ANNOTATION

to the dissertation work of Tazhen Aigerim Begimkhankyzy
«Diagnostics of pulsed plasma flux and processes in the nearwall plasma in an installation for simulation of plasma interaction with the first wall of fusion reactors», submitted for the degree of Doctor of Philosophy (Ph.D.) in the specialty «6D072300 – Technical Physics»

General description of work. The thesis is devoted to the problems of diagnostics of a pulsed plasma flow and its application to study near-wall processes, in particular damage and sputtering of the surface of facing materials during the interaction of plasma with the first wall of thermonuclear power reactors. To accomplish this task, modern and proven measuring instruments were used, as well as software and hardware for collecting and processing experimental data. The author's method was also used to study the dynamics of plasma flow formation in the channel of the PW-7 coaxial plasma accelerator.

Relevance of the topic. The potential of future energy based on controlled thermonuclear fusion is limited by a number of unsolved problems. One of these issues is related to the control and monitoring of plasma parameters in the near-wall region of thermonuclear reactors (TNR). Controlling plasma parameters in the near-wall region allows for effective heat exchange between the wall and plasma. Thus, the study and diagnostics of plasma processes in the near-wall region are extremely important and urgent tasks today.

It should be noted that a number of phenomena arise as a result of the interaction of plasma in the near-wall region with the first wall. Among these phenomena, the erosion of structural materials attracts special attention. A comprehensive study of the erosion of structural materials in existing and under construction thermonuclear reactors is very expensive in terms of the cost of experiments and, on the other hand, requires large computing resources. For this purpose, it is advisable to use small simulators capable of reproducing the conditions of the near-wall plasma in ITER. The idea of creating high-energy plasma flows by transferring high directional speeds to particles arose in the early 1950s. Thus, a new scientific direction in plasma physics - high-speed plasma accelerators - appeared and received rapid development. The acceleration of a plasma in these accelerators is due to the following factors: the action of the electrodynamic force (Ampere force) on the plasma, due to the pressure gradient in the accelerating channel, and the action of the electric field inside the accelerating channel (when the quasineutrality of the plasma is significant). Particular attention is paid to pulsed systems among electromagnetic plasma accelerators. Their simplicity and low cost make them more reliable and suitable for use in a wide range of applications. For example, physicists have discovered that plasma flow rates sufficient to initiate a fusion reaction can be achieved using pulsed plasma accelerators (PPAs). In the first experiments carried out within the framework of the controlled thermonuclear fusion (CTF) program, the energy of the directed plasma flow was reached up to 10^7 eV. Also, pulsed plasma accelerators were considered as powerful plasma electric propulsion systems

for space flights in conditions of weak gravitational fields. In addition, experimental work on studying plasma breakdowns on the inner wall of thermonuclear power reactors is being widely carried out at these facilities. Diagnostics are an integral part of understanding, describing and assessing the condition of any system under consideration. Diagnostics of plasma in PPAs is a complex process, since the plasma in these installations is a non-stationary and multicomponent system. The energy flux density (heat flux, energetic particle flux, radiation flux) onto solid walls can be preliminarily assessed using diagnostics. Diagnostics can also make it possible to predict a possible plasma breakdown on the first wall of a thermonuclear reactor and, thus, simulate near-wall processes. Also of particular importance are the understanding of the processes of obtaining and the dynamics of the formation of plasma flows, as well as the selection of suitable conditions and parameters leading to an increase in the specific energy of the flow.

Today, the problems of diagnosing high-temperature, dense plasma created by pulse-periodic discharges are very **relevant**. In pulsed modes, physical processes occur in a relatively short time compared to stationary discharge modes. It should also be noted that discharge reproducibility with the same parameters is not always achieved from pulse to pulse in the pulsed mode. These problems can be solved by developing diagnostic methods.

The dissertation work was carried out in accordance with the plans of fundamental research work (R&D) of the Committee of Science of the Ministry of Education and Science of the Republic of Kazakhstan "Grant financing of scientific research» on the topics: «Influence of radiation and thermal load on intrachamber materials and dust formation during disruption of a plasma pinch in fusion reactors» (2018-2020, code: AP05134671, state registration number: 0118PK00708); «Investigation of plasma properties and interaction of plasma column with intra chamber materials in thermonuclear power reactors» (2020-2023, code: AP09259081, state registration number: 0121PK00295);

The purpose of the work is to measure the distributions of electron density and temperature along the plasma flow and the self-generated magnetic field of the plasma column in the PW-7 simulation facility, as well as experimental modeling and study of the processes of interaction of the tokamak near-wall plasma with the first wall.

To achieve the goal, it is necessary to solve the following **tasks:**

– to develop a multielectrode probe method that allows simultaneous measurement of the distribution of temperature and electron density in one pulse of the plasma flow.

– to develop a method for measuring the magnetic field of a cylindrical plasma column, allowing one to determine its spatial configuration and position.

– study the behavior of candidate materials of the first wall when irradiated by plasma flows generated at the PW-7 simulation facility.

Object of research: pulsed plasma flow (plasma column), candidate materials of the first wall.

Subject of research: fluctuations in the density and temperature of electrons in a plasma flow, azimuthal distribution of the magnetic field of a plasma column, influence of plasma flows on candidate materials.

Research methods. The following research methods were used in the dissertation: the triple Langmuir probe method, the optical emission spectroscopy method, the scanning electron microscopy method, the X-ray diffraction method, the probe method for measuring the distribution of the azimuthal magnetic field and the high-speed photography method.

The scientific novelty of the work.

– the multielectrode probe diagnostic method has been improved, allowing simultaneous measurement of the density and temperature of electrons of a pulsed plasma flow moving at a speed of more than 30 km/s.

– the author's method is proposed for studying the dynamics and structure of a pulsed plasma flow (column) based on the spatial and temporal distribution of its self-generated magnetic field.

– new experimental data were obtained on the formation and propagation of microcracks and various defects on the surface of a tungsten plate under the influence of a pulsed plasma flow with a duration of 0.2 ms and a peak energy density of 1.1 MJ/m², corresponding to the near-wall plasma parameters of TNR.

The theoretical and practical significance of the research. The scientific and practical significance of the dissertation work lies in the fact that its results served as the basis for the comprehensive development of methods and means for diagnosing near-wall plasma in thermonuclear reactors. The research results may be useful for optimizing the designs of future thermonuclear installations, as well as for predicting possible emergency events.

Thesis statements for defense:

1. An improved multi-probe diagnostic method revealed disruption of the plasma column, leading to local inhomogeneity in the distribution of electron temperature and density in the range $n_e = 1{,}2 \cdot 10^{20}$ - $4{,}8 \cdot 10^{19}$ m^{-3} и kT_e = 12-62 eV.

2. Dependences of the azimuthal magnetic field of the plasma flow on time, obtained by a self-developed system of magnetic probes at a distance of z = 23 cm from the electrodes, made it possible to reveal the formation of a closed plasma-current column, expanding at a speed of 47 km/s.

3. Preheating the tungsten plate to 550°C prevents the appearance of cracks wider than 1 micron when irradiated with a plasma flow, which leads to a significant reduction in material sputtering.

The author's personal contribution lies in the fact that the entire volume of the dissertation work: assembly, setting up experimental and diagnostic systems, conducting experiments, analyzing the obtained results, preparing the manuscript for publication were carried out by the author independently. The formulation of scientific problems, discussion of results, and formulation of main conclusions were carried out jointly with scientific supervisors.

The reliability and validity of the obtained results are confirmed by publications in foreign journals with impact factor and publications recommended by the Committee for Control in Education and Science of the Ministry of Education

and Science of the Republic of Kazakhstan, and in the proceedings of international scientific conferences of near and far abroad.

Publications. Based on the materials of the dissertation work, 33 printed works were published: 7 in journals from the list of publications recommended by the Committee for Control in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan for the publication of the main results of dissertations for the degree of Ph.D., 1 article in a Russian scientific journal from the list of the Higher Attestation Commission, and 5 articles in foreign journals with an impact factor included in the international information resource Web of Knowledge (Thomson Reuters Clarivate Analytics, USA) and Scopus (Elsevier, the Netherlands); 19 works in materials of International scientific conferences and 1 innovative patent for an invention of the Republic of Kazakhstan.

Approbation of dissertation work. The results obtained in the dissertation work were reported and discussed:

at the 15th international scientific seminar on dusty plasma "Dusty Plasma Workshop" (2018, Baltimore, USA);

at the 24th international conference on atomic and molecular physics of ionized gases "ESCAMPIG-XXIV" (2018, Glasgow, Scotland);

at the 12th international conference on ion implantation and other applications of ions and electrons "ION-XII" (2018, Kazimierz Dolny, Poland);

at the 9th international conference on plasma physics and plasma technologies "PPPT-9" (2018, Minsk, Republic of Belarus);

at the international conference of students and young scientists "FARABI ALEMI" (2018, 2019, 2021, 2023 Almaty, Kazakhstan);

at the 34th international conference on phenomena in ionized gases "ICPIG-XXXIV" (2019, Sapporo, Japan);

at the 10th international conference of the Nanotechnological Society of Russia (2019, Moscow, Russia);

at the 21st international conference on modification of the surface of materials by ion beams "SMMIB-2019" (2020, Tomsk, Russia);

at the 6th international conference on laser, plasma research and technologies "Laplaz-2020" (2020, Moscow, Russia);

at the 7th international conference on laser, plasma research and technologies "Laplaz-2021" (2021, Moscow, Russia);

at the 9th international conference on dusty plasma "ICPDP-2022" (2022, Moscow, Russia);

at the 19th international conference on complex systems of charged particles and their interaction with electromagnetic radiation "CSCPIER-2023" (2023, Moscow, Russia).

Articles with impact factor according to the Thomson Reuters database or in publications included in the international scientific database Scopus:

– M.K. Dosbolayev, **A.B. Tazhen,** A.N. Kholmirzayev, Ye.A. Ussenov, T.S. Ramazanov. Studies of the formation and distribution of cracks and various defects on the heated tungsten plate surface during pulsed plasma flux impact // Nuclear Materials and Energy. – 2023. – Vol. 37. – № 101540. – P. 1-9;

– M.K. Dosbolayev, **A.B. Tazhen,** T.S. Ramazanov, Ye.A. Ussenov Investigation of dust formation during changes in the structural and surface properties of plasma-irradiated materials // Nuclear Materials and Energy. – 2022. – Vol. 33. – № 101300. – P. 1-11;

– **A.B. Tazhen,** M.K. Dosbolayev, T.S. Ramazanov. Investigation of self-generated magnetic field and dynamics of a pulsed plasma flow // Plasma Science and Technology. – 2022. – Vol. 24. – № 055403. – P. 1-8;

– **A.B. Tazhen,** Zh.R. Rayimkhanov, M.K. Dosbolayev, T.S. Ramazanov. Generation and Diagnostics of Pulse Plasma Flows // Plasma Physics Reports. – 2020. – Vol. 46(4). – P. 465-471;

– M.K. Dosbolayev, Zh.R. Raiymkhanov, **A.B. Tazhen,** T.S. Ramazanov // IEEE Transactions on plasma science. – 2019. – Vol. 47. – № 7. – P. 3047-3051.

Articles in publications recommended by CQAFSHE MSHE RK:

– **A.B. Tazhen,** M.K. Dosbolayev, Zh.B. Igibaev, A.U. Utegenov, T.S. Ramazanov. Investigation of the plasma column evolution and dynamics in the PW-7 plasma accelerator // Physical sciences and technology. – 2023. – Vol. 10. – № 1. – P. 42-49;

– **A.B. Tazhen,** M.K. Dosbolayev, T.S. Ramazanov. Pulsed plasma flow diagnostics // Recent Contributions to Physics. – 2022. – Vol. 81. – № 2. – P. 35-39;

– M.K. Dosbolayev, **A.B. Tazhen,** T.S. Ramazanov. Investigation and diagnostics of plasma flows in a pulsed plasma accelerator for experimental modelling of processes in tokamaks // Eurasian Journal of Physics and Functional Materials. – 2021. – Vol. 5. – № 4. – P. 198-210;

– **A.B. Tazhen,** M.K. Dosbolayev. Measuring the self-generated magnetic field and the velocity of plasma flow in a pulsed plasma accelerator // Recent Contributions to Physics. – 2021. – Vol. 77. – № 2. – P. 30-39;

– **А.Б. Тажен,** A. Thilo, J. Jacoby, М.Қ. Досболаев, Т.С. Рамазанов. Спектральная диагностика импульсного плазменного потока методом Штарковского уширения линии H_β // Вестник КазНИТУ. –2020. – № 3. – С. 153-158;

– **А.Б. Тажен,** Утегенов А.У., Райымханов Ж.Р, Қамбаров Ә.А. Тепловая эрозия графитовой мишени под воздействием интенсивного импульсного плазменного потока // Вестник КазНУ им. аль-Фараби. Серия физическая. – 2018. – Том 67. – № 4. – С. 1-6;

– **Ә.Б. Тәжен,** Қ. Нұрболат, М.Қ. Досболаев. Импульсті плазма ағынына спектроскопиялық диагностика жасау // Журнал ПЭОС – 2018. – Том 2. – № 20. – Б. 45-51.

Publications in scientific journals included in the list of the HAC:

– **А.Б. Тажен,** Ж.Р. Райымханов, М.Қ. Досболаев, Т.С. Рамазанов. Получение и диагностика импульсных плазменных потоков // Успехи прикладной физики. – 2019. – Том 7. – № 5. – С. 463-471.

Innovative patent of the Republic of Kazakhstan:

– for the invention “Method and apparatus for measuring the spatio-temporal distribution of magnetic field of a pulsed plasma flow”, No. 35200 dated 03.12.2021.

The volume and structure of the dissertation. The dissertation work consists of an introduction, 3 sections, a conclusion, and a list of 166 references, and contains 107 pages of basic computer text, including 79 figures and 4 tables.