A HIGH ENERGY GAIN DEUTERON LINAC

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Abstract

The beam dynamic simulation of the SARAF 40 MeV, 4 mA deuteron beam superconducting linac is extended in this work to 90 MeV for the EURISOL driver. It is designed for a high energy gain gradient with a moderate emittance growth, based on an end-to-end 3D simulation using a detailed 40 k macro particles distribution at the RFQ exit. The linac consists of 84 superconducting HWRs and one superconducting solenoid per two HWRs. The result average energy gain is 2.0 MeV/m. At the linac first cryomodule, where the β mismatch is high, the emittance growth is controlled by considering the bunch acceleration phase at each of the HWR coupled acceleration gaps.

INTRODUCTION

In this work, a linac lattice based on the SARAF linac is considered for the EURISOL proton and deuteron driver. The lattice is tuned to supply an efficient 4 mA deuterons beam, accelerated up to 90 MeV with only a modest increase in the beam emittance.

The simulation in this work starts downstream a 4 m long 176 MHz RFQ. The linac lattice is then consists of three quadruples along the MEBT, two low energy cryostats containing six HWR of β_0=0.09 [1] each, five medium energy cryostats with eight HWR of β_0=0.15 at 176 MHz [2], and four high energy cryostats with eight HWR of β_0=0.31 at 352 MHz [3]. Each period in the cryostat consists of a solenoid followed by two HWRs, as described in fig. 1. The design includes minor modifications to the previous lattice [4] which are vital to the operation of the SARAF:

- The second cryostat was changed to β_0=0.09 HWRs in place of β_0=0.15, in order to reduce the β mismatch and to increase the energy gain for deuterons.
- A 6 mm diameter aperture, 20 mm long, was inserted at the RFQ exit to enable the required vacuum gradient along the MEBT.
- The solenoids 30 mm bore diameter was enlarged to 38 mm, to reduce beam loss risk.
- The medium and high energy 6 Tesla solenoid axial length, was increased by 30 mm to enlarge the solenoid effective length from 75 to 100 mm, in order to enhance the solenoid focusing strength.
- The space between each two consecutive modules was extended by 50 mm for diagnostic.
- The low β HWR RF Power Supplies (PS) were limited to an energy gain of 1 MeV per cavity while the medium and high β PS were not limited.

A preliminary beam dynamics evaluation for a lattice with further modifications, like the addition of a pre buncher in the MEBT is presented briefly at the end of this paper.

BEAM DYNAMICS

The initial distribution at the MEBT entrance is the output distribution of the 5 mA RFQ deuteron beam dynamics simulated using PARMTEQ [5] and normalized to 4 mA.

The MEBT quadruples field was adjusted using TRACE3D to enable smooth entrance to the first cryomodule with a beam transverse RMS size (x,y) of 2 mm, the typical transverse size along the cryostat, to eliminate mismatch ratio fluctuations instabilities [6,7].

The solenoid field of the low β cryomodule was taken from the manufacture cold test measurements [8]. The measured focusing strength (Bmax=6T, Leff=75mm) is not sufficient for the medium and high β modules. The solenoids parameters were evaluated and fit to minimize the integral of the square magnetic field along the solenoid axis, using analytic parameterization as found in GPT [9]. Based on these parameters the length of the solenoid for the medium and high β modules was enlarged by 30 mm in order to increase the effective length from 75 to 100 mm.

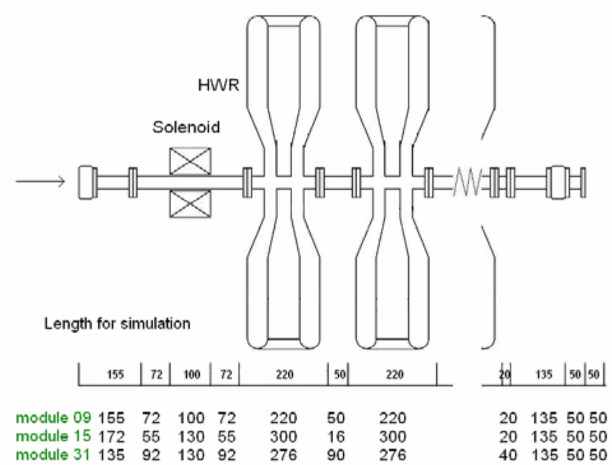

Figure 1: A period of one solenoid followed by two HWRs in the first cryomodule and a table of longitudinal dimension in the three types of modules.

The simulations in this work were performed using TRACK-35 [10]. The first HWR is used as a buncher with a low amplitude and mean phase of -90 degrees. The second cavity is turned off to enlarge the bunching distance. The first cavity tune enable convergence conditions at the third and fourth cavities so their synchronous phase near zero increases the energy gain through these cavities. The β mismatch conditions at the third cavity (β=0.056) shift this zero phase to an effective acceleration phase of -52 degrees at the first gap and +52 degrees at the second gap. Similar behaviour occurs at the fourth cavity. This shift moves the acceleration field at each gap to the linear acceleration region for the entire bunch particles. At the first cryo exit, using similar considerations, the last two cavities amplitude is decreased to 0.6 of the nominal value and their phases are -50 degrees and -20 degrees. At the second module entrance the first cavity phase is 60 degrees and the next one is 0 degree. From this point on the field phase varied around -20 degrees, excluding the entrance and exit module cavities. In those cavities the negative phase was enlarged (max value -28 degrees) to stabilize the particles transfer between modules.

The solenoid fields were adjusted according to the recommendation made by Ostroumov *et al.* [11]: use the minimum amplitude that is required to control the 'last particle' at the bunch. The transverse period was taken as the distance between consecutive solenoids according to the recommendation to keep the geometric period as small as could be reached [12]. These recommendations contribute to a reduction in the phase advance in each beam period which enhances beam stabilization. The beam transverse envelope size for 40 k macro particles simulation is kept under 0.9 cm were the bore radius in the cavities is 1.5 cm. The envelope radius is sufficient to eliminate the normal particle distribution (machine errors are NOT included) from reaching the bore radius. An addition significant reduction in the envelope radius might increase the phase advance per period along the linac and contribute to halo formation.

The longitudinal phase focusing was increased in order to enlarge the longitudinal acceptance and as consequence minimize beam loss due to introduction of random errors. The errors distribution data is given in table 1. The static errors are uniformly distributed at the range [-1, 1]. Phase and amplitude dynamic errors are described by a Gaussian distribution with the given RMS value, truncated at three standard deviations [10].

In order to study the effect of random errors, along the linac, 100 simulations were performed each with a different realization of the random errors.

The deuteron energy at the linac exit, 42 m downstream the 3 MeV RFQ exit, is 89.4 MeV. This energy gain is achieved with 1% increase in the RMS longitudinal emittance (fig. 2a) and 31% increase in the normalized RMS transversal emittance (fig. 2b). The phase advance per period for zero current along the linac is presented at figure 2c. Each period consists of a solenoid followed by two HWR. Between the first and the fifth period the periodic transversal phase advance is below the longitudinal one due to initial beam matching conditions at low beta. After the fifth period, at the end of the second cryostat untill the seventh cryostat the periodic longitudinal phase advance is below the transversal and the transversal phase advance is moderately reduced to well below 90 degrees. At the β_0=0.31 cryostats both periodic phase advances are in the order of 30 degrees. The maximum longitudinal bunch width is 40 degrees (fig. 2d) while the local synchronous phase is -20 degrees. The maximum envelope transversal size for the errors simulation is 1.1 cm, while the cavities bore radius is 1.5 cm (fig. 2e).

A second lattice was studied in this work. It includes a buncher with an enlarged MEBT. This enlarged MEBT enables the required cryostat vacuum to be achieved in more conventional manner and without the need to use an aperture at the RFQ exit, where beam particles can hit the aperture. The buncher fields are the HWR β_0=0.09 superconductor cavity fields at 27% of their nominal operational value. The feasibility of this value for a normal conductor cavity should be verified. The first and the second module include eight, instead of six, β_0=0.09 HWRs. In this way, the beta mismatch is reduced for the deuteron beam. The next four modules consist of eight β_0=0.15 HWRs at 176 MHz. The last five modules consist of eight β_0=0.31 HWRs at 352 MHz. With this 88 cavities lattice, the deuteron energy at the linac exit, 45.3 m downstream the 3 MeV RFQ exit, is 96.65 MeV. This energy gain is achieved with 18% and 30% normalized RMS emittance growth in the longitudinal and transversal spaces, respectively.

Table 1: Fabrication, misalignment and operation errors amplitude for static error & RMS value for dynamic error.

Error Type	**Tolerances at** [13]	**TRACK** (this work)
Quadruples		
Misalignments [x,y,z] (mm)	[0.1, 0.1, 0]	[0.1, 0.1, 0.1]
Z rotation (mrad)	0	1.5
Amplitude [static, dynamic](%)	[1, 0]	[1, 0.25]
Solenoids		
Misalignments [x,y,z] (mm)	[0.1, 0.1, 0]	[0.1, 0.1, 0.1]
Amplitude [static, dynamic](%)	[1, 0]	[1, 0.25]
HWR		*
Misalignments [x,y,z] (mm)	[0.4, 0.4, 0]	[0.2, 0.2, 0.2]
Z rotation (mrad)	0	3
Amplitude [static, dynamic](%)	[2, 0]	[1, 0.25]
Phase [static, dynamic](deg)	[1, 0]	[0.5, 0.125]

* A half range of these values were used at the 1st HWR

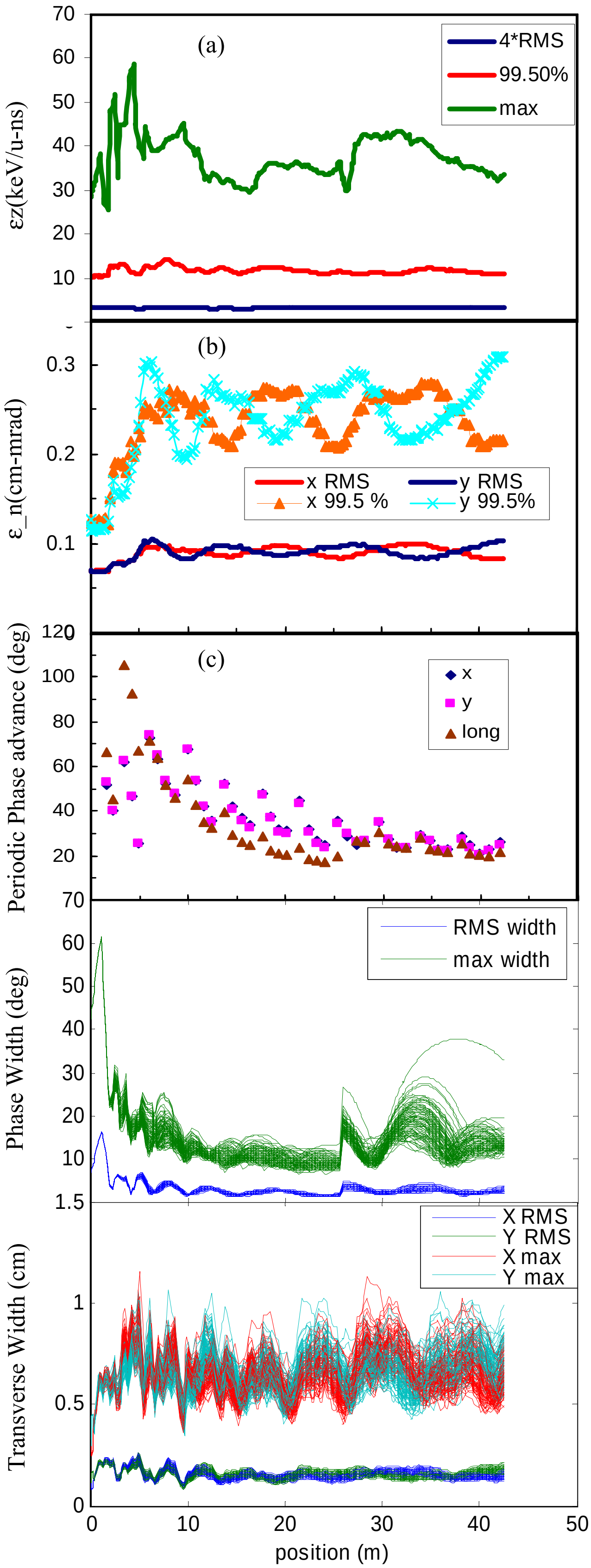

Figure 2: Beam dynamics simulation results described in the text as function of position along the linac starting at the RFQ exit.

SUMMARY

- The extended SARAF SC linac is a good candidate for an injector to the EURISOL driver with an average energy gradient of 2.0 MeV/m.
- The axial MEBT length could be enlarged if normal conducting bunchers at the MEBT are feasible.
- At the low beta range, a tune with linear acceleration field along the entire bunch width at both HWR acceleration gaps could reduce the longitudinal emittance growth.

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