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The high-heat-flux test facilities in the joint stock company "D.V. Efremov Institute of Electrophysical Apparatus"

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HIGHLIGHTS

- The IDTF was created for the high heat flux tests of the PFUs of the ITER divertor.
- At the present on the TSEFEY-M a brazing of fingers a FW semi-prototype is performing.
- The IDTF and TSEFEY-M facilities are ready for the HHF testing of the ITER components.

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ABSTRACT

The current ITER design involves beryllium and tungsten as plasma facing materials for in-vessel components. Due to a high number of operating cycles and to the expected surface heat loads, thermal fatigue is one of the most damaging mechanisms for the plasma facing components (PFCs) of the ITER machine. Therefore, it is essential to perform an assessment of the behavior of PFCs under cycling heat loads to demonstrate the fitness for purpose of the selected technologies.

This article summarizes the features of high heat flux facilities designed and constructed in the Efremov Institute for the performance of high heat flux (HHF) tests under ITER procurements as well as related R&D works.

The TSEFEY-M facility was commissioned in 1994. The main purpose of this facility is thermal fatigue testing of mock-ups with various plasma-facing materials (carbon fiber reinforced composite (CFC), tungsten, beryllium, etc.) and with various cooling agents (water or gas).

The ITER divertor test facility (IDTF) was created in the framework of ITER project, specifically for the HHF tests of the vertical targets (inner and outer) and domes of the ITER divertor.

After commissioning in 2008, the IDTF facility was qualified in 2012–2013 for HHF tests of ITER PFCs.

1. Introduction

1.1. Common purpose of the test facilities

- Investigation of local material damage caused by HHF surface loads, including short-pulse loads (thermal shock, melting, evaporation, etc.);
- Investigations aimed to improve the heat transfer coefficient of actively cooled elements subjected to a HHF load;
- Studies on lifetime of multilayer structures having high temperature gradients due to high thermo-mechanical cyclic loads and examination of various technologies requiring high level vacuum, temperatures, heating and cooling rates.

The designated purpose of both testing facilities is HHF tests of in-kind contributions of ITER in-vessel components from Russia to the project [3]. A difference between the facilities is that the TSEFEY-M facility is Be compatible.

1.2. The facilities key-components

Both facilities include the following key components:

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- Vacuum vessel and manipulator;
- Electron beam system;
- High-pressure hot water cooling loop;
- High-pressure helium cooling loop;
- Masks' cooling loop;
- Water purifier and water chemistry diagnostic unit;
- Diagnostic equipment and data acquisition system.

2. Vacuum vessel and manipulator

2.1 Vacuum vessels of both facilities are designed for unhindered pass of the electron beam from an electron beam gun to the test object.

The TSEFEY-M vacuum vessel is axisymmetric and consists of a 1.5 m diameter central cylindrical shell with two semi-elliptical covers. The volume of the vacuum vessel is about 4 m^3.

The volume of IDTF vacuum vessel is about 11.5 m^2.

2.2 Both vacuum vessels are equipped with water cooling. The thickness of the vacuum vessel's walls is sufficient in terms of personnel protection against possible X-ray radiation.

2.3 Manipulators of both facilities are used for fixation and movement of test objects inside the vacuum vessel.

Motions of manipulator's table are set by a cam rail and driven by the motogear mounted on the outer side of the vessel. High-vacuum bellows rotary motion feedthrough is used to ensure motions inside the chamber without any vacuum failure. The water supply to the test object is realized via flexible metal hoses.

One of the most important features of TSEFEY-M is that small and medium scale mock-ups (surface area up to 300–200 mm^2 and up to 10 kg in weight) subjected to HHF tests may be mounted onto the manipulator through the vacuum lock chamber. Employment of the lock chamber in combination with the manipulator allows prompt and reproducible replacement of tested objects without any vacuum deterioration. This aspect is particularly important for HHF tests campaigns of similar components. Large scale components (up to 700–500 mm^2 surface and up to 200 kg weight) are accommodated inside the vacuum chamber with the help of a target device.

Both manipulator and target device are equipped with inputs/outputs for the connection to the cooling system and diagnostics.

3. EBS 800/60 and EBS 200/40 electron beam systems

Electron beam systems (EBSs) are used in both facilities to generate an electron beam which creates thermal loads of an appropriate profile on the surfaces of tested components. EB systems for both facilities are designed and produced by Von Ardenne ANLAGEN-TECHNIK GMBH.

IDTF is equipped with EBS 800/60 consisting of the following key-components:

- High-voltage power supply system HS800/60;
- Electron beam gun (EBG) EH800V;
- Electron beam control system BGS-C1.

TSEFEY-M is equipped with EBS 200/40 consisting of the following key-components:

- High-voltage power supply system HS200/40;
- Electron beam gun (EBG) EH200V;
- Electron beam control system BGS-C1.

Table 1
Technical characteristics of the high-voltage power supply systems.

Parameter	IDTF	TSEFEY-M	Unit
Output power	0–800	0–200	kW
Accelerating voltage Ub	0–60	10–40	kV DC
Max. beam current Ib	16	5	A
Control accuracy dIb/Ib (0–10 s) ca.	5		%
Control accuracy dIb/Ib (long-term average)	≤1		%
Control accuracy dUb/Ub	≤1		%
Ripple (dUb/Ub) RMS	≤2.5		%
Filament heating supply Uf/If	0–10/0–65	0–10/0–40	V/A AC
Bombardment voltage Us	1.2–1.4	0.9–1.2	kV DC
Bombardment current Is	0–1.4	0–1	A
Control accuracy dUs/Us	≤1		%
Ripple (dUs/Us) RMS	≤1		%
Arc recovery time	100–250	50–250	ms

3.1. High-voltage power supply systems

The purpose of a power supply system is to supply and control the power of the electron beam.

Comparative technical characteristics of both systems are given in Table 1.

3.2. Electron beam gun

Both EBG EH800V and EBG EH200V belong to the category of high-power electron guns with the nominal power range of 10–800 kW. These are axial electron guns generating a rotary symmetric electron beam at the peak accelerating voltage of 60 kV (for IDTF) and 40 kV (for TSEFEY-M) and power of 800 kW (for IDTF) and 200 kW (for TSEFEY-M).

Both guns are located on the top of the facilities in the vacuum vessels.

Technical parameters of both EBGs are shown in Table 2.

3.3. Electron beam control system BGS-C1

This unit is the same in both EBSs.

BGS-C1 functions are the following:

- Control of lens No. 1 which focuses the beam after its passage through the gun anode hole and lens No. 2 which adjusts an electron beam spot diameter on the surface of a tested object.
- Determination and calculation of power losses in the gun by measuring the temperature gradient in the gun cooling system.
- Control of the deflecting system coils along two axes (X and Y) in order to obtain required power density distribution on the target surface.
- Power supply system interlocks in case of central control processor failure.

Beam guidance software has all the necessary options to control the electron beam parameters, including location, type, scanning scheme, exposure time, frequency setup, setup of the motion track and limits, and compensation for distortion. All configuration profiles are stored on the hard disk.

Technical characteristics of the BGS-C1 are given in Table 3.

4. Cooling loops

4.1. High-pressure hot water cooling loops

These loops provide parameters of the coolant (water) required for the appropriate high heat flux tests execution.

Main parameters of hot water cooling loops are reflected in Table 4.