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ABSTRACT.

A new Control and Monitoring (C&M) system is being developed for the TOFOR and MPRu fusion neutron spectrometers within the JET enhancement program. The system, which is an evolution of the existing C&M system of the MPR spectrometer, consists of a controlled pulsed light source distributed by an optical fiber network to all photomultiplier tubes used in the plastic scintillator based spectrometers. The light source is a green Nd:LSB solid state laser complemented by blue LED sources. Pulse height distributions for each detection channel are recorded to set the spectrometers to prescribed working points and monitor deviations. Absolute reference is obtained complementing the controlled light source with radioactive sources. In this paper we report on the C&M prototype design and component tests for the MPRu spectrometer. The results show that the laser and the associated optics provide a controlled light pulse of intensity covering a dynamic range of more than four orders of magnitudes. The choice of optical fiber diameters is critical for achieving the desired stability and uniformity of the light intensity collected by each MPRu detector.

1. INTRODUCTION

New operating requirements for fusion plasma diagnostics arise in connection with the need for reliable and reproducible diagnostic performance over extended time periods (years) and for long pulse operation (hours). In order to meet these requirements, diagnostic techniques should have an intrinsic high level of reliability and stability of their working points. Furthermore, one should be able to remotely control and monitor the working point stability of these diagnostics, i.e. they should be equipped with a suitable Control & Monitoring (C&M) system to ensure that they operate within the specified stability boundaries at all times.

A C&M system is being developed for the MPRu [1] and TOFOR [2] neutron spectrometer within the JET enhancement program. The system is an evolution of the existing C&M system [3] for the MPR spectrometer in use for seven years. It consists of a Controlled Light Source (CLS) coupled to an optical fiber network distributing the light pulses to all photomultiplier tubes in the spectrometers. The CLS common to both spectrometer is a green laser located in the roof laboratory, above the JET tokamak, nearby TOFOR. This choice gives the advantages of having a simplified system of reduced cost and accessibility of the CLS for maintenance. Pulse height distributions for each detection channel are recorded to set the spectrometers to prescribed working points and monitor deviations. In particular, the main functions of the C&M system are to monitor the values of the PM-tube gains, discriminator thresholds and time delays. Additional LEDs complement the laser source. Absolute reference is provided by radioactive sources.

In this paper the basic functions of the C&M system are presented together with the C&M prototype design and component tests for the MPRu spectrometer.

2. C&M FUNCTIONS AND PROTOTYPE DESIGN

A description of the MPRu and TOFOR spectrometers can be found in Ref. [1] and [2], respectively. Both spectrometers have a detector system based on an array of plastic scintillators connected via light guides to photomultipliers tubes (PM-tubes). The MPRu spectrometer measures 14 MeV neutrons in DT and 2.5MeV neutrons in D plasmas. An array of 32 phoswich scintillators, each connected via light guides to two PM-tubes, records the recoil protons generated by (n,p) scattering reactions at the target and momentum dispersed by the magnet along the focal plane. The measured proton spatial distribution at the focal plane represents the energy distribution of the incoming neutrons. TOFOR is a 2.5MeV neutron spectrometer which works on the time-of-flight principle and is optimized to operate at high count rate [2, 4]. Neutrons emitted by the plasma are collimated and hit a start scintillator which acts both as a scattering target and a recoil proton detector. The start scintillator is connected to three PM-tubes in order to maximize the amount of collected light. Neutrons that scatter in the start scintillator hit, after a flight path of about 70ns, a second array of 32 stop scintillators which are placed on the constant time of flight sphere [2]. From the time of flight spectrum of the neutrons one can directly derive the incoming neutron energy spectrum.

The experience offered by the MPR neutron spectrometer at JET has shown that in order to guarantee a reliable operation over an extended time period it is essential that a neutron spectrometer is fully characterized and calibrated before the installation [5]. During such instrument characterization phase the operational working points are determined, e.g. the gains of the PM-tubes, the discriminator thresholds and delays. This is done using accelerator beams, radioactive sources and Controlled Light Sources (CLS), such as LED or laser, available with the C&M system. After the spectrometer installation at JET the function of the C&M system is to guarantee that the two instruments are working within the prescribed working points at the specified accuracy level.

The main function of the C&M system is to monitor over time the relative and absolute *stability of the gains* of the PM-tubes; there are a total of 32 pairs of PM-tubes for MPRu and 47 PM-tubes for TOFOR. This is done by collecting pulse height spectra of known amplitudes from the CLS for each detector channel. Monitoring of the absolute gain stability is obtained with a radioactive source located on one detector channel of each of the two spectrometers. For MPRu, the absolute reference is a 4mm diameter pulser consisting of a 241Am alpha source embedded in a YAP:Ce scintillator (YAP pulser) [6]. The YAP pulser generates about 5500 photoelectrons on a bialkali photocathode, at a rate of 20Hz. For TOFOR absolute reference is provided by a 241 Am alpha source (50Hz rate) located on one of the stop plastic scintillators. A second C&M function is needed for TOFOR, namely to monitor the *timing stability* of the whole electronic chain. The timing can be monitored by sending pulses from the CLS at the same time to one start and stop scintillator. By doing a scan with CLS pulses of variable intensity one can also monitor the position of the discriminator thresholds. All the monitoring is done off-line over long-term periods, i.e. between plasma discharges, and over short-terms, i.e. during a plasma discharge [3].

The schematics of the prototype C&M system for MPRu is sketched in Fig.1. The laser light is sent through optical elements which are used to filter, attenuate and focus the light into a $100\mu m$ fiber pigtail (fiber n.1). A 1x2 optical switch is used to switch the light between TOFOR and MPRu.

In this work we have characterized the components of C&M system for MPRu except for the 1x2 optical switch. The CLS signal is brought to the MPRu, installed in Octant 4 of the JET torus hall, with a 170m long optical fiber (fiber n.2). The fiber is made from silica UV grade (Ceramoptec [7]) with a core of 100 μ m; this offers low attenuation over a broad spectral range and good insensitivity to radiation effects. The long fiber terminates nearby the MPRu patch panel, where it is connected to fiber n.3. This brings the light via a vacuum feed-through to the 1×38 bundle. Each fiber of the bundle is coupled on the opposite end to one detector channel; six fibers are spare. The bundle is made by gluing together 38 fibers of 100 μ m core into a commercial SMA connector of 1 mm diameter hole. The vacuum feed-through is made of a steel cylinder with a hole containing a 1 mm fiber with SMA connector on both ends.

The laser is a diode pumped Nd:LSB solid-state laser of green wavelength (531nm, see Table 1). It can be switched on remotely and operates in pulsed mode at the fixed count rate of \approx 5kHz, delivering about 1.5µJ energy per pulse. The wavelength of the laser matches the quantum efficiency curve of the PM-tube cathode and the transmission curve of the optical fibers. Attenuation of the laser light is obtained with the combination of a half waveplate which can be rotated manually and a motorized polarizing beamsplitter cube. The polarizer can be rotated around its polarization plane with a small motor controlled via PC serial communication with a precision of 24000 steps over an interval of 360°, i.e. 0.015°/step. This combination of optical elements allows us to remotely adjust the laser intensity over a dynamic range of more than four orders of magnitude. A wide dynamic range is required to satisfy the different light intensity requirements for TOFOR and MPRu.

3. TESTS

The prototype C&M system of MPRu has been tested in the laboratory with the scheme illustrated in Fig. 1. In these tests fiber n.2 was a 10 m long fiber, of the same type of the 170m long fiber which will be used at JET, and was directly connected to the fiber n.1. The laser light emerging from fiber n.3 was measured before entering the vacuum feed-through. This is shown in Fig.2 where the images were obtained projecting on a screen the light emerging from two fibers of different diameters. The image elongation is due to the projection geometry. With a 200 μ m silica fiber the light pattern shows grains and spots; the pattern changes when the fibers are moved. This effect, which is a consequence of the propagation of coherent light into fibers, affects the stability of the light intensity distributed to the 100 μ m fibers of the bundle. The instability can be mitigated by replacing the 200 μ m fiber with a thicker plastic fiber which homogenizes the light distribution [8]. This is shown in Fig.2 for the case of a 1mm thick plastic fiber. A plastic fiber of diameter ≥ 1 mm will be selected for the final design. We note here that going from small diameter fibers into thicker ones ensures both good light collection efficiency and stability/homogeneity of the illumination.

The uniformity of the light intensity at the 1×38 bundle was measured with a blue LED source illuminating fiber n.3. The LED, being an incoherent light source, shows indeed a uniform light illumination emerging from fiber n.3. For the tests a LED of the highest available luminosity was

selected (model LXHL-LR5C from Lumileds [9]) and was run in pulsed mode by a home made driver. LED pulses were 25ns wide (FWHM) with a repetition rate of 5 kHz [10]. The set-up of the measurement consisted of a PM-tube coupled to a 20cm long cylindrical light guide, supported by a PVC frame (Fig.3). The YAP pulser was directly located on the PM-tube cathode to provide absolute reference. Each optical fiber of the bundle was connected in turn to the light guide. The light emerges from the fibers with a numerical aperture of 0.22, or $\pm 12.7^{\circ}$, and spreads over the whole cathode. Pulse height spectra were collected with a standard nuclear electronic chain for all the fibers of the bundle; the 38 fibers were labeled according to their position in the bundle (see map in Fig. 4a). Measurement of the light intensity output from each fiber indicated that the present vacuum feed-through introduces a non uniform pattern (Fig.4(a)); the light intensity increases with the fiber distance from the center. This is not understood but is probably due to a defect in the vacuum feed-through. When a 1mm plastic fiber is directly connected to the fiber bundle (Fig.4(b)) no characteristic pattern is observed, except for the last five fibers which show reduced light intensity. This can be explained by an imperfect alignment: the last five fibers lye on the edge of the lightened area. Good uniformity is obtained with a 2mm fiber directly connected to the fiber bundle (Fig.4(c)). Based on these results a new vacuum feed-through with a fiber of 2mm diameter or more will be designed in order to provide the best uniformity of illumination at the bundle.

The time stability of the laser light intensity measured at the beginning of the optical fiber network, i.e. at the output of the fiber n. 1, showed an acceptable stability (<2% over 1hr). We underline here that drifts of the laser intensity will not affect the absolute monitoring capability of the C&M system, as long as the relative illuminations of the fiber bundle is not perturbed. The best time stability of the laser light received by the MPRu fibers of the bundle was obtained with the experimental set up of Fig.4(c). The results indicate a time stability of about 5% over a 1hr period. This is mostly caused by fast fluctuations (characteristic time of \approx 1min) which can be smoothed by time averaging [10]. Measurements have also shown that a bundle made of thicker (300 µm) diameter fibers would further reduce the fluctuations below 2%, i.e. at the level of the laser source fluctuation [10]. A new bundle made from fibers of thickness greater than 100µm is being considered.

Measurement of the LED light intensity showed an excellent stability (<0.5%) over a 15hr period. This motivates the use of LED sources to complement the C&M system, in particular with reference to the monitoring of the PM-tube's gains. Compared to the LED the laser offers the advantages of very fast pulses (FWHM<1ns), needed for the timing of the TOFOR spectrometer, and a easily adjustable pulse intensity which can be controlled reliably over a wide dynamic range

CONCLUSIONS

This paper reports on the new Control and Monitoring (C&M) system which is being developed for the TOFOR and MPRu fusion neutron spectrometers. The tests showed that the laser and the associated optics provide a controlled light pulse of intensity covering a dynamic range of more than four orders of magnitudes. The choice of optical fiber diameters is critical for achieving the desired stability and uniformity of the light intensity collected by each MPRu detector. In particular, results have shown that by using fibers of 2mm diameter one can achieve the desired light uniformity among the 38 MPRu fibers which bring the light to each detector channel. The LED source, which will complement the laser, has shown to have excellent timing stability. The C&M system development continues, in particular with reference to the C&M system for TOFOR.

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Producer / Model	STANDA/STA01-SH
Wavelength	531mm
Pulse Duration (FWHM)	0.65ns
Pulse repetition rate	4.88kHz
Pulse energy	1.5µJ
Pulse width	0.5ns
Polarization Ratio	>1:100
Stability	5%

Table 1. Specification of the ND:LSB laser.



Figure 1: Schematics of the prototype C&M system design. The Laser light is distributed to each detector channel via an optical fiber network. The dashed components have not been tested. Different types of fiber n.3 have been tested.



Figure 2: Images of the laser light output from a 200µm (left) and a 1mm (right) fiber projected on a screen.



Figure 3: PM-tube and light guide assembly set-up used in the tests.



Figure 4: Measurement of the light intensity output from the 38 fibers taken with the LED source for three different set-up. The position of the fibers in the bundle is indicated in the map shown in (a). In each plot the same symbols correspond to fibers lying at about the same radial position. In (a) a 2 mm fiber was connected via the vacuum feed-through to the fiber bundle. In (b) and (c) a 2 mm and 1 mm fiber were directly connected to the fiber bundle, respectively.