Fusion Engineering and Design 96–97 (2015) 217–221

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Analysis of the thermomechanical behavior of the IFMIF bayonet target assembly under design loading scenarios

D. Bernardi[a,*], P. Arena[b], G. Bongiovì[b], P.A. Di Maio[b], M. Frisoni[c], G. Micciché[a], M. Serra[a]

[a] ENEA Brasimone, Camugnano, BO, Italy
[b] Dipartimento di Energia, Ingegneria dell'Informazione e Modelli Matematici, Università di Palermo, Viale delle Scienze, Palermo, Italy
[c] ENEA Bologna, Via Martiri di Monte Sole 4, Bologna, Italy

ARTICLE INFO

Article history:
Received 5 October 2014
Received in revised form
14 December 2014
Accepted 18 December 2014
Available online 12 January 2015

Keywords:
IFMIF
Target assembly
Bayonet backplate
Engineering design
Thermomechanics

ABSTRACT

In the framework of the IFMIF Engineering Validation and Engineering Design Activities (IFMIF/EVEDA) phase, ENEA is responsible for the design of the European concept of the IFMIF lithium target system which foresees the possibility to periodically replace only the most irradiated and thus critical component (i.e., the backplate) while continuing to operate the rest of the target for a longer period (the so-called bayonet backplate concept). In this work, the results of the steady state thermomechanical analysis of the IFMIF bayonet target assembly under two different design loading scenarios (a "hot" scenario and a "cold" scenario) are briefly reported highlighting the relevant indications obtained with respect to the fulfillment of the design requirements. In particular, the analyses have shown that in the hot scenario the temperatures reached in the target assembly are within the material acceptable limits while in the cold scenario transition below the ductile to brittle transition temperature (DBTT) cannot be excluded. Moreover, results indicate that the contact between backplate and high flux test module is avoided and that the overall structural integrity of the system is assured in both scenarios. However, stress linearization analysis reveals that ITER Structural Design Criteria for In-vessel Components (SDC-IC) design rules are not always met along the selected paths at backplate middle plane section in the hot scenario, thus suggesting the need of a revision of the backplate design or a change of the operating conditions.

1. Introduction

IFMIF (International Fusion Materials Irradiation Facility) is a high-flux neutron irradiation source which is currently being designed with the aim of providing the fusion community with a machine for testing candidate materials to be used in future fusion power reactors [1]. The IFMIF source basically consists of two accelerated deuteron beams (40 MeV, 125 mA each) which impinge on a liquid lithium target producing an intense neutron flux with a spectrum similar to that of D-T fusion reactions. Specimens of testing materials are placed behind the target (inside the test modules) in order to be irradiated under controlled conditions at a level above 20 dpa/fpy.

In the latest years, significant progresses have been made in the development of the European concept of the IFMIF target assembly (TA) (the so-called TA bayonet concept [2,3]) and its status is now in a well-advanced stage [4]. With the aim of evaluating the performances of the system and supporting its engineering design, a close collaboration with the University of Palermo has been established to perform the thermomechanical analysis of the bayonet TA under both nominal and design steady state conditions. The calculations have been carried out by means of a qualified finite element (FE) code implementing a realistic 3D model [5–7] which takes into account all the mechanical and thermal loads including the nuclear heating due to neutron and gamma fields generated in the liquid target. The latter have been calculated as part of a separate, extensive neutronic analysis carried out through the MCNP transport code and then passed as input to the thermomechanical model.

While the results of the analyses referring to nominal operating conditions have been presented in [7] and in [8] for steady state and transients cases respectively, the main outcomes for two selected design scenarios (a "hot" scenario and a "cold" scenario) are reported and discussed in this paper.

---

* Corresponding author. Tel.: +39 0534801118.
E-mail address: davide.bernardi@enea.it (D. Bernardi).

http://dx.doi.org/10.1016/j.fusengdes.2014.12.027
0920-3796/

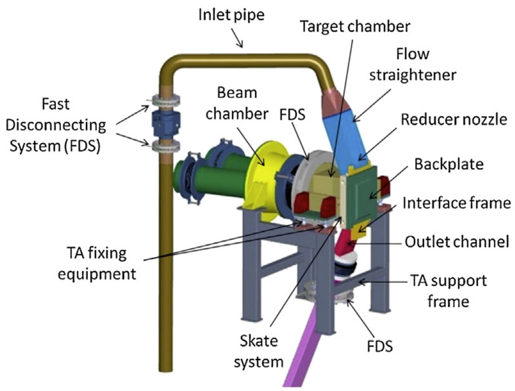

Fig. 1. European TA with bayonet backplate.

2. Finite element model

2.1. Geometry and mesh

A sketch of the latest design of the European TA with bayonet backplate (BP) is presented in Fig. 1. The FE discretization employed in the thermomechanical model is shown in Fig. 2. A mesh independency analysis has been performed to select an optimized mesh which allows accurate results to be obtained saving calculation time. A mesh composed of ∼207,000 nodes connected in ∼880,000 tetrahedral elements has been used, allowing numerical simulations to be carried out in about 9 h.

2.2. Materials

European reduced activation ferritic/martensitic (RAFM) steel EUROFER has been considered as TA structural material. Lithium flow has also been modeled in order to properly simulate its thermal interaction with the TA. Materials have been considered homogeneous, uniform and isotropic. A linear elastic mechanical behavior has been assumed for EUROFER steel.

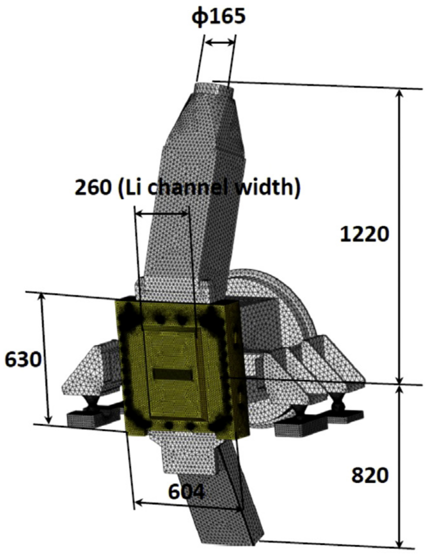

Fig. 2. Calculation domain and FE mesh. The BP is indicated in color. Dimensions are in mm. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

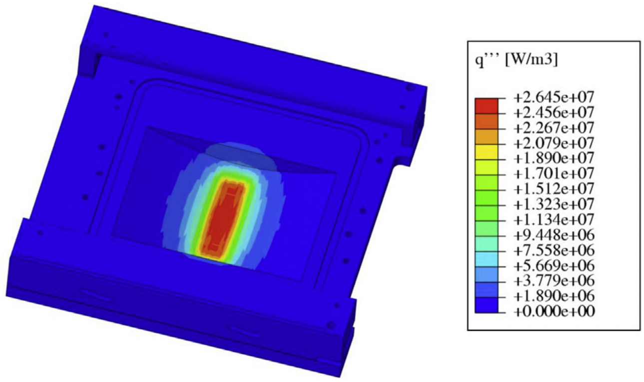

Fig. 3. Nuclear thermal power density deposition: detail of the BP.

2.3. Thermal loads and boundary conditions

The following thermal loads and boundary conditions have been adopted:

- Volumetric density of nuclear thermal power deposited in the footprint region of the lithium flow (only in the hot scenario, cf. Section 3.1). An average value of 40 GW/m^3 has been assumed.
- Volumetric density of nuclear thermal power deposited in the TA (only in the hot scenario, cf. Section 3.1), as calculated by a parallel nuclear analysis performed through the MCNP transport code (Fig. 3) [9]. Decay nuclear heating in the cold scenario (cf. Section 3.1) is not included since, being a time-dependent phenomenon, it cannot be reproduced by the steady-state analysis performed in this work. However, this represents a conservative assumption for what concerns the thermal configuration of the cold scenario.
- Forced convection between lithium and TA surfaces assuming a constant convection heat transfer coefficient of 34,000 W/m^2 K [7].
- Radiation and conduction heat transfer through the He gap between BP and high flux test module (HFTM) assuming $h = 0.1616/d$ W/m^2 K (d being the gap between BP parts and HFTM). HFTM surface has been considered at 50 °C.
- Conduction heat transfer between target chamber and beam duct. This has been modeled through a convective-type heat transfer coefficient assumed equal to 15.8 W/m^2 K according to [10], and a non-uniform bulk temperature analytically derived from a 1D simplified model of the conductive–radiative heat transfer in the beam duct.
- Internal radiation heat transfer between lithium free surface and TA internal surfaces. EUROFER and Li emissivities have been assumed equal to 0.3 and 0.06, respectively [7].
- External radiation heat transfer between target chamber and test cell (TC) environment and between external surfaces of BP and frame and that of HFTM [7].

2.4. Mechanical loads and boundary conditions

The following mechanical loads and boundary conditions have been imposed:

- Thermal deformations.
- Internal and external pressures on the TA. Internal pressure has been applied to lithium wetted surfaces according to the results of the thermohydraulic analysis [4].
- BP tightening screw loads. These loads have been calculated by imposing that the tightening forces exerted by the screws induce a specific linear load onto the gasket horizontal segments equal to the optimum sealing value provided by the supplier (180 N/mm).