Tokamak KTM Complex for Material Investigation

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Abstract. The experimental complex on the basis of spherical tokamak KTM is intended to study and test the first wall materials and designs of divertor tiles of a reactor-tokamak, to try out the methods for reducing loads at a divertor and various methods of heat- and energy removal, as well as the methods of fast exhaust of divertor volume and development of the methods to prevent failures of in-chamber components. Parameters of energy loads and wide range of the used methods and diagnostics allow for studies and tests in the divertor space and at the first wall, which will be of great importance for the study of plasma facing materials in ITER and DEMO project, as well as for other experimental and power fusion reactors. The paper contains basic parameters of spherical tokamak KTM, test bench for simulations, plasma-physical and material test tasks and KTM project status activity. The activities of 2007-2008 are aimed at completion of the tokamak construction and commissioning of the facility. The potentials are being discussed to use the tokamak KTM as a physical prototype for the compact fusion power unit with warm electromagnetic system.

1. Introduction

The experimental complex on the basis of tokamak KTM with aspect ratio A=2 is being created in the National Nuclear Center of the Republic of Kazakhstan (NNC RK) thanks to the common efforts of Kazakhstani and Russian organizations. The tokamak KTM complex is planed to study and test the first wall and divertor materials and also designs of divertor tiles as models for reactor-tokamak and to investigate the methods for reducing the loads at a divertor and various methods of heat- and energy removal, as well as the methods of fast exhaust of divertor volume and development of the methods to prevent unscheduled destruction in-chamber components. Parameters of energy loads and wide range of used methods and diagnostics allow for studies and testing in the divertor area and at the first wall, which will be of great importance for support studying of materials in ITER and for DEMO project, as well as for other fusion reactors. The main results are represented in [1-4].

2. KTM General Description

Tokamak KTM is a middle size tokamak, where elongated plasma column is formed in high vacuum chamber by central solenoid (inductor) in the toroidal and poloidal electromagnetic system and sustained in steady state mode by additional heating system. The conception of KTM tokamak as material testing device is the creation of condition for powerful steady state flow of boundary plasma into divertor volume by power ion cyclotron IC-heading. The tokamak design features provide for a unique possibility to easily access into the vacuum chamber (VC) and to replace divertor tiles without loss of the vacuum conditions. The KTM tokamak will be a base facility of unique test-bench complex for the systematical studies of the first wall and divertor materials under energy flux of 0.1÷30 MWt/m^2 in wide range of exposures.

Main power of the boundary plasma flow (70%) is directed to divertor area at the receiving tiles. Research and test of the divertor tiles made from various materials and of various designs is main goal of the tokamak operation. It can be important part of the international program for creation of science and technical date base for fusion energy.
Movable divertor device (MDD) provides for several vertical and angle positions of divertor tiles and replacement of all the tiles through sluice chamber. Removable MDD components are moved into loading- unloading area by vertical moving and horizontal rotation of the block of removable components.
Transport sluice device (TSD) is intended for loading-unloading of the MDD removable components in the vacuum vessel without loss of vacuum in the tokamak chamber. TSD consists of the following components: sluice chamber with sealed cover, manipulator, roller guide, gate valve with remote control, and silphon isolator.
The KTM basis parameters are represented in Table I below.

TABLE I. KTM BASIS PARAMETERS

Plasma major radius	0.9 m
Plasma minor radius	0.45 m
Aspect ratio, A	2.0
Plasma elongation, K	1.7
Toroidal magnetic field, B	1.0 T
Plasma current	0.75 MA
Duration of current plateau	4 - 5 s
Additional RF-heating power	5 MW
Thermal load on the divertor tiles	2 –30 MW/m2

2.1. KTM Vacuum Chamber

KTM vacuum chamber and its main characteristic are given below (*see FIG. 1* and Table II).

TABLE II. BASIC CHARACTERISTICS OF VACUUM CHAMBER

Vacuum chamber volume	m^3	13.5
Inner surface area	m^2	33
Weight of chamber shell, ports and divertor	t	12.5
Chamber material – stainless steel		08Cr18Ni12Ti
Electrical resistance in toroidal direction at 20°C	μΩ	86
Baking temperature	°C	200±10
Power of heating system	kW	45

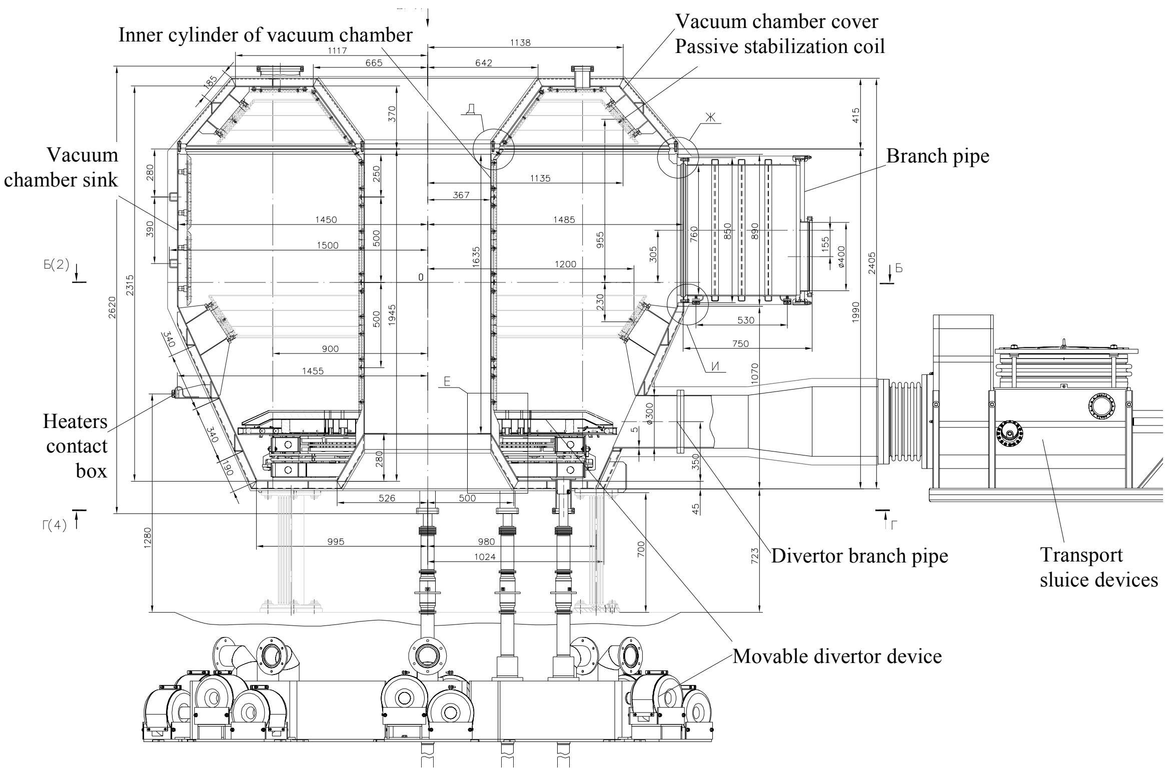

FIG.1. KTM vacuum chamber.

Fundamental provisions underlying the physical model of KTM tokamak (as basis for operation scenario and parameter calculations for design of the systems, units, and components of KTM tokamak) are:

1. Plasma core has aspect ratio of A=2 elongation K=1,7, and single null configuration;
2. Five second discharge duration corresponds to the steady state discharge mode and allows for setting up temperature field in divertor and inside of receiving divertor tiles;
3. The additional RF-heating of up to 5MW power is used to sustain quasi-stationary plasma discharge;
4. Initiation, start, rise of current in tokamak up to 750 kA and its keeping is provided by central solenoid, poloidal coil system and equilibrium coils;
5. Power of plasma flow is controlled by:
    - Distance between X-point and divertor tiles;
    - Angle of divertor tiles to tokamak vertical axis;
    - Sweeping X-point using an additional poloidal field coil.

2.2. Development of Plasma Scenario for KTM Tokamak

Variant of the nominal ohmic scenario for KTM was developed by using DINA code. Programmed parameters are presupposed to be plasma current, elongation, minor and major radii, plasma density. The initial plasma configuration corresponds to the plasma current meaning, its profile, the currents in central solenoid and poloidal foil coils, obtained by modeling of the stage of plasma initiation by using of TRANSMAK code.
Plasma parameters of discharge in KTM are given below (*see FIG. 2, 3* and Table III).

TABLE III. MAIN PARAMETERS OF DISCHARGE IN KTM

t, ms	9,0	259,0	899,0	4500,0
Te axis,eV	414,1	732,6	816,6	3079,0
<Te>, eV	156,8	283,3	308,7	1220,0
Ti axis, eV	218,6	596,7	671,8	2360,0
<Ti>, eV	114,4	253,9	276,7	1060,0
τE, ms	5,1	38,7	40,7	30,0
IBS, kA	4,0	35,0	38,0	200,0
PRF, MW	-	-	5,0	5,0
Ures , V	2,3	1,6	0,2	0,2
Te axis,eV	414,1	732,6	816,6	3079,0
<Te>, eV	156,8	283,3	308,7	1220,0
Ti axis, eV	218,6	596,7	671,8	2360,0
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PRF, MW	-	-	5,0	5,0
Ures , V	2,3	1,6	0,2	0,2

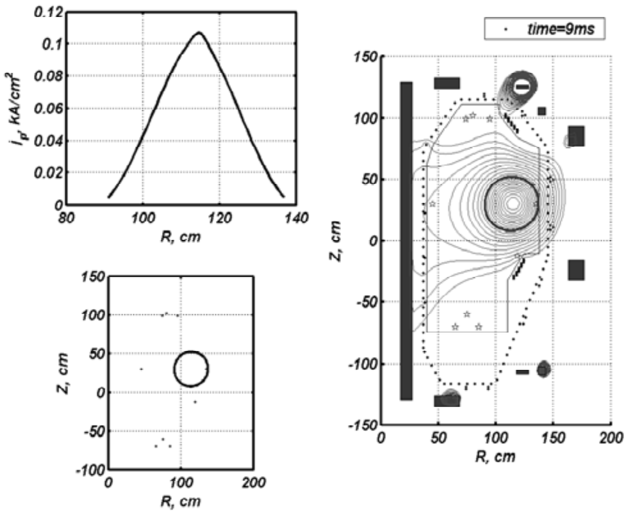

FIG. 2. Plasma configuration at the beginning of current ramp-up.

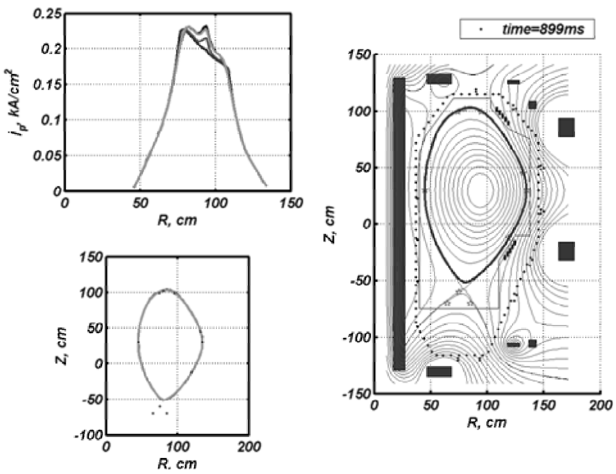

FIG. 3. Plasma configuration at the flattop.

3. KTM Experimental Complex Project Status

Now the following activities were completed:

1. The technical and the working design of all the systems have been worked out;
2. Prototypes of movable divertor, transport-sluice device were manufactured and tested. The movable divertor manufactured;
3. Vacuum chamber shell has been manufactured;
4. The material for first wale, FP-479 graphite (Germany), was purchased;
5. The manufacture of electromagnetic systems (central solenoid and poloidal system), as well as diagnostics systems and vacuum pumping system is in process now;
6. First diagnostics were passed to NNC RK in the end of 2005;
7. Boronization and plasma predionization systems were completed;
8. Manufacturing of plasma RF-heating system was begun;
9. Reconstruction of the laboratory building was completed;
10. Reconstruction of main building for KTM tokamak was begun;
11. Control and data acquisition systems of KTM tokamak is in process now;
12. External electropower system and physical protection for safety were mounted;
13. Construction of experimental test-benches for equipment, pre-commissioning tests and training of KTM personnel were begun.

The following activities are going to be carried out in 2006:

1. Manufacturing of graphite tiles;
2. Mounting of in-chamber components technological diagnostics, graphite tiles covering of VC internal surface, components of VC heating system;
3. Manufacture of toroidal magnetic system, transport sluice device;
4. Assembling and testing of the MDD and TSD together with vacuum chamber;
5. Manufacture of RF-antenna module;
6. Development of the technical project of generation system of RF-heating;
7. Work on creation of physical diagnostics;
8. Completion of reconstruction of reactor vessel and technological buildings of the complex;
9. Completion of the complex external electric power supply;
10. Work on construction of vacuum system and control and date acquisition system;
11. Manufacture of the system for vacuum pumping chamber heating and conditioning;
12. Continuation of manufacturing of subsystems of the short time power supply systems and physical diagnostics.

2007-2008 activities are aimed at completion of the tokamak construction and commissioning of the facility, namely: delivery of the equipment to KTM site, installation of the complex technological systems, mounting of impulse supply system, and commissioning of the facility. The experimental complex will include some additional experimental test-benches for developing, for example RF-heating system, diagnostics and so on, and for training of personnel who operate separate systems of KTM. Experiments on KTM tokamak will help to develop the modern methods of control and diagnostics of plasma–material interaction as technological diagnostics for future fusion reactors.
The potentials are being discussed to use the tokamak KTM as a physical prototype for the compact fusion power unit with warm electromagnetic system.

4. Conclusion

Experimental complex tokamak KTM includes not only a tokamak itself with physical and technological diagnostics but also a laboratory for material investigation and test–benches both for trial and optimization of separate subsystems and diagnostics, and for modernization and development new one's.
Tokamak KTM after putting into operation in 2008 can be a base for wide international collaboration in materials study, testing and development.

References

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