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Numerical Simulations of Electro-Magnetic Transients in ITER Cryopumps with Use of TYPHOON Code

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A set of calculation models has been developed and computations have been performed with the use of the TYPHOON code for ITER cryopumps to study behaviour of eddy currents and EM loads. A computational approach is described that allows detailed simulation of a cryopump components with respect to surrounding conducting elements of the tokamak.

Key words and phrases: International Thermonuclear Experimental Reactor, cryopumps, centered plasma disruptions, vertical plasma displacement events, toroidal and poloidal field coils fast discharge, eddy currents, electromagnetic loads numerical simulations.

1. Introduction

The reference design of the International Thermonuclear Experimental Reactor exhaust pumping system is based on eight cryopumps, connected to the torus via four ducts, each of them containing a pump in a direct line of sight and a branched pump. The torus cryopumps will be installed in the lower port cells of ITER.

The cryopump is made for the most part of non-magnetic stainless steel, and eddy currents induced in the cryopump and adjacent structures electrically connected to the cryopupmp during transients will cause additional mechanic and thermal loads on the conducting components.

The cryopump assembly can be separated into four main sub-components: the pump housing assembly, the 80K system, the 4.5K system, the pump valve assembly.

The events when eddy currents are induced in the cryopump structure include: centered plasma disruptions, vertical plasma displacement events, toroidal and poloidal field coils fast discharge.

The objective of this work was to estimate electromagnetic (EM) loads on the ITER Torus Cryopump for most dangerous loading conditions from EM loads point of view.

2. Simulation

The TYPHOON code [1] was used for this analysis. The TYPHOON code is designed for an advanced 3D simulation of transient electromagnetic processes using a conducting shell approach. The code is dedicated to 3D simulation of quasi-stationary eddy currents using a shell approximation in an integral-differential formulation to model conducting multi-connected shells, spaced arbitrary, in terms of a electric vector potential (the T-Ω method) [2–4].

Preliminary simulations made in 2001 with the use of a simplified cryopump model [5] demonstrated low EM loads on the cryopump if the cryopump is electrically insulated from Vacuum Vessel (VV). The problem was divided into two low-dimension sub-tasks solvable successively:

1) simulation of eddy currents in VV components (ignoring the cryopump influence on VV eddy currents) due to the plasma current variations;
2) simulation of eddy currents in the cryopump due to the VV eddy currents and the plasma current variations.

According to the reference design, the cryopump has 2 electric contacts with the conducting structures of the VV cryoport: 1) the pump plug has electrical contact with the cryoport flange all around; 2) the cryoport bellow is welded to the pump housing front flange. To allow for the electric contact, the cryopump and surrounding structures should be modelled together. Due to electric contact between the cryopump and VV components, a cross-flow of eddy currents may occur, that results in increasing EM loads on cryopump as compared with the previous results in [5].

Due to geometry complexity and a variety of conducting details of the cryo-systems, it was decided to consider them as detailed as possible. This resulted in a model requiring all computation resources available on a standard PC. The highly detailed calculation model developed for the cryopump allows accurate modeling of the cryopump subcomponents to be carried out without losing the calculation accuracy. The whole calculation model describes a 40-degrees sector of the ITER machine. The sector includes: double walled VV with ports and ribs, divertor inboard and outboard rails, blanket triangular support, upper and equatorial port plugs, cryopump, plasma, CS, PF and TF coils. Necessary portions of the existing FE mesh can be re-built if the design will be modified or another operation scenario be taken.

For each considered plasma event the total EM loads: forces, moments and AC losses have been calculated for the cryopump components. Using special numerical procedures and software [6], the obtained EM loads can be transformed into nodal loads in the format suitable for further structural or thermal-hydraulic analysis with the use of finite elements codes (for example, ANSYS or VINCENTA [7]).

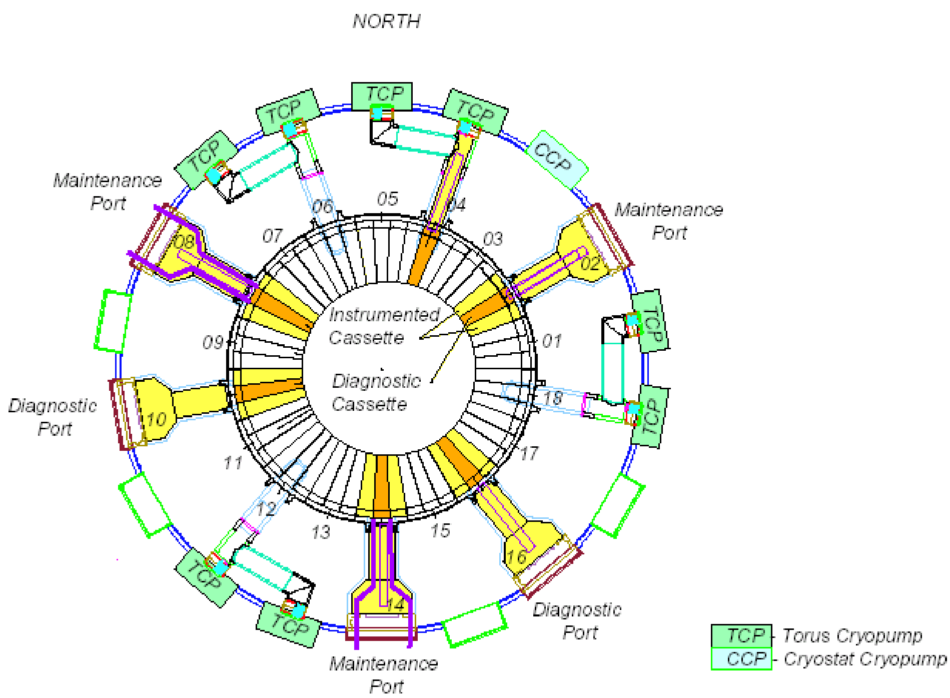

Figure 1. **Arrangement of 8 Torus Cryopumps (TCP) in the ITER machine**

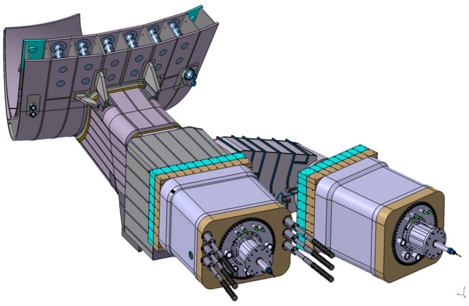

Figure 2. **Vacuum vessel cryoport with installed torus cryopump. CATIA drawing**

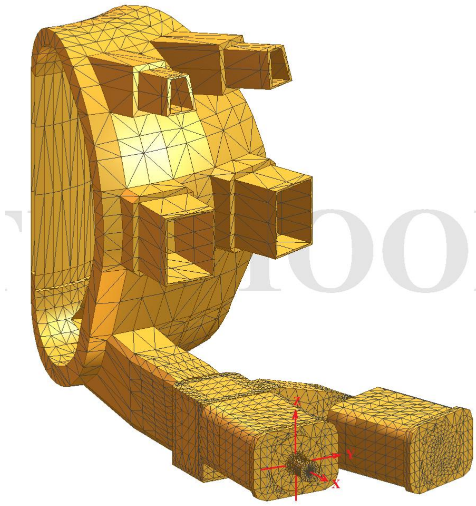

Figure 3. **Calculation region: 40-degree sector of VV with regular ports and cryopump. Cryopump is positioned at the end of lower port**

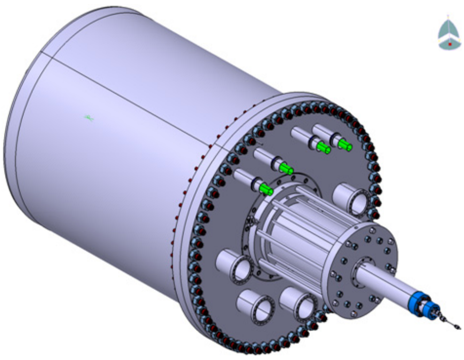

Figure 4. **Cryopump assembly. CATIA drawing**

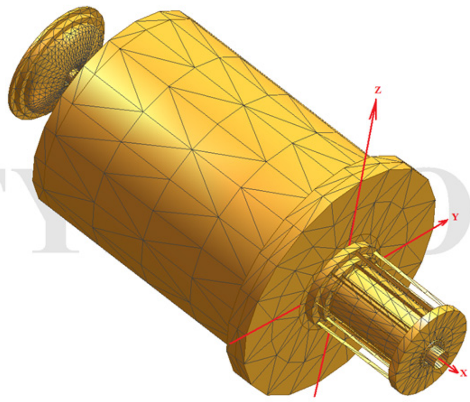

Figure 5. **Calculation model of cryopump assembly**

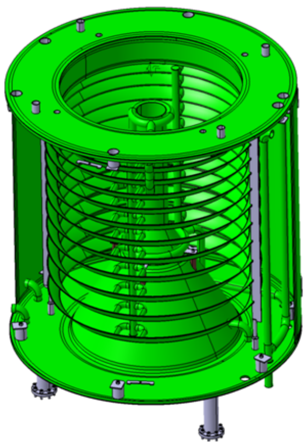

Figure 6. **Torus cryopump 80K assembly. CATIA drawing**

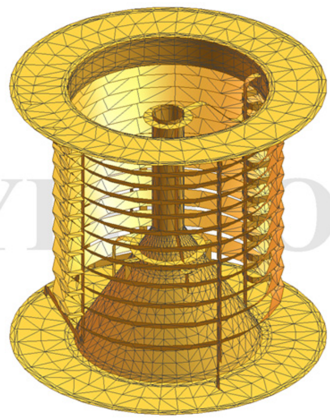

Figure 7. **Calculation model of 80K assembly of torus cryopump**

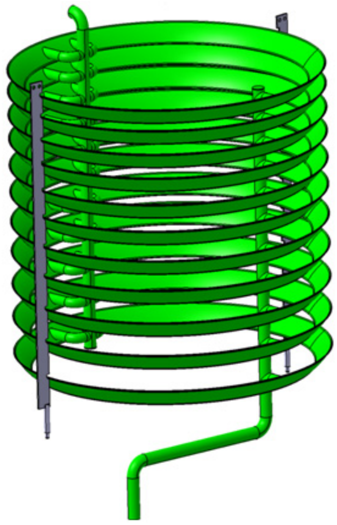

Figure 8. **Torus cryopump 80K louver assembly. CATIA drawing.**

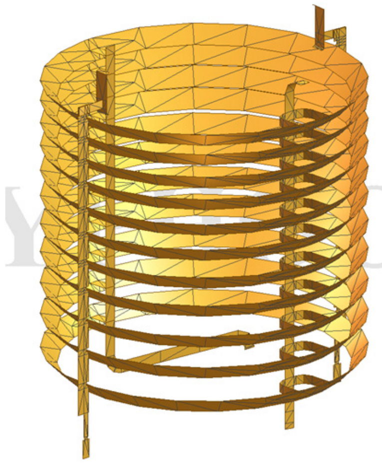

Figure 9. **Calculation model of 80K louvers assembly of torus cryopump**

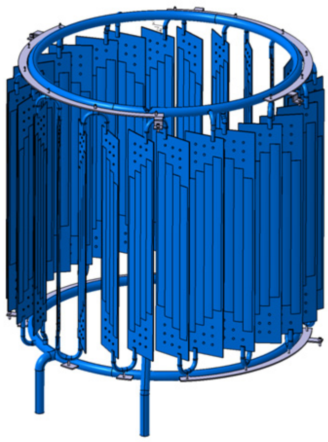

Figure 10. **Torus cryopump 4K panels assembly. CATIA drawing**

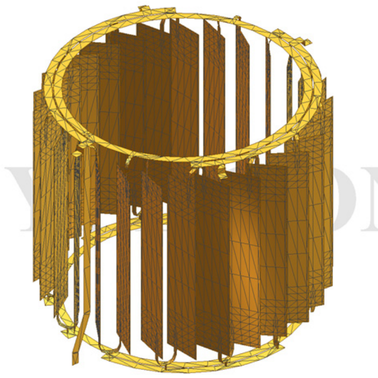

Figure 11. **Calculation model of 4K panels assembly of torus cryopump**

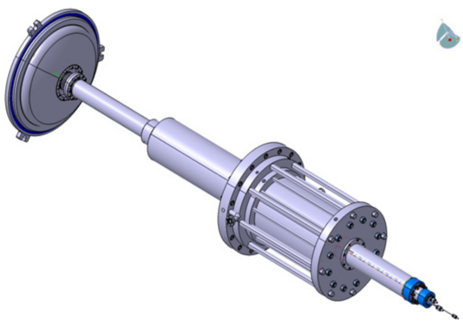

Figure 12. **Torus cryopump valve assembly. CATIA drawing.**

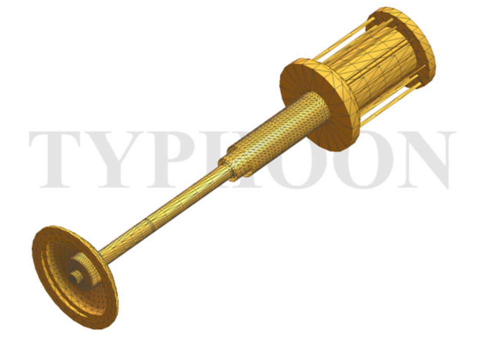

Figure 13. **Calculation model of valve assembly of torus cryopump**

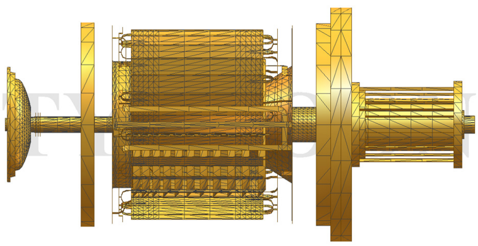

Figure 14. **Calculation model of torus cryopump. The carrier tube of housing and carrier tubes of 80K radiation shield are not shown**

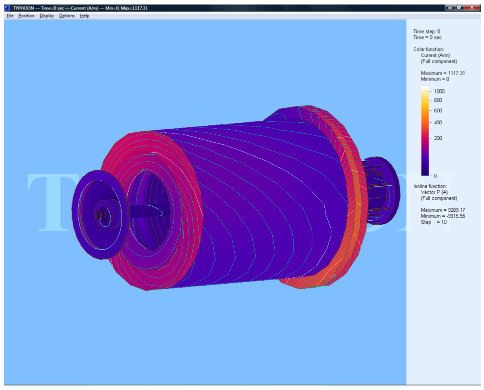

Figure 15. **Steady state distribution of eddy current over the cryopump assembly caused by simultaneous discharge of CS and all PF coils. The step of current lines is 10A**

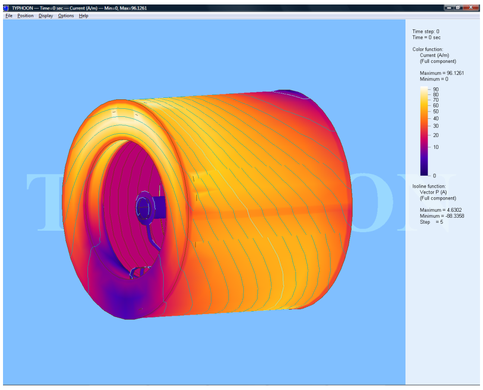

Figure 16. **Steady state distribution of eddy current over the 80K assembly of the cryopump caused by simultaneous discharge of CS and all PF coils. The step of current lines is 5A**

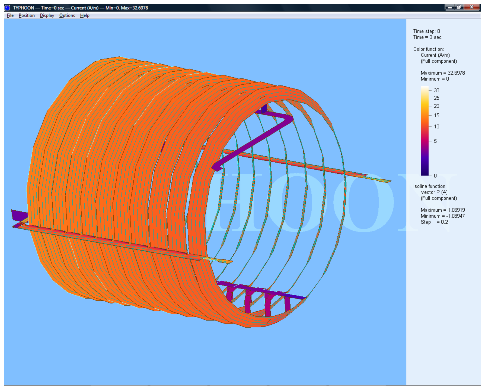

Figure 17. **Steady state distribution of eddy current over the 80K louvers assembly of the cryopump caused by simultaneous discharge of CS and all PF coils. The step of current lines is 0.2A**

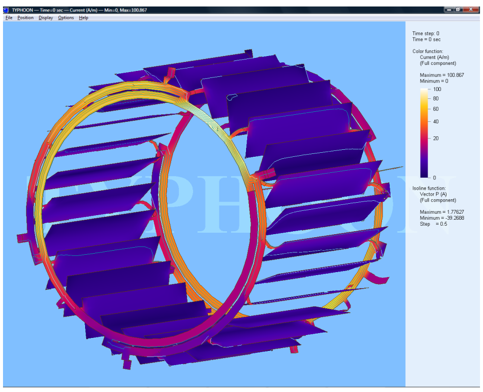

Figure 18. **Steady state distribution of eddy current over the 4K panels assembly of the cryopump caused by simultaneous discharge of CS and all PF coils. The step of current lines is 0.5A**

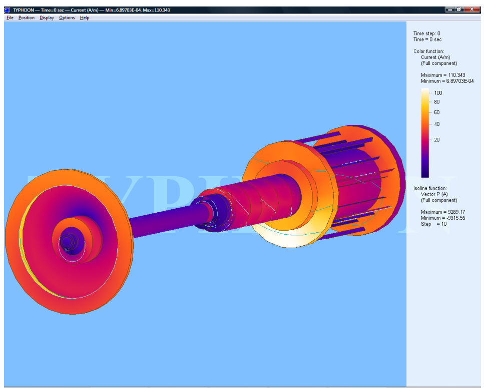

Figure 19. **Steady state distribution of eddy current over the valve assembly of the cryopump caused by simultaneous discharge of CS and all PF coils. The step of current lines is 10A**

References

1. Transient Electromagnetic Analysis in Tokamaks using TYPHOON Code / A. V. Belov, N. I. Doinikov, A. E. Duke et al. // Fusion Engineering and Design. — 1996. — Vol. 31. — Pp. 167–180.
2. *Frenkel Y.* Selected Works', Vol. 1: Electrodynamics. — Moscow-Leningrad: USSR Academy of Science Publisher, 1956.
3. *Carpenter C. J.* Theory and Application of Magnetic Shells // Proc. IEEE. — 1967. — Vol. 114, No 7. — Pp. 995–1000.
4. *Kameari A.* Transient Eddy Current Analysis on Thin Conductors with Arbitrary Connection and Shapes // J. of Computational Physics. — 1981. — Vol. 42, No 1. — Pp. 124–140.
5. *Belov A., Gapionok E., Komarov V. et al.* Structural Analysis of the Torus Cryopump. — RF Design Office Task ID No: Ref 17-01. — 2001. — Efremov Institute, St. Petersburg, Russia. Efremov Institute, St. Petersburg, Russia.
6. On the Calculation of Concentrated Loads at Finite-Element Mesh Nodes as Equivalents of a Given Spatial Distribution of Volume Force Density / A. Alekseev, A. Arneman, A. Belov et al. // Plasma Devices and Operations. — 2002. — Vol. 10, No 4. — Pp. 269–284.
7. Validation of VINCENTA Modelling Based on the Experiment with the Model Coil of the ITER Central Solenoid / V. Amoskov, A. Belov, V. Belyakov et al. // Plasma Devices and Operations. — 2006. — Vol. 14, No 1. — Pp. 47–59.

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Численное моделирование электромагнитных переходных процессов в крионасосах международного термоядерного экспериментального реактора ИТЭР с использованием комплекса программ TYPHOON

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Разработан набор вычислительных моделей и выполнены вычисления с использованием программы TYPHOON с целью изучения поведения вихревых токов и электромагнитных нагрузок для крионасосов реактора ITER. Дано описание вычислительного подхода, который позволяет провести детальное моделирование компонентов крионасоса относительно окружающих проводящих элементов токамака.

Ключевые слова: Международный Термоядерный Экспериментальный Реактор (ИТЭР), крионасосы, центральный срыв тока плазмы, срыв тока плазмы с учётом вертикального смещения, быстрый вывод тока из катушек тороидального и полоидального поля, вихревые токи, численное моделирование электромагнитных нагрузок.