THE IFMIF-EVEDA ACCELERATOR ACTIVITIES

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Abstract

The International Fusion Materials Irradiation Facility (IFMIF) aims at producing an intense flux of 14 MeV neutrons, in order to characterize materials envisaged for future fusion reactors. This facility is based on two high power CW accelerator drivers, each delivering a 125 mA deuteron beam at 40 MeV to the common lithium target. In the framework of the EU-JA Bilateral Agreement for the Broader Approach for Fusion, the Engineering Validation and Engineering Design Activities (EVEDA) phase of IFMIF has been launched in the middle of 2007. The objectives of EVEDA are to produce the detailed design of the entire IFMIF facility, as well as to build and test a number of prototypes, including a high-intensity CW deuteron accelerator (125 mA @ 9 MeV). The major components and subsystems will be designed and developed in Europe, and will be then assembled and operated at Rokkasho in Japan. The individual components are developed in Spain, Italy and France and an european accelerator team has been settled for the coordination of the accelerator activities. The design and the layout of the accelerator are presented as well as the development schedule.

INTRODUCTION

In the framework of the EU-JA Bilateral Agreement for the Broader Approach for Fusion, the EVEDA phase [2] of IFMIF (Engineering Validation and Engineering Design Activities) has been launched in June 2007. The objectives of the accelerator activities are twofold:

- to validate the technical options with the construction of a prototype accelerator (P.A.), which will be installed and commissioned at Rokkasho (Japan) ;
- to produce the detailed integrated design of the future IFMIF accelerator, including complete layout, safety analysis, cost and planning, etc.

In order to test thoroughly the technical options, the P.A. is identical to the final IFMIF accelerator, running at full beam current (125 mA), except that the high energy portion will comprise only the first accelerating module, resulting in a lower output energy of 9-10 MeV. It will include the ion source and LEBT, the RFQ, the matching section and the DTL, the transport line to a 1.2 MW beam dump, as well as the 175 MHz RF systems and the beam instrumentation, required for the tuning, commissioning, operation. From the IFMIF CDR [1], technical updates have been brought in order to optimise, with the present knowledge, the design of the entire linac. In addition to the RFQ, which looks now shorter, the major change is the switch from the room temperature DTL to super-conducting technology for the high energy portion of the linac and a linked complete redesign of the RF system.

INJECTOR

The injector has to deliver a 140 mA, low emittance deuteron beam with high reliability. An ECR type (Electron Cyclotron Resonance) ion source has been selected owing to its intrinsic high efficiency, high availability and limitless lifetime. Starting from the SILHI source, developed at CEA-Saclay, the extracted energy has been increased from 95 keV to 100 keV, then the extracted intensity from 150 mA to 175 mA in order to meet the 140 mA D^+ requirement (26 mA D_2^+, 9 mA D_3^+) as required. A four electrode extraction system allows an easy tuning to minimise beam losses and back-streamed electrons. In order to decrease the risk of sparking, the maximum electric field has been kept around 100 kV/cm at the expense of a slight emittance increase.

The baseline approach for the Low Energy Beam Transport (LEBT) is a dual solenoid transport system with space charge compensation. A total length of 2.10 m allows to include classical diagnostics (movable Faraday cup and insulated screens associated with cameras, current transformers, emittance measurement unit) as well as non destructive optical diagnostic based on residual gas fluorescence to measure steadily the species fraction by Doppler shift analysis. Numerical simulations, using a back-and-forth process between the TRACEWIN code and a specially developed code, capable of calculating the space charge compensation, showed that the required emittance (0.25 π.mm.mrad) at RFQ entrance can be met, provided that a Krypton gas is injected in addition to deuterium in order to better compensate the space charge effect (typically $P_{D2} = 1.10^{-5}$ hPa, $P_{Kr} = 4.10^{-5}$ hPa).

RFQ

The RFQ has to bunch the dc beam from the injector and to accelerate the beam from 100 keV to 5 MeV. The four-vane structure has been preferred to the four-rod structure because its ability to run in CW mode has been demonstrated and for a given field, the power consumption is lower. The peak surface electric field has been limited to the reasonable value of 1.8 x Kilpatrick's criterion, as a compromise between the risk of sparking and a minimal RFQ length, as well as a focusing strength, strong enough to compensate the high space charge forces. The final RFQ structure [3] is 9.8 m long and consists of three different functions: shaper, gentle buncher and accelerator (Figure 1). As activation of the RFQ cavity is of main concern for maintenance, extensive multi-particle simulations [4] have been performed to evaluate the loss of particles along the RFQ, as well as the non-accelerated particles which will be lost in the following matching section. Assuming an input beam of

0.25 π.mm.mrad rms emittance with uniform distribution, the output rms transverse and longitudinal emittances are 0.29 π.mm.mrad and 0.27 deg.MeV, respectively. The transmission is about 99% and the losses above 1 MeV are kept at a very low level. Any deviation from these ideal conditions will increase the losses in the RFQ and spoil the emittance. If one consider an input beam, of Gaussian distribution and 20% larger in emittance, the transmission drops to 92%., still acceptable.

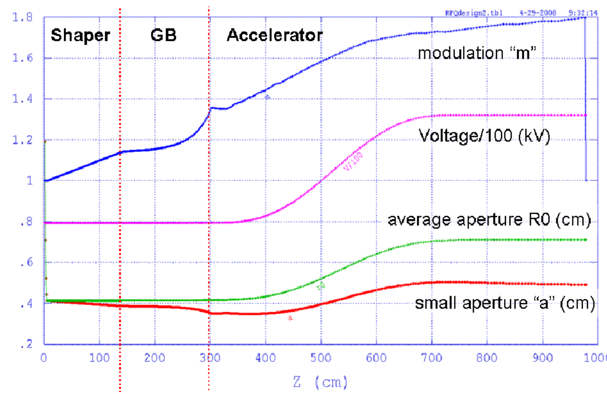

Figure 1: Main parameters along the RFQ.

An overall view of the RFQ with the location of the RF couplers and vacuum ports is shown in Figure 2. Field stability will likely be provided by segmentation (one coupling cell) and finger dipole correctors. The brazing technique will be used for the assembling of the different sections. The total RF power required is about 1.6 MW and will be delivered by eight 200 kW RF power sources.

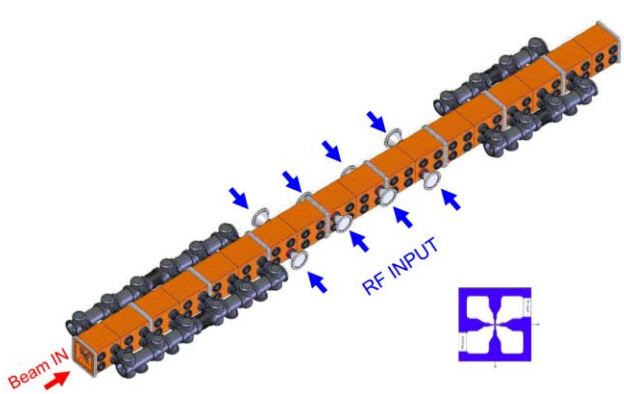

Figure 2: Overall view of the RFQ.

DTL

A Drift Tube Linac (DTL) has then to accelerate the beam from 5 to 40 MeV. While intensive activities on conventional Alvarez DTL have been carried out all around the world in the past decade, all these developments were done for lower beam intensity and pulsed operation, then for much lower average dissipated power. Since they could offer many technological and financial advantages (RF power reduction, leading to 6 MW saving on the grid; higher flexibility and reliability; mature technology and better suited to existing teams and industries; less sensitive to all machining and assembly errors) two other options, based on superconducting technology, have been under investigation [5]. The proposal, based on Half Wave Resonators (HWR) and close to existing and widely used technology, was finally selected for the EVEDA phase. The baseline design is the result of a conservative approach for both resonators (large aperture, moderate gradient of 4.5 MV/m) and focusing lattice (phase advance lower than 90°). Four cryomodules for an overall length of 22 m housing a total of 42 resonators are used to cover the acceleration from the RFQ (5 MeV) to the final energy (40 MeV). Table 1 lists the main parameters of the HWR Linac and Figure 3 shows an overview of a possible cryomodule design.

Table 1: Main parameters of the HWR Linac.

Cryomodules	**1**	**2**	**3 & 4**
Cavity β	0.094	0.094	0.166
Cavity length (mm)	180	180	280
Beam aperture (mm)	40	40	48
Nb cavities / period	1	2	3
Nb cavities / cryostat	1 x 8	2 x 5	3 x 4
Nb solenoids	8	5	4
Cryostat length (mm)	4.64	4.30	6.03
Output energy (MeV)	9	14.5	26 / 40

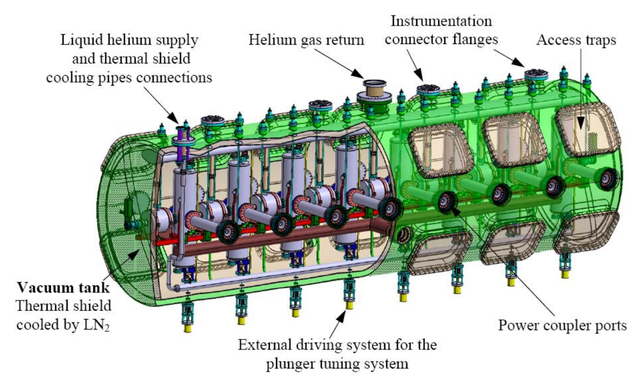

Figure 3: Overview of a possible cryomodule design.

Particle tracking simulations have shown that the HWR scheme can sustain very conservative alignment and field errors [6] while keeping a large safety margin between the beam occupancy and the pipe aperture (Figure 4). The first module only is included in the P.A. of the EVEDA phase, giving the output energy of 9 MeV.

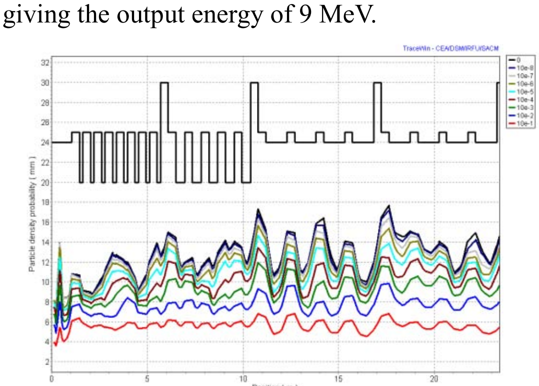

Figure 4: Particle density plot along the HWR linac, with errors and beam orbit correction.

RF POWER SYSTEM

Last, the RF Power System [7] is simpler and more reliable, because based on smaller and more conventional power units using tetrodes: 18 units of 105 kW and 24 units of 220 kW. As a positive side effect, these 220 kW units will also be used for the RFQ, standardizing the whole accelerator. In addition, the same RF chain is used for all power sources, only the high voltage power supply changes: one 400 kW HVPS feeds one 220 kW RF amplifier or two 105 kW RF amplifiers. In order to optimize space, maintenance and availability, a symmetric modular system, composed by removable modules with 2 complete RF chains each, has been proposed (Figure 5).

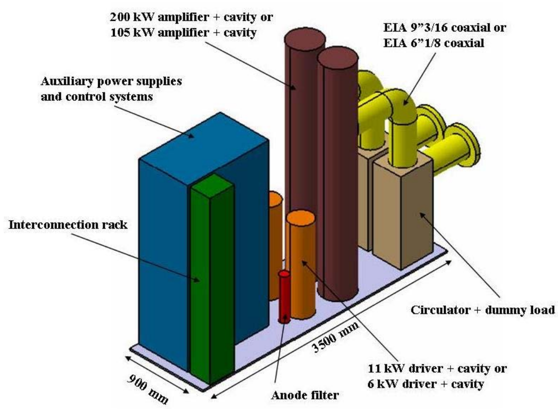

Figure 5: Removable RF power module

HEBT & BEAM DUMP

While the HEBT of IFMIF includes non-linear multipole lenses in order to achieve the beam footprint requirement (20 cm x 5 cm, uniform distribution) on the lithium target, the HEBT of the P.A. [8] includes the following elements (Figure 6): a first triplet to drive the beam through the 3 m diagnostics plate; a doublet to compensate the variations of the first triplet in case emittance measurement by means of the quad-scan method; a bending magnet (angle 20°) to avoid neutron back-streaming into the accelerator and to possibly measure the energy spread; a last triplet to expand the beam at the location of the downstream beam dump.

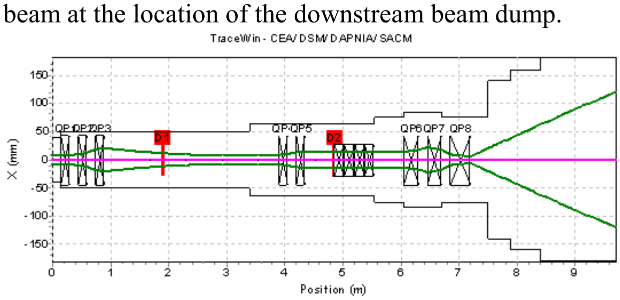

Figure 6: Layout of the HEBT of the P.A.

The EVEDA beam dump has to stop deuteron beams with a maximum power of 1.125 MW. While the profile of the beam power deposition depends on the geometry of the cartridge, the choice of the beam facing materials should take into account the neutron production and activation level, as well the thermal stresses [9].

DIAGNOSTICS

Beam instrumentation in the P.A. is essential to tune the linac and monitor the beam from the ion source to the beam dump, to minimize the beam loss and to characterize the beam properties. Furthermore, a complete set of diagnostics will be implemented at the exit of the HWR Linac, in the so-called Diagnostics Plate, for the measurement of the main beam parameters [10]: current, phase, position, transverse profile, energy, transverse halo, transverse emittance and longitudinal profile. Non interceptive transverse profile monitors are specially developed for the P.A. [11] and will be the first step towards the IFMIF diagnostics, required for the proper characterization of the beam shape near the target.

CONCLUSION

The layout of the P.A. in the vault of the building at Rokkasho is shown in Figure 7. The commissioning of the injector and the whole accelerator are planned to start at Rokkasho in October 2011 and June 2013, respectively.

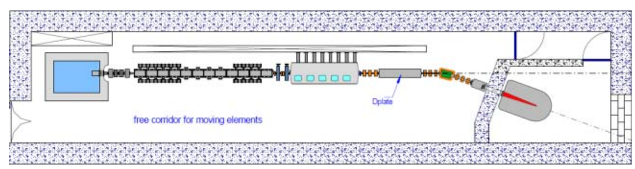

Figure 7: Layout of the P.A. in the vault at Rokkasho.

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