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PRELIMINARY DESIGN OF THE IFMIF-DONES SUPERCONDUCTING LINAC

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Abstract

The linear accelerator for the IFMIF-DONES facility (DEMO Oriented Neutron Source) will serve as a neutron source for the assessment of materials damage in future fusion reactors. The DONES accelerator, which is based on the design of IFMIF/EVEDA LIPac (Linear IFMIF Prototype Accelerator, which is under construction in Rokkasho, Japan [1]) will accelerate deuterons from 100 keV up to 40 MeV at full CW current of 125 mA. This paper presents the preliminary design of the superconducting linac which is based on five cryomodules.

INTRODUCTION

The DONES Facility will be a Plant containing all the necessary buildings and systems to house and run an accelerator-based D-Li neutron source to produce high energy neutrons at sufficient intensity and irradiation volume to simulate as closely as possible the first wall neutron flux and spectrum of future nuclear fusion reactors. The Facility will produce a 125 mA deuteron beam, accelerated up to 40 MeV and shaped to have a nominal cross section in the range from 100 mm x 50 mm to 200 mm x 50 mm, impinging on a liquid lithium target 25 mm thick cross-flowing at about 15 m/s in front of it. The stripping reactions generate a large number of neutrons that interact with the materials samples located immediately behind the Lithium Target, in the Test Modules. Figure 1 shows a 3D Model of the DONES Facility.

Figure 1: 3D model of the DONES Plant.

The DONES Plant is composed of five major areas [2]: the Accelerator Systems (AS) devoted to produce the high power beam, the Lithium Target Systems (LS) were are produced the neutrons, the Test Systems (TS) which include the irradiation test module(s) and the Test Cell, the Central Instrumentation and Control Systems (CI&CS) gathering the systems in charge of performing the global control of the Plant, and finally the Site, Building and Plant Systems (PS) which includes the buildings and the systems providing power, cooling, ventilation, remote handling of components and services to the other systems.

THE IFMIF-DONES ACCELERATOR

IFMIF-DONES baseline engineering design is based on the IFMIF engineering design developed in the framework of the EDA phase of the IFMIF/EVEDA project [3]. The low energy section of the IFMIF-DONES accelerator is similar to the IFMIF/EVEDA one: the Injector System produces and extracts a 140-mA deuteron beam at 100 keV by its Electron Cyclotron Resonance ion source. A Low Energy Beam Transport (LEBT) section guides the deuteron beam from the source to a Radio Frequency Quadrupole (RFQ) accelerator. This one bunches the beam and accelerates 125 mA to 5 MeV. The beam is injected through a Medium Energy Beam Transport (MEBT) section that conditions it in transverse mode with quadrupoles and in longitudinal mode with rebuncher cavities in order to properly match it to the superconducting linac where it is accelerated to a final energy of 40 MeV and directed to the neutron production target by a High Energy Beam Transport Line (HEBT). The HEBT, which consists of a series of magnetic optics elements, is required to tailor the beam to provide a flat rectangular beam profile on the flowing lithium target.

SRF LINAC LAYOUT

In order to minimize the beam losses to meet the 'hands-on maintenance' machine requirement, all the components of the linear accelerator as well as the distances between adjacent components are made as short as possible. This led to a very compact design of the accelerator. For the SRF Linac, distances between the successive components are subject to different constraints related to the RF coupler footprint, the amplitude of frequency tuner displacements, the flexible elements interleaved between the superconducting components, the room needed for the assembly and so on.

Thanks to the developments already performed in the IFMIF/EVEDA project, as-built dimensions of the SRF Linac components (low beta cavities, solenoids, RF couplers, cold-warm transitions, etc.) are available. Consequently, dimensions of the second cryomodule (equipped with low-beta cavities too) can be precisely defined, and those of the cryomodules equipped with high-beta cavities may be easily extrapolated.

By taking into account these as-built dimensions, lengths of 3 over 4 cryomodules of the reference SRF-Linacs [3] are increased. New beam dynamics studies performed with this updated design have given evidence of some weaknesses, mainly: beam losses in the cavities locally exceeds

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the acceptable threshold (1W/m) and accelerating fields of the cavities have to be increased by 10 to 15% to keep unchanged the output energy at 40 MeV, so that risks during operation are increased and RF power margins strongly consumed.

Among the various options envisaged to resolve these weaknesses, it has been decided to improve the SRF-linac design by adding a fifth cryomodule and using shorter high-β lattices (1 sol + 2 cavities) [4]. However, the first cryomodule of the SRF-Linac is intentionally kept similar to the LIPAc one. Other characteristics of the second cryomodules and the three lasts identical cryomodules (Fig. 2) are given in Table 1.

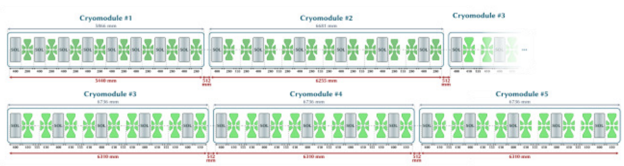

Figure 2: Layout of the 5-cryomodules SRF Linac.

Table 1: Cryomodules Parameters of the DONES SRF-Linac

Cryo-module	Output energy	Solenoids	Cavities	Type of cavities
CM1	8.3 MeV	8	8	Low-β
CM2	13.9 MeV	6	11	Low-β
CM3	21.3 MeV	5	9	High-β
CM4	30.3 MeV	5	9	High-β
CM5	40 MeV	5	9	High-β

CAVITIES, COUPLERS AND SOLENOIDS

Specifications for the low beta cavities, the power couplers and the solenoids of the new RFS-Linac design are identical to the LIPAc ones, as they are already proven to be achievable [5]:

- the cavities are all above the requirements (Q_0>5x10^8 at the nominal accelerating field E_{acc}=4.5 MV:m),
- the power couplers have been conditioned up to 100 kW CW which is enough for low beta cavities (more conditioning up to 200 kW is needed for operation of high beta cavities),
- the magnetic fields of the solenoids are within the specifications (1.1 T.m for the main coils and 3.51 mT.m for the H and V steerers).

Same results have been obtained during high power tests of accelerating units (HWR, tuning system and power couplers) in cryomodule-like configuration [6].

The other family of cavities for DONES is a 175 MHz high beta (0.18) half-wave resonator whose accelerating field is 4.2 MV/m and main RF parameters are summarized in Table 2.

Table 2: RF Parameters of the DONES High β HWR

Parameter	Value	Unit
Frequency	175	MHz
Optimum beta	0.18	
Nominal accelerating field Eacc	4.2	MV/m
Epk/Eacc	4.65	
Bpk/Eacc	8.03	mT/(MV/m)
r/Q	270	Ohm

The electric peak surface field Epk is located on the central drift tube area (Fig. 3). Its value is 19.5 MV/m at the nominal gradient (4.2 MV/m). The peak magnetic field Hpk is located in the stem with a value of 33.7 mT at the nominal gradient. Both electric and magnetic peak fields at nominal gradient remain under the ones of the low-beta cavity.

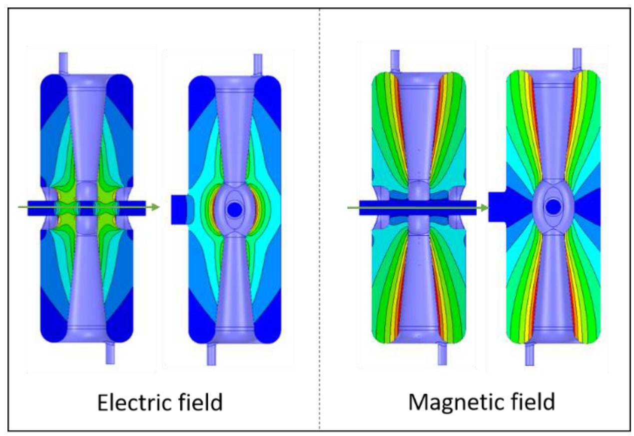

Figure 3: Field distribution in the high beta cavity.

CRYOMODULE DESIGN: LESSONS LEARNED

Considering our previous experiences of design and/or fabrication of QWR and HWR cryomodules (SPIRAL2, IFMIF/EVEDA, SARAF-Phase II) [7], it is concluded that the insertion of the cold load into the vacuum vessel following a "top loading" approach has several advantages with respect to the "side loading" one.

The principle of the IFMIF/EVEDA side loaded cryomodule and the process of the insertion of the cold mass has already been presented in [8]. It is a complex operation, which required dedicated tooling. Moreover, a number of operations is needed to complete the assembly, most of them being done through the small lateral access doors in the vacuum vessel: assembly of the current leads with the welding of the superconducting wires of the solenoid packages, completion of the helium circuitry, including pressure and leak tests, cabling of the sensors and actuators, installation of the multi layers insulation blankets on the cold mass, installation of some panels of the thermal shield. Finally, the closing of the vacuum vessel end doors is performed. This critical operation also needs a dedicated tooling to support the vacuum valves of the cavity string while approaching the several hundred kilos door.

The principle of the DONES top loaded cryomodule is presented in Fig. 4. The cold mass identical to the IFMIF/EVEDA one: A titanium frame supports the cavity string and a phase separator distributes liquid helium to the superconducting components and helium gas for the cooling of the outer conductor of the power couplers. The cold mass is hang to the top lid of the vacuum vessel thanks to titanium alloy tie rods and horizontal tie rods allows is horizontal positioning in the vessel. A thermal shield cooled with helium gas at 50 K limits the radiation load on the cold mass. A global magnetic shield protects the superconducting cavities against the background magnetic field in order to avoid trapping magnetic flux while cooling down through transition. Following the manufacturing of the IFMIF/EVEDA magnetic shielding and the problems of the interfaces with the vacuum vessel, it has been decided not to fix every panels of the magnetic shield on the vessel inner surface, but to have a "floating" shield between the vacuum vessel and the thermal shield [9].

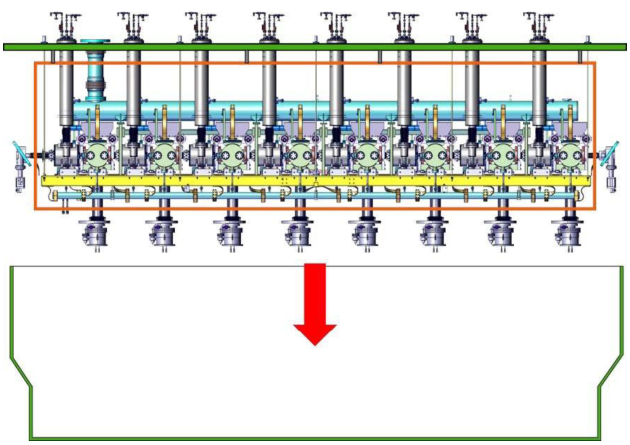

Figure 4: Conceptual design of the DONES cryomodule and principle of the insertion of the cold mass (upper mock-up) in the vacuum vessel (lower sketch).

With the top loaded configuration, it is important to assess the deformation of the support frame, the top lid and the vacuum vessel in order to respect the alignment tolerances of the cavity string. For the DONES cryomodule, the same methodology as for the SARAF cryomodule is used [10], starting with the design of the support frame.

Taking into account the assembly tests performed on mock-ups [11], the linear guide type used for the assembly of the cavity string in clean room is changed. Drylin® T type dust free linear guides are implemented on the support frame for the IFMIF/EVEDA cavity string assembly. However, solenoids and cavities did not slide as well as expected due to the small width of the rails. For DONES, it is planned to use Drylin® W type or equivalent. Therefore, the interface between the frame and the rails must be changed as depicted in Fig. 5.

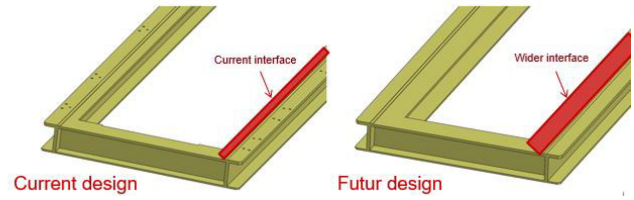

Figure 5: Widening of support frame interface for cavity string assembly.

Another change it is to design the frame with standard titanium plates and beams instead of special made I-beam as done on IFMIF/EVEDA frame. Mechanical studies are currently under way for design optimisation.

CONCLUSION

The design of the DONES cryomodules is based on the LIPAc cryomodule developed in the framework of the IFMIF/EVEDA project. Lessons learned during the manufacturing and the tests of the LIPAc components led to some modifications and improvements which are implemented in the new design of the DONES superconducting linac. This design is well advanced, and current optimized layout is still to be confirmed by beam dynamics errors studies.

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