TEST FACILITY FOR FISSION CHAMBER ASSEMBLIES

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ABSTRACT

The Institution "Project Center ITER" with participation of the National Research Nuclear University MEPhI are developing the neutron diagnostics "Divertor Neutron Flux Monitor" (DNFM) for the International Thermonuclear Experimental Reactor (ITER). This diagnostics shall ensure measurement of the total neutron yield and ITER fusion power. Assemblies of fission chambers (FC) with different fissile materials and sensitivities are planned to be used for the neutron flux measurement. Study of fission chambers characteristics and acceptance testing of the diagnostic system will be carried out at the testing facility of the neutronic laboratory of the "TRINITI" Institute. The facility includes: compact powerful neutron generator with the power, control and monitoring system; remote handling system for FCs positioning and movement; novel three channels data acquisition and processing system. Each acquisition channel contains some measuring circuits with signal processing. This set of circuits provides neutron flux measurement in the range of at least 10 decades for each single FC. Data acquisition and processing system features are: signal digitizing with sample rate up to 125 MHz; real time data processing with computation and data update cycle from 0.1 ms. This paper examines the structure, composition and specification of the test facility. Application software, hardware solutions and the results of fission chambers prototypes tests are discussed.

Key Words: fission chamber, test facility, ITER, data acquisition system, neutron generator

1 INTRODUCTION

According to the design requirements neutron diagnostics "Divertor Neutron Flux Monitor" shall ensure measurement of the total neutron yield and fusion power of the experimental thermonuclear ITER reactor in all operational modes. Range of the total neutron yield change during ITER operation is from 10^{14} to $5{\cdot}10^{20}\,s^{-1}$. Generated thermonuclear power shall be monitored in the range of 0.1÷1500 MW. Measurements shall be carried out with the timing resolution of 1 ms, measurement error shall not exceed 10%. Along with that, another requirement shall be met by the diagnostic system – is to ensure absolute system calibration. This requirement widens the necessary range of the neutron flux density measurements practically to 10 orders of magnitudes. These requirements can be achieved by using a neutron flux monitoring system consisting of a set of different sensitivity fission chambers and a special wide-range data acquisition and signal processing system. The special test facility with the NG-24M neutron generator was built to study characteristics of individual components and the "Divertor neutron flux monitor" diagnostic system at all.

2 TEST FACILITY

The test facility is built in the neutronic laboratory of the "TRINITI" (State Research Center of RF Troitsk Institute for Innovation & Fusion Research) Institute. Compartment of the testing facility is 6×6×4 m and it is surrounded by the 2.0 m thick concrete walls. Such shielding allows safe operation with fast neutron sources with the intensity of up to 10^{11} s^{-1}.

The main components of the facility are:

- neutron generator with power, cooling and control systems;
- radiation detector – neutron yield monitor;
- system for position control and displacement of tested samples;
- three-channel fission chambers signals data acquisition and processing system.

Developed by VNIIA neutron generator NG-24M is a main part of the test facility [1]. Neutron generator consists of irradiator, power supply and cooling system. The generator has gas-filled neutron tube with a Penning ion source. The neutron tube and accelerating high voltage source are integrated in the irradiator unit. The target of the sealed neutron tube is grounded.

GNT1-100 sealed neutron tube is a crucial component which defines neutron generator characteristics. The stuffing target is used in the neutron tube. Neutron flux is controlled by the ion current and accelerating voltage. Feedback loops are used for flux control and stability. In this case the neutron flux produced by the neutron generator remains constant with the error less than 5%. Depending on the working gas type of the gas-filled tube the generator is a source of neutrons with the energy of 2.45 MeV or 14.1 MeV (for neutrons emitted at the right angle to the movement direction of accelerated deuterons). NG-24M works in the continuous mode. High neutron yield is achieved due to accelerating voltage up to 240 kV and ion current up to 2.5 mA. During operation the target of gas-filled neutron tube is heated by the accelerated deuteron beam. Therefore the water cooling system of the target unit has been provided as a part of the NG-24M.

The neutron generator NG-24M is equipped with the radiation detector – neutron yield monitor. The high purity U^{238} fission chamber KNT 30-8 is used as the radiation detector-monitor. To prevent electromagnetic interference the signal from radiation detector-monitor to the facility control room is transmitted via the fiber-optic communication lines.

The test facility is equipped with the position control system with remote handling. The position control system allows moving objects weighing up to 50 kg in the vertical (up to 1.4 m) and horizontal (up to 2.7m) with positioning error less than ± 1 mm.

The generator and position control system are remotely handled from the facility control room. The control software allows operate in automatic or semi-automatic mode to control the accelerating voltage, ion current, irradiation time and position of the investigated sample. During generator operation the control software records reports for all current parameters of the test facility basic components. All neutron generator parameters, neutron yield radiation detector-monitor indications, as well as the studied object position coordinates are storage into the database.

The metrological support of neutron measurements at the test facility is based on the use of the reference fields of neutrons with the energies 2.45 and 14.1 MeV [2]. The certification of the neutron generator NG-24M modeling reference fields has been performed by the Metrology Institute "VNIIFTRI". Neutron field characteristic measurements were carried out for the distances of 50 and 100 mm from the generator target. The sets of tracking fission detectors and activation detectors were used to determine neutron flux density [3].

Three-channel data acquisition and processing system used for registration and processing signal of the investigated fission chambers. Each systems channel is independent and designed to work with the one fission chamber. The design and operation principles of the measuring channels are identical to those used in the prototype of the data acquisition system for the neutron diagnostic “Divertor Neutron Flux Monitor”.

3 DATA ACQUISITION AND PROCESSING SYSTEM

Data acquisition and processing system provides pulse-current signals acquisition of three fission chambers and contains of three independent measuring channels. Each channel contains several measurement chains: pulse-mode, Campbell-mode and current-mode.

Fast analog to digital data conversion and signal preprocessing is based on National Instruments (NI) PXI platform. This platform is one of the permitted basis for data acquisition and control systems in ITER project.

Data acquisition system performs the following functions:

- fission chambers bias supply;
- data acquisition of all measuring chains and control channels signals;
- conversion of measured data into neutron flux at FC-site installation;
- calibration of measuring chains;
- diagnostic of measuring channels as a whole and its components;
- display information about the measured, calculated and controlled parameters, as well as data about the measuring channels current state;
- archiving of the measured data.

The block diagram of the system is shown in Fig.1 . Data acquisition system includes:

- preamplifier unit;
- optical transceivers unit;
- PXI system;
- data acquisition system control unit (personal computer - PC);
- coaxial and fiber-optical communication lines for analog and digital signals transmission.

Each preamplifier unit measuring channel consists of preprocessing module PM and optical converters module OCM1. The preprocessing module includes signal converters and amplifiers and of the measuring chains. The optical converters module includes electrical-optical converters, analog and digital optical transmitters. Fast analog signals through the analog optical transmitters passed to the optical transmitters unit via analog optical links. Slow analog signals and auxiliary data is converted into digital data in preamplifier unit for each measuring channel and passed to the optical transmitters unit via digital optical links. By the same digital links preamplifier unit receives commands to control of fission chambers supply voltage as well as control commands of measuring modes and built in test generators.

The optical transceivers unit converts optical signals of the preamplifier unit into electrical signals for processing them into PXI system. The optical converters modules OCM2 convert fast optical analog signals to electrical signals. Service module SM converts all digital optical signals to electrical and to reverse side.

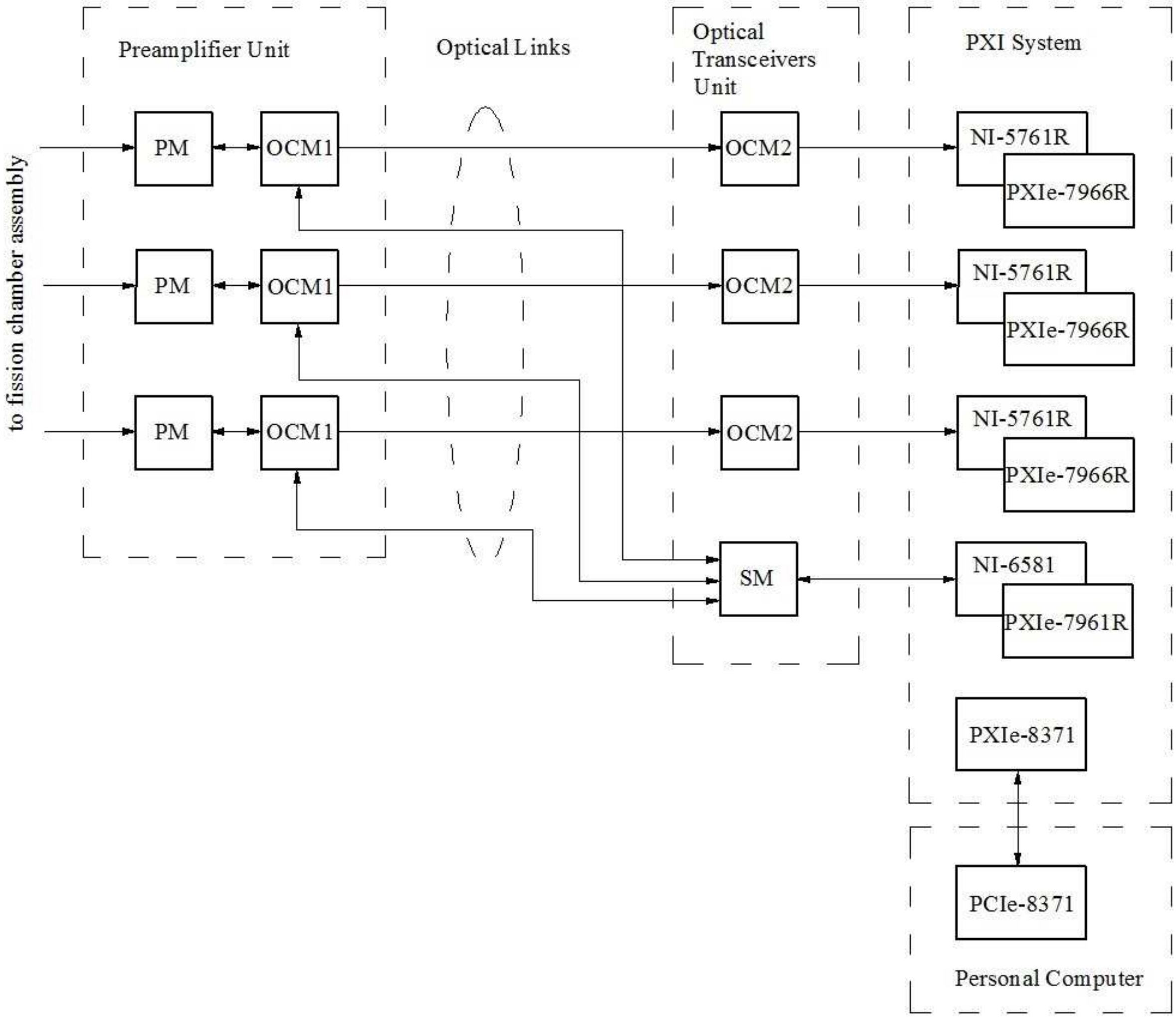

Figure 1. Block diagram of the data acquisition system

Analog signals of the pulse and Campbell chains comes into PXI system modules PXIe7966R with NI5761 (three channels) for analog-to-digital conversion and real time digital pre-processing (calculation of "raw" data - the counting rate and the variance of noise component). Measuring and diagnostic as well as control commands and digital data exchange between optical transmitter unit and PXI system performed with use of PXI modules PXIe7961R with NI6581. The "raw" data is transmitted in PC with clock of 100 μs.

The build in test signal generator is possible to apply for functionality testing. It is directly connected to the preprocessing modules inputs in each measurement channel.

The PC-based data acquisition system control unit is using for operator convenience placing and subsequent operation of the system. Connecting the PC to the PXI chassis is performed through the MXI-express link.

PC software runs on Microsoft Windows 10 operating system. This software provides NI FlexRIO modules configuring by loading special firmware that implement the required operation modes and data processing functions. Self-test and calibration function allows to check all stages of modules software loading, interacting with NI hardware, test signals generation and control of their passage. As a self-diagnosis result is issued for conclusion about the system readiness for operation and set the calibration factors. The calibration factors can be changed depending on the use conditions for different measurements. The user interface provides a real time display of the data in the graphs, waveforms, and tabular forms. All measured data saved to archive. The software also supports work with archived files and provides the ability to display, process and export of the fission chambers test results.

4 FISSION CHAMBER TESTS

The tests were performed to check the functionality and performance of the test facility and to develop the measurements techniques of fission chambers parameters.

Two fission chambers with U235 (#1) and U238 (#2) were tested. The following characteristics and parameters were determined:

- fission chambers pulse shape and pulse-height analyzer spectrum;
- fission chamber discrimination curve;
- fission chamber voltage-counting curve;
- dependence of the chains output signals versus neutron generator yield and fission chambers location;
- neutron generator dynamic performance.

Pulse shape recording was done with clock cycle of 8 ns and at pulse count rate approximately 10^3 s^{-1}. Fig. 2 shows the fission chamber #1 pulse shape averaged over 64 measurements. The pulse full width at half maximum is about 100 ns.

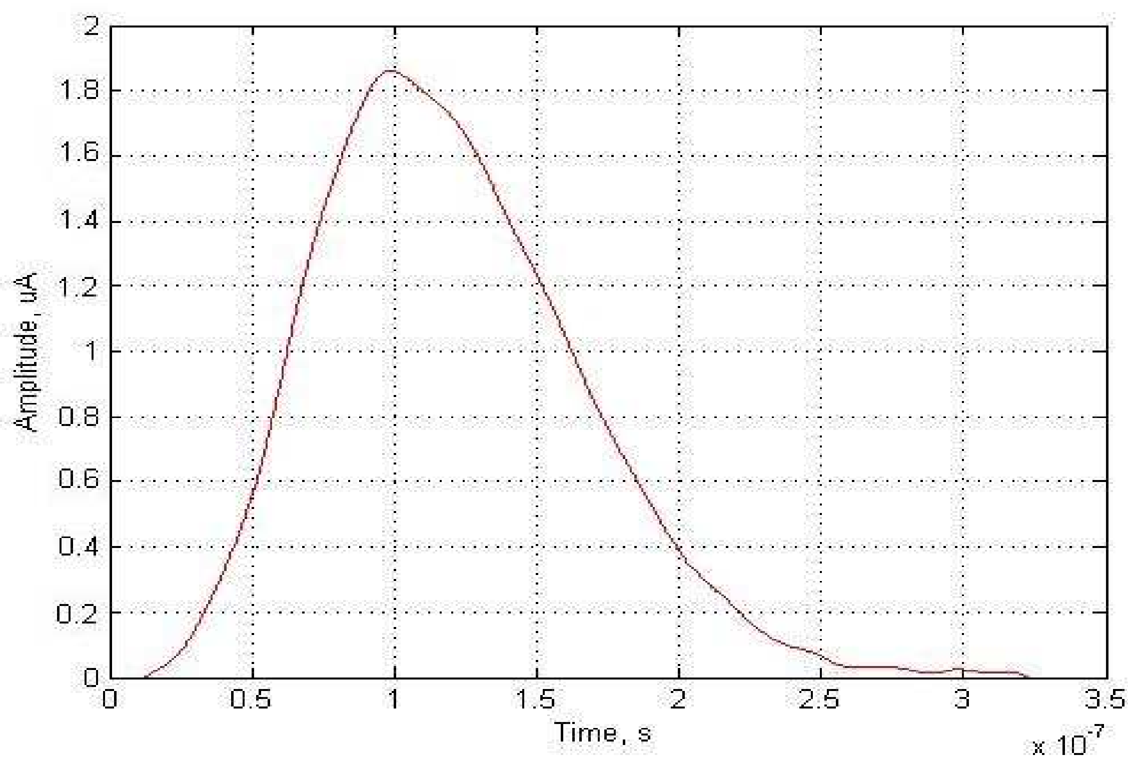

Figure 2. Averaged pulse shape of fission chamber #1

The pulse-height spectrum for fission chamber #1 is shown in the Fig. 3. As a result of spectrum processing the average charge per pulse was determined at $1{,}8 \cdot 10^{-13}$ C.

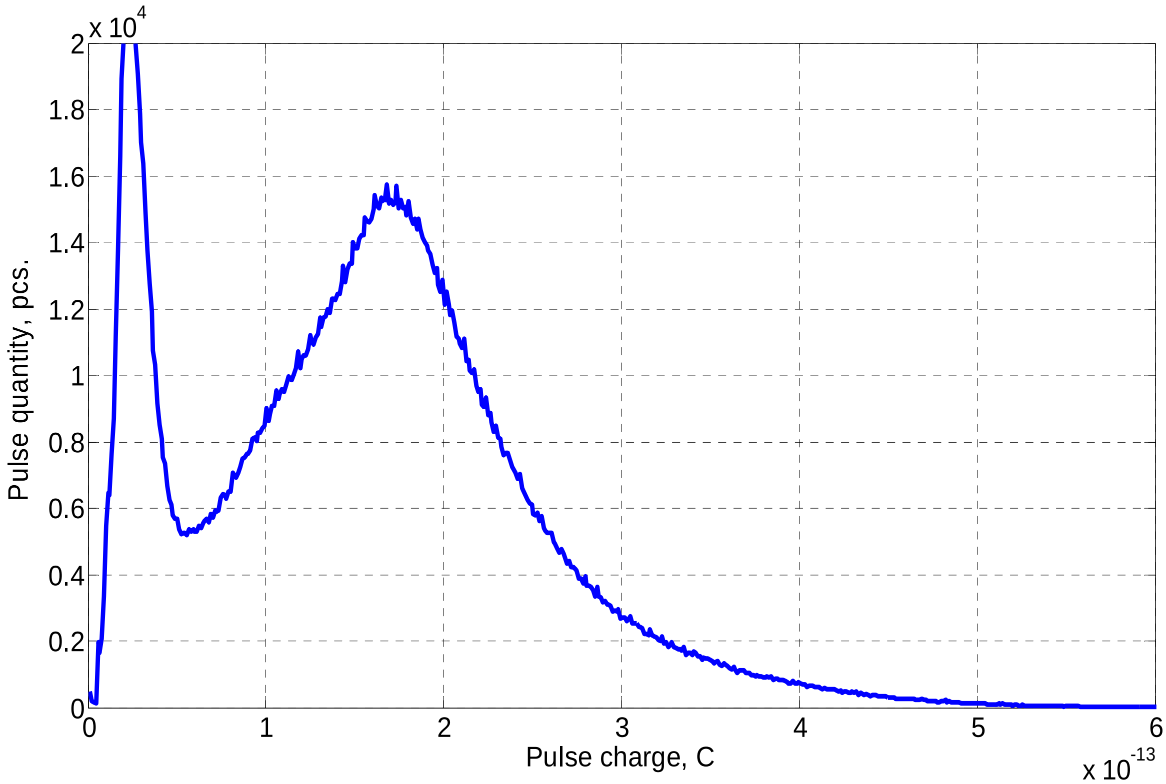

Figure 3. Pulse-height spectrum of fission chamber #1 calibrated in charge

The modes of the automatic registration of fission chamber discrimination and voltage-counting curves were verified. Fission chamber supply voltage has been varied from 50 to 300 V with a pitch of 25 V, threshold in the pulse chain has been varied from 0 to 4 V with a pitch of 0.2 V. The plateau slope of the voltage-counting curve for the fission chamber at working supply voltage and the parameter of discrimination curve were determined by data processing. The discrimination parameter is the ratio of the pulse count rates at two fixed thresholds.

The signals depends on neutron generator yield and fission chambers position were measured to determine the operation range and the static characteristic calibration. Neutron yield was varied by adjusting of the accelerating voltage and the ion current. Taking into account the sensitivities of fission chambers, the maximum values of the neutron flux density at the detectors position was evaluated. The max thermal neutron flux is up to 10^6 $n \cdot cm^{-2} \cdot s^{-1}$ and the max fast neutron flux is up to 10^7 $n \cdot cm^{-2} \cdot s^{-1}$ at the same time.

The dynamic processes when neutron generator switch-on and switch-off were recorded to show the test bench facility dynamic performance. Charts of effective count rate F, s^{-1} for some of measuring channels are shown in Fig. 4 and Fig. 5. The neutron generator switch-off time is less than 12 ms.

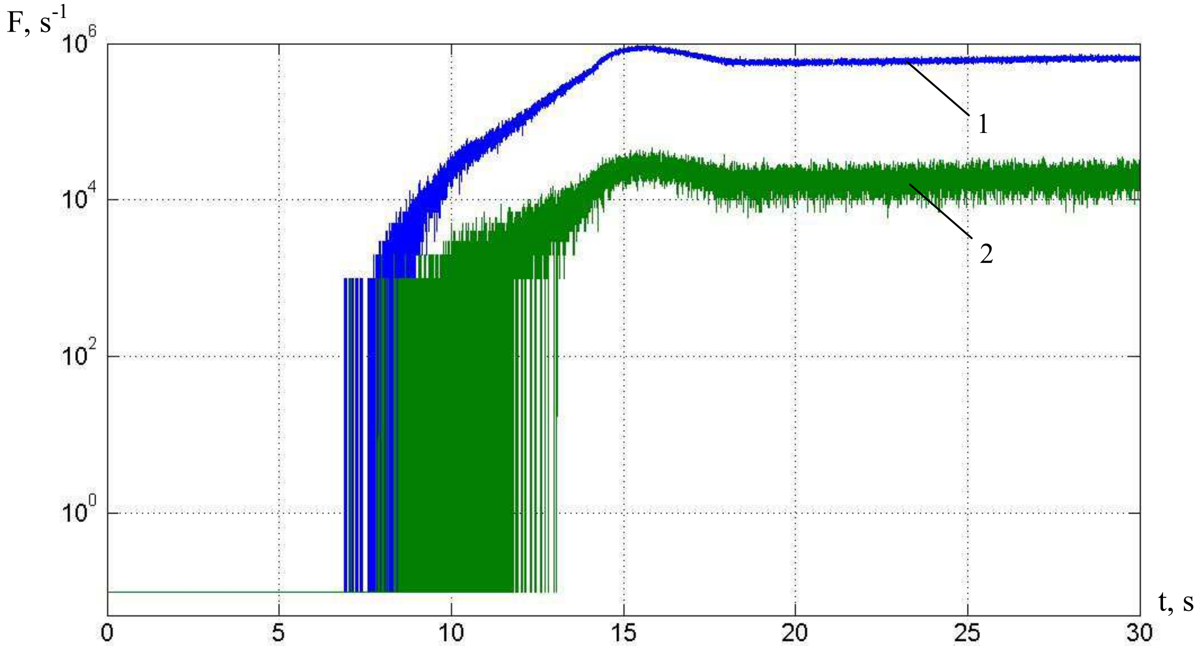

Figure 4. Fission chamber #1 (1) and fission chamber #2 (2) pulse measuring chains data at neutron generator switch-on

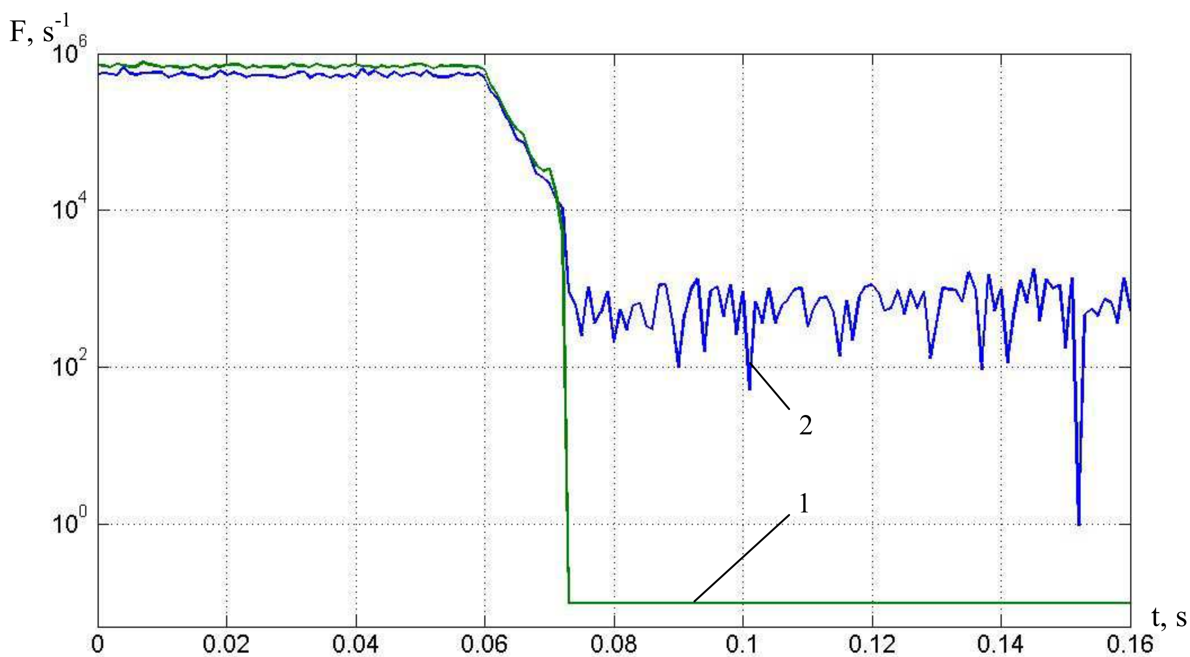

Figure 5. Fission chamber #1 pulse measuring chain (1) and Campbell measuring chain (2) data at neutron generator switch-off

5 CONCLUSIONS

An inexpensive and compact neutron test facility was created to study the characteristics and fulfill of acceptance tests of the neutron diagnostics fission chambers for the ITER project. It provides a maximum density of the thermal neutron flux up to 1×10^{6} $n \times sm^{-2}$ s^{-1} and fast neutrons up to 1×10^{7} $n \times sm^{-2} \times s^{-1}$.

The test facility can be used to determine the fission chambers specifications of any type and purpose. In case of calibrated fission chamber will be used as a reference it is possible to measure the absolute sensitivity of the studied fission chambers.

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