ISBN: 978-3-95450-201-1 doi:10.18429/JACoW-IBIC2018-MOPA06

RECENT ADVANCES IN BEAM MONITORING DURING SEE TESTING ON ISDE&JINR HEAVY ION FACILITIES

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Abstract

SEE testing of candidate electronic components for space applications is essential part of a spacecraft radiation hardness assurance process in terms of its operability in the harsh space radiation environment. The unique in Russia SEE test facilities have been created to provide SEE testing [1]. The existing facilities, including ion beam monitoring system have been presented at IBIC 2017[2]. However, this system has a number of shortcomings related to the lack of reliable online ion fluence measurement on the DUT, and inability to measure energies of the high-energy (15-60 MeV/nucleon) long-range (10-2000 μm) ions on the DUT. The paper presents the latest developments and their test results of the ISDE and JINR collaboration in the field of real-time flux monitoring (including, on the DUT) during tests using scintillation detectors, and ion energy measurement by total absorption method. The modernization of the standard beam monitoring procedure during testing is proposed.

WIDE-ANGLE COMPLETE-OVERLAP ION BEAM PROFILE MONITORING SYSTEM

This system is designed to monitor the stability and non-uniformity of the ion beams during heavy-ion testing on the low-energy test facilities. The system is based on an array of scintillation detectors consisting of 64 (8x8) sensors and designed for measuring such ion beam parameters as flux and integral fluence in real-time during heavy-ion testing, as well as non-uniformity. An important advantage of the system is the ability to obtain data without stopping the irradiation, i.e. in real time during testing, through the use of vacuum actuator installed in close proximity to the DUT.

Table 1 shows the technical features of the system, and Figures 1 and 2 show the appearance of the system after assembly and already mounted at the test facility.

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Table 1: Technical features of the wide-angle complete-overlap ion beam profile monitoring system

Feature	Value	Unit
Ion species	Ne to Bi	
Energy range	3-6	MeV/nucleon
Fluxes	$1\text{-}10^5$	$cm^{-2}*s^{-1}$
Area	200x200	mm
Number of detectors	8x8	
Visualization system	Yes	
Input/output to/from the beam	In real-time	
Measurement and data output time	1	min
Ion flux determination error	Less than 10	%
Non-uniformity indication	Yes	

Figure 1: Wide-angle complete-overlap ion beam profile monitoring system (ready-assembled, before installation).

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Examples of measurement results visualization (software interface) are shown in Figs. 3 and 4. In addition to the instantaneous flux value for each of the 64 detectors, it is possible to calculate the average fluence over the entire irradiation area, as well as the non-uniformity.

Figure 2: Wide-angle complete-overlap ion beam profile monitoring system (installed in the beam channel).

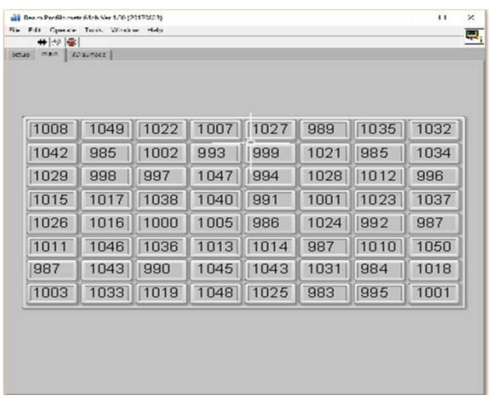

Figure 3: Software interface for the wide-angle complete-overlap ion beam profile monitoring system.

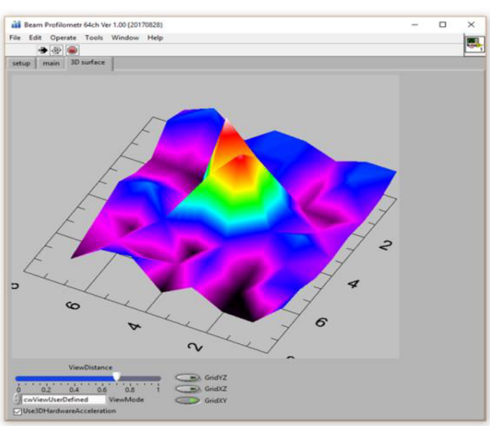

Figure 4: Example of measurement results visualization for wide-angle complete-overlap ion beam profile monitoring system.

A series of irradiation sessions was performed for the purpose of experimental testing of the system. The irradiation sessions were carried out at beam fluxes of 100000 and 50000 particles/cm^2*s by accelerated beam of Xe heavy ions with energy of 3.82 MeV/nucleon, and also at beam fluxes of 10000 and 1000 particles/cm^2*s by accelerated beam of Kr heavy ions with energy of 3.1 MeV/nucleon. During each session, the metrological certified track detectors were placed near each wide-angle complete-overlap ion beam profile monitoring system to compare the integral fluxes. The results coincided within the error margins.

15-CHANNEL BEAM PROFILE MONITORING SYSTEM

This system is equivalent to the previous one in terms of physical principles of ion flux registration. The system is used to monitor the beam of high-energy ions, which allows obtaining data on the spatial distribution of the ion beam uniformity in real time (during tuning the beam, pretest setup, etc.).

Table 2 shows the technical features of the system.

Table 2: Technical Features of the 15-channel Beam Profile Monitoring System

Feature	Value	Unit
Ion species	Ne to Bi	
Energy range	15-60	MeV/nucleon
Fluxes	$1\text{-}10^5$	cm^{-2}*s^{-1}
Diameter	60	mm
Number of detectors	15	
Visualization system	Yes	
Input/output to/from the beam	In real-time	
Measurement and data output time	1	min
Ion flux determination error	Less than 10	%
Non-uniformity indication	Yes	

The design features are shown in Fig. 5.

Figure 6 shows the software interface. On the left side of the screen, the user can see the current value of ion flux per each detector, as well as average flux versus irradiation time plot. The right side of the screen displays the instantaneous flux and the integral fluence. At the bottom right, the required ion fluence is shown during the tests. For beam quality monitoring there is an option to display the non-uniformity.

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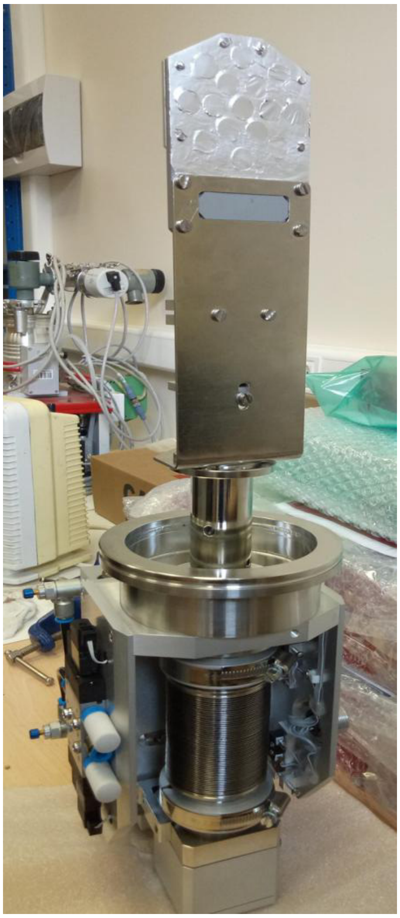

Figure 5: Appearance of the 15-channel beam profile monitoring system.

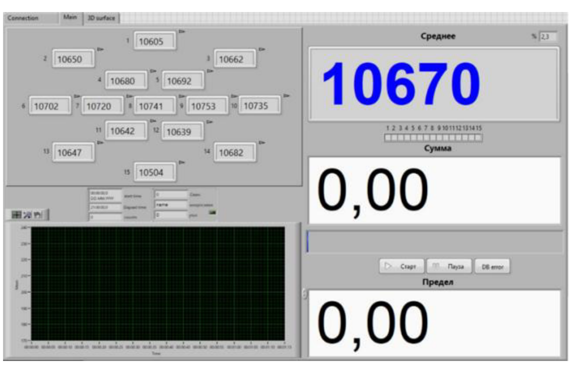

Figure 6: Software interface for the 15-channel beam profile monitoring system.

SCINTILLATION ONLINE DETECTORS SYSTEM FOR TEST SUPPORT

This system is designed for in-situ measurement of ion flux on the DUT during testing. In terms of design, the detector consists of a plastic scintillator, flexible WLS (wavelength shifting) fibres, and photomultiplier tube. The flexible structure allows the sensitive volume of the detector to be placed in close proximity to the DUT. Up to 8 such detectors can be placed in the test chamber simultaneously.

Table 3 shows the technical features of the system.

Table 3: Technical Features of the Scintillation Online Detectors System for Test Support

Feature	**Value**	**Unit**
Active surface area	1	cm^2
Ion species	Ne to Bi	
Energy range	3-60	MeV/nucleon
Fluxes	$1\text{-}10^5$	$cm^{-2}*s^{-1}$
Scintillator thickness	1-2 (for 3-10 MeV/nucleon) 5 (for 10-60 MeV/nucleon)	mm
Ion flux determination error	Less than 10	%
Non-uniformity indication	Yes	

Figure 7 shows an example of detectors positioning in the irradiation chamber.

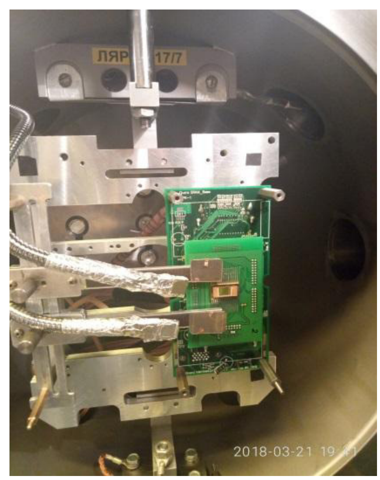

Figure 7: Positioning of scintillation online detectors system for test support on the DUT.

The software interface is similar to the previous one and is shown in Figure 8. The detectors can be turned off in order to ignore readings from unused sensors during calculation of the average flux.

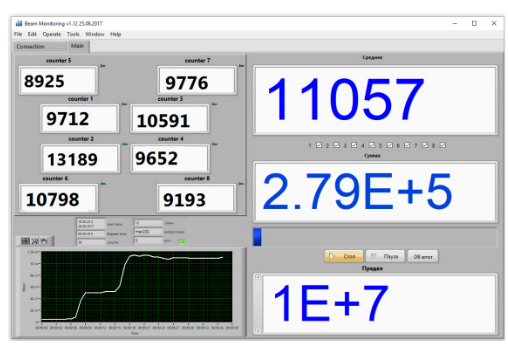

Figure 8: Software interface of scintillation online detectors system for test support.

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ION ENERGY MEASURING SYSTEM

This system is designed to measure the ion energies on the DUT surface. The system consists of semiconductor silicon detector (detector thickness – 500 µm) and charge sensitive preamplifier for Xe, Kr and Bi ions, as well as scintillation detector CsI (detector thickness – 5 mm), photomultiplier tube, and photon counter for lighter ions. When working with the system, it is necessary to calibrate the detector by taking the readings of amplitude spectra of the detector from the heavy ion beam at different energies (at least three; the energy is changed by placing aluminium foils of different thickness in the ion beam line) and comparing the results with the readings of time-of-flight detectors. After calibration, energy can be measured directly on the DUT.

During experimental testing of the system we obtained the amplitude spectra from accelerated heavy-ion beams of Xe with energies of 22.94, 19.28, 14.39 and 9.92 MeV/nucleon, Kr with energies of 25, 22.20, 18.49 and 15.19 MeV/nucleon, Ar with energies of 33.8, 24.68 and 12.17 MeV/nucleon, and Bi with energies of 12.12, 6.87 and 4.49 MeV/nucleon. Figure 9 shows an example of measurement results for Xe.

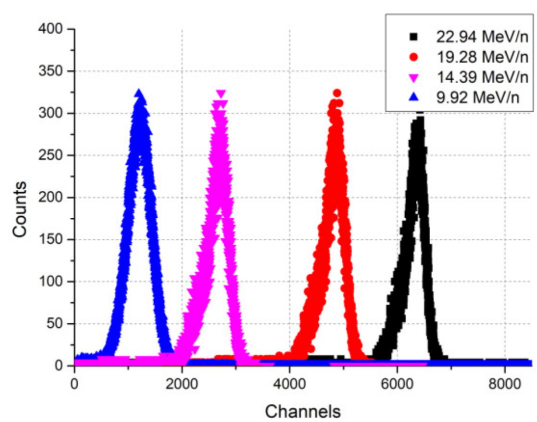

Figure 9: Amplitude spectra from accelerated heavy-ion beams of Xe with energies of 22.94, 19.28, 14.39 and 9.92 MeV/nucleon, obtained by silicon detector.

The calibration was followed by the ion energy measurements on the DUT. The measurement results of ion energies in the beam channel and on the DUT are presented in Table 4. We can see a close agreement of measurement results with estimated energies, especially for high energies.

Table 4: Results of ion energy measurements

Ion species	Ion energy in the beam channel, MeV/nucleon	Measured ion energy on the DUT, MeV/nucleon	Estimated ion energy on the DUT, MeV/nucleon
Xe	22.94	20.39	20.53
Kr	25	23.09	23.15
Ar	33.8	32.78	32.93
Bi	12.12	9.65	8.74

CONCLUSION

The paper presents the recent advances of ISDE & JINR collaboration in the field of beam parameters monitoring in the physical field of irradiation before and after the heavy-ion testing. Four systems have been developed that allow to monitor the ion beam fluxes, integral fluence and non-uniformity over the entire irradiation area for the low- and high-energy test facilities; to make real-time measurements of the ion fluxes, integral fluence directly on the DUT; to measure ion energy directly on the DUT. The introduction of the developed systems in a test process of candidate space electronics allows to increase the reliability of test data and to minimize errors in ion beam parameters determination.

ACKNOWLEDGEMENTS

The authors thank Aleksey Konyukhov from ISDE for his participating in formatting and translating the article into English.

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