DEVELOPMENT OF A HIGH CURRENT PROTON LINAC FOR FRANZ*

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Abstract

The FRANZ Facility, a planned worldwide unique pulsed neutron source, will be built at Frankfurt University. A single RFQ or an RFQ-IH combination working at 175MHz will be used to accelerate a 200mA proton beam to the energy which can meet the demands of required neutron production. The beam dynamics study has been performed to design a flexible, short-structure and low-beam-loss RFQ accelerator. The design results and relative analyses are presented.

INTRODUCTION

Using the $^7Li(p, n)Be^7$ reaction, the FRANZ (Frankfurter Neutron-Quelle am Stern-Gerlach-Zentrum) Facility is planned to produce extremely short (ΔT=1ns), intensive neutron pulses with the pulse repeat rate until 250kHz and the flux in the order of 10^7 /(cm^{2}s). Fig.1 shows the layout of the facility, which mainly consists of an ion source, a linear accelerating structure, a bunch system and a ^{7}Li target.

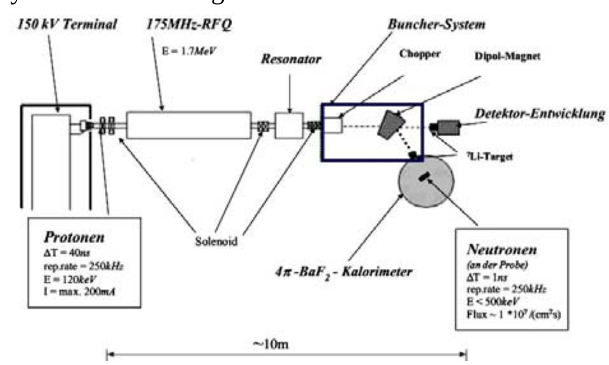

Figure 1: Layout of the FRANZ Facility [1].

The main acceleration of the proton beam will be done by a single RFQ or an RFQ-IH combination working at 175MHz. In the first case, the output energy of the RFQ will be 1.7MeV; otherwise it will be 1.0MeV. The RFQ beam dynamics studies for the two cases were both performed. The results will be shown in the next section, but the focus is put on the 1.0MeV RFQ.

RFQ BEAM DYNAMICS DESIGN

Based on the rapid development in the last two decades [2], RFQ has shown a great capability to accelerate high-current beams (for proton, typically several tens of mA) to ~ several MeV, nevertheless, to accelerate a 200mA beam like for FRANZ is still an unusual challenge.

Because of the special considerations for decreasing the very strong space-charge effects at the low energy end as well as for the ease of the possible downstream IH structure, the input energy is chosen as 120keV. At the same time, the rms, normalized transverse input emittance and inter-electrode voltage are properly adopted as 0.4 π mm-mrad and 100kV respectively.

The design strategy is mainly after the so-called New Four-Section Procedure [3], which has been also successfully used in the low-beam-loss design for a 50mA deuteron RFQ [4]. The basic concepts of this procedure are:

1) To control the speed of the beam bunching process for decreasing the longitudinal unstable particles;

2) To use a non-constant transverse focusing strength along the RFQ and to adapt it to the changing space-charge conditions in different positions of the channel.

Simulated by PARMTEQM [5] with 100,000 macro-particles, the beam transmission efficiencies for both cases are over 95% with acceptable emittance growths. The Kilpatrick Factors, which are both 1.68, are low and safe enough for the CW operation. The beam dynamics design results for the both cases are given in Table 1.

Table 1: Parameters of the two designs

Parameters	**Design-I**	**Design-II**
Particle	Proton	Proton
Frequency [MHz]	175	175
Input Energy [MeV]	0.120	0.120
Output Energy [MeV]	**1.700**	**1.000**
Inter-Electrode Voltage [kV]	100	100
Beam Current [mA]	200	200
Kilpatrick Factor	1.68	1.68
$\varepsilon_{in}^{trans., norm., rms}$ [π mm-mrad]	0.40	0.40
Synchronous Phase $_{out}$ [°]	-35.5	-39.18
Minimum Aperture [cm]	0.43	0.46
Maximum Modulation	1.76	1.63
$\varepsilon_{out}^{x., n., rms}$ [π mm-mrad]	0.50 (100%) 0.38 (90%)	0.51 (100%) 0.40 (90%)
$\varepsilon_{out}^{y., n., rms}$ [π mm-mrad]	0.50 (100%) 0.38 (90%)	0.58 (100%) 0.43 (90%)
$\varepsilon_{out}^{z,\ rms}$ [MeV-deg]	1.99 (100%) 0.18 (90%)	1.07 (100%) 0.16 (90%)
Cavity Length [cm]	324.38	221.31
Beam Transmission [%]	95.8	96.5

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The detailed output phase-space projections as well as the output phase- / energy-spectrum for the Design-II are demonstrated in Fig.2 and Fig.3.

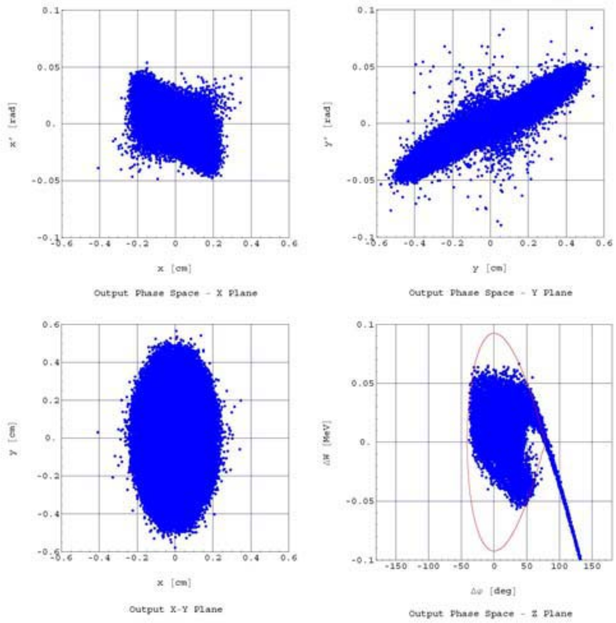

Figure 2: Phase-space projections at output (Design-II).

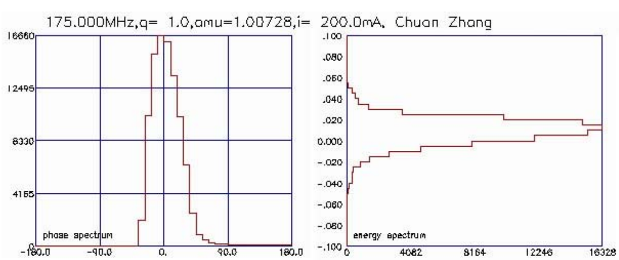

Figure 3: Phase- / energy-spectrum at output (Design-II).

Fig.4 shows the lost particle distribution for the Design-II (it has totally 112 cells) in a 3D picture, which shows not only the positions and the ratios of the beam losses but also the energies of the beam losses.

It is clear that:

1) The space-strong charge effects caused by the very high beam current are to some degree successfully controlled by the design strategy, though there are still some small beam loss peaks in the beam bunching (because the RFQ accelerator is expected to be short for saving costs, the bunching has to be still a little too fast);

2) The total beam loss is quite low, only 3.5%;

3) Most lost particles happen in the energy range of less than 400keV and just very few losses appear at the high energy end.

Therefore, this is a safe design, which will lead to a low risk of radioactivity from the reactions between the beam losses and the cavity wall. Then the maintenance and operation of the machine will be not too complicated.

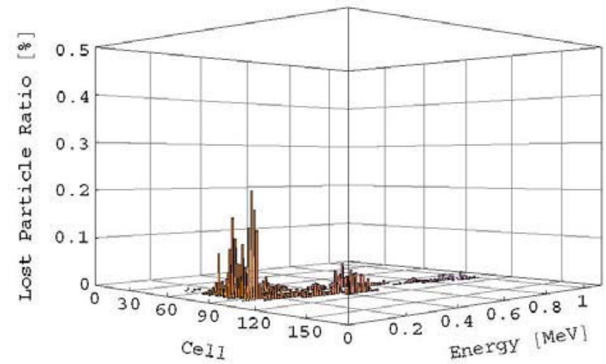

Figure 4: Lost particle distribution (Design-II).

DESIGN STABILITY TESTS

Because the conditions in reality could not be ideal as in simulation or some non-designed beams might be used for special purposes, many tolerance analyses about the 1.0MeV RFQ are made to check the stability of the design.

For the convenience of comparison, the sensitivity studies are started with the premises of fixing the designed electrode structure and varying only one input beam parameter at a time. Therefore, in most cases only the reference design has a matched input beam. The following results of the other designs for comparison could be a little better if the input beam parameters are adjusted to be matched.

Limited by the length of the paper, here only two main tests are introduced.

Firstly, the beam current is changed from 0mA to 300mA for every 25mA, and the beam quality as a function of beam current is tested. Fig.5 and Fig.6 show that the beam transmission efficiency and the transverse output emittance are not sensitive to the change of the beam current. Though the 100% longitudinal output emittance has a big increase at the high energy end, the 90% curve tells us that this is just caused a few additional lost particles. Essentially speaking, it is also stable.

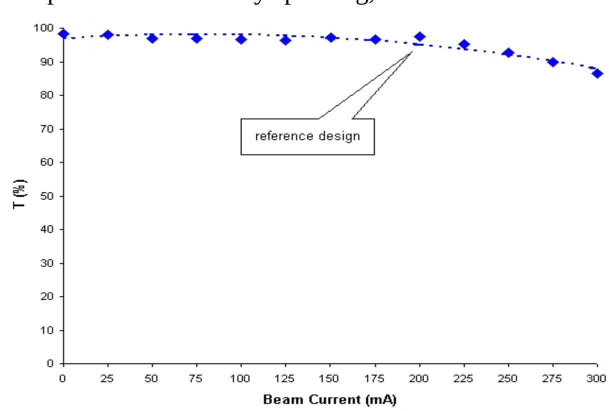

Figure 5: Beam transmission vs. beam current (Design-II).

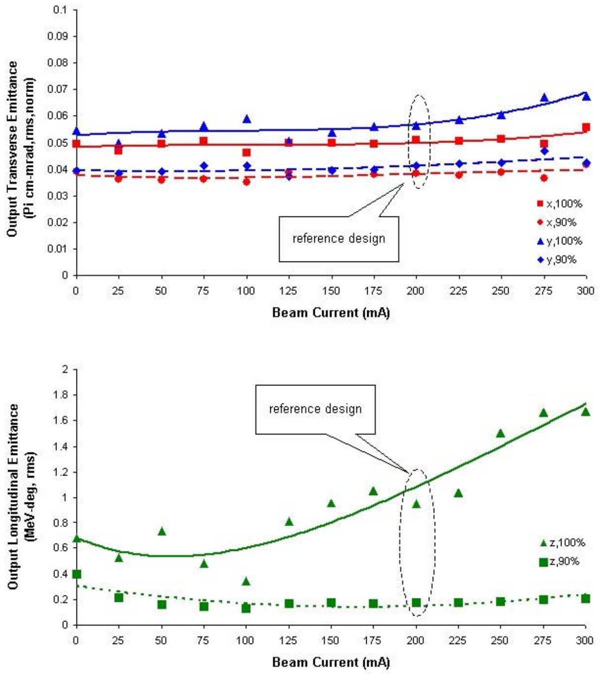

Figure 6: Transverse (top) / longitudinal (bottom) output emittance vs. beam current (Design-II).

Secondly, the influences from the variation of the unnormalized, real, transverse input emittance are explored. The design value of the transverse input emittance is 0.015 cm-rad, and the low and upper limits for the comparison values are 0.011 cm-rad and 0.029 cm-rad respectively.

Obviously, the beam transmission in Fig.7 is totally insensitive to the perturbation and it is still about 90% even when the transverse input emittance=0.029 cm-rad, nearly 2 times of the design value. It leaves a big margin for the ion source.

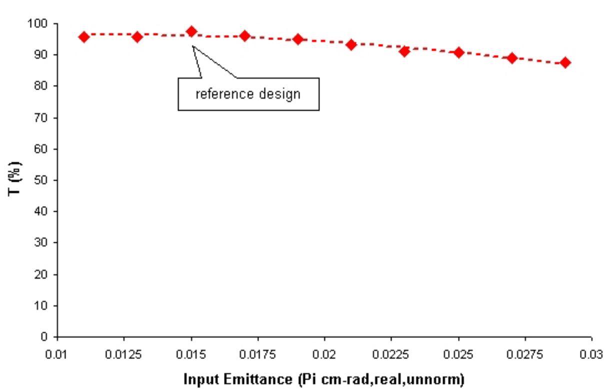

Figure 7: Beam transmission vs. input transverse emittance (Design-II).

Fig.8 shows the relationships between the input transverse emittance and the transverse / longitudinal output emittances (100% and 90%). We can see that:

1) The transverse output emittance is approximately linearly and slowly increasing with the increasing input transverse emittance;

2) The variation of the longitudinal output emittance especially the 90% one is fairly stable.

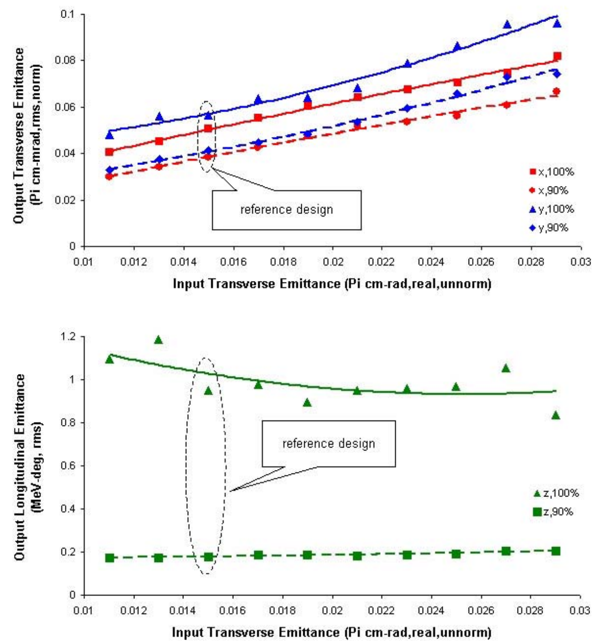

Figure 8: Transverse (top) / longitudinal (bottom) output emittance vs. input transverse emittance (Design-II).

To sum up, the analyses show that this 1.0MeV design is not sensitive to deviations from the design conditions.

CONCLUSIONS

The design studies of the 200mA FRANZ RFQ demonstrate that the RFQ is really an excellent low-energy linear accelerating structure even for an ultra-high beam current like 200mA if the structure is well designed. Also, it proves that the so-called New Four-Section Procedure is a useful approach to take advantage of the capacity of the RFQ accelerator furthest.

REFERENCES

[1] UniReport 2, J.W. Goethe-Universität, Apr. 12, 2006.

[2] Lloyd Young, “25 Years of Technical Advances in RFQ Accelerators”, PAC’03, Portland, Oregon, USA, May 2003, p. 60.

[3] C. Zhang, Dissertation, Peking University, 2004.

[4] C. Zhang, Z.Y. Guo, A. Schempp, R.A. Jameson, J.E. Chen and J.X. Fang, “Low-Beam-Loss Design of a Compact, High-Current Deuteron Radio Frequency Quadrupole Accelerator”, Physical Review Special Topics-Accelerators and Beams, Vol.7, 100101, p.1.

[5] LANL Manual of RFQ Design Codes (LANL Report No. LA-UR-96-1836), 1996.