A Fully Automated Test Facility for Multi Anode Photo Multiplier Tubes

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Abstract: Multi-anode photo multiplier tubes (PMT) are commonly used in astroparticle physics observatories as well as in other applications. They need to be automatically tested when they are to be used in large numbers. Such a test facility has been developed to evaluate multi-anode PMTs. The facility, located at ITeDA in Buenos Aires, is capable of fully testing a 64 pixel PMT per day. It automatically measures the following parameters for each pixel: gain, dark pulse rate, single photoelectron distribution, and cross-talk. The test system is able to perform all relevant data analyses both in pulse amplitude and/or charge. It can also make uniformity plots of relevant parameters for all pixels. Using this facility, ultra bi-alkali PMTs have already been tested and evaluated. The test results and the schematics of the test system are presented in this work.

Keywords: test system, multi-anode, photo multiplier tube, PMT, UBA, ultra bi-alkali, cross-talk, spe, darkpulse, gain, 64 pixel, multi-pixel

1 Introduction

The test facility, located at ITeDA (Instituto de Tecnologías en Detección y Astropartículas), Buenos Aires, Argentina, was originally developed in order to automatically test large numbers of different type of photo multiplier tubes (PMTs). However, the test setup is currently tuned to perform multi-anode PMTs testing due to the current scientific projects in which this facility is involved. The system is currently dedicated to characterize and ensure the quality of Hamamatsu H8804-200MOD PMTs for the enhancement project called AMIGA (Auger Muons and Infill for the Ground Array) [1] of the Pierre Auger Observatory. These PMTs have a built-in R7600 64 channels PMT, ultra bi-alkali (200) photocathode, standard polarization chain (like the one for the H7546), and a special casing for alignment purposes (MOD).

The PMTs are generally tested for different reasons depending on the phase of the projects in which they are used. In this case, the aim is: 1) to characterize certain parameters of the PMTs which have incidence on the design and simulation [2] of the particle detectors where they will be used, 2) to have a better idea of the capabilities of such PMTs, and 3) to accomplish the quality assurance plan of the project.

Testing the 64 channels of a PMT automatically is a challenging job since it is like testing 64 PMTs at the time, so it requires novel means to manage the 64 output signals and to perform the automatic control of individual light injection to the 64 pixels. Furthermore, due to the testing requirements of different projects, the knowledge of different parameters of the signals is required such as the signals peak, area, rise-time, fall-time, etc. Thus, the test system must be able to sample the traces with fast digitizers (i.e. very fast ADCs, analog to digital converter boards) instead of just sensing the signal charge by using QDCs (charge to digital converters). The sampling data acquisition system imposes a very delicate treatment of many signals to avoid any external and internal interferences (described in the following sections). This last characteristic makes a big difference in increasing the capabilities of the system in respect to other automated PMTs test facilities, such as the one at the Pierre Auger Observatory [3] which inspired this work.

Finally, testing multi-anode PMTs has an additional difficulty compared to test regular PMTs. It requires to have an alignment system to match the light source to the corresponding pixel, to be able to perform the light-injection to different pixels of the PMT independently. The accuracy of the alignment system must be of hundredths of mm otherwise, very important tests such as cross-talk (described later) cannot be performed.
2 Test Facility

2.1 Setup

As shown in fig. 1, the test system setup is currently tuned to test one 64 pixels PMT at a time. The light-proof facility is performed with "dark-boxes" due to the fact of the reduced size of the H8804 PMTs. The external dark-box provides the required optical shielding and the interlock system to automatically shut down the high voltage for safety reasons.

Due to the location of this facility, handling high frequency and low level signals is not trivial because the radio broadcasting is very crowded in the region, and generates a big EMI (electromagnetic interference). Besides, good cabling shielding is needed to avoid any capacitive/inductive interaction between the signals. Thus, following the system EMC design, the cabling for signals carriage is performed with high quality 50 Ω coax-cables with improved shielding and high density polystyrene core to reduce the signals attenuation. Gold plated connectors are used for all the signal cabling connections.

The signals extraction of the H8804 PMT is not trivial either, because the 64 outputs are concentrated in a 2 cm × 2 cm array and must feed the 64 coax cables. This operation is performed through a 4 layer custom designed board (called socket board) that also supplies the HV to the PMT, and extracts some monitoring parameters from the system. Again, this board has a special design to provide good EMC.

The complete transmission lines from the PMT output to the oscilloscope input (socket board, cables and connectors, and multiplexer) were characterized with a vector network analyser, and the transmission parameters are used to compensate the signals measured by the oscilloscope. Thus, all the results plotted by the system are equivalent to the results that would be obtained right at the output of the PMT.

2.2 Methodology

First, the PMTs must be aligned to the optical fibers before being able to test the PMTs. This alignment must be very precise because the optical fibers have a diameter of 0.8-1.2 mm (depending on the type of detector being manufactured) and the pixel size of the H8804 PMTs is 2 mm × 2 mm. Any deviation in the alignment may lead to a wrong XT measurement. Thus, the alignment of the PMT to the fibers is performed in the same way than the alignment of these PMTs to the AMIGA detector [4], i.e. by using a floating plastic piece (called "cookie") which holds the optical fibers. The cookie has two fixed holes that match up with two metal pins inserted into the wings of the PMT case (special case that gives the MOD characters to the PMT name). The metal pins are previously fixed in the correct place with respect to the dynode assembly of the PMT through the usage of a high definition camera and a micro-meter 3 axes (x-y-w) positioning system.

Thus, the PMT testing procedure consists of the following steps:

1. Align the PMT to the cookie that holds the optical fibers.
2. Connect the PMT into the testing dark-box.
3. Wait until the PMT cools down and gain stabilizes.

Currently, it is decided to wait about 24 hs. for all the PMTs because we know that it is long enough even
for some atypical PMTs, and because the amount of PMTs being tested in not large so far. However, this step can be automatically monitored by the system and the waiting period can be adjusted automatically for each PMT.

4. Run the tests. The testing period depends on which tests are performed, but it generally takes between 12 to 24 hs. for the 64 channels. The testing period requires absolutely no human intervention.

5. An operator analyses the monitoring parameters and the test results, and approves the test or re-runs it if needed. Some of these analyses can be performed automatically but specification limits are being defined to better set the rejection criteria.

6. Complete the database with the test results. Even if the system stores most of the data analysis plots, test system monitoring variables, timestamps, etc., the operator must complete a database with the test results and remarks, as required by the QA (Quality Assurance) plan of the facility.

The stability of the test system during the testing period of one complete PMT (about a day or more) is ensured by the monitoring parameters and the consistency of the test results, defining the re-test of the PMT if any abnormal situation is detected. Reference PMTs are used to check the reproducibility of the measurements by following the test procedure many times consecutively, and these PMTs are also used to monitor the mid and long term stability of system. However, the reference PMTs may vary their parameters with long periods of time so the transmission lines of the system are also checked periodically with a vector network analyser to see if there are changes in the system itself that may lead to a possible misinterpretation of the reference PMTs long-term parameters.

3 Tests Performed and Results

Every test is performed to each of the 64 channels of the H8804 PMTs, giving parameters both in signal charge and peaks. All of the results can be automatically plotted for each channel individually or they can be presented all together in 2D or 3D plots as a function of the pixel number to evaluate the uniformity of the parameters all around the PMT.

Even if there are many different tests that can be performed with such a versatile system, only the main tests performed to the first twelve H8804 tested PMTs are briefly described bellow. It is worth to mention that some of the plots have some particular entries that are known to be a little biased (at the tails of the distributions) because of the automatic nature of the test system and the fitting failures that it can produce. However, the automatically generated histograms presented below were not used to reject PMTs, they were used to get the general trend of the parameters. Nevertheless, the operator is able to analyse the results individually and manual fitting or PMT re-testing can be performed if needed to reject a PMT.

3.1 SPE distribution

The SPE (Single Photo-Electron) distribution for the signals areas gives the absolute gain of the dynode chain for each PMT channel.

![Figure 2: Gain histogram of the all the channels of the first twelve H8804-200MOD PMTs tested.](image)

However, because of the particular usage of these PMTs, it is also important to perform the SPE distribution for signal peaks. This gives a better idea on how the analog front-end of the detectors must be designed, and it also gives an estimation of the threshold level to be set in the discriminators.

![Figure 3: Average signal peak histogram generated by a SPE for all the channels of the first twelve H8804-200MOD PMTs tested. The PMT channels where loaded with 50 Ω.](image)

As shown in fig. 2 and fig. 3, the gain and the average signal peak produced by a SPE of any pixel of these PMTs is assumed to be \((14.3 \pm 2.4) \times 10^6\) and \((57 \pm 10)\) mV, respectively.

3.2 Dark-pulse rate

It is the emission rate (in Hz) of pulses at the PMT output that surpasses a determined threshold, with no photocathode excitation. In the case of the H8804, this thresh-
old is set to 1/3 of the average SPE peak since it is the approximate threshold to be used in the discriminators at the analog front-end of the AMIGA detectors. As can be seen in fig. 4, the average dark-pulse rate of any pixel is assumed to be $(3.5 \pm 2.8) \text{ Hz}$. However, care must be taken when using this value in simulations since the distribution is not symmetric. The average dark-pulse rate is low because the photo-cathode section corresponding to each pixel is very small, even if these PMTs have ultra bi-alkali photo-cathode which seems to be not noisier than regular bi-alkali photo-cathode.

![Figure 4: Dark-pulse rate histogram of all the channels of the first twelve H8804-200MOD PMTs tested. The threshold has been set to an amplitude of $\sim 1/3$ average SPE peak.](image)

### 3.3 Cross-talk (XT)

It is the ratio of the currents measured between two different channel anodes when the photo-cathode region corresponding to only one of the channels is excited. Because each pixel can have up to 8 neighbours, it is defined as total XT to the sum of the XT introduced to any other pixel. Thus, one pixel is illuminated with a pulse of light and then the output signal of this pixel is compared with the signal of all its surrounding pixels. Even if the XT ratio is basically independent of the type (continuous or pulsed) and the level of the excitation, the system is tuned to emulate the behaviour of the AMIGA detector so it generates light pulses so that a few photo-electrons reach the first dynode of the channel under test.

In PMTs, XT is caused by several reasons but mainly because of the numerical aperture of the optical fiber (and its diameter) and the broadening of the electron flow inside of the PMT. Therefore, the test-bench uses the same type of optical fiber and HV (High Voltage) than the ones to be used in the detectors where the PMTs will be working in. It is shown in fig. 5 the total XT of each channel using a Saint-Gobain 0.8 mm optical fiber (69929-MC which is similar to the BCF92 from [5] but more doped). Thus, the total XT of any pixel using this fiber can be assumed as $(3.5 \pm 0.9) \%$, to avoid differentiating the pixels with different amount of neighbouring pixels.

Even if it is still not fully analysed, it is believed that the distribution in fig. 5 has two peaks due to the fact that the pixels at the border of the PMT will generate lower XT (left peak) because they have less neighbours than the pixels at the middle of the PMT (right peak).

![Figure 5: Total cross-talk histogram of all the channels of the first twelve H8804-200MOD PMTs tested, measured with a 0.8 mm multi-clad WLS optical fiber at a voltage of -1000 V.](image)

### 4 Conclusions and future work

Twelve 64 channels Hamamatsu H8804-200MOD PMTs with ultra bi-alkali were completely tested using this unique and fully automated test facility. All the tested PMTs were fully operational and the main parameters were inside the specifications stated by their datasheets, so there were no rejections. Characterization of their gain, dark-pulse rate, SPE peak, and cross-talk, was performed for each channel of all the PMTs. General trends of these parameters were successfully obtained and used as data input for the particle detectors design, and to accomplish the quality assurance plan of the project in where these PMTs will be used.

Some other tests like after-pulsing and quantum efficiency are currently being developed, although some preliminary non-automatic tests were performed. Specification limits to all of the parameters are also being defined to provide better order requirements to Hamamatsu for the production phase of the project.

### References