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SACM

SERVICE DES ACCELERATEURS DE CRYOGÉNIE ET DE MAGNÉTISME

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CEA-DSM-DAPNIA-SACM Contribution to IFMIF

2004

1 Introduction

A neutron source from the Deuterium-Lithium (D-Li) stripping reaction has been selected as the basic concept of the International Fusion Materials Irradiation Facility (IFMIF).

The mission of IFMIF is to provide an accelerator-based, D-Li neutron source to produce high energy neutrons at sufficient intensity and irradiation volume to test samples of candidate materials up to about a full lifetime of anticipated use in fusion energy reactors. IFMIF would also provide calibration and validation of data from fission reactor and other accelerator-based irradiation tests. It would generate an engineering base of material-specific activation and radiological properties data, and support the analysis of materials for use in safety, maintenance, recycling, decommissioning, and waste disposal systems.

The objectives require generation by a linear accelerator (linac) of 250 mA continuous current of deuterons at a nominal energy of 40 MeV, with provision for operation at lower energy. The basic approach is to provide two linacs modules, each delivering 125 mA to a common target. This approach presents availability and operational flexibility advantages.

The Transition year(s) were initiated in 2003 with the objective of continuing the "Key Element Technology Phase" (KEP). The activities defined here concentrate on a follow up of the previous work, delivery to the other team of the previous works, transition meetings, reflection on the present design and it's possible evolution.

The IFMIF work is carried out at the CEA in the framework of a considerably larger activity presently undergoing in the field of high-intensity linear accelerators [1,2,3].

2 The reference design

The ion source generates a cw 140-mA deuteron beam at 95 keV. A Low Energy Beam Transport (LEBT) guides the deuteron beam from the operating source to a Radio Frequency Quadrupole (RFQ). The RFQ bunches the beam and accelerates 125 mA to 5 MeV. The 5 MeV RFQ beam is injected directly into a Room Temperature (RT), Drift-Tube-Linac (DTL) of the conventional Alvarez type with post couplers, where it is accelerated to 40 MeV.

The rf power system for the IFMIF accelerator is based on a diacrode amplifier operated at a power level of 1.0 MW and a frequency of 175 MHz. Operation of both the RFQ and the DTL at the same relatively low frequency is a conservative approach for delivering the high current deuteron beam with low beam loss in the accelerator. The use of only one rf frequency also provides some operational simplification. Beam loss in the accelerator is to be limited so that maintenance can be "hands-on", i.e., not requiring remote manipulators. However, the accelerator facility will be designed in such a way that remote maintenance is not precluded. As shown later, the DTL output beam is carried to the target by a High Energy Beam-Transport (HEBT) that also provides the desired target spot distribution tailoring and energy dispersion. This HEBT must perform a variety of functions, complicated by the presence of strong space-charge forces within the beam.

The design improved since the referenced CDA in 1996. Several options were evaluated, and the work lead to the selection of a single reference for each subcomponent. There is no showstopper in the present reference design, but it does not mean that this 10 MW accelerator will be easy to build. Each subsystem will have to be carefully built and assembled. The project remains the most powerful in the word. The reference design is based on a conservative basis for this reason, most of the subcomponents having been fully tested or used. The design did not significantly change during the year 2004. The most interesting points are a confirmation on some choices.

Even if the reference design exists, the delays observed in the process of decision can be profitably used in exploring new possibilities, which will have to prove there ability to replace the present choices.

2.1 The ECR Source

The ECR source was selected as a result of the IFMIF KEP development program. This choice has been validated after extensive parallel development in Europe (CEA-Saclay and Frankfurt) and in Japan (JAERI). It has been selected mostly because of its intrinsic availability compared to other source types, and its efficiency. No further development on the D^+ source is required.

We need to use H_2^+ particles instead of D^+ during the commissioning of the accelerator in order to minimise the activation during the tuning. Therefore work was provided on this basis in CEA-Saclay and IAP-Frankfurt. In both places, the results are not in accordance with the objectives. The source is optimized for atomic ions production and extraction; it remains extremely difficult to tune it for molecular ions production. Around 30 mA can be extracted at the cost of a big amount of other species.

Opinion was received that H^+ could be used by running the accelerator at half voltage, thus avoiding the need for H_2^+ injector which requires development. The Accelerator Team does not fully agree with this position as it ignores the most important aspect of reliability. At half-voltage, the accelerator is not at its operating condition. Extensive experience at LEDA showed that the most difficult conditioning and tuning problems occurred within 10% of the design conditions. The main (only ?) advantages of running H^+ is to check the obvious errors like quadrupoles misplugged or badly misaligned.

The requirement for an H_2^+ injector for commissioning and tuning will remain on the requirements list. This supposes the development of a new source, which has to start very soon in order to meet the requirement on time for the commissioning. As this new source will be used only during commissioning, it has to be easily plugged. Also one has to understand that the beam parameters (like emittance) will be different from the final source. A complete study will have to be made during EVEDA to assess the gain of such source. If no solution could be found, the commissioning will have to be made in pulsed mode to minimize the activation. The acceptable losses vs beam duty factor will have to be calculated by the safety group during EVEDA.

The whole accelerator has to be able to work also in pulsed mode, and this includes the source, the RF system and diagnostics.

2.2 Beam diagnostics.

The development of diagnostics continues but is clearly not sufficient. The IFMIF program may profit from other project like SPIRAL2 [3], IPHI [1] or SNS [4], J-Park [5] and GSI [6] in order to develop non interceptive diagnostics. Some techniques are promising like the Doppler shifted line analyses or the backscattered particles detection that will be use during the IPHI tests in Saclay, or the profiler based on residual gas ionization in use in GANIL.

Nevertheless the specificity of the IFMIF accelerators (very high beam power, low energy) makes the development crucial. They are also difficulties in finding good diagnostics for the longitudinal plane (transition RFQ-DTL and DTL tanks). It appears that the beam footprint monitoring instrumentation is not needed any more. This is a good point that needs to be clarified, as it is a crucial point at the intersection of 2 groups : target and accelerator.

Beam diagnostics specific to IFMIF have to be developed during EVEDA.

2.3 RFQ

RFQ are expensive components. They are also crucial to bunch and accelerate the beam. The output beam energy has been part of an optimization of the whole design, and decreased from 8 to 5 MeV in 1999.

There are 2 designs available, with similar performances. They were compared with different codes. It is important to know that only one of the 2 (the Saclay design) was used in the end-to-end error study performed by the Saclay group, including the HEBT [7]. Also the Saclay team has performed SUPERFISH calculations and 2D shape optimizations which provided good RF power consumption. The tuning knowledge of 4-vanes RFQ was a result of a strong CEA effort. It might be exported.

Two types of cavity were evaluated for the IFMIF accelerator: 4-vanes and 4-rods types. One can quote that:

- Four vanes structures are the less consuming structures
- Four rods RFQs show a very high peak power loss. The value cannot be easily managed and induces engineering difficulties and possible deformations in CW mode.

The Frankfurt team looked seriously in the 4-rod options and recommends using 4-vane RFQ.

Taking these results into account, we do not recommend changing from the 4-vane RFQ type.

The 2-D transverse section is completely defined [8]. The optimization leads to an RF consumption estimated to ≈1600 kW, "everything" included. One RF source has been saved.

The work that needs to be done concerns the RF coupling in the cavity (engineering), the optimization of the 3D extremities, detailed design and integration. A high power RFQ cavity load must be build. It will help the design and will be useful as a load for the RF system and coupling loop tests. Tests using beam injection should also be included. Obviously, if the budget profile allows a fully-constructed RFQ, time and money will be saved.

2.4 DTL

A good and conservative design exists. It was included in the multiparticle end-to-end beam simulations performed in 2003. A hot model had good success in proving the feasibility. This hot model was developed at 352 MHz with similar or stricter parameters.

Detailed design and integration have to be performed. Engineering prototypes at the right frequency for manufacture of the DTL is now required. The RF coupling to the cavity has also to be studied.

2.5 The IFMIF High Energy Beam Transport line

The HEBT was studied [8] based on the reference concept (multipole expanders). It reaches performances close to the requirements. Nevertheless the differences need to be validated by the target group.

The detailed design and integration of the line needs to be done. This will include the magnet specifications. The HEBT scrapers must be studied, and may have an impact on the line length (shielding).

We already know that the magnetic elements of the end part of the line will have to be aligned with concepts coming from the 4^{th} generation electron light machine. Their placement and displacement will have to be monitored with an active system (2 μm). A cheaper solution may exist with a raster scanner technique. A safe and rigorous system may be built with a good benefit for the project.

2.6 RF system

We now have at least one manufacturer able to deliver a 1MW CW tube at 175MHz. The tube was tested for more than 1000 hours on a dummy load with success.

The RF system remains the most expensive part of the accelerator. Therefore it is necessary to have a good control of the costing of these elements. We recommend to quickly developed, buy and test a full RF system. An experienced team is already working on this topics, it is a good point to maintain.

The test can be made on the RFQ hot cavity, with beam coming in (test of the RF low level, RF high level, and beam injection capability). This supposes the availability of a test stand, as always stated by the accelerator group.

2.7 *Miscellaneous*

- The first point concerns the test stand. As stated by R. Jameson: "Probably the largest "hole" in the EVDA definition is that the costs for the engineering validation tests assume the existence and underwriting of a powerful test facility, capable of installing and operating the D^+ and H_2^+ injectors, RFQ load cavity, complete RF system with one coupler, and beam diagnostics instrumentation (…/…) as a test stand".
- The safety analysis should start as soon as possible. It has a big impact on the accelerator and building designs. Experience with other projects showed that it may also lead to huge planning delays if not started on time. A call for work package was tendered by EFDA.
- The main beam parameters are defined at low energy. So, if one wants to qualify the accelerator, it is necessary to build and test a source, LEBT, full RFQ and the first tank of the DTL. This will have to be followed by a diagnostic line. Doing so, each sub-component is fully tested (the first DTL tanks is the most difficult one), as well as the transitions which are crucial in a high-intensity/high-power accelerator (space charge regime).

2.8 *Other development*

The project is a 2×5 MW beam power project. This is one of the most powerful projects in the world (with ILC- International Linear Collider). Therefore it was always based on conservative specifications. As the project is delayed, it might be interesting to support new developments like design based on superconducting cavities. This supposes that the new options MUST be compared at the level than the reference design, to be able to prove their advantages. The technical baseline will be frozen with the construction decision phase.

2.9 *Year 2004 - Review of the work*

During the year 2004, reviews were made on the present design, next R&D, schedule and costing with the Ad-Hoc committee and some of the accelerator team members.

One of the point explained by the Ad-Hoc Committee in the "technical assessment report" is that "In an aggressive realisation scenario it should be possible to shorten significantly the total time planned for the EVEDA, construction and commissioning phases (currently 15 years to full exploitation), which would be in the best interest of the Project's mission.". It is necessary to keep in mind that the EVEDA phase was proposed to allow a spreading of the investment over the years. It was also pointed out at the time of the suggestion that it could lead to a global cost increase.

3 Conclusion - Contacts list

We have a reference design. This design has to enter in a detailed study phase, with prototypes or final parts. Integration, RF system, engineering models have to be made. This supposes a major investment and a decision on ITER/IFMIF has to be pronounced. Such an "announce effect" might be crucial for the project.

The team needs to be reinforced, once the construction decision is made. The CEA is on a "waiting position". Even if the CEA-Saclay team is not directly involved in the near future development, they can answer questions that may arise on the linac design. The **main** contact persons are:

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