DESIGN OF THE ACCELERATOR STAND WITH THE ECR-SOURCE FOR SIMULATION EXPERIMENTS ON THE OF RADIATION DAMAGE OF THE STEELS OF THE NUCLEAR INDUSTRY

B.B. Chalykh, R.P. Kuybeda, T.V. Kulevoy, A.V. Ziyatdinova
Institute of Theoretical and Experimental Physics, Moscow, Russia
E-mail: 4alihx@gmail.com

The imitation experiments of irradiation resistivity for steels used in nuclear industry by heavy ion beams are promising demand for material properties investigation. The formation of the defects on the real-existing reactors is fraught with many difficulties such as a long-term session of exposure and induced radioactivity in samples. Simulation of radiation defects on accelerators of charged particles does not have such a drawback. To form radiation defects in matter, it is necessary to have beams of various ions with different energy. The concept of the test bench based on a ECR heavy-ion source for the imitation experiments of the materials resistance under irradiation is presented and discussed.

PACS: 29.17.+w

INTRODUCTION

Elaboration of new grades of steels and alloys for nuclear industry is continuously connected with the studying of the properties changes in these materials as a result of reactor irradiation. For operation of nuclear industrial installations, a deep study of radiation damage in the materials under irradiation is required. To date, a high-temperature low-corrosive steels are the most promising materials for construction of a new nuclear reactors generation. The most well-known foreign materials from this class are the ferritic steels EUROFER-97, JLF-1, F82H. In Russia such steels are also under development. The most promising one is a 12% chromium steel EK-181 (RUSFER EK-181) [1 - 4]. There are increased requirements for fire resistance and radiation resistance of these steels. The analysis of materials irradiated in real-operating reactors is difficult by several reason. First of all, the long radiation session is required. For example, the accumulation of a ~100 dpa (displacement per atom) dose upon neutron irradiation is achieved for several years even in fast fission reactors. It is also necessary to take into account that induced radioactivity complicates further investigation of the samples and requires a special tools. Low-energy ions can simulate the primary knock-on atoms produced by the reactor neutron irradiation, and thus simulate cascades that are typical neutron irradiation [1]. Therefore, methods using ion beams for rapid analysis of materials have been developed for a long time. Ions have cross section of interaction with crystal structure bigger in a few times than neutrons one. It is possible to control temperature and chemical kind of implanted ions during ion beam experiment. From 2008 year in ITEP the heavy ion RFQ HIP-1 is used for accelerated ion beams imitation experiments. It enables comparative analysis of steels exposed into the real-existing reactors with ones irradiated by accelerated heavy ion beam [2 - 5]. Nevertheless, the requirement of irradiation dose higher than HIP-1 provides, as well as the need to conduct experiments with a controlled heating of samples resulted the development of multi-functional facility based on the ECR source and the electrostatic tube. For imitation experiments it is necessary to irradiated the sample with beams of different species. For example the irradiation of samples for further study on the tomographic atom probe (TAP) requires Fe beams with energies of ~ 150 keV. Meanwhile sample for investigation by transmission electron microscopy (TEM) should be irradiated by beams of Fe ions with significantly more energy 1…6 MeV. Coupled with the needs of sample irradiation by ions of different materials define it requires the experimental facility providing 1) the broad energy spectrum of the ions, 2) a different chemical composition of the ions and 3) the possibility of simultaneous irradiation with different ions. All this can be realized on the test-bench presented in this article.

1. EXPERIMENTAL TEST-BENCH FOR RADIATION DEFECT FORMATION

The scheme of multifunctional test-bench is shown in Fig. 1. The installation consists of the ECR ion source, the bending magnet, and four experimental channels. Two of experimental channel have an accelerator tube and high-voltage platform for placing on them the target assembly.

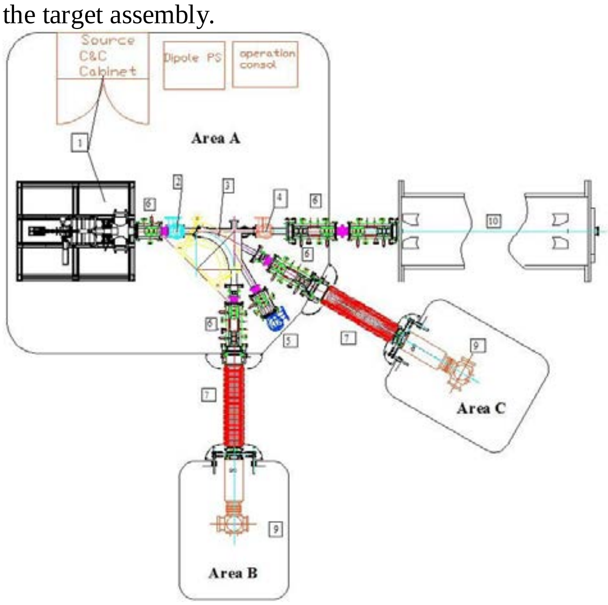

Fig. 1. The multifunction test-bench:
1 - ECR ion source and its control cabinet; 2 – comon focusing system; 3 - bending magnet; 4 - Faraday cup; 5 - target assembly; 6 - focusing elements; 7 - accelerating tubes; 8, 9 - target assembly; 10 - linac

Bending magnet provides beam separation and directs the required ions into one of four channels:

1. 90^0 for imitation experiments for futher sample investigation by TEM researches
2. 60^0 for imitation experiments for futher sample investigation by TAP researches
3. 30^0 for experiments with plasma targets
4. input in the accelerating structure with radio frequency quadrupole.

For 90^0 channel the depth of different ions penetration into the steel samples as a function of accelerating voltage at the accelerating tube was carried out by using the SRIM / TRIM code. The results for ions Fe^{10+}, Cr^{10+}, He^{1+}, H^{1+} are shown in Fig. 2. The simulation showed that 200 kV at the accelerator tube provides the sufficient depth of ion penetration into the steel samples, to avoid the influence of surface effects influence on the sample features. Therefore, beam dynamics simulation into 90^0 channel was carried out for the acceleration tube voltage of 200 kV.

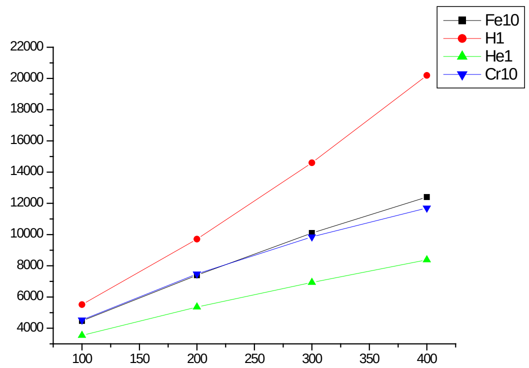

Fig. 2.The result of SRIM/TRIM simulation for ion beam interaction with iron specimen

60^0 channel is designed for the irradiation of samples prepared for their subsequent studies by TAP. It is planned that target assembly which is successfully underway on the injector output HIP [2] will be moved on this channel. As a result, it will be possible to increase the dose up to 10^{18} particle/cm^2 (which corresponds to more than 100 DPA).

It is planning to create one more HV platform for developing plasma target on the 30^0 channel.

Straight-fly line is reserved as an injector line for future RFQ.

2. BEAM DYNAMICS SIMULATION

Simulation of beam transportation in different facility channels have been made in ideal field approximation. The simulation of the beam dynamics for ion beams of Fe^{10+} and H^{1+} into the 90^0 channel and Fe^{10+} 60^0 channel was carried out. Modeling beam dynamics in 30-degrees bending channel will be done as soon as the requirements to the beam for experiments with plasma target is defined. Before the bending magnet electrostatic quadruple triplet is used. This type of focusing system allows providing the beam transportation throughout magnet separator without loses for all ions used. The diaphragm is installed at the exit of magnet to provide beam separation needed for experiment. Beam dynamics simulations for ions Fe^{10+} in 90^0-channel are shown in Fig. 3. The second triplet placed after diaphragm and provides the low beam diverges along accelerator tube. Simulation shown, that there is no any necessity to use other focusing elements after accelerator tube in front of the target assembly. All needed beam parameters can be achieved by using the second triplet. A similar result is obtained for H^{1+} ion beam transportation in the channel.

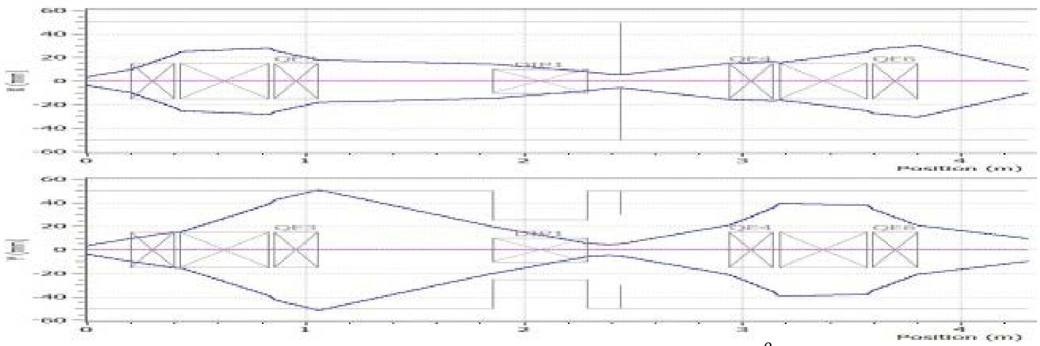

Fig.3. Beam dynamics simulations for ions Fe10+ in 90^0-channel

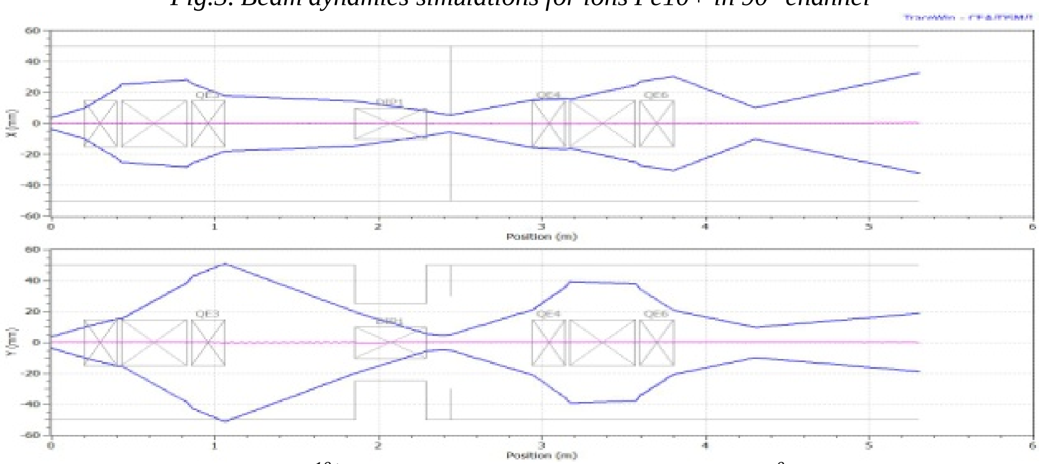

Fig. 4. The Fe^{10+} ion beam dynamics simulations for a 60^0-channel

The Fe^{10+} ion beam dynamics simulations for a 60^0-channel was carried out for ion source accelerating voltage of 15 kV (Fig. 4) to provide the ion energy of 150 keV needed for TAP investigation. Taking into account the Child-Langmuir low, the dynamics throughout the channel for Fe^{6+} ion beam extracted with for ion source accelerating voltage of 25 kV was carried as well. It was found that for this beam the reqiared parameters can be provided as well.

CONCLUSIONS

Multifunction test-bench based on the ECR source is proposed for the development of the experimental work on rapid radiation hardness analysis for materials used in the nuclear and thermonuclear reactors construction.

The test bench provides the sample irradiation for further study both by TAP and by TEM. Beam dynamics simulations for different ions in two test-bench channel have been carried out. At moment the beam dynamics simulations in approximation of real fields is going on.

REFERENCES

1. A.A. Aleev, N.A. Iskandarov, M. Klimenkov, R. Lindau, A. Mslang, A.A. Nikitin, S.V. Rogozhkin, P. Vladimirov, A.G. Zaluzhnyi. Investigation of oxide particles in unirradiated ODS Eurofer by tomographic atom probe *// J. Nucl. Mater.* 2011, v. 409, p. 65-71.
2. S.V. Rogozhkin, A.A. Aleev, A.G. Zaluzhnyi, A.A. Nikitin, N.A. Iskandarov, P. Vladimirov, R. Lindau, A. Mцslang. Atom probe characterization of nano_scaled features in irradiated ODS Eurofer steel // *J. Nucl. Mater.* 2011, v. 409, p. 94-99.
3. O.V. Borodin, V.V. Bryk, V.N. Voevodin, A.S. Kal'chenko, J.E. Kupriyanov, V.V. Melnichenko, I.M. Nekludov, A.V. Perm. Radiation swelling of ferritic-martensitic steels EP-450 and HT-9 irradiated metal ions to extremely high doses // *PAST. Series «Physics of radiation damage and radiation material» (97).* 2011, №2, p. 10-15.
4. S.V. Rogozhin, T.V. Kulevoy, N.A. Iskandarov, N.N. Orlov, B.B. Chalykh, A.A. Aleev, N.Y. Grachev, R.P. Kuibida, A.D. Fertman, V.B. Shishmaref. Simulation experiment to study the radiation hardness ferritic-martensitic promising steel, hardened dispersed inclusions // *Atomic Energy.* 2013, v. 114, №1, p. 12-17.
5. S.V. Rogozhin, A.A. Aleev, A.G. Zaluzhny, R.P. Kuibida, T.V. Kulevoy, A.A. Nikitin, N.N. Orlov, B.B. Chalykh, V.B. Shishmaref. Effect of heavy-ion irradiation on the nanostructure of advanced materials of nuclear power plants // *Physics of Metals and Metallography.* 2012, v. 113, №2, p. 212-224.

Article received 29.10.2013

РАЗРАБОТКА УСКОРИТЕЛЬНОГО СТЕНДА С ЭЦР-ИСТОЧНИКОМ ДЛЯ ЭКСПЕРИМЕНТОВ ПО МОДЕЛИРОВАНИЮ РАДИАЦИОННЫХ ПОВРЕЖДЕНИЙ В СТАЛЯХ АТОМНОЙ ПРОМЫШЛЕННОСТИ

Б.Б. Чалых, Р.П. Куйбида, Т.В. Кулевой, А.В. Зиятдинова

Моделирование радиационных дефектов в сталях и сплавах атомной промышленности на данном этапе является одним из самых легкореализуемых методов изучения свойств материалов под потоками высокоэнергетических частиц. Создание дефектов на реально-действующих реакторах сопряжено с немалыми трудностями, включающими в себя длительные сессии облучения, а также наведённую радиоактивность в образцах, что затрудняет дальнейшее исследование при помощи стандартного инструментария. Моделирование радиационных дефектов на ускорителях заряженных частиц лишено подобных трудностей. Для создания радиационных дефектов на ускорителях необходимо создание установки, позволяющей вести облучение образцов различными ионами с широким энергетическим спектром. Представлены результаты первоначального этапа разработки ускорителя с ЭЦР-источником, позволяющим проводить моделирование радиационных дефектов.

РОЗРОБКА ПРИСКОРЮВАЛЬНОГО СТЕНДУ З ЕЦР-ИСТОЧНИКОМ ДЛЯ ЕКСПЕРИМЕНТІВ ПО МОДЕЛЮВАННЮ РАДІАЦІЙНИХ УШКОДЖЕНЬ В СТАЛЯХ АТОМНОЇ ПРОМИСЛОВОСТІ

Б.Б. Чалих, Р.П. Куйбіда, Т.В. Кулевой, А.В. Зіятдинова

Моделювання радіаційних дефектів в сталях і сплавах атомної промисловості на цьому етапі є одним з самих легко реалізованих методів вивчення властивостей матеріалів під потоками високоенергетичних часток. Створення дефектів на реально-діючих реакторах зв'язано з чималими труднощами, що включають тривалі сесії опромінення, а так само наведену радіоактивність в зразках, що утрудняє подальше дослідження за допомогою стандартного інструментарію. Моделювання радіаційних дефектів на прискорювачах заряджених часток позбавлене подібних труднощів. Для створення радіаційних дефектів на прискорювачах потрібне створення установки, що дозволяє проводити опромінення зразків різними іонами з широким енергетичним спектром. Представлено результати первинного етапу розробки прискорювача з ЕЦР-джерелом, що дозволяє проводити моделювання радіаційних дефектів.