BEAMS DYNAMICS END TO END SIMULATIONS IN IFMIF LINAC

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Abstract

The IFMIF project (International Fusion Materials Irradiation Facility) requests two linacs designed to accelerate 125 mA CW deuteron beams up to 40 MeV. After extraction and transport, the deuteron beams with strong internal space charge forces have to be bunched, accelerated and transported to targets for the production of high neutrons flux. This paper presents the reference design linac for this project. It is a combination of RFQ and DTL structure. Beams dynamics end-to-end calculations with errors studies and cavities design are detailed.

1 INTRODUCTION

The International Fusion Materials Irradiation Facility (IFMIF) requires generation, by a linear accelerator , of 250 mA continuous current of deuterons at a nominal energy of 40 MeV, with provision for operation at 30 MeV and 35 MeV [1]. The basic approach is to provide two linacs modules, each delivering 125 mA to a common target. This approach has availability and operational flexibility advantages.

The accelerators are comprised of a deuteron source ion source, a low energy beam transport to a radio frequency quadrupole (RFQ) up to 5 MeV, and a drift tube linac (DTL) to 40 MeV. A high energy beam transport system carries the beam from the accelerator to the lithium target. Very low beam loss along the linac is required in order that maintenance can be performed without remote manipulators. This study presents the reference design for the RFQ and DTL parts. The design of each cavity is shown. Beams dynamics with and without errors are detailed. This work is done for the fusion community and supported by the EFDA contract 2000/10 .

2 RFQ DESIGN

2.1 Cavity

The IFMIF RFQ is a four vanes structure. This ensures a minimum power consumption compared to coaxial RFQs. The cavity, designed with BELENOS [2], has a total length equal to 12.482 m and is segmented in three parts. Cavity segmentation ensures a efficient longitudinal damping of field errors [3]. This segmentation induces two resonant coupling gaps. The first gap is located at 4.161 m and the second one at 8.321 m. From mechanical considerations, in particular size of the welding furnaces, each segment is cut in four pieces of 1,04 m. The picture 1 shows a 3D view of the segmented IPHI RFQ [4]. The different parameters are summarized in table 1. It can be noticed that the final synchronous phase is -40 degrees. One may think that this value is too high and penalizes the accelerating efficiency of the structure. This choice induces appreciable margins for the longitudinal acceptance. This point is particularly relevant for such level of current. The high voltage (130 kV to 100 kV) compensates this high synchronous phase and allows a strong focusing.

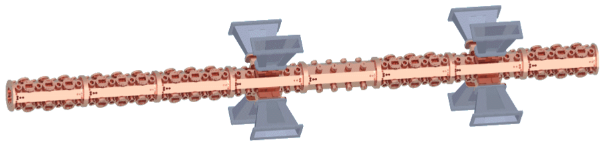

Figure 1: 3D view of IPHI segmented RFQ.

Table 1: Main parameters of IFMIF RFQ

Parameters	Values
Length	12.482 m
Frequency	175 MHz
Voltage	130→ 101.2 kV
Minimum aperture (a)	6.41→ 3.97 mm
Mean aperture (R_0)	6.41→ 5.16 mm
Modulation (m)	1. → 1.6
Transverse curvature radius (ρ)	$0.75\times R_0$
Synchronous phase (Φ_s)	-90°→ -40°
Peak field	1.8 Kp
Copper power (+20%)	683,9 kW
Beam power	613,1 kW
Total power	1297 kW

The figure 2 shows a SOPRANO [4] calculation for the transverse section.

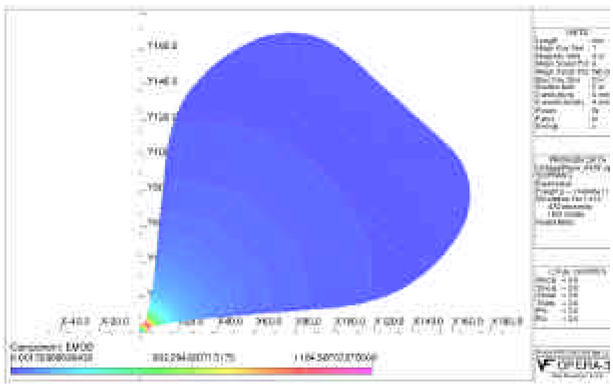

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Figure 2: Electrical map computed by SOPRANO.

2.2 Beam dynamics

In order to ensure the required 125 mA, a 130 mA current is injected. The input normalised rms emittance is 0.25 π.mm.mrad at 95 keV. These values are in agreement with the present performance of SILHI [1]. The table 2 shows the main results of simulation performed with the code TOUTATIS [6]. The output phase space distribution is plot in figure 3.

Table 1: Main performances of IFMIF RFQ

Parameters	Values
Transmission	97,9%
Transverse emittance growth X/Y	-1.2%/-0.4%
Output long. rms emittance	0.212 deg.MeV

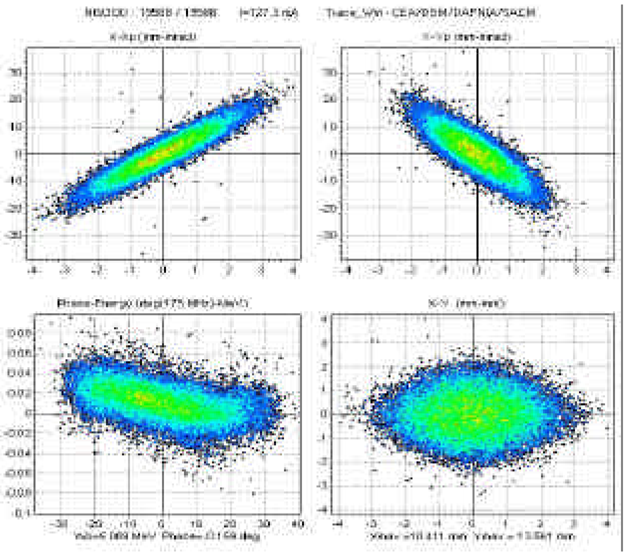

Figure 3: Beam distribution phase space at RFQ exit.

3 DTL DESIGN

3.1 Cavity

The DTL cavities has been designed with the GENDTL code [7]. The DTL part is comprised of 10 tanks. Each cell has been computed with SUPERFISH [8]. Main parameters (phase, field law) are computed by a step by step transport of a reference particle. The table 2 summarized the main parameters.

Table 2: Main parameters of IFMIF DTLs

Parameters	Values
Length (10 tanks)	31.8 m
Frequency	175 MHz
Max. Z_sT^2	39.53 MΩ/m
Maximum quad. gradient	74 T/m
Synchronous phase (Φ_s)	-45°; -35°
Peak field	1.3 Kp
Copper power (+20%)	1907,1 kW
Beam power	4550 kW
Total power	6.46 MW

3.2 Beam dynamics

The figure 4 shows behaviour of X and phase beam distribution along DTL tanks. No emittance growth and no loss are produced. This obtained output current of 127 mA fills the IFMIF requirements with a small margin.

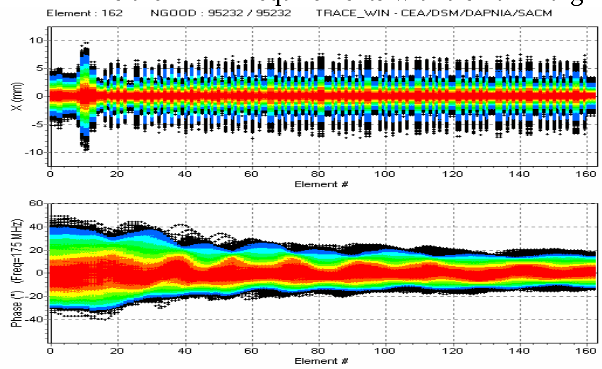

Figure 4: X and phase beam distribution along DTL.

4 ERRORS STUDIES

4.1 Strategy

The study is first uncoupled. Each defect is studied separately. For example, if the sensibility to error on the modulation until a value of M has to be tested, the range [0→M] is discretized in 10 steps: ten per cent of M, twenty per cent of M, ...For each step, one hundred linacs are generated with a randomly distributed error. The step is similar than machining step for each drawing.

Once this first study is performed, it is possible to find the maximum error amplitude for each defect. Finally, all errors are combined with a maximum excursion which has been determined in the first study. The combination is also discretized in ten stages of 100 linacs. At the end, it is easy to determined the required threshold for each defect.

4.2 Codes

The GUI for errors studies is TraceWin [9]. User can easily choose errors types: phase, voltage, field, segment or tank tilt and misalignment…The calculations are distributed on several computers via a client/server architecture (multiparameters scheme) [10]. Ten PCs have been used for the IFMIF linac study during two weeks.

4.3 Results

For the RFQ cavity, the machining defect and misalignment have been studied separately. The machining defect is simulated by a wrong transverse and longitudinal curvature. Misalignments are segments tilts, rotations, and shifts. The figure 5 shows emittances and losses growth in respect to a fraction of the maximum machining defect (100 µm). It can be noticed that below 60 µm, the performances are stable. The study for segment misalignments shows than a 120 µm error is acceptable. The combined study decreases the tolerances to 50 µm for machining and 100 µm for misalignment.

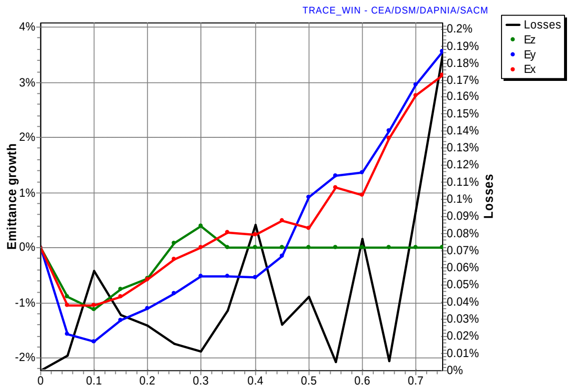

Figure 5: Emittances and losses growth in respect to machining defect (fraction of 100 µm).

The DTL and matching line defects are quadrupoles errors (displacement and rotation in three directions, gradient). To correct beam misalignments, a couple of steerers are placed into the last tubes of each tank and a couple of Beam Position Monitor (BPM) are placed between tanks. A first errors study gives tolerances of 100 µm for displacement, 0.25 ° for rotation and 1 % for the gradient.

Once each part has been studied, the whole linac is simulated. The figures 6 and 7 show the size of beam for 100 runs of 10 000 macro particles without and with full combined errors and correctors respectively. The red line corresponds to 90 % of the beam; the blue one 99%, and so one. The black line includes all the beam.

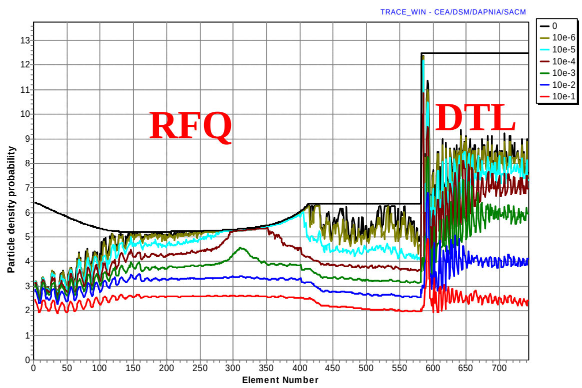

Figure 6: Beam size along the whole linac without error

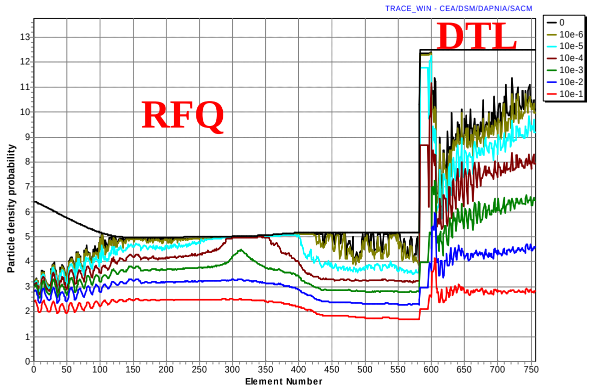

Figure 7: Beam size along the whole linac with full errors

The figures 8 shows the output beam distribution in phase space for the two cases (without errors case on top).

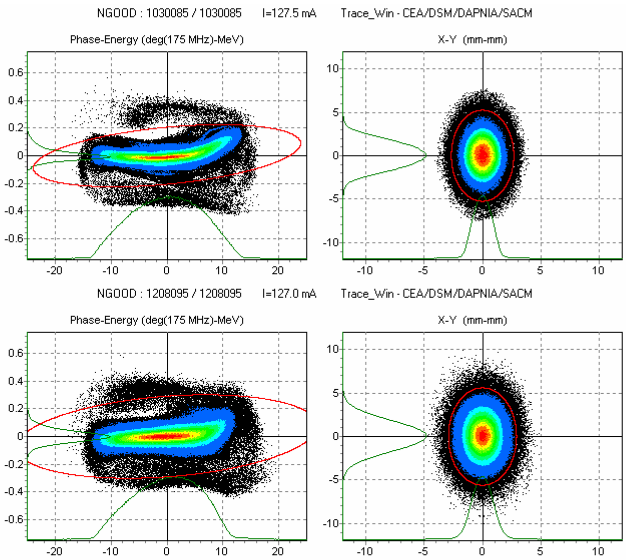

Figure 8: Beam distribution in phase space at linac exit.

The rms emittances growth is 50 % in the transverse planes and 14 % in the longitudinal one. No extra loss is produced with errors due the efficiency of the correction scheme.

5 CONCLUSION

A complete beam dynamics study in favour of IFMIF project is presented. The reference design fulfills the IFMIF requirements. With errors and corrections, the transmission is expected to reach 98 %. No loss occurs in the DTL part.

6 REFERENCES

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