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Structural analysis of large-scale SS collecting mirrors for ITER diagnostics

V.S. Modestov [a,*], I.D. Kirienko [a], I.V. Buslakov [a], I.N. Loginov [a], O.B. Shagniev [a], V.A. Lavrova [a], V.A. Senichenkov [b], E.E. Mukhin [b], A.E. Litvinov [b], D.S. Samsonov [b], S.Yu. Tolstyakov [b], N. A. Babinov [b], P.V. Chernakov [c], G.V. Marinin [d], D.V. Terentiev [d], R.S. Bulkin [d], S.M. Pashkovsky [d], A.N. Mokeev [e], S. Tanaka [f], P. Andrew [g]

[a] Peter the Great St. Petersburg Polytechnic University, 195251, St. Petersburg, Russia
[b] Ioffe Institute, 194021, St. Petersburg, Russia
[c] JSC Spectral-Tech, 194021, St. Petersburg, Russia
[d] Ltd "RUSSIAN TECHNOLOGIES", 195279, St. Petersburg, Russia
[e] Institution 'Project Center ITER' RF DA, Moscow, 123182, Akad. Kurchatova sq. 1, Russia
[f] Naka Fusion Institute, National Institutes for Quantum and Radiological Science and Technology, Naka, Ibaraki 311-0193, Japan
[g] ITER Organization, CS 90 046, 13067 St. Paul Lez Durance Cedex, France

A R T I C L E I N F O

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A B S T R A C T

ITER is a nuclear fusion research and engineering project. It is supposed to be the first fusion device designed for testing the integrated technologies, materials, and physical aspects necessary for development of the commercially available fusion-power plant. One of the important components of the project is optical diagnostic systems with collecting mirrors. These mirrors have to provide stability of optical systems under severe loads of different types that could possibly arise in the tokamak. The collecting mirrors of several ITER diagnostics have a large scale and should be installed into diagnostic ports. Thermal stress analysis of the mirror updated design is aimed to obtain deformation and rotation values of the mirrors' reflecting surfaces in order to conduct ray tracing analysis and to edit mirrors alignment to provide correct functioning of the optical systems. The maximum temperature values of the Divertor Thomson Scattering collecting mirrors were estimated for the normal operation mode. The FE model of the second mirror takes into account all the force boundary conditions, basic kinematic boundary conditions and constraints. Boundary conditions taken for the simulation were applied on surfaces contacting with the diagnostic rack. Thermally stressed state was calculated and corresponding displacement and rotation distributions were obtained.

1. Introduction

ITER Divertor Thomson Scattering (DTS) system consists of two main parts: Front and Back racks. They are mainly made as supporting structures of diagnostic subsystems and mounted on external interfaces.

Rack containing the ITER Thomson scattering system in-vessel components is attached to the vacuum vessel and to the lower divertor port.

DTS construction is designed to measure profiles of electron temperature and relative profiles of electron density in the outer divertor plasma by means of Thomson scattering method. In-vessel diagnostic elements are mirrors installed into front and back diagnostic racks [2]. DTS in-vessel elements including mirrors are made of 316L(N)-IG steel.

This report represents main and the most important results of the calculations made using ANSYS finite element modeling. The objects of this research are collecting mirrors under thermal loading. Their deformation and rotation values should be estimated in order to simulate properties of the DTS optical layout caused by mirrors' optical stability and structural integrity under thermal loading in the ITER Normal Operation mode. The explored system is shown in Fig. 1.

2. Thermal analysis

During ITER Normal Operation (THO), all diagnostic components including collecting mirrors will be subjected to the heating caused by neutron/gamma ray fluxes.

* Corresponding author.
E-mail addresses: vmodestov@spbstu.ru, vicmod@mail.ru (V.S. Modestov).

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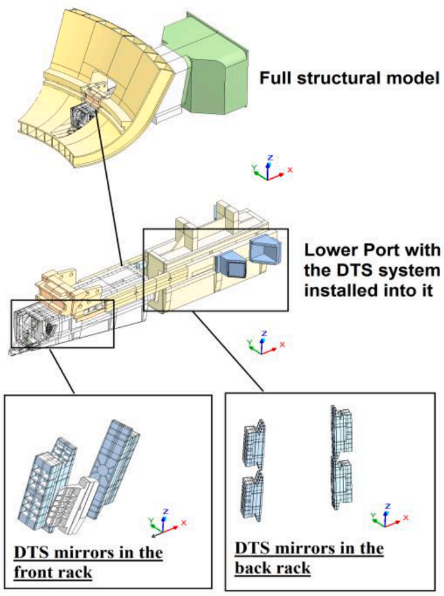

Fig. 1. Full structural model: parts of the vacuum vessel and lower port, DTS system latest design including collecting mirrors.

Normal Operation mode is represented with 10 cycles [1,4]; each of them consists of two sub-cycles (so-called heating and cooling). Heating is formed of three time periods: linear raise of the fusion power up to 500 MW (50 sec), maintaining it at the peak value (500 sec) and linear decrease down to the zero value (100 sec). Cooling between cycles (900 sec) means absence of any fusion power loads applied. Fig. 2 illustrates sequence of these cycles and a single cycle with timelines.

Distribution of nuclear heating power is presented in Fig. 3. Specific nuclear heating of the mirrors varies depending on their closeness to the fusion plasma.

Cooling channels with water at the temperature of 70 °C provide extra cooling of the DTS structures. Fig. 4 shows cooling water channels in the diagnostic front rack. Convection film coefficient is assumed as 1000 W/m^2•°C based on the values applied previously to the other systems.

DTS system is supposed to exchange heat with surrounding ITER structures such as Vacuum Vessel and Lower Port, where the DTS system is installed. Temperature of these structures is applied as 70 °C because they contain a system of cooling channels with the coolant temperature of 70 °C. Radiation power exchange between surfaces marked with yellow and blue in Fig. 5 was taken as a radiation boundary condition assuming the emissivity $\varepsilon = 0.25$.

Temperature maps for the collecting mirrors at the peak of the last heating cycle are shown in Fig. 6.

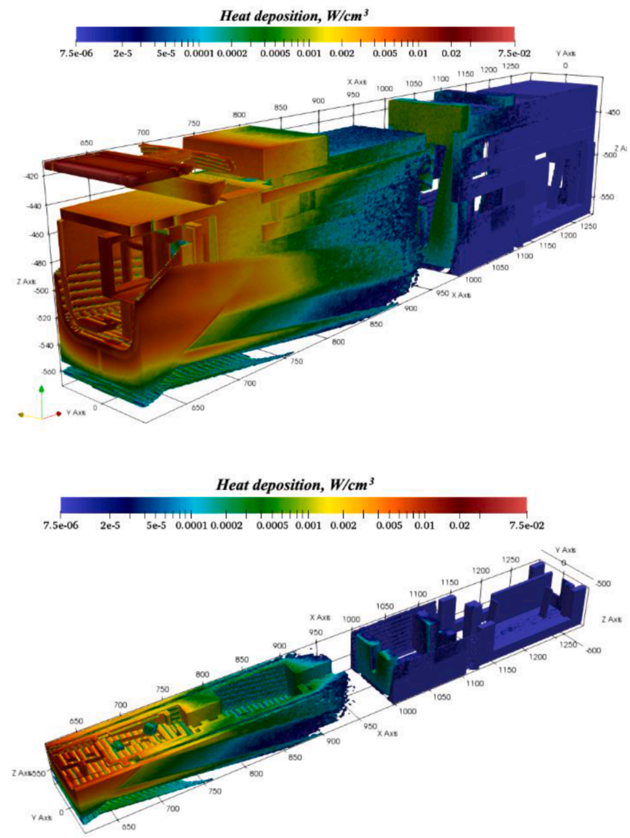

Fig. 3. Nuclear power density in the DTS system (above) and in its horizontal longitudinal cross-section (below), W/cm^3.

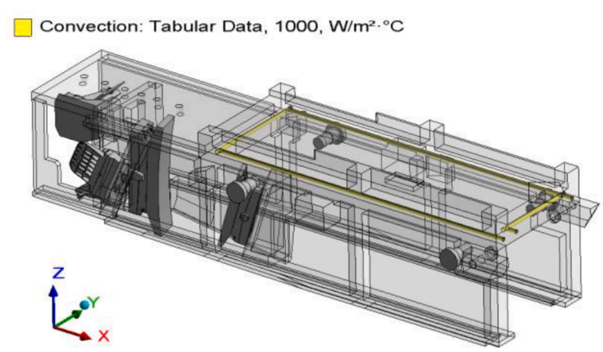

Fig. 4. Cooling water channels (yellow) of the front rack. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

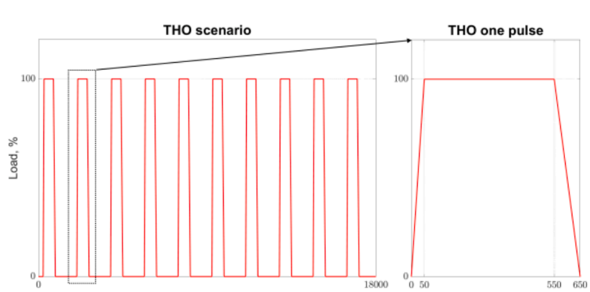

Fig. 2. Loading cycles during normal operation.

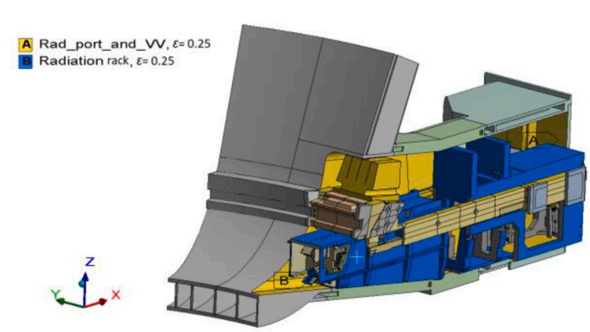

Fig. 5. Radiation boundary conditions.

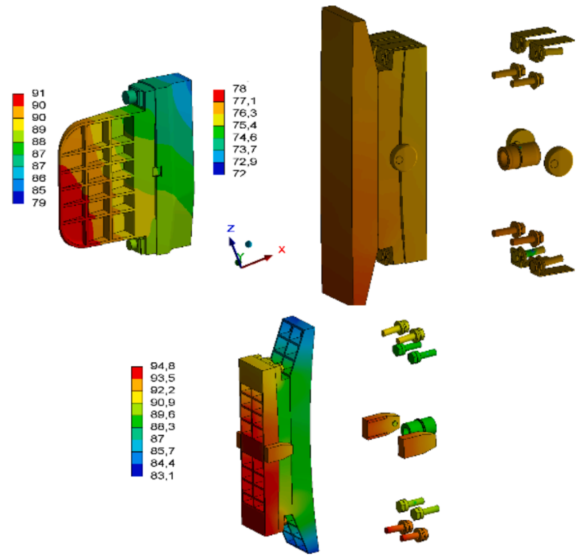

Fig. 6. Temperature distribution in the mirrors.

3. Thermo-structural analysis

Temperature distribution in collecting mirrors at the time moment with the highest thermal gradient was applied as a boundary condition in corresponding thermo-structural analysis. Translation, deformation and rotation of the mirrors' reflecting surfaces had to be estimated to become an input data for the ray tracing analysis and for development of mirrors alignment procedures providing correct operation of the DTS optical system.

Structural boundary conditions are represented in Fig. 7.

Displacements and rotations of the mirror surfaces were derived with the Multipoint constraint option of the ANSYS Workbench software. Deformations are shown in the local mirror coordinate system and include deformation values of the port as well. Fig. 8 and Fig. 9 represent 1st mirror coordinate system and directional deformations of its surface.

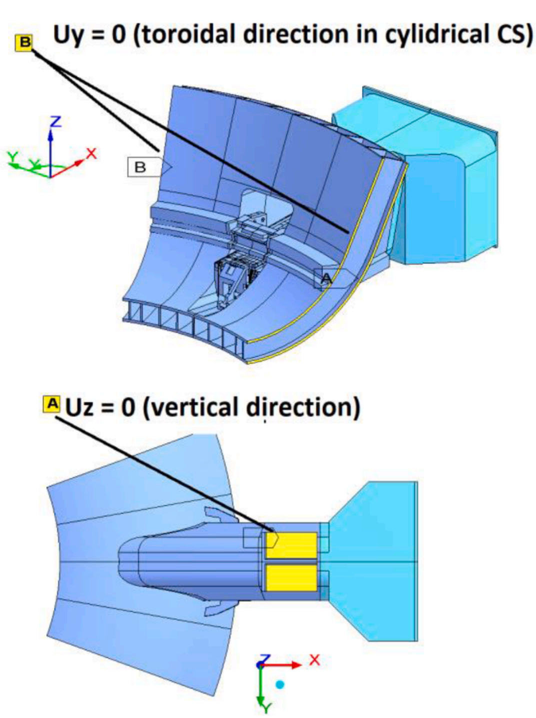

Fig. 7. Structural analysis boundary conditions.

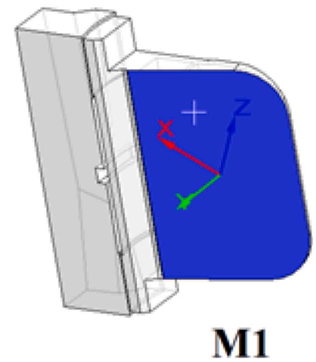

Fig. 8. Orientation of the 1st mirror coordinate system.

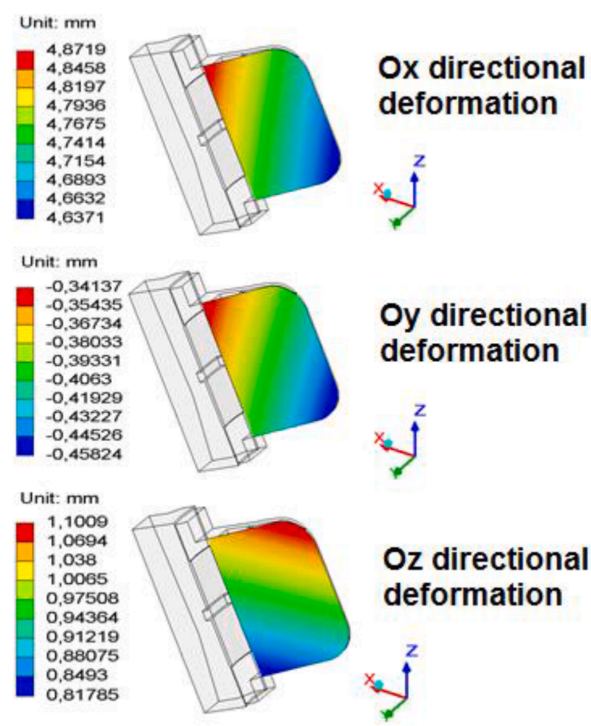

Fig. 9. Deformations of the mirror #1 reflecting surface caused by the normal operation thermal loads, mm.

Maximum deformation values of the mirrors as well as deformation values of the surface center point and rotation values about the center point are shown in Table 1.

Conclusions

This article is dedicated to the ITER Divertor Thomson Scattering

Table. 1
Deformation and rotation summary for the mirrors #1-3.

Parameter	Mirror 1	Mirror 2	Mirror 3
Max. deformation along OX, mm	4.87	5.47	5.08
Max. deformation along OY, mm	-0.46	0.15	-0.13
Max. deformation along OZ, mm	1.1	0.91	1.07
Centre deformation along OX, mm	4.75	5.37	5.02
Centre deformation along OY, mm	-0.40	0.08	-0.04
Centre deformation along OZ, mm	0.97	0.68	0.79
Rotation about OX, °	-0.01343	0.00077	-0.00174
Rotation OY, °	0.00170	-0.00034	0.00341
Rotation about OZ, °	0.01362	-0.00207	-0.00251

collecting mirrors' thermal and structural analysis. Thermal loads expected at the ITER Normal Operation mode were applied and, as a result, temperature maps of the diagnostic front rack for every time moment were obtained.

The temperature maps at the time moment with the highest thermal gradient were used as boundary conditions for Thermal-structural analysis. Obtained deformation and rotation values of the mirrors' reflecting surfaces should be used in the optical analyses of the DTS optical layout providing correct functioning of the DTS diagnostic system.

Other loads, such as electromagnetic, inertial, seismic etc. will be estimated in the further research in order to understand their influence on the DTS system collecting optical layout and estimate the system's structural integrity following [3].

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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