The ESS-CONCERT Funnel Line

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Abstract

The CONCERT concept aims to deliver high power pulsed beams to a various number of applications : mater studies with spallation neutrons, waste transmutation, exotic beam production, irradiation tools… It is one of the extension of the European Spallation Source project (ESS) dedicated to spallation neutrons production for mater studies. Both protons and H- have to be accelerated and guided to each target. Two 50 mA H^- branches are funnelled with one 100 mA H^+ branch at around 25 MeV. A low energy H^- branch is constituted of one RFQ from around 50 keV to 2 MeV, a chopper line (for ring injection at high energy), an other RFQ to 5 MeV, and a DTL to the funnel line. The low energy H+ is constituted of one RFQ from around 95 keV to 5 MeV and a DTL to the funnel line. The beams are then accelerated through a SDTL, a CCL and a Superconducting cavity Linac (SCL). The goal of this paper is to present the detailed design of the funnel line, including the funnel cavity design and the beam dynamics through the line.

1 INTRODUCTION

The specificity of the CONCERT concept is that its accelerator has to be able to accelerate both H^- and H^+ beams. The H^- beam is injected into a ring (stripped to protons) and compressed to a 650 ns high intensity pulse. It is used to create short spallation neutrons pulses for mater study (ESS project). The H^+ beam is used for the others applications: long spallation neutrons pulse, waste transmutation, exotic beam production, irradiation tools… For consideration of power, 100 mA beams are needed. The H^- pulsed is about 1 ms long, 70% chopped (@2.05MeV), with 50Hz repetition rate. As 5% duty-cycle H^- sources, with emittance lower 0.3 π.mm.rad and high reliability are highly challenging at 100 mA peak current, it has been chosen to funnel two 50 mA H^- beams lines at 23.5 MeV. Because high duty-cycle (>5%) are challenging even at 50 mA for H^- sources, H^+ line is necessary for the other applications. The funnel line should then inject 3 beams (2 H^- and 1 H^+) coming from 3 different lines in one. After the funnel line, H^- and H^+ beams are accelerated to 1.34 GeV in the same structures : Separated Drfit Tube Linac (SDTL); Coupled-Cavity Linac (CCL); Superconductive Cavity Linac (SCL).

The main challenges are :

- design a RF deflector allowing at least ±5° deviation for H^- beams and no deviation for H^+ beam,
- design transport lines giving a good separation between the line, having room enough for the transport elements and diagnostics, able to match independently the beams to the following structure, minimising the emittance growth and as easy as possible to tune.

2 THE DEFLECTING CAVITY

The principle of the deflector is very simple : A cavity is designed with a dipolar (or quadrupolar) mode oscillating at the RF frequency. The electric field deflecting component is reinforced with electrodes close to the axis. The electrode periodicity induces an alternatively positive and negative electric field transverse component along the beam path (π-mode). The distance between electrode centres is $\beta\lambda/2$ (figure 1).

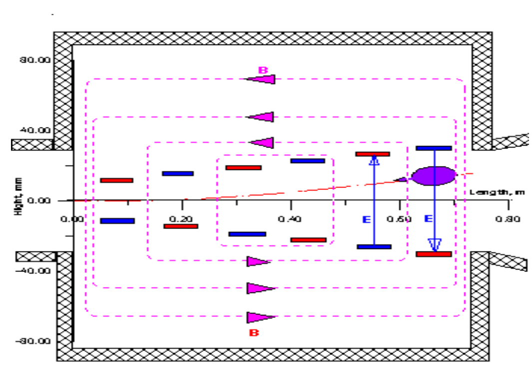

Figure 1 : 6-gaps cavity scheme.

Different kinds of deflecting cavities have been studied [1][2]. At 176.1 MHz, the preferred one is rectangular (figure 2), exciting the TE101 mode.

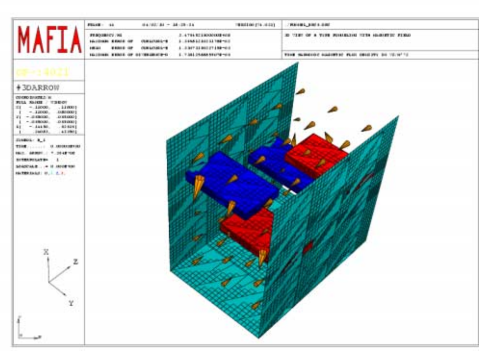

Figure 2 : TE101 rectangular structure.

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The field has been computed with MAFIA. The deflecting component of the 4 gaps cavity is represented on figure 3.

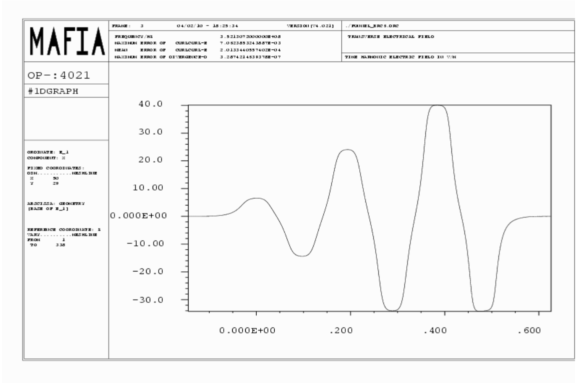

Figure 3: The transverse electrical field in the TE211 and TE111 mode structures.

Three factors having an influence on the funnel construction are the necessary deviation angle, the maximum field and the maximum RF power absorbed by the cooling system. The multi-gap funnel device has a big advantage over the one-gap device, since the deviation angle is nearly proportional to the length of device (number of gaps), and we can get the necessary deviation angle by the appropriate choice of the length. However, simultaneously with the angle deviation the space deviation grows with the length to the square. Therefore the initial gaps have to be more open and the efficiency of funnel device goes down with the transverse field $E \propto \frac{U}{d}$ as well.

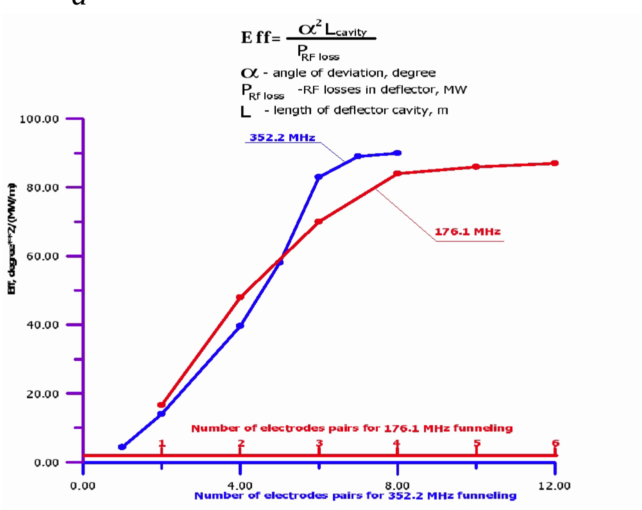

Figure 4: The efficiency of the funnel device versus the gaps number.

To characterize the efficiency of the deflector, we have introduced the value $Eff = \frac{\alpha^2 L_{cavity}}{P_{RFlosses}}$ measured in the dimension of degree**2/(MW/m). Figure 4 shows the efficiency of the funnel device versus the gaps number for two frequencies 352.2 MHz and 176.1 MHz. You can see the significant gain of the 5-6 gaps (3-4 gaps for 176.1 MHz) over the one-gap device. But then the efficiency is almost constant. It is because the growth of the gap size is starting to compensate the advantages of the multi-gap device. From this data one can see that in the one-gap device deviating the beam by 2 degrees the RF power 1MW has to be absorbed in CW regime, what is not realistic even for 6 % duty cycle machine like for ESS project.

The CONCERT-ESS goal being 5° over a 6% duty-cycle, the dissipated power per unit length in the chosen 4-gaps cavity will be below 20 kW/m.

3 THE TRANSPORT LINES

Line description

The low energy baseline of the linac (until the SDTL) is represented in ref.[3]&[4]. The funnel line, including the element sizes, is represented on figure 5. Diagnostics have not been positioned yet, but it seems that there is enough room for them in all the free spaces between elements.

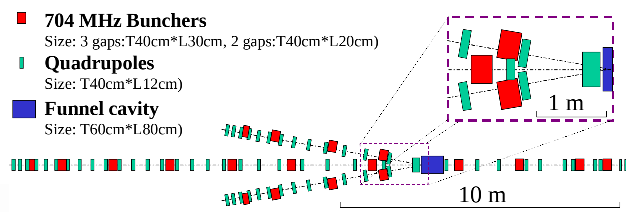

Figure 5 : The funnel line.

The angle between the lines H^- is ±10°. A deviation of 5 degrees is given by the deflecting cavity, and another 5 degrees by the deflecting quadrupole (called QuaDev) placed just before.

To reduce the size of the RF bunchers and increase their efficiency, they have been designed at 704.42 MHz. At this frequency, the bunch length is about ±40°.

To generate the line, a morphing procedure has been used: The DTL FODO focusing scheme period is progressively increased to a distance between quad large enough to insert the deflecting cavity (~1m). The focusing scheme is then decreased, becoming a doublet scheme, to the SDTL period. The bunchers are as close as possible to each others.

Beam dynamics

The H^- and H^+ beam envelopes have been represented on figures 6 and 7. In H^- line, the deviation is seen, and a frame change is used at the position where the elements are centred on an other trajectrory.

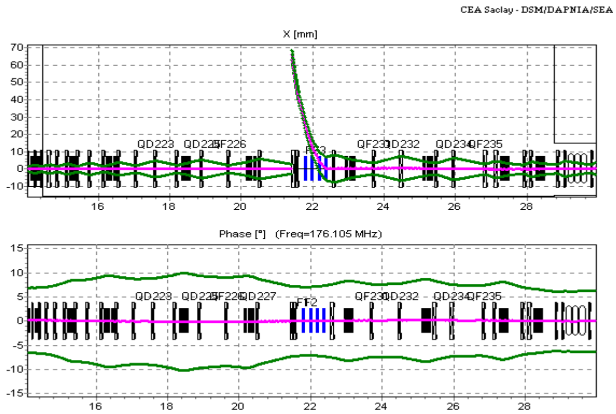

figure 6 : H$^-$ beam X and phase envelopes. A (66.5mm; 10°) frame change is applied at QuaDev entrance.

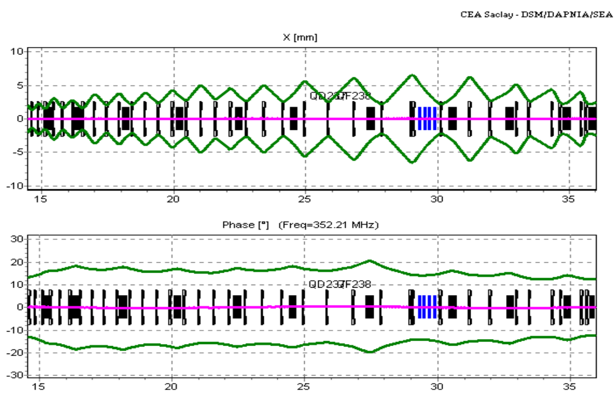

figure 7 : H$^+$ beam X and phase envelopes.

Some emittance growth can be observed (figures 8 and 9) coming from :

- The space-charge non linearity in a rapidly changing focusing scheme,
- A coupling between X and Z direction induced by the deviation,
- A deflexion in the funnel cavity that depends on the particle phase, introducing an other longitudinal-transverse coupling.

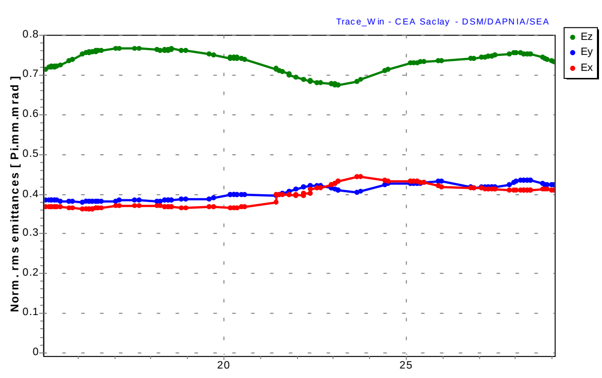

figure 8 : RMS emittance evolution of the H$^-$ beam in the funnel line.

In the second part of H$^+$ line, a large transverse emittance growth occurs. This effect, which seems to be resonant is not completely understood at that time.

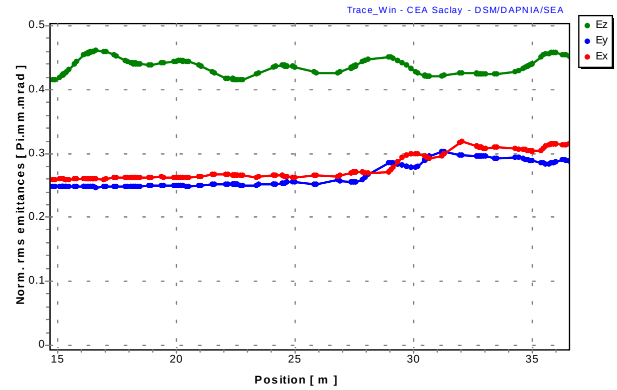

figure 9 : RMS emittance evolution of the H$^+$ beam in the funnel line.

4 CONCLUSION

A RF cavity has been studied to deflect the 23.5 MeV beam to a 5° angle. A beam line has been designed to transport and match the beams from the DTL output to the SDTL input. Some emittance growth has been observed, but it doesn't seem to be dramatic. However, the transport could be probably improved a little bit. The beam matching is done with quadrupoles and bunchers before the funnel (where the lines are independent). The tuning of the deviation is done with steerers, the deflecting cavity field and the deflecting quadrupole coupled with BPM downstream the deflector cavity. The detail study of this tuning procedure has to be done.

REFERENCES

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[4] R. Ferdinand et al., "Low energy part of the CONCERT high-power proton Linac", this proc.