LINAG 1: A LOW ENERGY, HIGH INTENSITY DEUTERON AND ION LINEAR ACCELERATOR AT GANIL

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Abstract

The conceptual design of a linear SC accelerator, LINAG, was started a few months ago to satisfy a request for high intensity deuteron and ion beams for the short- and long-term developments in the study of nuclei far from stability at GANIL.

LINAG's first step, LINAG 1, will accelerate ions with m/q = 3 up to 14.5 MeV/u (1 mA max.) and D^+ up to 20 MeV/u, 5 mA max., which corresponds to a beam power of 200 kW. With the use of the D^+ beam on a uranium target, our second-generation facility for Rare Ion Beams (RIB), SPIRAL II, will add medium-mass nuclei to those available at present.

In the longer term, the machine should evolve towards a heavy ion driver, in the energy domain of 100 MeV/u, able to accelerate m/q = 3 to 6 (low to medium-mass nuclei) with a maximum beam power of 300 kW, in order to upgrade the GANIL facility for the production of secondary beams.

The paper presents the preliminary choices and the points still under discussion of the LINAG 1 design.

1 INTRODUCTION

The study of nuclei far from stability has become one of the major activities at GANIL. With SPIRAL phase II (2008), secondary beam intensities more than a factor 100 higher (10^{13} fission/s) will be available and the uranium target fission method will be added to the present RIB production possibilities [1]. The fission method requires a 20 MeV/u, 5 mA deuteron primary beam and the present cyclotron driver cannot handle such a high beam power. A solution based on an RFQ and a 40 MV super conducting linac is under study in collaboration with other French accelerator groups and with two international laboratories already operating heavy ion linacs: Argonne and Legnaro [2].

2 ACCELERATOR LAYOUT

The proposed linear accelerator aims to get maximum transmission efficiency and to profit from the future progress of high charge state, heavy-ion sources. It is a continuous wave (CW) mode machine with no strippers, to avoid the problem of high power in the stripper targets, and it is split into an injector and a super conducting (SC) linac as shown in figure 1. The LINAG 1 injector is based on two ion sources followed by a radio-frequency quadrupole (RFQ) optimised for m/q=3, and suitable to accelerate a 5 mA, D^+ beam.

In future, a second injector equipped with a source and an RFQ optimised for m/q=6 could be added in parallel and then the possibility of adding a stripper should be considered, following recent work on multiple-charge transport in linacs.

The LINAG 1 booster must be able to accelerate D^+ and other ions with maximum energy gain, and be able to be extended to heavier ions in the future. A linac based on independently-phased SC resonators is thus proposed. SC quarter-wave resonators (QWRs) will be used at 87.5 and 175 MHz, together with SC solenoids. Sub-harmonic frequencies of 350 MHz have been chosen to guarantee the availability of power sources.

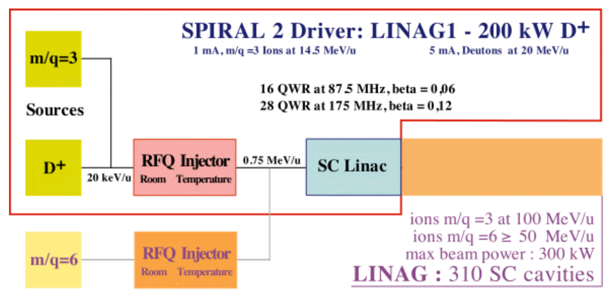

Figure 1: Schematic layout of the linear accelerator and possible upgrading

3 THE RFQ INJECTOR

The RFQ must operate in CW mode, at a frequency of 87.5 MHz. The input energy has been fixed at 20 keV/u and the output energy, will be around 0.75 MeV/u, corresponding to a beta of 0.04. This should allow the first cavities of the SC linac (beta = 0.06) to have a field value higher than 5 MV/m, at 7W.

3.1 Main parameters

The RFQ parameters are described in detail in [3], while Table 1 presents a summary of the main design parameters.

Table 1: Main RFQ design parameters

PARAMETER	VALUE
Length	6.076 m
Minimum aperture (a)	5.1…7.5 mm
Mean aperture (R_0)	6.9…7.5 mm
Modulation (m)	1…1.8
Frequency	87.5 MHz
Voltage	90-101 kV
Peak field	1.43-1.66 Kp
Synchronous phase	-90…-30 deg

In particular, the maximum peak field value is kept to a conservative level, lower than in LEDA and the Chalk River RFQs, which also work in CW mode.

3.2 Mechanical and RF design.

The relatively low value of the frequency presents some advantages:

- the RF power density is quite small at this frequency, and leaves more choice on the possible cavity structures and technologies.
- the RF power required at 87.5 MHz, 150 kW, is around 1/3rd of the power dissipated at 175 MHz by a structure of the same length.
- the inter-vane distance is larger at lower frequency, and allows a higher margin for the mechanical tolerances.

In the case of a vane structure, maximum loss densities are as small as 0.4 W/cm^2 and a very cheap solution based on Cu-plated steel has been proposed.

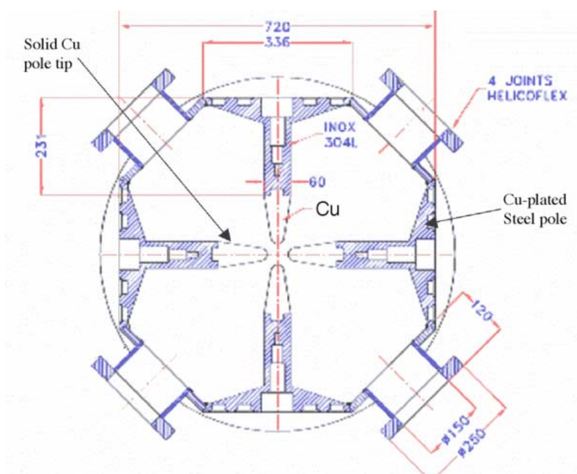

Figure 2: RFQ structure with stainless-steel vanes

The use of steel could be critical if unexpected losses due to multipacting or other parasitic phenomena were present. At the same time, the transverse dimensions of the tank could be reduced to 400 mm, if the hybrid structure with arched vanes (fig.3) were used.

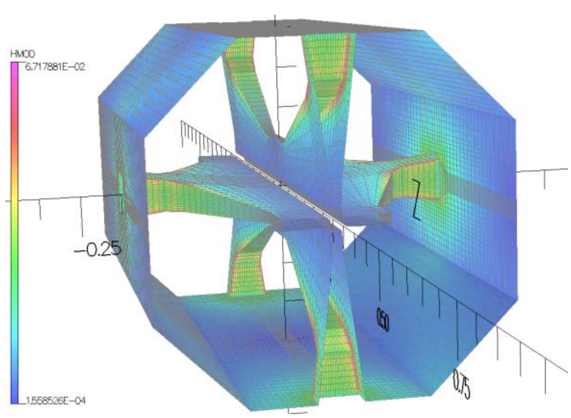

Figure 3: RFQ structure with arched vanes

In this case the losses densities would rise to 12 W/cm^2, and the total RF power to 230 kW, but the use of solid copper would help to avoid any unexpected problem.

3.3 Beam Dynamics

An RMS normalised emittance of 0.4 π.mm.mrad, has been considered for the ion beam, and 0.2 π.mm.mrad, for the deuteron beam. The transport efficiency is 100% in both cases. Figure 4 summarises the results obtained for the D^+ beam.

Error simulations have also been performed, assuming mechanical tolerances of ± 0.1 mm on the vane machining and ± 0.2 mm for misalignments. The results confirm that the deuteron beam transmission remains very close to 100%, with a 5 10^{-5} loss rate exactly. This gives a quite comfortable situation from the safety point of view, since losses of up to 3% were considered in estimating the biological protection.

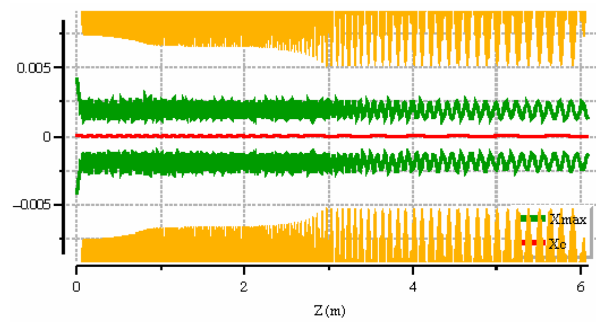

Figure 4: Horizontal envelope of deuteron beam

4 THE SC LINAC

LINAG 1 design is based on accelerating voltages of the order of 1 MV/cavity or 5.6 MV/m (at 7 W) and 10 tesla solenoids. A combination of 16 low beta (β=0.06 at 87.5 MHz) and 28 high beta (β=0.12 at 175 MHz) cavities has been used, with conservative field values for the cavities and solenoids, in order to ensure reliable and easy operation of the accelerator.

Low-beta SC cavities in the beta range 0.04 to 0.2 are typically QWRs, operated at 4.2 K as the frequency is less than 500 MHz. QWRs at 87.5 and 175 MHz are used, as sub-harmonic frequencies of 350 MHz.

The large spread of ions and intensities available at the source, will directly affect the beam loading. The maximum expected beam power per cavity with ions is about 1 kW but it will range from a few hundred watts, for most ion species, up to 5 kW in the case of the deuteron beam. Moreover, low beam intensities will probably be used during the tuning phase. The design of the coupler, amplifier, control electronic and other ancillary equipment around the cavities will be strongly influenced by this.

4.1 Cavity technology

Two technologies for these cavities have been analysed up to now: bulk niobium and sputtered niobium on a copper layer: Nb/Cu. Both kinds are presently used in heavy ion accelerators, e.g. at Argonne and Legnaro, and both laboratories are working on upgrading for future projects [4,5]. An important difference in the two technologies lies in the thermo-mechanical stability of the cavity. Here SC resonators are very demanding, owing to their very narrow natural bandwidth: < 0.1 Hz. Niobium cavities present a higher sensitivity to pressure variation and need mechanical dampers and/or fast tuners in order to compensate for the mechanical vibration effects. Fast tuners have been developed and routinely used at ANL for a decade and today they are extremely reliable.

There is as yet very little operational experience with the new Legnaro type of solid-Nb QWR, using a mechanical damper of the electrode stem that should avoid the need for fast tuners.

For the accelerating field, both Legnaro types of high beta cavities (> 0.1) can be operated with almost 7 MV/m at 7 watts. At low beta, the comparison between the two technologies is not easy, owing to the lack of significant samples, and thus manufacture and testing of prototypes with all the latest innovations is needed.

There is no existing experience on several-kW power couplers with SC QWRs, but the design for power of less than 10 kW should not present any particular problems, as power levels more than a factor 10 higher are already handled in SC cavities. Nevertheless, this element will complicate the design of both the cavity and the cryostat, adding some extra cost.

Owing to our wide range of beam intensities, a variable coupler could be necessary in order to reduce the RF power consumption when working with low intensities. Calculations [6] show that the over-coupling required with maximum beam intensity when the power P is completely absorbed by the beam, demands a power P/4 to produce the same accelerating field without beam. This amount of power is of the order of 1.5 kW and could be difficult to handle: a variable coupler could reduce it by a factor 10 to 20, resulting in reduced operating costs.

Couplers, slow tuners, dampers and fast tuners, are important accessories for the cavities as they strongly affect the operating reliability and the ease of operation, as well as the cost. Several systems have proved their efficiency with low intensity beams and driving amplifiers of a few hundred watts but the solution for several kilowatts amplifiers still needs some development.

4.2 Beam dynamics

Beam dynamics calculations have been performed, with the Argonne code TRACK [7]. 3D field maps of Legnaro type QWRs where used to include the field asymmetry proper to these cavities and the magnetic field, so that the QWR steering effect is taken into account. The SC linac input conditions, (equal to the RFQ output ones) for a D^+ beam are:

- $\varepsilon_x=\varepsilon_y=0.6\ \pi$.mm.mrad (full and normalized)
- $\varepsilon_z=1.35\ \pi$.ns.keV/A (full and normalized).

The results are shown in figure 5 (calculation performed with 2000 particles) and it seems that we should not need more complicated shapes or even half wave resonators.

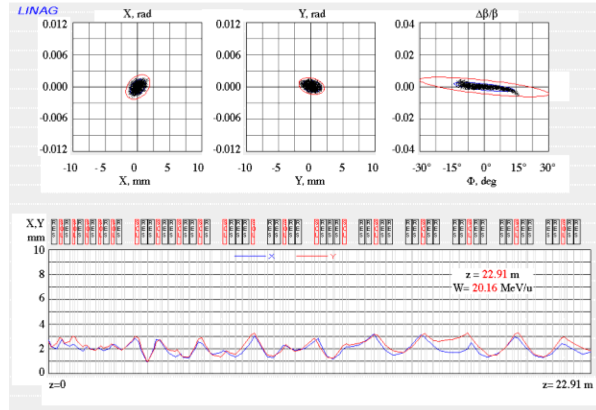

Figure 5: D^+ beam envelope in the SC linac

A small steering effect was observed and corrected by a progressive misalignment of the cavity axes, ranging from 0.05 to 0.3 mm, while the effect of steering magnets has still to be checked. Error simulations have to be performed with TRACK in particular. Space-charge effects are not included in the calculations and have to be performed: a GANIL code is being adapted for this.

5 CONCLUSION

The conceptual design of LINAG 1 is in a fairly advanced phase and we have now to develop the main element prototypes. The R&D work that is done for other ion linac projects (ISAC, RIA, EURISOL) for RIB facilities will be of great help with the RFQ, the SC cavities and the cryostat design. Problems linked to the high intensity beam loading will be peculiar to this project and the design of the RFQ and of the power couplers will require the experience of other linac communities.

The future intention to add a second injection line (dedicated source and RFQ) for heavier ions with m/q = 6 has also to be kept in mind, particularly in the design of the RFQ/SC-linac interface, and in the choice of β values for the cavities.

6 REFERENCES

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