The development and the tests of the electrostatic probe for dust particle collection in thermonuclear reactors

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Abstract. Formation of dust particles in thermonuclear reactors can greatly affect the plasma parameters and lead to accumulation of tritium. The rates of formation and deposition of dust need to be measured, and the parameters of formation of dust particles and clusters need to be studied. A model of a device for collection of fine conductive particles capable of removing them from the reactor chamber for future research is proposed in this paper. The dust collector’s operation is based on a principle of applied electrostatic field. The model was tested in different operating conditions: in vacuum, at the atmospheric pressure in the atmosphere of air and dry nitrogen. The experiments were conducted with a stationary system and with the dust collector in motion relative to the dusty surface. It is shown that, during the probe moving relative to the surface, it can remove up to 95% of fine tungsten particles with sizes ranging from 1 to 10 μm.

1. Introduction
Formation of dust particles and clusters has been observed in almost every modern thermonuclear reactor. Accumulation of dust in the next-generation thermonuclear reaction chambers can have a strong effect on plasma parameters and lead to accumulation of unacceptable amounts of tritium. For this reason, a device able to collect dust formed during the work of reactor and extract it from the chamber for investigation is necessary.

A model of such device (electrostatic dust collector) is proposed in this paper, a working model is produced and tested. During the trials the model of the dust collector was used for the removal of fine metallic particles composed of tungsten in different conditions: in vacuum, in air and in the atmosphere of dry nitrogen gas. The experiments were conducted for the dust collector in stationary condition and in motion relative to the dusty surface. It is shown that during the movement of the dust collector relative to the surface covered with fine particles with the size range of 1-10 μm, accumulation of up to 95% of particles is achievable.

2. On the possibility of the removal of metallic dust from the surface via applied electric field
The behaviour of fine tungsten dust particles in electrostatic field was investigated in [1]. For the experiments, tungsten powder with W content ≥ 99.5% and particle size between 1 and 10 μm was used. The size of the particles of tungsten powder was comparable to the size of dust particles formed in the chambers of modern thermonuclear reactors [2]. Additionally, investigation of powder under electron microscope has lead to a discovery of most powder particles forming clusters of different shapes and sizes of up to approximately 50 μm (figure 1).
The experiments on the effects of the electrostatic field on tungsten powder were conducted in vacuum at room temperature. The layer of tungsten powder was located on a horizontal plate. A second plate was located parallel to the first plate and above it, then an electric field was generated between the two plates. When the field was applied, the powder particles were also biased towards the upper plate and were attracted to it. It was shown that with the intensity of the electric field equaling to 600 V/mm, an emission of powder particles between the plates going from the lower electrode to the upper one occurred independent of the direction of the electric field. Additionally, the electric field intensity value was enough to remove both powder particles of all sizes and particle clusters from the lower plate. The rate of emission was increasing with the increase of the electric intensity. This phenomenon was proposed as a technique to clean dust-covered surfaces.

3. Separate deposition of zirconium and yttrium at floating potential on the substrate
A model of a dust collector was prepared. The main element of a model is a reservoir made of a thin sheet of stainless steel, with two sides being horizontal rectangular plates positioned one above the other. The plates are bounded by vertical walls from three sides, with the fourth wall made as a grid and tilted relative to the surface. The width of the horizontal sides of a dust collector was 25 mm, and the height of a probe was 10 mm. A potential difference enough for fine particles to overcome gravitational pull and adhesion was applied between the dust-covered surface and the collector. The fine particles then entered the collector’s reservoir by going through the grid in the tilted wall. During the movement of a dust collector parallel to the surface with the gridded wall being in the front during the movement, a particle removal from the surface was conducted (figure 2).

4. Joint deposition of zirconium and yttrium at floating potential on the substrate
The dust collector was tested both in vacuum with pressure of approximately $1 \cdot 10^{-4}$ Torr and at the atmospheric pressure. The gases used in the latter trials were air and dry nitrogen.
A series of tests was run in vacuum with a stationary dust collector. The dust particles formed a pile with the diameter of up to 10 mm and a height of approximately 1 mm, located on a grounded metal surface under the tilted wall of the dust collector. The interval between the bottom of the collector and the dust-covered surface was 3 mm. When the bias voltage above approximately 2000 V was applied to the dust collector, most of the fine particles disappeared from the surface and entered the reservoir in about 6-8 minutes. The rate of dust collection and the quantity of particles removed increased with the increase of bias voltage of the collector. The sign of the bias on the collector did not affect the rate of transfer of dust from the pile into the reservoir. At the potential difference of 5000 V, the highest value used in the experiment, the maximum amount of particles collected in the reservoir was 86% for the dust collector with the gridded wall at 30° relative to the surface. About 3% of the powder was left in place, and 5% stuck to the outer surface of the dust collector. The remaining 6% of the powder was scattered sideways in the gap between the surface and the collector.

The results of the tests conducted in the atmosphere of dry nitrogen were comparable with the results obtained in vacuum. For air, increased adhesion of powder to the outer surface of the dust collector as well as increased adhesion to the grounded surface was observed. Accumulation of particles did not exceed 60-65%.

In the conditions of the experiment, motion of the collector relative to the surface was achieved by moving the grounded plate with the powder while keeping the collector stationary, as this was the most convenient option. The dust collector with bias voltage of 5000 V was fixed in place, and the powder was located on a grounded plate and moving towards the collector. The powder was poured on the plate in a line up to 50 mm in length. The width of the line varied for the purpose of investigating the properties of the removal of fine particles located at different distances from the axis of the collector. An optimization of the shape of the collector’s gathering part was made based on the results of the experiments, which allowed for the reduction of the amount of fine particles scattered and stuck to the collector’s exterior and practically removed the difference between the removal of fine particles from central and peripheral parts of the collector. Additionally, it was found that during the movement of the collector relative to the powder the amount of dust left on the grounded plate is greatly decreased due to all the fine particles are nearing the dust collector in the area of the highest electric field intensity. As a result, the experiments had shown that permanent losses of dust due to scattering could be reduced to about 5% of the total mass of particles, and, additionally, the direction of further improvement of the dust collector was found.

5. Conclusion
A model of an electrostatic dust collector for removing fine metal particles in thermonuclear reactor chambers was developed and produced.

The effectiveness of the dust collector model for removing fine metal particles composed of tungsten from flat horizontal surface was tested in various conditions: in vacuum, at the atmospheric pressure with atmospheres of air and dry nitrogen. The experiments were conducted in a stationary system and with motion of the dust collector relative to the dusty surface.

The dust collector is shown to remove approximately 95% of tungsten fine particles with sizes ranging from 1 to 10 μm while moving relative to the dusty surface.

Acknowledgments
This work was supported by National Research Nuclear University MEPhI in the framework of the Russian Academic Excellence Project (contract No. 02.a03.21.0005, 27.08.2013) and by the Ministry of Education and Science of the Russian Federation (agreement contract №14.575.21.0049 of 27.06.14).

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