First results from gamma ray diagnostics in EAST Tokamak

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First results from gamma ray diagnostics in EAST Tokamak

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Gamma ray diagnostics has been developed in the EAST tokamak recently. Six BGO scintillator detectors are arranged on the down-half cross-section and pointed at the up-half cross-section of plasma, with space resolution about 15 cm and energy range from 0.3 MeV to 6 MeV. Three main gamma ray peaks in the energy spectra have been observed and are identified as the results of nuclear reactions $^{207}Pb(n,n')^{207m}Pb$, $H(n,\gamma)D$, and $D(p,\gamma)^3He$, respectively. Upgrading of the system is in progress by using LaBr3(Ce) scintillator, fast photo-multiplier tubes, and a fully digital data acquisition system based on high sample frequency digitizers with digital pulse processing algorithms. *Published by AIP Publishing.* [http://dx.doi.org/10.1063/1.4955481]

I. INTRODUCTION

Gamma ray diagnostics is an important technique used to study fast ion behaviour in tokamak plasma. This is due to the fact that gamma ray emission is produced during nuclear reactions between fast ions and fuel ions or plasma impurities.[1] By analysing the gamma ray energy spectra measured with spectrometers, different fast ion species in the plasma can be identified.[2,3] Gamma ray emission profiles measured with a multi-collimated detector array can be used to study the radial distribution of the fast ions.[4,5] Also, by analysing the Doppler broadening of the gamma ray peaks, information on the fast ion energy distribution can be inferred.[6,7]

Recently, gamma ray diagnostics has been developed in the EAST tokamak. Six BGO scintillator detectors are used to compose a radial gamma ray camera (RGC). Both the gamma ray energy spectra and emission profiles have been obtained. First results from this gamma ray diagnostic system are obtained during deuterium neutral beam injection (NBI) experiments in EAST. In this article, system setup of the gamma ray diagnostics is described in Sec. II. Some first results are shown in Sec. III. The status of the system upgrading is presented in Sec. IV. At last, a summary is given in Sec. V.

II. SYSTEM SETUP

In the gamma ray diagnostics of EAST tokamak, six well calibrated and collimated bismuth germanate (BGO) (50 mm × 50 mm) scintillator detectors are arranged on the down-half cross-section of the tokamak. Because those detectors are located inside of the experimental hall, they have to be well-shielded from background gamma ray and neutron flux. Polythene (total thickness of 60 cm) is used as the main neutron absorber, and lead (total thickness of 30 cm) is used as the main gamma ray absorber. Lead is placed inside of polythene, because gamma rays from neutron capture reaction $H(n,\gamma)D$ exist due to the polythene, which must be absorbed by lead. Besides, to get rid of the effect of the magnetic field on the Photo-Multiplier Tubes (PMTs) that are used inside of the detectors, all detectors are surrounded with soft iron cylinders and permalloy. Six collimators (diameter of 5 cm) are made to make sure the detectors are pointed at the up-half cross-section of the plasma, with space resolution about 15 cm. In order to absorb the neutron flux that comes through the collimators, polythene (thickness of 15 cm) is used to fill in the collimators. A schematic of the gamma ray diagnostic system is shown in Figure 1.

At present, data acquisition system (DAQ) of the gamma ray diagnostic system in EAST is operated in the pulse counting mode based on the traditional analog chains. A block diagram of the DAQ system is shown in Figure 2. A preamplifier is located close to the detector, and the amplifier is selected to output unipolar shaped pulses with a shaping time of 0.5 μs to work in the high count-rate environment. Signal from the amplifier is sent into a signal splitter. Then, one branch of the signal from the splitter is sent to a single-channel analyzer (SCA) with a programmable pulse-height window. At last, a pulse counter gives the gamma ray counts with a time resolution of 1 ms. The other branch of the signal from the splitter is sent to a multichannel analyzer (MCA) (512 channels). Then through the computer interface, gamma ray energy spectra are obtained with a time resolution of 50 ms.

Measurable energy range of the system is selected as (0.3–6) MeV. The system has been calibrated using a group of radioactive reference sources with energy covered from 0.344 MeV to 6.13 MeV. The calibration results show energy resolution of the system is about 19% at 0.662 MeV with good energy linearity. The maximum count-rate that the system can suffer is about 200 kHz due to the limitation

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[b]See Appendix of B. N. Wan *et al.*, Nucl. Fusion **55**, 104015 (2015).

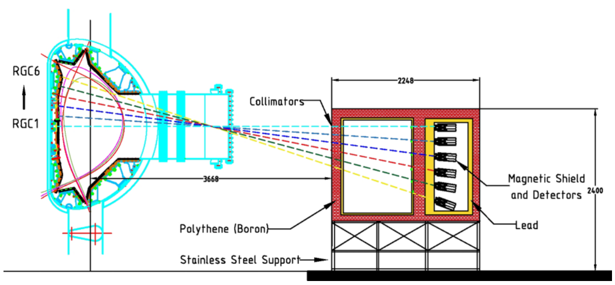


FIG. 1. Schematic of gamma ray diagnostic system in EAST Tokamak.

from the traditional DAQ system. Relative detection efficiency is calibrated between signals from the six detectors, and correction has been made to the signals to make sure that signals from the six detectors can be compared with each other.

III. FIRST RESULTS

First results from this gamma ray diagnostic system will be presented in this section. A typical discharge in EAST experiments is shown in Figure 3. Runaway electrons are generated during the start-up phase of the discharge, and suppressed when LHW is injected into plasma because loop voltage will decrease. In this phase, bremsstrahlung emission in hard X-ray range from runaway electrons is detected in the RGC1 signal, which has a continuous energy spectrum.[8,9] When NBI is injected into the plasma, intense neutron and gamma ray emission are produced for 3s–5s.

Gamma ray spectra measured in two time windows are shown in Figure 4(a), in which (1s–2s) and (5s–6s) correspond to the time period of hard X-ray from runaway electrons and gamma ray, respectively. As expected, continuous energy spectrum is obtained during 1s–2s. As for energy spectrum for 5s–6s, three distinct features are noticed: (a) energy peak at 0.57 MeV from reaction $^{207}Pb(n,n')^{207m}Pb$; (b) a prominent energy peak at 2.22 MeV from neutron capture reaction $H(n,\gamma)D$ due to the polythene used inside the collimators, and the single escape peak (labelled as "se") of 2.22 MeV; (c) a clearly enhanced spectrum with energy range from 3 MeV up to 6 MeV, which might arise from neutron reactions with impurities in plasma and materials in the vessel walls.[10] An energy peak around 5.7 MeV is superimposed on this continuous spectrum, which is identified as the result of reaction $D(p,\gamma)^3He$ considering that there is a 3% error from the energy calibration.

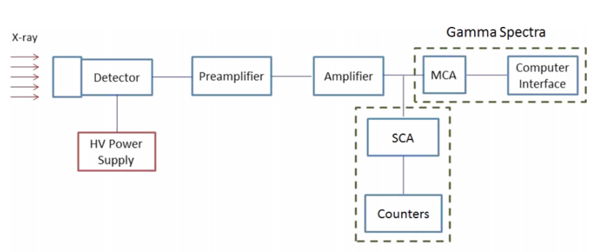


FIG. 2. Block diagram of the data acquisition system based on traditional analog chains.

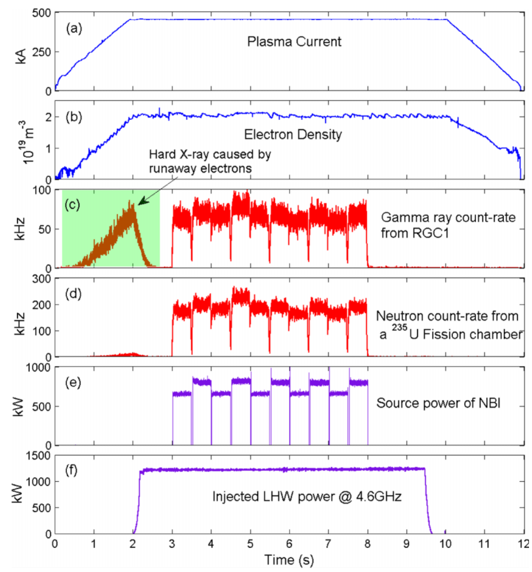
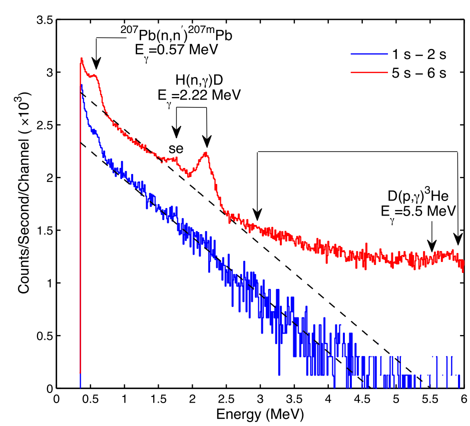
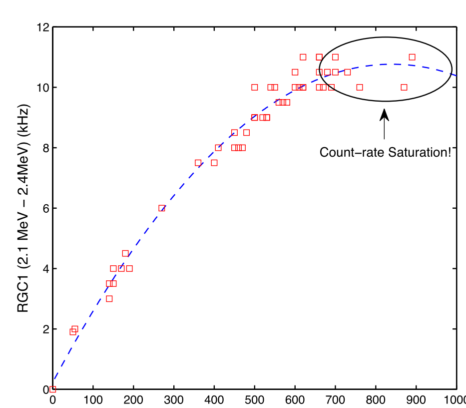


FIG. 3. A typical discharge with NBI and Lower Hybrid Wave (LHW) injection in EAST experiments.

$E_\gamma = 2.22$ MeV is the most prominent peak on the spectrum. The area below this peak is integrated from 2.1 MeV to 2.4 MeV to compare with neutron count-rate from a ^{235}U fission chamber. The statistical result from a wide range of



(a)



(b)

FIG. 4. (a) Gamma ray spectra measured in two time windows, (1s–2s) and (5s–6s). (b) Comparison between neutron count-rate from a ^{235}U fission chamber and integrated area from 2.1 MeV to 2.4 MeV on the gamma ray spectrum.

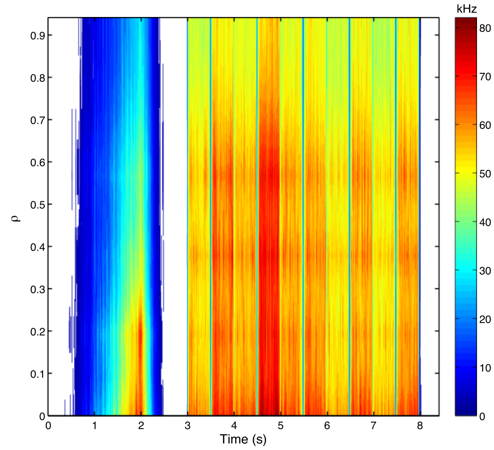


FIG. 5. Contour plot of all 6 signals from the gamma ray diagnostic system from 0 s to 8 s.

neutron count-rate during NBI experiments is shown in Figure 4(b). It indicates that they are linearly correlated, which is expected because this gamma ray peak is produced due to reaction $H(n,\gamma)D$. However, in the high count-rate region, count-rate from RGC1 starts to decrease. The maximum count-rate that the fission chamber can suffer is well above 1 MHz. So, RGC1 is suffering from count-rate saturation in this count-rate region, and the total count-rate of RGC1 from whole energy range is about 200 kHz in this condition.

Tomography of gamma ray emission from this diagnostics is not possible now. But useful information still can be obtained by comparing signals from the 6 channels with each other. Contour plot of all 6 signals from the gamma ray diagnostic system is shown in Figure 5. It indicates that runaway electrons are generated mainly in the center of the plasma ($\rho < 0.3$) during start-up phase of the discharge, while a gamma ray is produced in a more broad plasma region ($\rho < 0.7$). Further analysis will be performed in our future work.

IV. SYSTEM UPGRADING

At present, there are two main drawbacks in the system: bad energy resolution and low maximum count-rate capability. So, upgrading of the system is ongoing. LaBr3(Ce) scintillator (38 mm × 38 mm) is selected as the detector material considering its high energy resolution (~3.5% at 0.662 MeV), short scintillation decay times (~30 ns), insensitive to neutrons, but high cost.[11] Fast PMT (time response ~5 ns) is used to connect with the LaBr3(Ce) scintillator. Then, a fully digital DAQ system based on high sample frequency digitizers (14 bit 500 MS/s) with Digital Pulse Processing (DPP) algorithms is used. Test results show that this upgrading system can provide energy spectrum at count-rate above 2 MHz with high quality. Operating the upgrading system in EAST experiments will be performed at the end of 2016.

V. SUMMARY

A gamma ray diagnostic system has been developed in the EAST tokamak by using six well calibrated and collimated BGO scintillator detectors. Using the DAQ system with conventional MCA, the maximum count-rate that the system can suffer is about 200 kHz. First results from this gamma ray diagnostic system are obtained during deuterium neutral beam injection (NBI) experiments in EAST. Upgrading of the system is ongoing to obtain energy spectrum with good energy resolution and high maximum count-rate capability. Test results show that this upgrading system can provide energy spectrum at a count-rate above 2 MHz with high quality.

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