DESIGN OF MULTIFUNCTIONAL FACILITY BASED ON ECR ION SOURCE FOR MATERIAL SCIENCE

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Abstract

The traditional experimental method for new materials radiation resistance investigation is a reactor irradiation. However, there are some difficulties during steel exposure in reactor. Simulationmethod based on ion irradiation allows accelerating the defect generation in the material under investigation. Also a modification of materials by ion beams represents the great practical interest for modern material science. The design of the test-bench based on ECR ion source and electrostatic acceleration is presented. This paper describes the results of beam dynamics simulation in the transport channels of the test-bench. Simulation was carried out in the "real" fields. Continuous ion beam achievable at the test-bench enables beam fluence on the target up to 10^{16} p/m^2.

INTRODUCTION

The creation of new high-tech energy systems is associated with the use of new radiation-resistant materials. A necessity emerges to study and test the new materials. Neutron flux irradiation of samples occurs in the reactor. Certain difficulties arise when steel is exposed to radiation in the reactor. These problems are primarily associated with the time it takes to reach required doses. Even in fast reactors the exposure to the required doses may take years. There is a need to take into account the complexity and high cost of reactor-based systems and, consequently, of the tests themselves. High level of induced radioactivity of the materials is another factor which complicates their study. It emerges in the course of long-term irradiation in the reactor core and makes it difficult to further study the irradiated samples. Low-energy ions can be used to model the process of kicking out atoms formed in the course of neutron irradiation. Ion beams irradiation is an express analysis method which was offered in the 80-s[1]. This method allows to accelerate the process of defect emergence in irradiated materials due to the speeding up of dose accumulation. It must be taken into account that the speeding up of the dose accumulation during the simulation may lead to discrepancies in the results as compared to the real condition that exist in the reactor. Hence, it is considered necessary to reproduce the conditions of the reactor as closely as possible. The process of defect formation depends on the temperature, so the irradiatiated target will be specially heated. Now, experiments are carried out using a pulse beam on HIP-1 RFQ [2]. Oscillation of samples temperature must not exceed 1-3 degrees Celsius. This criterion is very hard to achieve when using a pulse beam.

In order to be able to reproduce the processes in the reactor with greater accuracy our target will not only be heated but defect containing area will be implanted with ions of hydrogen and helium. This will be done with the intention to model the accumulation of He and H in the reactor wall under the influence of the neutron flux.

Besides radiation-resistant material research, modification of materials by high energy ion beams is of great practical interest. Vanadium, chromium, tungsten ions beams can be used for this purpose. A great increase in durability and surface strength can be achieved by irradiation with powerful beams[3].

TEST-BENCH SET-UP

It is planned that apart from material science related tests experiments to study the interaction of the ion beam with plasma and metal vapor targets will be carried out as well. For plasma target and material modification experiments ion beams of 1-2 MeV are necessary. In order to achieve this installation of electrostatic accelerating tube has been planned.

ITEP is developing a multifunctional facility which will make possible the ion beam experiments that will allow to investigate materials by means of express analysis based on imitation of damages materials sustain in the reactor.

The test-bench is designed to have four experimental channels:

1. For experiments simulating of damage caused by neutrons
2. For both modifications of material surfaces and simulation experiments
3. For plasma target experiments
4. For injection of ion beam into accelerating structure

Experimental channels will exit the bending magnet at 90°, 60°, 30°, 0° angles correspondingly.

Specifications of the last two channels are still being discussed. So modeling of their beam dynamics will be carried out at a later date.

Geometry and tract elements of the test-bench were chosen on the basis of beam dynamics modeling.

It had two stages:

1. Modeling of beam dynamics in approximation to “ideal” fields[4].
2. Modeling of beam dynamics in approximation to “real” fields.

Modeling for Fe^{10+}, H^+, He^+ ions was done in both channels.

In order to minimize the possible effects of chemical reactions on the experiment it is best to use the ions of the same element of which the target is built. In this case the Fe ions are going to be used as it is the main constituent of construction steel. A modern ECR ion source can

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generate highly charged particles and when working with Fe^{10+}a continuous ion beam with a current of 50-70 µA can be reached [6].

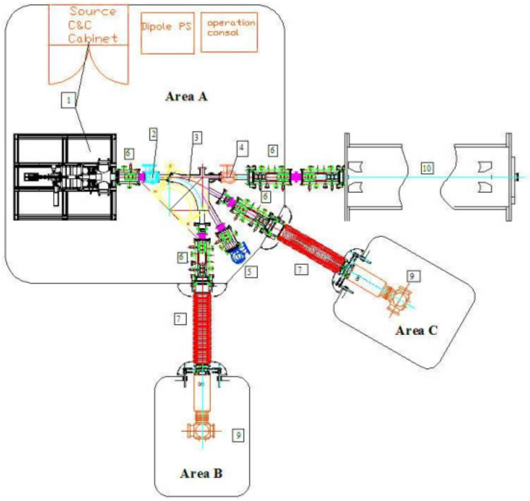

Figure 1: Principal scheme of the multifunction test-bench. 1-ECR ion source and its control cabinet, 2-focusing system, 3-bending magnet, 4-Faraday cup, 5-target assembly for specimen irradiation for atom probe analysis, 6-focusing elements, 7-accelerating tubes, 8,9-target assembly for high-energy experiments, 10-linac [5].

As has been mentioned the area in which the defects appeared when it is bombarded by the main beam is implanted with H and He ions.

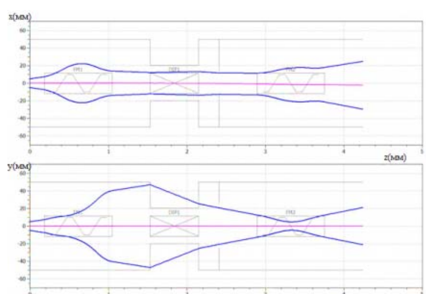

Figure 2: Fe^{10+} ion beam envelope in 60° channel.

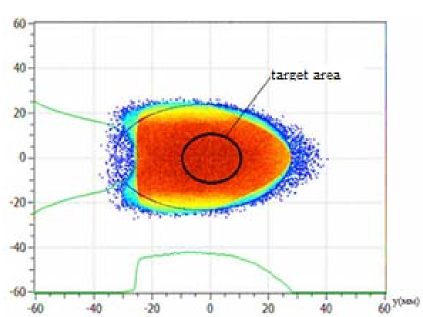

Figure 3: Fe^{10+} ion beam form in output of 60° channel.

For samples placed in the channel turning 60 degrees energies on the order of 150 keV are necessary. In order to reach such energy for Fe^{10+}a voltage of 15 kV has to be applied at the source. This may lead to a decrease of beam intensity as max voltage is 25 kV. For this reason modeling for Fe^{6+}has also been done in this channel. The final decision will be made after the facility is commissioned.

During the initial modeling which was done in order choose the type of the focusing system for the channel that would enable the passage of the beam through the bending magnet with no losses. As a result the system of triplets of quadruple electrostatic lenses was chosen. After the simulation in approximation of "ideal" fields triplet of quadruple electrostatic lenses model was created in CST STUDIO. This was done to calculate the distribution of the "real" fields generated by the lenses.

MODELING OF BEAM DYNAMICS IN APPROXIMATION TO "REAL" FIELDS FOR 60 DEGREES CHANNEL

The date received from the above simulation was used to generate a more realistic picture of the influence of the field distribution on the trajectories of the particles.

The envelope of the beam and the beam profile at the outputs for Fe^{10+} and Fe^{6+} are shown on the fig. 2 and 3.

N, C, O, Fe of different charges may be present inside the beam due to residual gases and ion generation technologies. Below is the Table 1 for the most "dangerous" ions whose mass/charge relation is closest to that of the working ions.

Table 1: Energy for mass/charge relation like Fe^{10+}/ Fe^{6+}

Element	Ion	A/Z	Energy, keV
Iron(56)	Fe^{10+}	5,6	150
	Fe^{11+}	5,1	165
	Fe^{9+}	6,2	135
	Fe^{6+}	9,3	150
	Fe^{5+}	11,2	125
	Fe^{7+}	8	175
Oxygen(16)	O^{3+}	5,3	45
	O^{2+}	8	30
	O^{1+}	4	60
Carbon(12)	C^{1+}	12	25
	C^{2+}	6	30
	C^{3+}	4	45
Nitrogen(14)	N^{1+}	14	25
	N^{3+}	4,6	45
	N^{2+}	7	30

Also, the quality of the separation system's operation was estimated under the parameters from the computer simulation described above. In order to ensure the efficiency of mass separator the modeling of the working and the "contaminated" beams was carried out simultaneously.

For Fe^{10+} it also indicated that ions O^{3+} and C^{2+} partially stopped by the magnet and the diaphragm. 17% of oxygen ions and 2% of carbon ions reached the end of

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the tract, but they don't hit the target. The profile of the beam at the output is shown on the fig. 4 and 5.

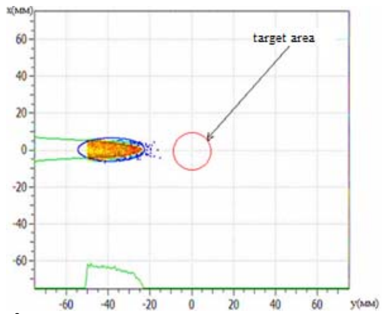

Figure 4: O^{3+} ion beam form in output of 60° channel at joint calculation with Fe^{10+}.

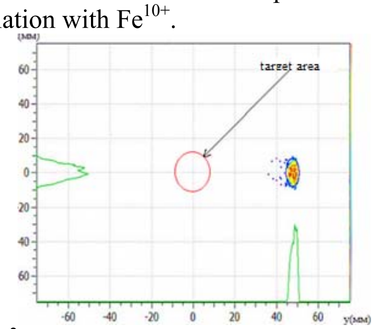

Figure 5: C^{2+} ion beam form in output of 60° channel at joint calculation with Fe^{10+}.

MODELING OF BEAM DYNAMICS IN APPROXIMATION TO "REAL" FIELDS FOR 90 DEGREES CHANNEL

The same kind of simulation was done for the 90 degrees channel. Fig 6 and 7 show envelope and the profile of the Fe^{10+} beam. As well a similar simulations were done for Va, Ti and Cr ions under the same parameters.

The efficiency of the separation system was checked. It showed that all non-working ions were stopped by the separator.

CONCLUSION

As a result of the beam dynamic simulation the geometry of the two channels has been developed and its constituent elements parameters for planned experiments were determined. The formation of the necessary beam profile, uniform distribution of the ions in the point of the samples location as well as the purity of the ion flux have all been achieved.

The results of the simulation became the basis for the engineering project. As of now the measurements of the room that is going to house the facility have been completed. The preliminary blueprints of test-bench installation have also been developed.

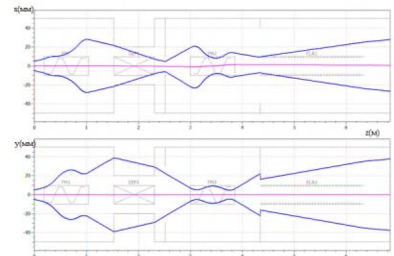

Figure 6: Fe^{10+} beam envelope in 90° channel.

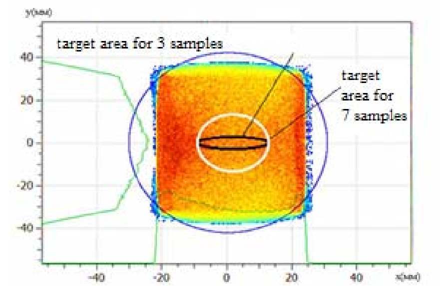

Figure 7: Fe^{10+} ion beam form in output of в 90° channel.

REFERENCES

[1] Nelson R.S., Mazey D.J. // The use of ion accelerations to simulate fast neutron-induced in metals / J.Nucl.Mater. – 1970. – V.37. – P. 1-12.

[2] V.Batalin, Y. Volkov, T. Kulevoy, S.Petrenko, "Report on ITEP MEVVA Development"Proc. WorkshoponVacuumArcIonSources, Berkeley, USA. – 1996.–P.37-39

[3] Shulov V.A. "Modification of the properties of high-temperature alloys continuous and pulsed ion beams" abstract, Minsk, Belarus. – 1995. 42 p.

[4] T. V. Kulevoy, B. B. Chalykh, R. P. Kuibeda, G. N. Kropachev, and A. V. Ziiatdinova "Project of electro-cyclotron resonance ion source test-bench for material investigation", Rev. Sci. Instrum. 85, 02A910 (2014); doi: 10.1063/1.4824642

[5] B.B. Chalykh, R.P. Kuybeda, T.V. Kulevoy, A.V. Ziyatdinova //Designe of the accelerator stand with the ECR-source for simulatuion experiments on the radiation damage of the steels of the nuclear industry/ ISSN 1562-6016. VANT. 2014. №3(91).

[6] H. Koivisto, P. Heikkinen, V. Hänninen, A. Lassila, H. Leinonen, V. Nieminen, J. Pakarinen, K. Ranttila, J. Ärje and E. Liukkonen // The First Results with the New JYFL 14 GHz ECR ion source /Department of Physics, University of Jyväskylä, P.O. Box 35, FIN-40351,Jyväskylä, Finland.

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