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High Rate Measurements of the Neutron Camera and Broadband Neutron Spectrometer at JET

L. Giacomelli[a,b,*], S. Conroy[a,c], F. Belli[d], G. Gorini[b,e], E. Joffrin[a], V. Kiptily[a], E. Lerche[a], A. Murari[a], V.V. Plyusnin[f], S. Popovichev[a], C. Reux[g], M. Riva[d], D.B. Syme[a], and JET EFDA Contributors[1]

[a]*CCFE, Culham Science Centre, Abingdon, Oxon, OX14 3DB, UK*
[b]*Department of Physics, Università degli Studi di Milano-Bicocca, Milano, Italy*
[c]*Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden*
[d]*Associazione EURATOM-ENEA sulla Fusione, Roma, Italy*
[e]*Istituto di Fisica del Plasma "Piero Caldirola", Milan, Italy*
[f]*Instituto de Plasmas e Fusão Nuclear, Associação EURATOM-IST, Lisboa, Portugal*
[g]*CEA IRFM, Cadarache, France*

Abstract

The Joint European Torus (JET, Culham, UK) is the largest tokamak in the world. JET has been upgraded over the years and recently it has also become a test facility of the components designed for ITER, the next step fusion machine under construction in Cadarache (France). At JET, the neutron emission profile of Deuterium (D) or Deuterium-Tritium (DT) plasmas is reconstructed using the neutron camera (KN3). In 2010 KN3 was equipped with a new digital data acquisition system (DAQ) based on Field Programmable Gated Array (FPGA). According to specifications, the DAQ is capable of high rate measurements up to 0.5 MCps. A new compact broadband spectrometer (KM12) based on BC501A organic liquid scintillating material was also installed in the same year and implements a similar DAQ as for KN3. This article illustrates the observations on the DAQ high count rate performance of both KN3 and KM12 in the latest JET D plasma experiments related to hybrid scenario and runaway electrons. For the latter, >1 MCps event rate was achieved with consequences on the behavior of the FPGA and on the reliability of the measurements.

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Keywords: JET plasmas; n/g discrimination; digital data acquisition system; FPGA high count rate measurements.

1. Introduction

During the Joint European Torus (JET, Culham, UK) (1) shutdown in 2010, the new ITER-like-wall (ILW) (2) made of Beryllium tiles was assembled in the vacuum vessel to test it in view of ITER (3). The plasma neutron emission profile monitor KN3 (i.e., the neutron camera) was upgraded with a new digital data acquisition system (DAQ, 14

[1] See the Appendix of F. Romanelli et al., Proceedings of the 24th IAEA Fusion Energy Conference 2012, San Diego, USA
* Corresponding author: L. Giacomelli Tel.: +44-1235-464333; fax: +44-1235-464577.
E-mail address: luca.giacomelli@mib.infn.it

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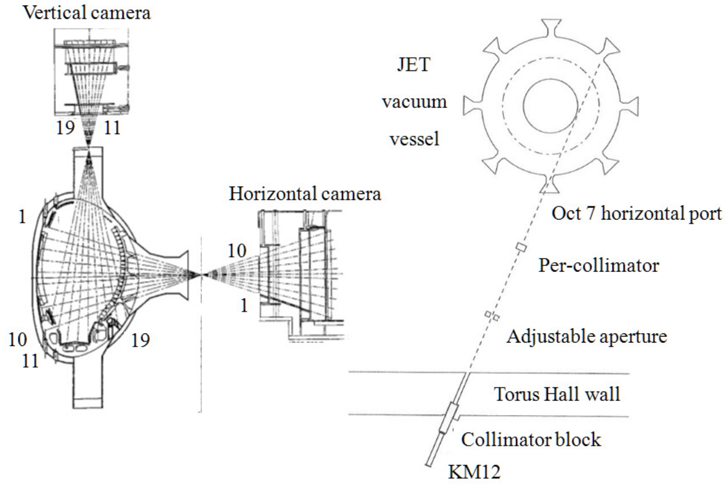

Fig. 1. Schematic of KN3 (left hand panel) and of KM12 (on the right) view lines at JET.

bit and 0.2 Gsample/s) (4) and a brand new compact broadband liquid scintillator neutron spectrometer (KM12) was installed (5). KN3 implements two different sets of detectors along horizontal (1-10) and vertical (11-19) radial lines of sight (Fig. 1). NE213 liquid scintillators are used for the diagnosis of D plasma 2.45 MeV neutron emission while thin Bicron BC418 plastic scintillation detectors are selected for DT 14 MeV neutrons (6). KN3 DAQ consists of 10 boards each with 2 independent acquisition channels. Each channel (ch) records its NE213 signal according to the setting loaded into the Field Programmable Gated Array (FPGA). The FPGA manages the acquisition of the signal digitalized by two Analog-to-Digital Converters working in interleaved mode in terms of pulse amplitude (larger than the predefined threshold), pulse length and offset removal (7). JET time signal is used as absolute reference for KN3 DAQ clock (4). KM12 (Fig. 1) features a horizontal tangential view line across the plasma equatorial plane and implements a similar DAQ (one board-one ch) but with an independent internal clock (5). The DAQ system was tested in the lab with a pulse generator and it was proven stable up to 0.9 MCps.

2. KN3 and KM12 high count rate performance

Three recent JET D plasma discharges are reported here because of the high count rate measurements KN3 and KM12 performed. JET shot 84806 is part of the development of hybrid plasmas to lower triangularity and density. The discharge featured 25 MW neutral beam injection (NBI) auxiliary heating with toroidal magnetic field B_t=2.3 T and plasma current I_p=2.0 MA. It provided the record neutron yield rate of $1.8{\cdot}10^{16}$ n/s in JET ILW. The other data relates to the generation of runaway electrons at major disruptions triggered by massive Argon (Ar) gas injection about 20 s after the onset of the plasma (8)(9). Runaway electrons emit Bremsstrahlung radiation (i.e., hard X-rays and γ's) which can induce photoneutron reactions depending on their energies (10). KN3 NE213 and KM12 BC501A detectors are sensitive to both neutron (n) and γ radiations which produce signals of different pulse shapes (11). The data were analyzed using the tomographic method presented in (12) which allows for an accurate determination of n and γ pulse height spectra and count rates at low energies.

KN3 and KM12 results are here presented in terms of count rates. Fig. 2 illustrates the n count rates (C_n) measured in JET shot 84806 during the NBI power phase due to nuclear fusion reactions of heated and bulk (i.e., thermal) D ions. KN3 chs 4 and 5 reached C_n>0.3 MCps, chs 15 and 16 C_n~0.4 MCps and KM12 C_n~0.25 MCps. All traces look plausible as they follow the pattern of the NBI power deposition in D plasma and resemble the total neutron yield measured by the JET fission chambers KN1 (13) which is shown in Fig. 2 bottom panel normalized to KM12 C_n. KN3 vertical chs 18 and 19 are missing because of a pc fault during the data acquisition. The differences between KN3 and KM12 C_n depend on the position and viewing angle of the detectors (see Fig. 1). Both KN3 and KM12

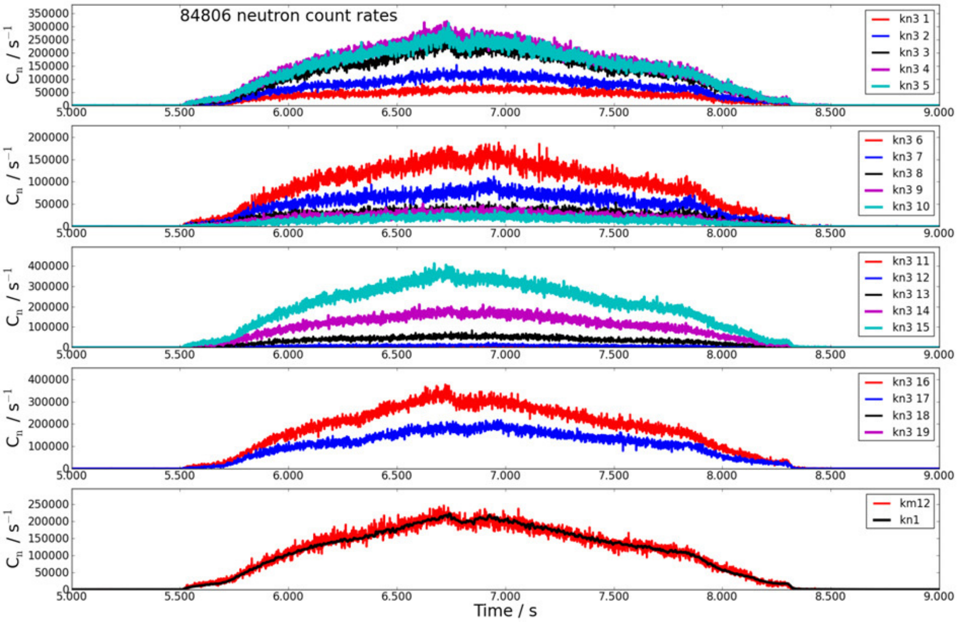

Fig. 2. C_n KN3, KM12 and KN1 measured during JET shot 84806 with a time resolution of 1 ms. KN1 C_n (bottom panel) are normalized to KM12.

DAQ FPGAs were severely stressed during the disruptions of the runaway electron experiments with recorded event rates well above specifications, which resulted in:

- A nonlinear behavior of the rejected event rate;
- a paralysis of the FPGA signal processing;
- an impact on the KM12 DAQ timing.

In JET shot 85946 (B_t=2.0 T, I_p=1.6 MA, Ar=100 %), KN3 chs 1, 3, 4, 6, 10, 12, 13 reached >0.7 MCps whilst chs 9, 14-19 received >1 MCps. Fig. 3 displays the recorded, rejected (i.e., pile-ups), good, n and γ event rates with the latter two obtained by processing the good events only with the tomographic analysis (12). KN3 chs 14 and 15 featured an extremely high recorded event rate with the fraction of good events dropping as it grows >0.6 MCps (Fig.s 3a and 3b). On the contrary, the rejected events, suddenly increase and remain high until the recorded event rate becomes <0.6 MCps at time t~20.0255 s for ch 14 and at t=20.027 s for ch 15. Both FPGAs then paralyzed at t=20.0271 s and the acquisition was interrupted.

KN3 channel 19 and KM12 reached >1.2 MCps recorded event rate (Fig.s 3c and 3d). KN3 ch 19 rejected events grows significantly after the spike at 1.4 MCps (t~20.0275 s) becoming dominant as long as the recorded event rate is >0.6 MCps (Fig. 3c). In Fig. 3d, the trend of KM12 rejected event rate is similar. Both the acquisitions were completed successfully. As indication for KN3 and KM12 behavior, Fig. 4a shows the measured KN1 fast ADCs neutron rate during the disruption in JET shot 85978 (B_t=3.0 T, I_p=1.8 MA, Ar=10 %). KM12 received >1.5 MCps (Fig. 4b). The onset of the rejected events at t~20.023 s seems more clearly related to the FPGA processing at rates >0.5 MCps (cf. Fig. 3d). Rejected and good events, mostly γ's, remain similar up to t~20.032 s. By comparison with KN1, KM12 data set appears shrunk as if the high rate processing of the FPGA would affect the KM12 DAQ internal clock. The FPGA could not cope with the disruption first spike detected by KN1 giving rise to the discontinuity of the recorded event rate at t~20.028 s and to its decrease until the disruption second spike occurs: This might have affected the FPGA acquisition timing. The acquisition terminated successfully although the FPGA processing of the events related to the third spike of the disruption collapsed (t~20.032 s). In this case, KM12 DAQ output was >1.5 MCps

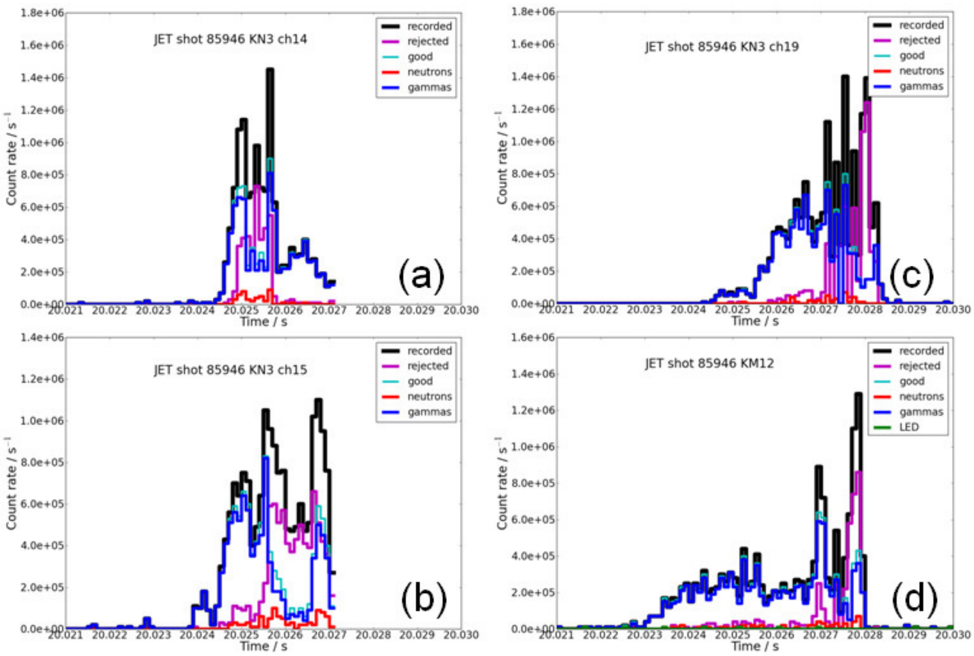

Fig. 3. Event rates of KN3 chs 14 (a), 15 (b), 19 (c) and of KM12 (d) during JET shot 85946 disruption with 0.1 ms time resolution.

recorded events which interpretation is unreliable. For this, KN3 and KM12 DAQs need to be tested in controlled conditions with input pulses of various amplitudes at rates in the range of 0.2-2 MCps.

Figures 4c and 4d show the response of KN3 chs 1 and 19 which were the top performing with 1.92 MCps and 1.67 MCps recorded events, respectively. These seem also to be their maximum limit in view of the comparison with KN1. The disruption first spike is not processed although KN1 1 ADC is installed at a few meters distance with respect to KN3 around JET tokamak. Only KN3 ch 1 instead shows the traces of the last two spikes of the disruption. Also here recorded event rates >0.6 MCps induce the growth of the rejected events. The time evolution of both KN3 measurements is similar to KN1 demonstrating the utility of the use of JET clock as DAQ absolute time reference.

3. Conclusions and outlook

KN3 and KM12 high count rate measurements were performed in JET high NBI power and runaway electrons experiments. According to specifications, KN3 and KM12 DAQs seem to work reliably at event rates <0.5 MCps. Controlled tests are necessary to verify their behavior when the FPGAs are stressed up to the MCps region. High NBI power experiments will also help to verify these observations in stable and sustained (few seconds) D plasma conditions. Reliable high performing FPGAs are essential for the ITER neutron camera since 5 MCps events rates are expected (14).

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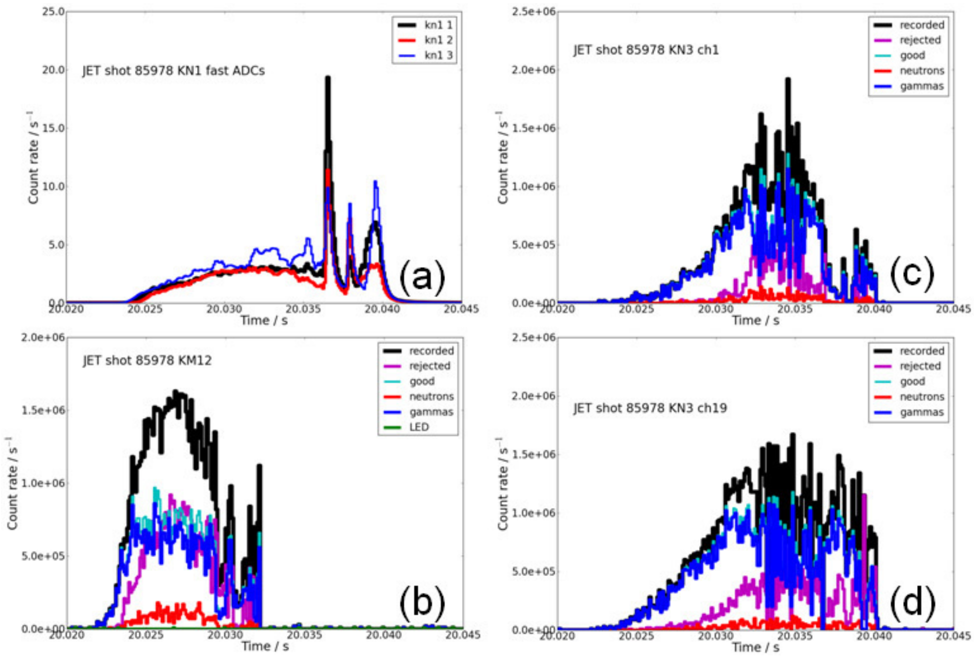

Fig. 4. Event rates of KN1 fast ADCs (a), of KM12 (b) and of KN3 chs 1 (c) and 19 (d) measured during JET shot 85978 disruption with 0.1 ms time resolution.

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