DEUTERON BEAM TEST FOR IFMIF

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Abstract

The IFMIF linacs are designed to accelerate 125 mA CW deuteron beams up to 40 MeV. The SILHI source designed to produce such CW high intensity protons or deuterons beams has been recently tested for the IFMIF project. More than 170 mA of deuteron beam have been extracted. In order to avoid neutron production in the Low Energy Beam Transport line the duty factor had to be kept below 0.2%. Dangerous neutron production level at the beam stop location was observed in less than 2 hours. Beam characteristics and neutron production in the LEBT are reported.

1 INTRODUCTION

Development of a practical fusion reactor requires significant progress with respect to a broad set of issues including environmental acceptability, safety and economic viability. In addressing these issues, development and qualification of radiation-resistant and low activation materials will be among the key factors. Materials required for the fusion reactor must be able to survive irradiation in a high intensity neutron flux with energy of 14 MeV and annual damage doses on the order of 20 dpa (displacements per atom.) and total fluences of ~200 dpa.

Concepts for an irradiation test facility suitable for identifying and validating such materials have been explored through a number of studies over the period of the last several decades. Having a potential to provide such a facility early in this century, an accelerator-based neutron source using the Deuteron-Lithium (D-Li) stripping reaction has been selected as the basis of the International Fusion Materials Irradiation Facility (IFMIF) studies [1]-[3].

IFMIF is a joint project of EU, Japan, the Russian Federation and the United States of America under the auspices of the International Energy Agency (IEA). In Europe, under the auspices of EFDA, the present results are under the contract EFDA 2000/10.

The deuteron production obtained with the source SILHI [5] injector of the IPHI project [4] is qualified and described in the next paragraphs.

2 IFMIF DESCRIPTION

The main specifications for the IFMIF facility are summarized in Table I. IFMIF is an accelerator-based D-Li neutron source for production of an intense flux of high energy neutrons within sufficient irradiation volume to enable realistic testing of candidate materials and components up to about a full lifetime of their anticipated use in DEMO and beyond.

Two accelerator modules operating in parallel will generate the required full value of the D^+ beam current. The two D^+ beams converge on the Li target, which consists of the target assembly exposing the flowing liquid Li jet to the beam and the Li loop that circulates the liquid Li.

Table 1 : IFMIF top level specifications.

Neutron Flux	≥ 2 MW/m2 (@ 500 cm3)
Operation Availability	70 %
D^+ Beam Current	250 mA (CW, 2 x 125 mA)
D^+ Energy	40 MeV
D^+ Beam Size	200 mm (w) × 50 mm (h)
Li Jet Thickness	25 mm
Li Jet Width	260 mm
Li Jet Velocity	10-20 m/s

Acceleration of high current CW D^+ beams (125 mA) has not yet been demonstrated, although recent experiments with the 100 mA CW proton beams at the LEDA in Los Alamos and the IPHI prototype under construction in CEA-Saclay represent a significant step towards this goal. In order to assure the high availability and reliability required for IFMIF, its key technology elements like the 125 mA D^+ linac and a continuously operating liquid Li system will require design and fabrication of suitable prototypes for performing the necessary endurance tests.

Table 2 : Availability requirement on the subsystem

Test facility	97.5%
Target facility	95.0%
Accelerator	88.0%
Conventional	99.5%
Central CS	99.5
Total (product)	80.7%
online/year	70%

The availability requirements of the overall facility push all the sub systems to their limits. The accelerator is supposed to be the most fragile element of the factory, but a constant effort is made to improve all accelerator components. Sources usually showed low lifetime, decreasing the overall accelerator availability.

The French IPHI project [4] is a high intensity proton injector dedicated to be a prototype of the low energy part of High Power Accelerators, including several tests for IFMIF. The IPHI objectives should lead to a great mastery of technologies and control concepts of rising generation of CW and pulsed high power accelerators.

SILHI (High Intensity Light Ion Source) is an ECR ion source developed since 1996 to produce high intensity proton and deuteron beams for the IPHI project. The SILHI main objectives are to produce 100 mA proton or 140 mA deuteron CW beam currents at 95 keV with rms normalized emittances lower than 0.2 π.mm.mrad. Experiments with SILHI are devoted to the production of deuterons for IFMIF, including reliability tests from 100h to 1000 hours [5]. These tests gave lots of information to optimise the source behaviour. Several weak points have been solved, leading to availability better than 99.5% over a 160h run. About one spark a day is observed with the full extracted beam.

3 DEUTERON TESTS

Neutron production was foreseen in the Low Energy Beam Transport (LEBT) line. The authorization to extract a pulsed deuteron beam has been obtained in June 2001 based on our experiment on the Saturne accelerator. At that time the duoplasmatron source was delivering up to 50 mA of deuteron at an energy up to 500 keV (1ms, 1Hz) without observing neutron production. On IPHI test stand, to minimize the neutron production (d,D reaction) the source was in pulsed running mode (2ms/s) with lots of voluntary breaks to minimize the activation. The experiment was done using the 120 mA proton extraction system and bad extraction condition in deuteron was expected.

3.1 Deuteron production

We observed excellent running conditions; SILHI source looks as well adapted for deuteron production as for protons. The source behaviour was very close to the proton production. The max extracted beam current was 170 mA at 100 keV, but with an ugly shape and a lot of beam noise (Figure 1).

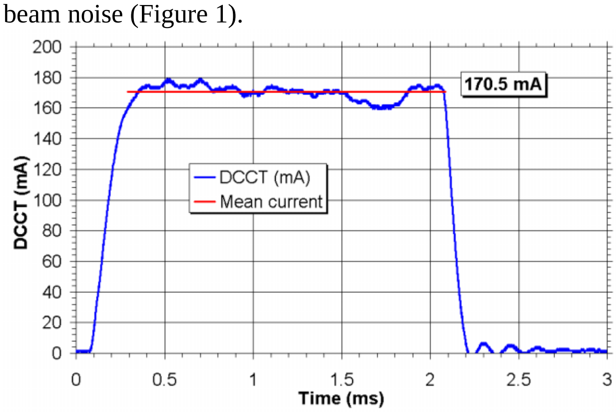

Figure 1: max extracted deuteron beam

A coherent set of measurements was made in order to get a good qualification of the beam characteristics. It consists in tuning the source in good running condition and doing simultaneously all the possible measurements. The results are:

- I > 130 mA (100 kV)
- D^+ > 96 % and D_2^+ < 4 % no measurable D_3^+.
- LEBT transparency = 75 %
- rms beam noise = 1.2 % (19 kHz)

Figure 2 shows the pulse measurement through the SILHI LEBT. In blue is the DCCT measurement of the extracted beam in the accelerator column. In red is the ACCT measurement, showing a better rising time since it has a much better bandwidth (see the beam noise paragraph). It shows also about 13% of beam loss at that point. This is due to the extraction electrodes adapted to a 120 mA proton beam. The last green curve is the beam stop measurement 4.4 m downstream the extraction aperture. It shows again some losses and the global LEBT transparency is only 75 %. This can be easily corrected to reach 100% with the appropriate set of electrodes. The rising time of the beam stop measurement is very low because of a filter.

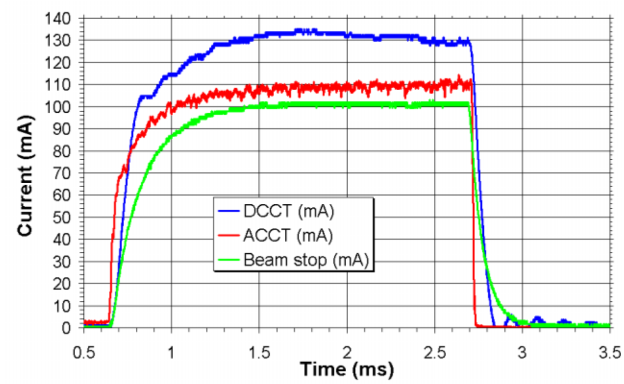

Figure 2 : 130 mA D^+ beam through the LEBT.

3.2 Deuteron proportion

SILHI source is equipped with 3 different species fraction measurement techniques. The most useful one is the Wien filter, part of the emittance measurement unit. The beam is stopped on a water-cooled copper target with a small tantalum aperture. Behind, a Wien filter selects the species and they are analysed on a biased wire. Figure 3 shows the measurement associated with the "coherent set of measurement" described above.

The 2 other techniques are a classical aperture-faraday cup measurement and a non-interceptive Doppler shift measurement.

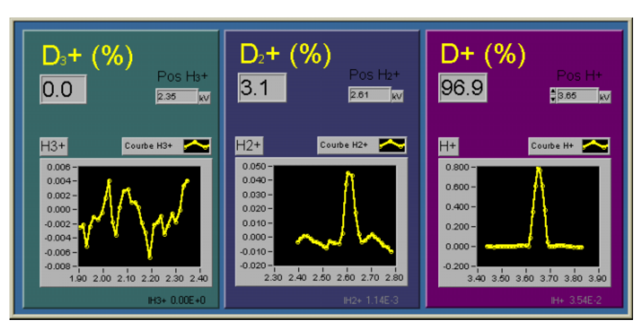

Figure 3 : typical deuteron proportion.

The 96.9% of D^+ species is much better that the classical 80% usually obtained in CW proton mode. In pulsed mode, the source is tuned with a lower gas pressure allowing the species fraction to increase.

Nevertheless, measurements in pulsed proton beam show that the species fraction is always better in deuteron production (96%) compared to proton production (92%). This observation is not yet understood.

3.3 Deuteron beam noise

The beam noise is measured using a 6MHz bandwidth ACCT, located between the 2 solenoids (about 2m downstream the aperture). Depending on the source tuning (pressure, ECR solenoid setting…) the rms beam noise is easily around 1.0% for good extraction condition ($80<I_{beam}<130$mA @ 100keV). This noise was deeply analysed, and is mostly due to the 19 kHz spaced lines induced by the magnetron power supply. Time raster plots are used to display long signal records versus time, and allow :

- Detection of isolated, out-of-range samples,
- Detection of minute, periodic pulses,
- De-interleaving of multiple pulse bursts

Accelerators people need a good qualification of the noise. They need to know not only the rms value but also the probability distribution function to which the numbers of noise random processes apply. Figure 4 shows such probability function, and one of the important point is to notice the deviation from a symmetrical signal (left picture) and the deviation from a Gaussian signal (right picture).

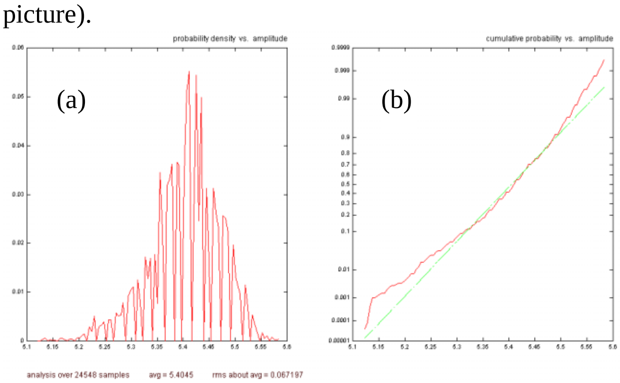

Figure 4 : (a) probability distribution function of the deuteron beam noise (1.2% in this case); (b) deviation from a Gaussian distribution represented by the green line

Checking noise amplitude distribution allow to :

- identify unsuspected noise sources,
- tune precisely the dynamic range of ADC's
- check for the linearity of these ADC's,
- quantify accurately the signal-to-noise ratio of the measurements.

The above results give an absolute value of rms beam noise compared to a “plus or minus” value, incompatible with the non-symmetrical distribution of the noise.

3.4 Activation

We ran the source for 2 days, 0.2% dc, with lots of voluntary breaks to minimize the activation. During the test, high-energy neutron production was checked with a specific probe (Bertold LB 6411). The observed reaction is the (d,D) reaction at the surface of the copper target, producing 2.45 MeV neutrons. Unless what was expected, the activation linearly and quickly increased to reach 11.5 µSv/h (1.15 mrem.h^{-1}) after 2 hours (measured 60 cm from the target). The saturation level was not reached at that time, but the level was already above the workers class B in CEA.

The neutron production is highly dependant on LEBT pressure (around 2×10^{-5} torr during the test) and this is the explanation of the difference between the Saturne duoplasmatron and SILHI sources. Fortunately, the neutron production stops with the beam (no detection without beam) and no activation was observed close to the target switching back to protons. It may become a serious problem for CW accelerator (IFMIF) on a mid to long-term scale because of the species fraction (D_2^+ and D_3^+ lost on the vacuum pipe).

The observed level of neutron production forced us to run in a discontinuous mode, stopping as often as possible. Each restart of the source resumes the neutron production to the previous level. The night gives only very little decrease in this production, while running a few moments in CW proton mode cleaned the surface by a heating process.

4 CONCLUSION

SILHI showed excellent running conditions in deuteron production. The source looks as well adapted for deuterons production as for protons, the behaviour being very close to the proton production. Up to 170 mA of deuteron beam was extracted in pulsed mode, and 130 mA in good condition. The neutron production in the LEBT rises rapidly to a dangerous level, and may lead to difficulties in the final IFMIF factory.

5 REFERENCES

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