THE ACCELERATOR PROTOTYPE OF THE IFMIF/EVEDA PROJECT

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Abstract

The objectives of the IFMIF/EVEDA project 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). Most of the accelerator components (Injector, RFQ, Superconducting RF-Linac, Transport Line and Beam Dump, RF Systems, Local control systems, beam instrumentation) are designed and provided by European institutions (CEA/Saclay, CIEMAT, INFN, SCK-CEN) while the RFQ couplers, the supervision of the control system and the building including utilities constructed at Rokkasho BA site are provided by JAEA. The coordination between Europe and Japan is ensured by an international project team, located in Rokkasho, where the accelerator prototype will be installed and commissioned. The design and R&D activities are presented, as well as the schedule of the prototype accelerator.

INTRODUCTION

Constructed in the framework of a bilateral agreement (Broader Approach Agreement) between Euratom and the Government of Japan, the accelerator prototype of the IFMIF/EVEDA project aims at demonstrating the validity of the design and technology envisaged for the two accelerators (2x5 MW) of the future IFMIF facility [1]. It consists of the low energy part of one IFMIF accelerator (125 mA, 9 MeV) up to the first section of the SRF Linac:

- The accelerator components are designed, manufactured and tested by European institutions (CEA/Saclay, CIEMAT, INFN, SCK-CEN): Injector, RFQ, MEBT, Superconducting RF-Linac, HEBT and Beam Dump, 175 MHz RF Systems, Local control systems, beam instrumentation.
- The building constructed at the Rokkasho Broader Approach site (Japan), the auxiliary systems, the supervision of the accelerator control system, as well as the RFQ couplers, are provided by JAEA.

Due to lack of space, this paper could not report on beam dynamics studies, beam transport lines (MEBT and HEBT) beam dump and beam diagnostics.

ACCELERATOR COMPONENTS

The accelerator components (sub-systems) are designed, manufactured and individually tested in Europe, and then transported to Rokkasho for installation in the accelerator building, sequential commissioning and operation of the whole linac [2].

Injector

The injector [3] has to produce a 100 keV, 140 mA, low emittance deuteron beam with high reliability. The ion source is based on an electron cyclotron resonance cavity, excited by a 2.45 GHz magnetron. Simulations have been carried out to optimize the electrode number, electrode shape, aperture diameter and to minimize the electric field which has been kept around 100 kV/cm. The Low Energy Beam Transport (LEBT) is based on a dual solenoid focusing scheme, with a minimal length (2 m) in order to restrict the beam emittance growth. Because of the high current density, it is essential to achieve the proper space charge compensation, in order to meet the requirements (low emittance and matching conditions):

- injection of krypton gas to enhance the compensation
- electron repeller to extend the compensation zone up to the RFQ entrance

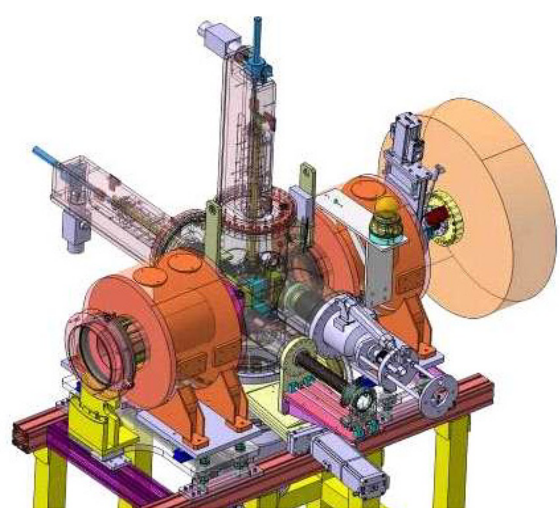

Figure 1: Schematic drawing of the Injector.

The assembly of the injector has started at the end of 2009 and first beam is planned at the end of November 2010 at CEA-Saclay.

Radiofrequency Quadrupole

The RFQ, which has to bunch the dc beam from the injector and to accelerate the beam from 0.1 to 5 MeV, is a four vane structure, well suited for CW operation. The optimisation [4] of the 175 MHz RFQ resulted in reduced length (9.8 m) and power consumption, with minimal beam losses at high energy (> 1 MeV). The cavity is composed of 18 x 0.55 m long modules flanged together (Figure 2). The peak surface electric field is limited to the reasonable value of 1.8 x Kilpatrick's criterion. The main parameters are listed in Table 1.

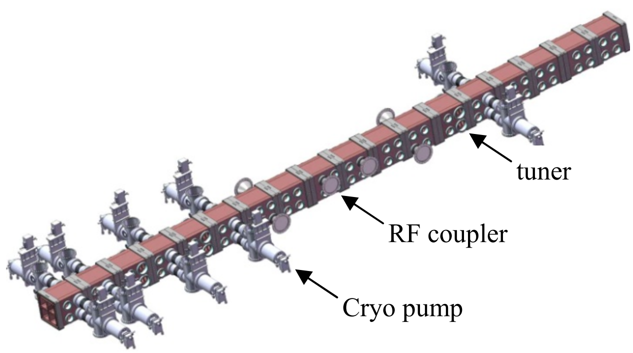

Figure 2: Schematic view of the RFQ with ports for cryo-pumps, tuners and RF coupler.

Table 1: Main RFQ Parameters

Particles	D+	
Frequency	175	MHz
Input current	130	mA
Input emittance	0.25	π.mm.mrad
Max Surface field	25.2	MV/m
Length	9.78	m
Voltage min/max	79/132	kV
R0 min/max	4.1/7.1	mm
Transmission (Gaussian)	96	%
Power dissipation in Cu	< 650	kW

An aluminium full scale RFQ model has been built to validate the tuning procedures and the mode stabilization by means of bead-pull measurements. The main technological processes [5] involved in the construction of the modules are: brazing in vacuum furnace, milling, deep drilling and EDM, plus various thermal and chemical surface treatments. The two functions vacuum tightness and mechanical connection are decoupled due to the relevant transversal dimensions of the cavity resulting on a very large diameter for a unique stainless steel bolted flange. A technological model, corresponding to two brazed modules, is under construction to check the main issues: brazing, mechanical connection, tightness, assembly, fabrication tolerances, etc. The first brazing results have shown that the construction process is adequate to guarantee the required precision in the final geometry. Power tests on a fraction of the structure, composed of 4 assembled modules, are planned at the beginning of 2012.

The 1.28 MW RF power is injected by 8 loop couplers, based on 6 1/8" RF windows. A detailed thermal analysis is required for the CW operation [6]. High power tests will be performed first with a high-Q load circuit at JAEA-Tokai and second with a dedicated test bench in TW mode at CEA-Saclay.

SRF Linac

The proposal, based on superconducting Half Wave Resonators (HWR) as an alternative to the initial Alvarez-type room temperature DTL was finally selected in 2008. The baseline design is the result of a conservative approach for both resonators and focusing solenoids:

- moderate accelerating field ≤ 4.5 MV/m and large beam aperture (40 mm) to allow max beam extension
- moderate focusing strength ∫ Bz dl ~ 1 T.m
- moderate alignment tolerances ± 2 mm for cavities and ± 1 mm for solenoids

The cryomodule (Figure 3) under construction for the accelerator prototype - the first one of the IFMIF SRF Linac - is about 5 m long and houses:

- 8 resonators (β=0.094) equipped with a capacitive tuning system (range ±50 kHz), a coaxial RF coupler (Qex=6.3 10^4) with a ceramic disk window;
- 8 solenoid packages, each of them including a superconducting magnet (field on axis B_z=6 T and residual field < 20 mT at cavity flange) with correction dipole coils and a Beam Position Monitor.

Two independent 4.5K helium cryogenic circuits cool down the cavities and the magnets while the thermal shield is cooled down at 80K by LN2 or 60K by GHe.

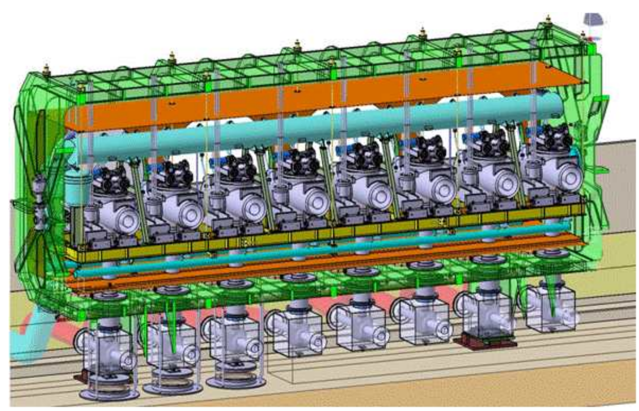

Figure 3: Overview of the EVEDA cryomodule.

Two HWR prototypes will be tested in fall 2010 while the start of integration of the whole cryomodule is planned at the end of 2012.

RF Power Sources

The RF Power System is composed of 18 RF power generators feeding the 8 RFQ couplers (200 kW), the 2 buncher cavities (105 kW) and the 8 superconducting half wave resonators of the SRF Linac (105 kW). The main components of each RF power chain are the Low Level RF system (LLRF), 3 amplification stages and a circulator with its load (Figure 4). For standardization and scale economies reasons, the same topology has been chosen for the 18 RF power chains: all of them use the same main components which can be individually tuned to provide different RF output powers up to 200 kW.

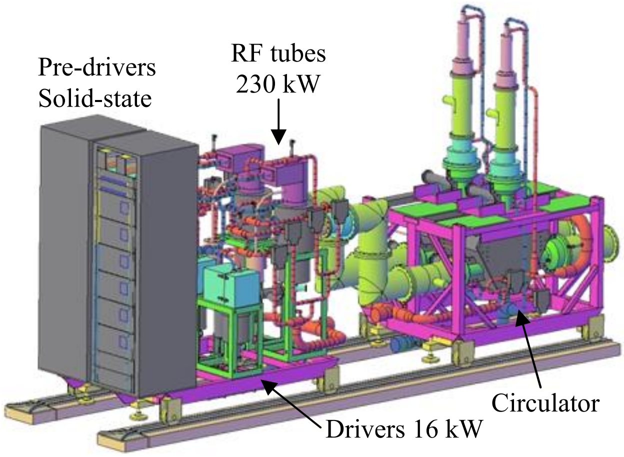

Figure 4: Schematic view of the RF power chain .

Though CW mode will be the normal operation, start-up and commissioning phases require pulsed mode operation, beginning with low power and low duty factor and finally switching to CW by extending the pulse length (repetition rate from 1 to 100 Hz, pulse width from 100µs to CW). The stability requirement are 1 % in amplitude and ± 1° in phase. A complete prototype RF Chain will be ready at mid-2011.

ACCELERATOR BUILDING

The specifications of the building had been drawn up in early 2008 and the construction has been completed in March 2009 (Figure 5). The building consists of an accelerator vault, a nuclear heating ventilation and air conditioning (HVAC) area, a heat exchange and cooling water area for both radiation controlled and non-controlled areas, an access room, a control room and a large hall for power racks, RF systems (HVPS and RF power chains) and 4K refrigerator. The accelerator vault is surrounded by 1.5 m thick concrete walls.

Figure 5: View of the Accelerator Building at Rokkasho.

In order to operate the accelerator remotely and to fulfil the safety conditions (personnel and hardware) compliant with the Japanese regulations, the control system is split up into six functional control subsystems [14]:

- Central Control System (CCS)
- Local Area Network (LAN)
- Personnel Protection System (PPS)
- Machine Protection System (MPS)
- Timing System (TS)
- Local Control System for each sub-system (LCS)

The main software will be EPICS, which fulfils the requirements in terms of reliability, robustness, availability, performance and user friendliness.

The commissioning of the first component (injector) and the whole prototype accelerator are planned to start at Rokkasho in September 2012 and June 2014, respectively.

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