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Design optimization and performances of New Sorgentina Fusion Source (NSFS) supporting materials research

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ABSTRACT

In the framework of fusion materials research, a neutron source has been considered a key installation to support EU plan toward DEMO reactor design. IFMIF facility being the present proposal, a pragmatic approach to EU fusion roadmap timeline considers complementary solutions mandatory, within a shared strategy. New Sorgentina Fusion Source (NSFS) has been recently proposed in order to populate an engineering database through materials irradiation tests. Proven technology of D–T neutron generators is implemented together with ion source and accelerator devices currently used in neutral injection systems at experimental tokamaks. Deuterium and tritium enriched hydride is on-line reloaded by impinging D–T beams via ion implantation onto a high-speed rotating target – D–T retention is allowed through temperature control. Hydride metal layer is re-deposited increasing plant availability factor. Target design is proposed to cope with thermal transients and mechanical loads. Solutions to thermal fatigue concerns are presented. Irradiation capability is then enhanced attaining relevant materials exposure. Main facility characteristics are provided as well as thermal and mechanical issues.

1. Introduction

Within the framework of European fusion technology program, a key issue for the validation of the DEMO design is the qualification of structural and functional reactor materials and components under relevant irradiation conditions. EU roadmap to fusion energy [1,2] intends to populate material database through irradiation testing of materials attaining the following irradiation levels by 2026: damage of about 30 dpa for structural steels, 10 dpa for copper and tungsten.

The agreement achieved at the international level on the need to build a dedicated large facility for this purpose, led to the definition of the IFMIF project which represents the ultimate solution to this problem. However, the time schedule for its construction suggests to undertake preparatory steps in order to make its exploitation faster and more effective. Present proposal intends to achieve this goal by means of a particular irradiation facility capable of providing neutron flux and fluence through a D–T spectrum which is expected for DEMO plasma facing components irradiation.

An intermediate and complementary facility, referred to as Sorgentina, has been proposed by ENEA with the aim of utilizing a D–T fusion neutron source to create a reference 14-MeV data library to qualify and validate irradiations performed through different neutron spectra, performing screening for material damage. Such a tool should be the calibration device for a European irradiation fleet utilized to maximize irradiation capability – even taking advantage of fission and accelerator-based facility spectra.

Among different proposals and designs, NSFS well-established technology and proved solutions are particularly perceived as positive and relevant features. In fact, shorter construction times and limited R&D programs allow ready solutions capable to cope with tight deadlines according to irradiation needs.

NSFS design strategy intends to implement robust solutions, taking advantage and properly improving previous RTNS-I and RTNS-II sources – successfully operated at LLNL over the past decades for fusion irradiation purposes.

Large rotating wheel technology is employed for water-cooled target. Moreover, accelerator and ion source components are implemented utilizing neutral beam injection systems

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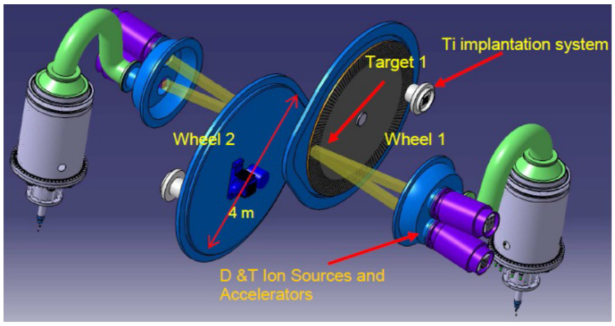

Fig. 1. General NSFS layout for beam accelerators and targets.

(NBIs) – currently used at experimental tokamaks. JET positive ions neutral injectors (PINIs) are considered in present facility. Therefore, critical source components rely – in this project – on well-established and already engineered assets.

Proposed NSFS project has been based upon a D–T neutron source made of two rotating targets facing each other (see Fig. 1). The irradiation zone is comprised in-between the two targets. Two ions beams (one deuterium and one tritium) deliver to a rotating target a power of 8 MW on both of two facing surfaces (16 MW on the two targets). A high irradiation zone of about 150 cm^3 and neutron flux of about 2.3×10^{13} n/cm^2/s producing about 2 dpa/fpy is available. In addition, volume up to 500 cm^3 is used for intense irradiation exceeding 1.5 dpa/fpy.

Target is covered with a thin metal hydride surface in which D–T ions are stored and continuously online reloaded by both beams ion implantation. In addition, metal hydride layer is online reformed via PVD techniques against beam current sputtering erosion. Both deposition and ion implantation reloading are the actual innovative design features for NSFS by which facility availability factor is extended – overcoming tritium target depletion of previous sources [3].

An enhanced design version is then described. It is possible to achieve average irradiation capability of some 3 dpa/fpy over 50 cm^3 and about 2.4 dpa/fpy over 500 cm^3. Maximum peak flux is 3.7×10^{13} n/cm^2/s.

Main facility characteristics and performances are described in present work. Thermal and mechanical analyses are reported as well as critical issues. In addition, the enhanced design is presented.

2. New Sorgentina Fusion Source design

NSFS facility layout is based on two rotating targets facing each other. Ion beams impinge on external sides through 10×20 cm^2 spots – neutron flux is collected in-between in a 3 cm gap irradiation chamber (see Fig. 1).

2.1. Ion beam stand

NSFS utilizes deuterium ion beam of 20 A impinging on the target together with 20 A tritium ion beam – yielding a 40 A total current on each plate – delivering 8 MW on each target – 16 MW total. Both deuterium and tritium beam energy is 200 keV in order to induce an optimal fusion reaction rate – high monoatomic yield is required for ion sources. PINI devices are thus expected to be optimized for that as in supercusp magnetic field configuration. Radiofrequency driven arc formation is planned to be implemented as well, in order to improve both monoatomic yield (approaching 100% yield) of the source and continuous source operation lifetime, reducing maintenance.

PINI sources operations with both deuterium and tritium ions have been successfully carried on – provided some dedicated gas loops and insertion flow mechanism modification. Minor design changes concerned use of all-metal seals and provision of pumped interspaces. Conversely, most extensive change regarded installation of a tritium and deuterium gas introduction system (TDGIS) supplied by a proper active gas handling system that share a secondary containment envelope.

Table 1
Beam stand characteristics.

Extraction voltage	200 kV
Extraction current	20 A (per beam)
Current density	0.1 A/cm^2
Current pulse duration	Continuous
Ion species	D^+ D_2^+ D_3^+/T^+ T_2^+ T_3^+
Ion species yield	~100:0:0 (RF source)
Operational pressure	0.3 Pa
Gas consumption	0.8 Pa m^3/s
Focal length horizontal	10 m
Focal length vertical	14 m
Beam divergence	0.5°

Assuming 200 keV the beam energy, grid gaps are optimized in order to reach current design levels fulfilling best beam perveance. Horizontal and vertical focal lengths may be optimized properly tuning aperture steering off set – in present evaluations they are considered as 10 m and 14 m respectively, as in JET standard configuration. Details are listed in Table 1.

In this regard, JET PINI injectors are currently operated at performances quite close to NSFS design parameters. In fact since 2003, octant 4 NBI has been operated with 6 tetrode 80 kV/52–58 A beam lines, 130 kV/60 A and 140 kV/30 A triode beam lines. Long pulse beam is a major concern impacting NSFS loading factor as well as all neutral heating systems at experimental tokamaks. Studies for next enhancements proved technical feasibility of longer pulses. Critical heat removal reduces global availability impacting several JET PINI beam-line components as neutralizer, ion dumps and beam scrapers. Conversely, in NSFS configuration only intermediate grids failure may induce plant performance reduction. Upgrade to continuous pulse is then considered feasible provided a minimum R&D phase.

2.2. Target design

Water-cooled 2 m radius rotating target is designed for fast rotation (1000 rpm) in order to accommodate and manage about 400 MW/m^2 thermal power density – which is thus turned into pulsed heating and related mechanical loads. Cooling is provided through the shaft and then by radial pipes providing water to small tubes inside plates (target) on outermost annulus of rotating wheel (Fig. 2).

D–T retention inside thin metal (titanium) hydride layer and online reloading feasibility [4] is strongly related to temperature behavior (limit around 400 °C).

Preliminarily thermo-mechanical evaluation of target performances have been carried out and a slice of the interacting plate have been analyzed (by 2D plain strain finite element (FE) model through the freeware software package CALCULIX [5]). At this stage, heat flux model considered is a square wave on–off and further evaluations will be carried out in next studies providing more details about beam shape of particular PINI device – being this approach coherent with a preliminary design. Moreover, calculations uncertainties are mostly related to input data provided by industries and technical offices in charge of customer consulting, and from literature wherever possible. In fact, at this design preliminary stage these details about results uncertainties has been considered sufficient and consistent.

Only one half of a single tube was modeled due to periodic and symmetry conditions. A water coolant pressure of about 30 MPa