a combined device consisting of the fast deflector (deflection angle 11°) described above, followed by a static (i.e. permanently biased) spherical electrostatic deflector (deflection angle 34.8°-38.5°), giving a total bending angle between 45.8° and 49.5° (Fig. 4) In order to facilitate manufacturing and spare part management, the same static deflector will be used to provide the slightly different bending angles at different positions of the beam line, by appropriately tuning the voltages of the electrodes. Preliminary simulation results show that this can be done without degrading the beam quality. The static deflector has an aperture (electrode-to-electrode gap) of 60 mm, and the height of the electrodes is 150 mm. The shapes at the top and bottom edges of the electrodes have been optimized to minimize the distortion of the electric field at the position of the beam. The frame around the spherical electrodes serves a twofold purpose: 1) supporting the electrodes via insulator rods, and 2) defining the fringe field of the device at its input and output, shielding the non-deflected beam from the stray electric field of the electrodes.
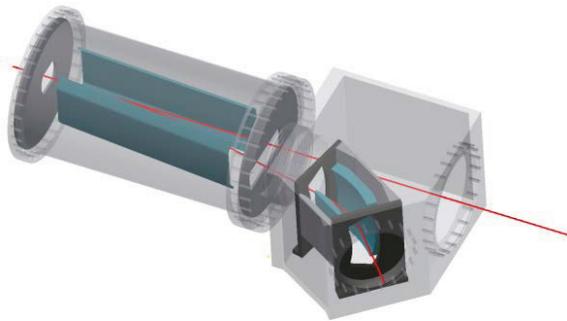

Figure 4: Fast deflector with bend assembly.

At points in the beam line where no switching is required, the full bending angle will be provided by the static spherical deflector described above.

Electrostatic Quadrupoles

The FODO structure of the extraction beam lines will consist of electrostatic quadrupoles (electrode length 100 mm, with a spacing of 1.4 m). These quadrupoles are realized as self-supporting units inserted and mounted at the CF flanges of 1.5 m long beam pipe segments. The preliminary design includes an integrated electrostatic corrector as well. This can be a corrector for both H and V planes (Fig. 5). Alternatively, a corrector for only one plane (alternating H and V from quadrupole to quadrupole) with taller electrodes in the transverse direction can be used in order to get rid of the higher order modes of the corrector field.

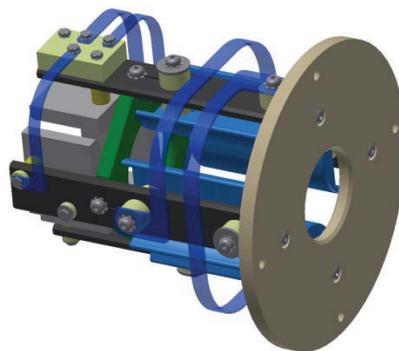The quadrupole multiplets of the matching sections will be constructed using the same design concept.

Figure 5: Lattice quadrupole (blue electrodes) with corrector (grey electrodes).

CONCLUSION

The feasibility study initiated after the approval of the GBar experiment has shown that the extraction from ELENA can be advantageously achieved using a fast deflector. This allows extraction of single bunches, but also a full turn can be extracted which avoids emittance blow-up due to intra-beam scattering at the extraction flat bottom.

The cost of the new device including design and development is lower than reusing existing kickers and building additional septa.

In the transfer lines, the design of the fast deflector is reused in combination with a bend, to provide bunch-to-bunch switching between experiments. Also the concept designs for electric field quadrupoles used for matching (as multiplets) and for the lattice (in combination with correctors) have been determined.

REFERENCES

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[3] G. Vanbavinckhove et al., "Geometry and Optics of the Electrostatic ELENA Transfer Lines", IPAC'13, Shanghai.