Temperature characteristics of PMTs and calibration light sources for the Telescope Array Fluorescence Detectors

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***Abstract*. The fluorescence detectors of the Telescope Array experiment are exposed to the air during operations, and then their responses for incident photons vary due to outside temperatures. While the relative gains of all the pixels of the detectors are monitored with the uniform Xe flasher light sources once per an hour and frequently calibrated with electron light source and a central laser, reducing systematic energy scale errors requires temperature corrections of the gains of standard PMTs which were absolutely calibrated in the laboratory. For this purpose, we measured the temperature characteristics of the standard PMTs and the calibrated light sources called YAP pulser, each of which is attached on the PMT cathode, on an experimental setup including UV LED pulse light source, optical fibers for distributions of LED photons, the incubator and the readout electronics exactly same as the fluorescence detector. As a result of the measurement for 23 standard PMTs in the temperature range between -10 and 40 degree Celsius, we obtained the temperature coefficient of -0.7 %/deg averaged over all the tested PMTs. Moreover, we found that the temperature coefficients decrease with increasing temperature. On the other hand, we found that temperature coefficients of the light intensities of YAP pulser are independent of temperature and the averaged value is -0.2 %/deg.**

***Keywords*: Ultra High Energy Cosmic Rays, Air Showers, Fluorescence Technique**

I. Introduction

The Telescope Array Project is an experiment designed to observe ultra high energy cosmic rays via a hybrid detection technique utilizing both fluorescence light detectors (FDs) and scintillator surface particle detectors (SDs) [1]. We have installed three FD stations and 507 SDs in the Utah desert, and initiated observations from March 2008. The northern FD station reuses 14 telescopes from the High Resolution Fly's Eye, HiRes-I station [2]. Each of the two southern FD stations contains 12 new telescopes.

For precise calibrations of FDs, we have developed and operate various light sources. One of them is the absolutely calibrated light source called CRAYS(Calibration using RAYleigh Scattering) for the measurement of QE $\times$ CE and gain–applied high voltage relations of PMTs in a laboratory [3]. On the observation site, we use the flash light source of a Xe lamp to make all the PMTs of each camera have gains of the same magnitude. Moreover, we have developed the UV spot light sources on the large XY moving stage and measured the non–uniformity of the camera sensitive area [4]. In addition, we have constructed a fluorescence light source with an electron linear accelerator for an end–to–end calibrations and placed it in front of the south-east station.

Each of the new cameras consists of 256 hexagonal PMTs of 60 mm diameter (Hamamatsu R9508). In front of each photo cathode, an UV band pass filter of more than 80 % transparencies for 320 nm–400 nm photons is placed. On the other edge of the tube it has a PC board full of the HV divider and preamplifier circuit. Three among 256 PMTs of each camera have been absolutely calibrated with CRAYS and their HV have been adjusted to the equal–gain of 8×10^4. For these absolutely calibrated PMTs, called "standard" PMTs, we constantly monitor their gains measuring responses for the calibrated YAP (Ytrium Aluminum Peroskite) [5] [6] pulsers. This UV pulse light source consists of YAP ($YAl0_3 : Ce$ scintillator) and ^{241}Am α–ray source. Its outside dimension is a cylinder of 4 mm diameter and 2 mm thick, and it is placed between a PMT surface and its UV band pass filter. Our YAP pulser's repetition is about 50 Hz, the peak wavelength is 365 nm, and the intensity stability is 5 %. The gains of the other 253 PMTs are adjusted to that of the standard PMTs with calibrations with the Xe flasher.

Since the telescopes are exposed to the air during observations, experimental environments vary considerably with time. Fig. 1 is monitored temperatures at the site for every day in summer, when the diurnal range of temperature is likely to be maximum. Although we are monitoring the sensitivity of all of the cameras with the Xe flashers once per one hour in observations , we cannot determine the sensitivity for any time between the Xe flasher calibration. In Fig. 1 it shows that changes in temperature can reach 3 degree in one hour. Thus, we should monitor temperatures of the cameras and correct for thermal changes on the sensitivity of PMTs and on emissivities of YAP pulsers. So that, in this experiment we measured temperature characteristics of

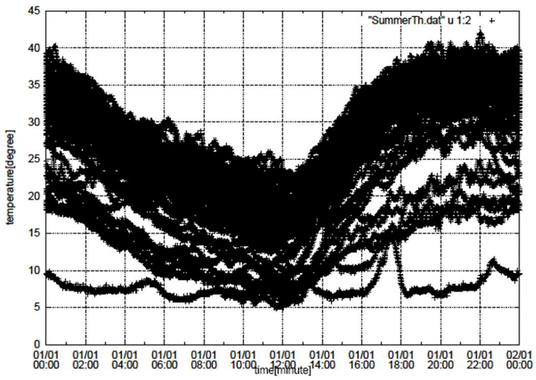

Fig. 1. The monitored temperature at the site for eery day in August 2008.

Fig. 3. Photos of instruments for the temperature characteristics measurement.

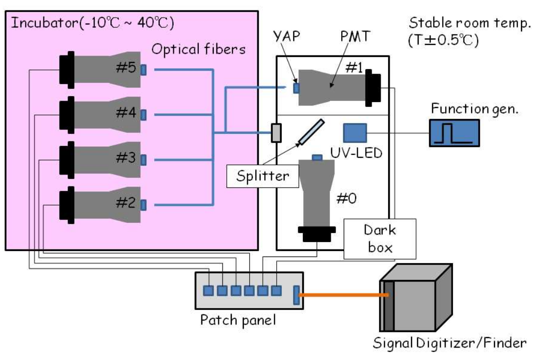

Fig. 2. A schematic figure of the temperature characteristics measurement.

the PMT gains and of the YAP pulser intensity for the 23 absolutely calibrated PMTs.

II. Experiment and analysis

A schematic figure of our experimental setup for the temperature characteristics measurement is shown in Fig. 2, and the photos are shown in Fig. 3. The whole systems are placed in the room air-conditioned and kept at a constant temperature which deviation is about ± 0.5 degree.

The light sources in the experiments are an UV LED and the YAP pulsers attached on PMTs. The UV LED is Nichia NSHU550B, and its peak wavelength is 365 nm. In one series of tests, we used ten PMTs. Among them eight PMTs are samples, and the other two were used for monitoring LED pulse intensities and the transmittance of an optical fiber.

Pulsed light from the LED is divided with the beam splitter, and one half falls on a collimator in front of the intensity monitor PMT (labeled #0). The other half enters the bundle edge of nine prastic optical fibers, and photons through the fibers fall on PMT photocathodes. All fibers enter the incubator, and eight sample PMTs are also placed in it. The edge of one fiber is attached in front of the fiber transparency monitor PMT (labeled #1). Every fiber has the same total length and also has th esame length inside the incubator. Thus, the temperature variation of each fiber's transmittance was controlled completely same.

The applied high voltages were adjusted for all of the PMTs to output comparable pulses for LED flashes, and their average is about -900 V. Electronics to record output signals are same as used in TA–FD, namely the patch panels and the Signal Digitizer–Finder [7].

The temperature setting of the incubator is as follows. The initial temperature is +40 degree Celsius. We maintained a constant temperature for six hours and then lowered the temperature by 5 degree, and we repeated this operation until -10 degree Celsius. On the other hand, the room temperature was kept constant with ± 0.5 degree deviation. However, since this magnitude of deviations is not negligible, gains of PMT #0 and #1, which were placed in the room temperature, were corrected with calculations based on measured room temperatures and their temperature coefficients.

DAQ procedures were self–triggered by LED or YAP photons, and continuously repeated in a series of the operations. However, signals caused by LED and YAP are distinguished by the pulse width. The measured LED signal intensity by every PMTs is divided by that of PMT #0 shot by shot, in order to cancel the thermal variation of the LED emissivity and its fluctuation. And then we calculated three hour averages of signal intensities by every PMTs, using last half of six hour data to be kept a constant temperature. Moreover, these three hour average intensities for LED shots are divided by that of PMT #1, in order to cancel the temperature characteristics of the fiber transmittance. Finally, we obtained temperature coefficients of the PMT gain and the YAP emissivity.

III. Results

We obtained the temperature coefficients of 23 standard PMTs, and among them the results for the typical eight PMTs are shown in Fig. 4. The result shows

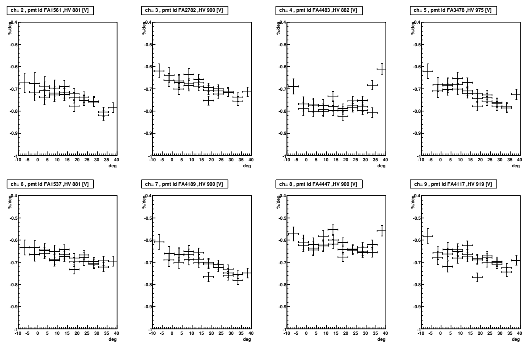

Fig. 4. The temperature coefficients of the gain of eight typical PMTs.

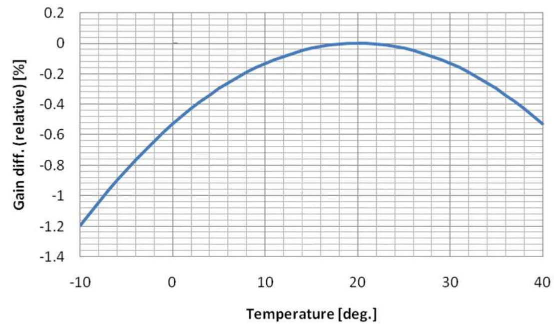

Fig. 6. Comparing between the relative gain calculated with a temperature-independent coefficient and that with linearly temperature-dependent coefficient for the same typical PMT.

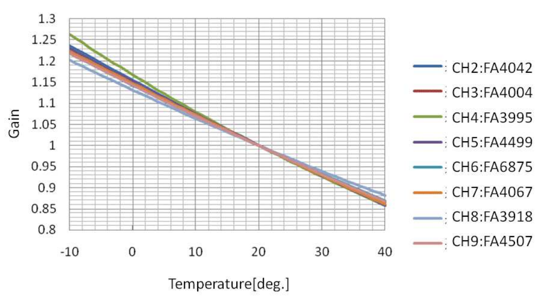

Fig. 5. The calculated relative gains of the eight PMTs on Fig. 4.

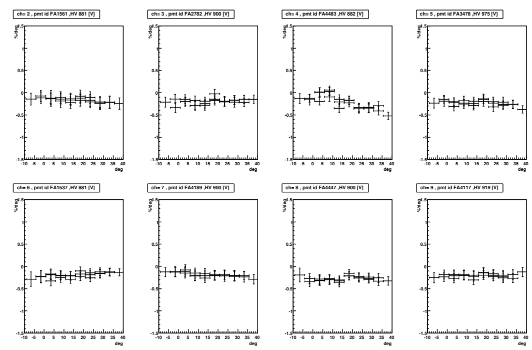

Fig. 7. The temperature coefficients of the YAP emissivity of the eight PMTs.

that the temperature coefficients of our PMTs (including the preamplifiers) depend on temperatures and decrease with increasing temperature. From the coefficients, the relative gains of eight PMTs of Fig. 4 normalized at 20 degree Celsius are calculated and shown in Fig. 5. From this plot we found that the gain variation at -10 degree Celsius is about ± 1 % if we adjust equal–gains for the PMTs at 20 degree Celsius.

The average and the standard deviation of the temperature coefficients at 20 degree Celsius is -0.720 ± 0.053 %/deg. In Fig. 6 we compare between the relative gain calculated with a temperature-independent coefficient and that with linearly temperature-dependent coefficient for the same typical PMT. For both case, the gains are normalized at 20 degree Celsius. From the figure we found that the effect of ignoring the temperature dependence is about 1 % at -10 degree. Since we normally calibrate gains of all PMTs once per an hour, this effect is reduced to one order of magnitude lower.

We obtained temperature coefficients of the emissivity of the YAP pulsers. The results are shown in Fig. 7 for YAP pulsers attached on the PMTs in Fig 4. In the coefficients of the emissivity, there is no clear temperature dependence, and the averaged coefficient for 23 sampled YAP pulsers is -0.225 ± 0.015 %/deg.

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