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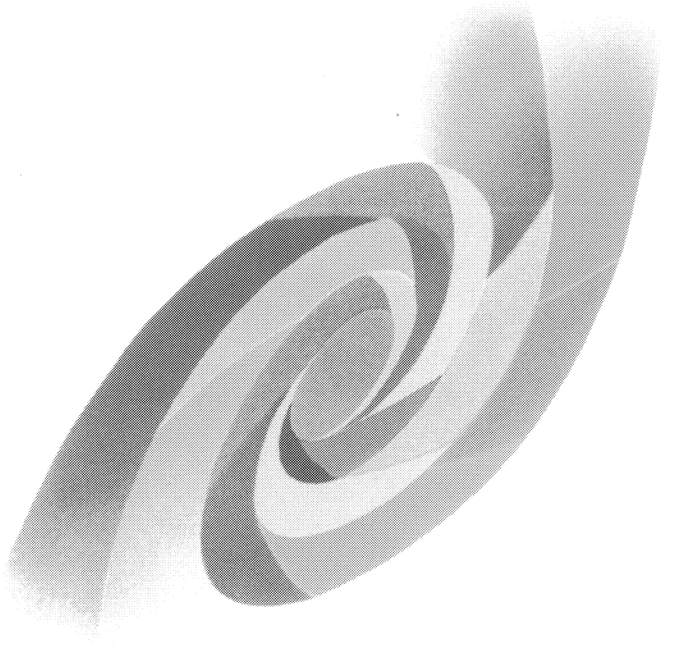

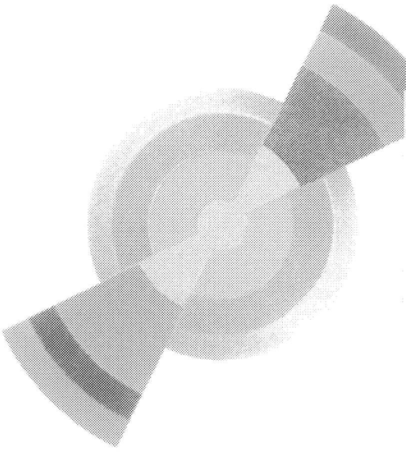

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Status report on the beam dynamics developments for the SPIRAL 2 project

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Abstract

The driver for the SPIRAL 2 project aims to accelerate a 5 mA D+ beam up to 20 A.MeV and a 1 mA beam for Q/A=1/3 up to 14.5 A.MeV. It operates in a continuous wave regime (CW) and is designed for a maximum efficiency in the transmission of intense beams. Recent studies have led to change the reference design. The current design consists in an injector (ECR sources + LEBTs with the possibility to inject from several sources + a Radio Frequency Quadrupole) followed by a superconducting section based on an array of independently phased cavities where the transverse focalisation is performed by warm quadrupoles. This paper presents the beam dynamics studies associated to these new choices, the fast chopping in the MEBT and the HEBT design.

INTRODUCTION

The possibility of a high intensity accelerator at GANIL, producing secondary beams of unprecedented intensity, is considered. A project named SPIRAL2 [1] is being under way in order to add medium-mass nuclei to those available with SPIRAL. The fission induced by deuterons is used for the production of the radioactive ions. With the same CW linac, the SPIRAL 2 project aims to accelerate also ions with q/A = 1/3. The driver consists of a double injector, one deuteron ECR source and one ion ECR source, followed by a common Radio Frequency Quadrupole cavity. This part is before a superconducting linac with independent Quarter Waves Resonators (QWRs). The requirements imply an accelerating optimization for ions with q/A=1/3 but acceleration of ions with q/A= 1/6 has to be evaluated for a possible upgrade with an additional injector (a new source and a new RFQ).

The input energy of 20 A.keV allows an extraction voltage of 60 kV which avoids an insulation platform. The output energy is set to 14.5 A.MeV for the 1-mA ion beam and to 20 A.MeV for the 5-mA deuteron beam. The input normalised rms transverse emittances are 0.2 and 0.4 $\pi.\mu$m.rad for deuterons and ions respectively. It is believed that this choice would give confortable margins for such beam currents. The operating frequency for the cavities is 88 MHz, a sub-harmonic of the popular frequency of 352 MHz. Synergies for the R&D with other projects and an easier upgrade of the machine are then possible. This single frequency ensures an efficient transition between the accelerating sections and gives an good compromise between the acceleration efficiency and the cost associated with the development of the cavities. We studied an alternate option with the single frequency of 176 MHz. Studies shown that this option could be problematic for the acceleration of q/A = 1/6 ions, induces higher power densities and a higher RF power consumption in the RFQ. At 176 MHz, the RFQ is also slightly more sensitive to errors (lower aperture). The optimization process for the choice of the frequency distribution in the linac has led to test a hybrid option with the two frequencies. This option implied more resonators (+50%) and induced a more difficult longitudinal matching at the transition. The reference [2] describes this optimization and the architecture of the SPIRAL2 linac with more details than this paper.

THE LEBT LINES

The deuteron line

The Low Energy Beam Transport (LEBT) line for the D^+ beam is mainly based on the use of a solenoid followed by an achromat section (two 45 degrees dipoles and one quadrupole triplet) to provide an efficient separation between the D^+, the D_2^+ and the D_3^+ beams. This part allows one to operate the source when the linac is running with ions (the last dipole is then turned off). After the achromat, a quadrupole triplet and a solenoid are used to match the beam into the RFQ.

As the accelerator will operate in a CW mode, space charge neutralisation has to be taken into account in our calculations. A beam space charge computed with TraceWin/PARTRAN [3] is applied but its force is weighed by 20%. This neutralization is conform to measurements done on the LEBT line of IPHI [4] but it is still a coarse modelisation with respect to the underlying physic of the problem. Between the last dipole and the triplet, a chopper section is included with a set of collimators. A slow chopping (8kV, 40 ns rise time) is used for pulsed regime during the commisioning. 3D maps are used to simulate the motion (D^+ and ions) in the quadrupoles in order to take into account the fringe field effect as these quadrupoles have a large aperture compared to their length ($\phi = 200mm$ and length $= 168mm$).

The ion line

This section of the linac has to separate efficiently the different charge states. For this purpose, an achromat with 90 degree dipoles and a quadrupole triplet after a first solenoid are used. A quadrupole is inserted in front of the first dipole to tune the separation. A resolution equal to 100 can be achieved. The achromat section is necessary to take into account the energy jitter of metallic ions produced by the ECR source. Following this line, the RFQ has a wide

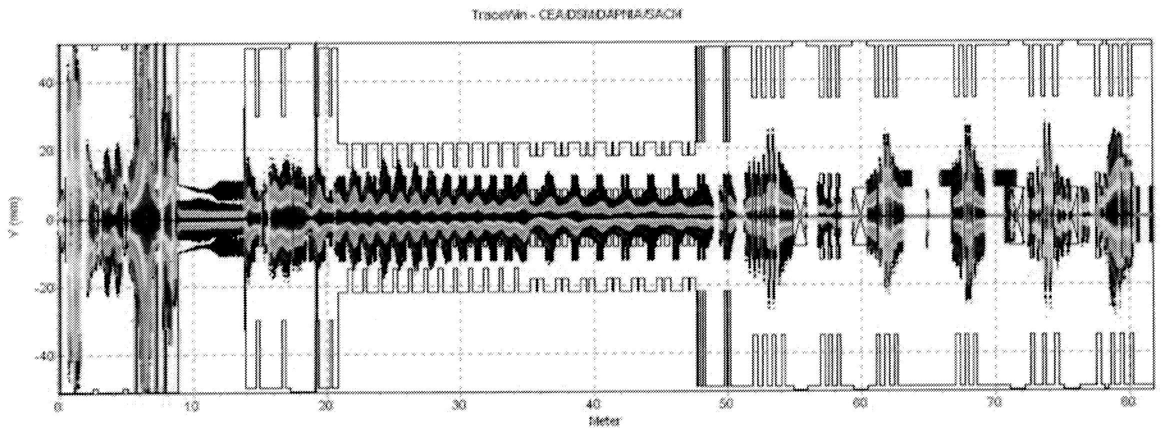

Figure 1: Beam density behaviour in the vertical plane with respect to the linac length for the deuterons.

enough longitudinal acceptance to allow for different injections β ($\Delta\beta/\beta \simeq 10^{-2}$). The energy at the exit is fixed by the RFQ geometry. After the achromat section, a transport section with 3 quadrupole triplets and a solenoid is used for the injection into the RFQ. This solenoid and the last triplet are common with the deuteron line.

THE RFQ

The RFQ output energy is selected for the first cavities of the SC linac to operate at low β to accelerate ions with q/A equal to 1/6. This means that values in the range [0.04, 0.08] are possible for the β of the SC cavities to avoid very long RFQ. The main parameters have been computed with the BELENOS code [3] and are detailled in reference [2]. The choice of the maximum peak field is a compromise between sparking rate and strong focusing required to compensate space charge. This parameter has been kept to a conservative level of 1.65 Kilpatrick [5], lower than LEDA (1.8 Kp) that also works in a CW mode [6]. The transverse radius of the pole is kept constant to 0.75 cm to simplify the machining of the electrode (2D tool).

The transmissions computed by TOUTATIS [3] are better than 99.8% with a gaussian distribution cut at $4 \times \sigma$ transported through the LEBT. No transverse rms emittance growth is observed in these simulations. The longitudinal rms emittances are respectively equal to 0.05 and 0.13 deg.MeV for the deuterons and the ions and are constant after the bunching process.

THE MEBT

The superconducting linac is linked to the RFQ by a Medium Energy Beam transport line (MEBT). The line contains two quadrupoles triplets followed by two quadrupole doublets. Four bunchers are included to transport and match the beam to the SC linac. The first triplet is used to get a round beam over a 1.5 m distance and allows the insertion of diagnostics and a dipole. This dipole could be used to inject the q/A=1/6 ions in the SC linac. The diagnostics would qualify the output beam of the RFQ.

The second triplet is included to produce a small round beam over around 1 m to insert two fast strip lines (two parallel plates of 45 cm long at ±2.5 kV with a rise time of 8ns). The fast chopping may be included to define different duty cycles for the physics needs. An additional doublet is used to enhance the beam separation and to begin a transition to a FDO lattice. A hollow beam dump stops the chopped beam and may scrap, if necessary, the unchopped beam (around 100 watts).

The last doublet facilitates the matching of the beam to the FDO lattice of the superconducting linac. A last drift provides space to insert diagnostics to measure the phase size of the beam before the linac entrance.

Due to a lack of experimental and theoretical knowledge, no space charge compensation is assumed for these calculations. No emittance growth is observed for the ion beam and the deuteron beam.

THE SUPERCONDUCTING LINAC

This section is based on independently phased superconducting QWRs. Two families of β are used. The linac design is optimized with a routine that loops on possible optimal β and transition β. For each set of parameters, the GENLIN code [3] transports one reference particle in electrical fields. The field can be interpolated from a field map or calculated with an analytical formula. The optimization criterion is the length of the linac. This process is performed with (01) period for the first family and (011) period for the second family where (0) is a SC solenoid or a conventional quadrupole doublet and (1) a cavity. Different ways to arrange elements have been studied: long tanks with 4, 5 or 6 periods, short tanks with 2 or 3 periods, transverse focalisation inside or outside the cryostats, homogenous or inhomogenous element distribution per β family. We converged to a linac architecture based on small cryostats with only QWRs and a focusing with conventional quadrupoles doublets outside the tanks. The main arguments are:

- a simplified support in the cryostat which relaxes the alignement tolerances (no solenoid tilt, alignement of the quadrupoles in the warm part);
- no compensation of magnet fringe field is required for the SC cavity; the possibility to insert diagnostics at each period;
- a maximum modularity in respect to the uncertainty for the accelerating field;
- a simplified tuning of the linac (FDO lattice with profiler between quadrupoles);
- an overcost induced by the multiplication of warm transitions compensated by the abandonment of expensive SC solenoids.

The optimization process has converged to β equal to 0.07 and 0.12 and a transition β of 0.11 for an accelerating field equal to 6.7 MV/m. The first family requires 12 cavities and the second one 14 cavities.

All simulations include an input beam coming from the low energy part (LEBT+RFQ+MEBT). These end-to-end simulations gives a more realistic estimate of the performances. No vertical displacement of the cavities or tilted shape of the accelerating gaps are used in the simulations to compensate the steering effect induced by QWRs. The beam is just realigned between each tank using the BPMs and the steerers included in the quadrupoles.

The beam dynamics have been performed with the z code TraceWin/ PARTRAN [3] and the t code LIONS_LINAC [7]. All these codes use 3D maps for the resonators. Tests of the quadrupole 3D map have been performed and have shown that a hard edge formalism can be used to speed up computations.

50 000 macro-particles are used for the simulations. The transmission of the superconducting part is 100% for the 1/3 ion beam. The deuteron losses are lower than 10^{-5}. These losses occur at the beginning of the linac and at the begining of the second family. This loss level is "tuned" by using a scraper in the MEBT (less than 3% of losses). The peak dissipated power in the linac is lower than 1 W. It is in agreement with the authorized cryogenic losses. For the ions, the longitudinal and transverse emittance and halo growths are negligible. For the deuterons, the longitudinal emittance growth is around 43%. For the transverse plane, the emittance growth is 13%. The halo coming from the previous sections and the space charge forces are responsible for this emittance growth (redistribution due to non equilibrium with respect to the channel, non linear forces).

THE HEBT

For the High Energy Beam Transport line, there are mainly two needs. It is first required to distribute the beams to the experimental areas or to the beam dump. One experimental area would be located in the north part of the building and another one under the linac. The second need is to obtain a uniform distribution of the beam on the target in the vertical direction. This facilitates the design of the target. Since the target is a wheel, the uniformity is only necessary in one direction.

In order to respond to these requirements, the scheme described in reference [2] is proposed. The different deviations are performed with 45 degrees dipoles. Two quadrupole doublets follow the end of the linac. They extend the linac lattice with two periods to allow the insertion of two spares which may help to reach the final energy if the accelerating field is too low. After this "spare" section, a quadrupole quadruplet with bigger magnets matches the beam to an achromat section (dipole + triplet + dipole) which drives the beam to the lower floor or to an other similar achromat section at the same level (north room). At the basement level, the achromat part is followed by two triplets which transport the beam to a last achromat system (two dipoles and one triplet). In front of the target, one triplet, two doublets and one octupole magnet are used to expand and uniformize the beam on the carbon wheel.

CONCLUSION

Our studies for the SPIRAL2 project have led to an architecture which fulfills the requirements. The computed loss level is in agreement with the radioprotection environment. Netherveless, the losses in the future machine will depend on the ability to tune each section and the optical quality of the input distribution (ECR sources) if we want to avoid an excessive use of scrapers. Other studies are being performed to estimate the robustness of this linac: sensitivity to errors, sensitivity to cavities failure, sensitivity to different injected distributions and emittances, interaction between the beam and the residual gas.

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