Aging Characterization on Large Area Photo-multipliers

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Abstract

An accurate study and measurement about the aging effects on two large area photomultipliers (PMT) has been performed for over three years. The PMTs type was 10 inches, 10 stages Hamamatsu R7081, one with standard bialkali and the other one with super-bialkali photocathode. The gain, dark count rate, charge and timing properties have been measured, as well as the fraction of the spurious pulses. During the aging cycles, the anode current of the two photomultipliers has been monitored and recorded in order to measure the total output anode charge and determine the aging grade. The aging conditions have been set by the use of a 400nm LED regulated to about 3 photoelectrons (pe) at about 400 kHz. The aging process was stopped when the total charge reached about 2000 C for both of the PMTs. Measurements of the parameters of the two PMTs have been performed periodically using a 400 nm pulsed laser in single photoelectron condition. Considering the main results, only the gain showed a variation while all the other parameters remained quite stable. During the aging, two phases were observed: a first phase of up-drift shows an increase of the gain of about 10% is followed by a final phase of down drift, which shows a faster diminution of the gain of about 30%. The mechanism of the gain drift has been modeled and compared with the results.

Keywords: Aging, Photomultiplier, Underwater Neutrino Telescope

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1. Introduction

Many experiments require the detection of feeble light sources for a long time. When the maintenance of the detector is very difficult and expensive, it is necessary to know in advance the change of the characteristics of the employed devices during the lifetime of the experiment. This is the case, for instance, for underwater Cherenkov neutrino telescopes [1], [2] instrumented by arrays of photosensors. The best choice, as a compromise between cost and sensitive area, seems to be large area photomultipliers as photo-sensor for these telescopes. The study of the change of characteristics over lifetime for photomultipliers is of great importance for the modelization and simulation of the detectors. Scientific literature [3], [4] reports the measurements of the photomultipliers changes of characteristics over lifetime for photomultipliers. In this work, the ageing has been accelerated with respect to the standard working condition without operating the sensors outside their specifications. In these conditions we have measured the main photomultiplier characteristics, such as the gain, the transit time spread (TTS) and the spurious pulses rate. The results of the measurement are compared with a model based on the technology used by the manufacturer to realize the electron multiplier.

2. Aging models

The PMT aging or loss of anode sensitivity is a function of the output current level, the dynode materials, and the preceding working history. The amount of average current that a given photomultiplier can withstand varies widely, even among tubes of the same type; consequently, only typical patterns of aging may be cited. A very likely reason for the variation of the gain may be due to the last dynode's coating material, which is subjected to a strong and continuous bombardment due to the electrons that hit it. The changes of the surface layer of this dynode, which is directly involved in the process of secondary emission, may lead to gain variations. In fact, the gain shows different behaviors for each type of photomultiplier tube. It is primarily the presence or absence of an excess cesium layer on the surface of the last dynode that determines such a behavior that is also dependent on the average anode current of the PMT. As a result of the review of several studies of PMT aging process in literature, two main models can be distinguished: the down-drift and the up-drift model. The down-drift model, shown in Fig. 1, is characteristic of the PMT dynode, for instance stainless steel, covered by a thin coating of materials to increase the secondary emission and a further protective layer, in Fig. 1 a very thin Cs layer. The gain characteristics, after an initial phase of short duration called the conditioning phase, reach a phase of stability, until there is a decrease of the gain. In the applications in which the PMT operates with an el-

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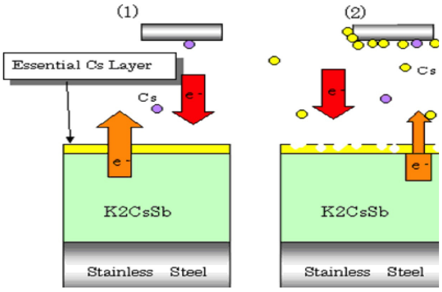

Figure 1: The scheme of the down-drift model.

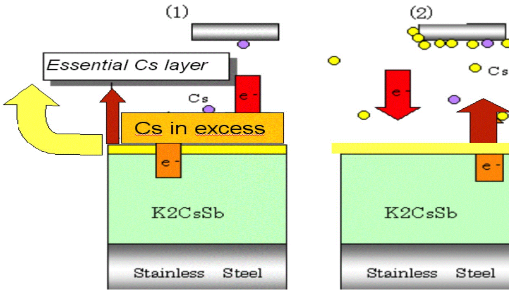

Figure 2: The scheme of the up-drift model.

evated value of the gain and, therefore, with a low value of the cathode current, the decrease of the gain is mainly due to the damages on the dynode's surface. This is commonly attributed to the mobility of the alkaline molecules, mainly K and Cs. Due to the high mobility, the continuous sputtering with electrons produces damage of the alkaline layer at a structural level. This diminishes the probability of electron secondary emission. The up-drift model, shown in Fig. 2, is characterized by the presence of a thicker cesium layer on the emitting surface of the dynode that is defined as excess layer. The higher thickness of this layer decreases therefore the time of the PMT increases. Nevertheless the thickness of the cesium layer cannot assume values too high respect to the optimal one because this causes the evaporation of a remarkable amount of cesium atoms with consequent worsening of the performances of the PMT especially regarding the after pulse type 2 (AP2). Besides, not all the secondary electrons reach the surface of the emitting dynodes because of the large protective layer. At the first use of the PMTs the coefficient of secondary emission does not reach its maximum rating, as the secondary emission is limited from the excess cesium layer. After a long period of operation, the Cs layer in excess is reduced because of the continuous sputtering action of the electrons. In this phase, the emission coefficient reaches its maximum value and an increase of the gain is observed. When the protective layer is depleted the down-drift phase takes place and the gain begins to decrease as described above. Other effects reduce the efficiency over the years as well: the He diffusion the glass, volume changes of the glass housing or the distribution of charges within the insulator. In PMTs with multi-alkali photocathode or dynode surfaces, in which a layer of CuBe or SbCs has been deposited, a smaller percentage of variation is found. Obviously, the aging of the electron multiplier should not result in detectable changes of Transit Time (TT) and TTS while the spurious pulses, depending on the free ions in the PMT, should increase. In summary, we can say that the behavior of the gain depends on the history of the PMT and the type of material with which the dynodes and the photocathode are realized. A stronger dependency originates in the operating conditions (referred to the value of the average anodic current) of the PMT.

3. Aging methodology

There are two ways to measure aging. The properties can be measured over time, in its realistic operative conditions, or by accelerating the aging process. In addition one can illuminate the photocathode using a continuous or a pulsed light source. In the first case the acceleration increases with the intensity of the light. In the second one it is possible to have few pe per pulse, in order to maintain the conditions of feeble light, and accelerate the aging process increasing the pulse rate in a controlled way.

4. Experimental set-up

A sophisticated experimental set-up has been designed to measure the PMT stability in accelerated aging condition.

4.1. PMTs under test

The studied PMTs are manufactured by Hamamatsu [5] and have the following characteristics: Standard (STD) Model R7081 10-inch photocathode with standard quantum efficiency (QE) (25% @ 400 nm). Super Bialkali (SBA) Model R7081 10-inch photocathode with higher QE (35% @ 400 nm). From the point of view of the design, the two models differ only in the PMT QE. In the case of SBA, the higher QE is achieved through the use of more refined technology used for the realization of the photocathode. The PMTs were characterized and set at the same gain at the beginning of the measurement campaign.

4.2. Measurement procedure

The measurement campaign consisted in two different phases: accelerated aging and full standard characterization in single photon electron (spe) conditions. In the first phase, the photocathodes of the two PMT are illuminated with the 400nm light produced by a current controlled LED and distributed by optical fiber splitters. A 20/80 splitter is used to continuously measure the LED power by a bolometer. From the 20% side of the splitter a second calibrated 50/50 splitter is used to illuminate the PMTs under test. The two ends of the 50/50 splitter are put at a distance from the photocathodes in order to illuminate

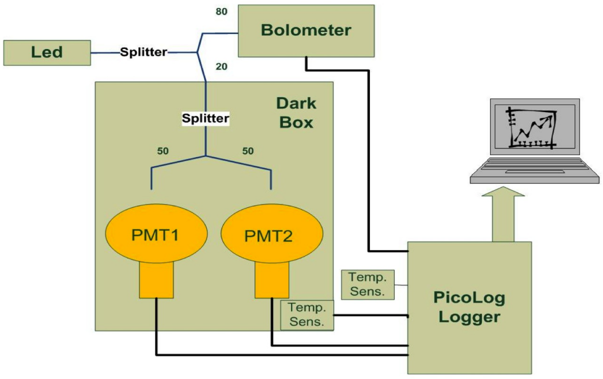

Figure 3: Experimental set-up in the ageing configuration.

them uniformly. The PMT power supply bases are two identical passive DC coupled bleeder following the scheme recommended by the manufacturer. The LED power supply has been regulated in order to produce pulsed signals for the two PMTs. The average PMT pulse amplitude and frequency have been precisely measured. The experimental set-up in the aging phase is shown in Fig. 3. The anode current of the two PMTs is continuously measured and acquired, together with bolometer output and temperature, by a calibrated Data Logger during the aging phase. From this data it is possible to calculate the total anode output charge for the two PMTs and calibrate for light source power and temperature variations. Every week the PMTs aging phase was stopped. The LED was turned off and after a suitable short reconditioning phase the full standard characterization phase started each lasting about two hours. The main splitter was disconnected from the LED and connected to the optical fiber coming from a 400 nm pulsed laser. The laser power had been previously calibrated in order to have SPEs at the photocathodes. In the full characterization phase, the gain, the transit time spread and the percentage of spurious pulses were measured employing a very precise standard DAQ system [6].

4.3. Experimental Aging conditions

The portion of luminous power from the LED sent to the two PMTs has been selected in order to produce an aging equivalent to 10 years, a typical detector lifetime, in a period of about 3 months, that is an acceleration factor of about 40. The base assumptions for selection have been that: the typical experimental condition is single-photon detection; the average rate is about 30 kHz; a suitable gain for the front-end electronics is $5 \cdot 10^7$; The regime of operation of the PMT had to remain impulsive, to avoid fatigue effects (a reduction of gain, induced by the huge photons rate incident on the photocathode); the anodic signal must not saturate, that means not more than 100 pe at a gain of $5 \cdot 10^7$, therefore, a mean light intensity of few pe has been chosen. In the first phase of the aging process for about one year we have fixed the anode current to 10μA. The mean value of the charge spectrum corresponded to 3.6 pe, so the average pulse rate was about 340 kHz. So we have had the expected acceleration rate of about 40. Only after the end of the up-drift phase the high voltage power supply was increased to accelerate the aging process and to detect the down-drift phase.

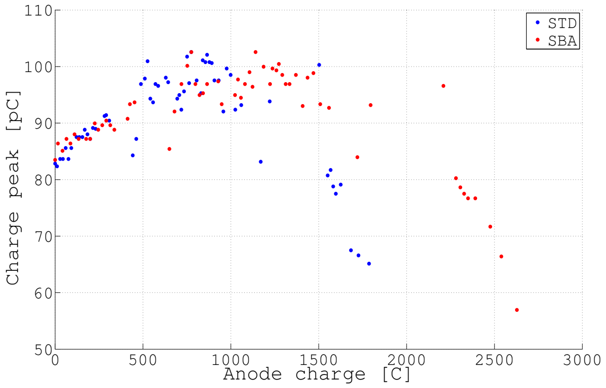

Figure 4: Charge peak position versus the total anode output charge.

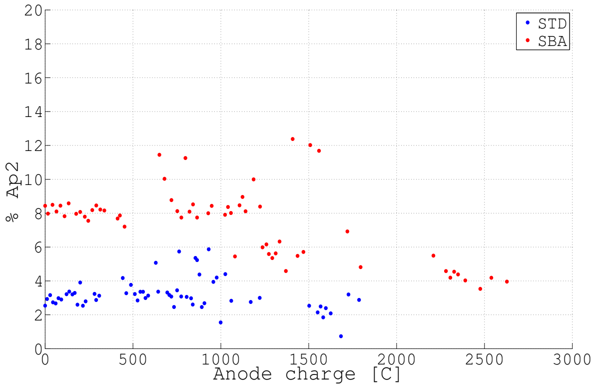

Figure 5: The After pulses type 2 percentages measured for the STD and SBA PMTs versus the total anode output charge.

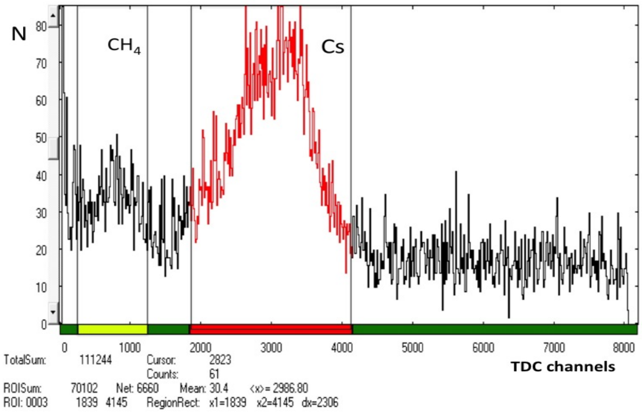

Figure 6: The STD AP2 time spectrum in February 2009.

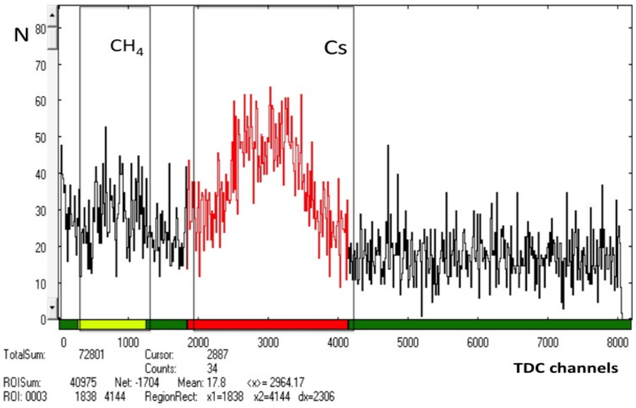

Figure 7: The STD AP2 time spectrum in May 2011.

		STD		SBA	
	Unit	Mean	σ	Mean	σ
TTS	ns	2.630	0.149	2.689	0.171
AP1	%	0.819	0.024	0.79	0.021
Late Pulses	%	4.681	0.221	4.869	0.255
Pre-pulses	%	0.088	0.031	0.090	0.033
Dark	Hz	1120.33	278.66	1748.41	633.26

Table 1: Summary of the STD and SBA PMT full characterization over the accelerated aging process.

5. Results

The measurement campaign has been carried out without stop for about 3 years. The two PMTs went through the up-drift phase and into the down-drift phase as predicted by the previously described model in the case of the presence of an excess cesium layer over the dynode surfaces. In Fig. 4, the charge peak position measured for both PMTs versus the total anode output charge is shown. A steep descend of the gain can be noticed at about 1500 C and 2300 C for the STD and SBA PMTs. respectively. In Fig. 5, the percentages of the after pulses type 2 versus the total anode output charge is shown. It is evident in the figure that the SBA has about twice the AP2 percentage with respect to the STD. In Fig. 6 the AP2 time spectrum for the STD PMT as measured in 2009 is shown. In the figure are also boxed the two regions of the spectra related to CH4 and Cs ions present in the vacuum of the STD PMT. The TDC channel corresponds to about 5 ns. In Fig. 7 the same time spectrum was measured in 2010. Comparing the two results, it is evident that Cs ions decrease. A similar behavior can be noticed for the SBA, but the decrease is larger for the STD one, about 52.3% for STD and 13% for SBA, respectively. The ratio of the total charges measured in the same time interval is proportional to the ratio of the quantum efficiency of the two PMTs as expected because they are illuminated at the same intensity level. Nevertheless the Cs/CH4 concentration of the STD PMT is reduced between 2009 and 2011 measurements by about 50%, while for the SBA PMT the decrease is only about 15%. The meaning of this two different ratio is that the SBA must have a thicker excess layer and this fact is supported from the results in Fig. 5. This hypothesis is also confirmed by the fact that the gain plot of the STD PMT has a steep decrease at lower anode charge values with respect to the SBA one, as shown in Fig. 4. In Tab. 1 the mean values and the standard variations of all the other measured parameters are listed. They are essentially independent from the aging and the photocathode type, apart from the dark rate whose value is a little larger for the SBA PMT, maybe due to the excess layer thickness.

6. Conclusions

This work was aimed at measuring the life characteristics of two large area PMTs in accelerated and controlled aging conditions. These tests are of considerable importance for the precise definition of the operating conditions of these sensors in the experimental environment. The measurements have been carried out in a period of almost three years. The measurements have shown that not all the characteristics of the PMTs change in the same way, only the PMT gain and the percentage of afterpulses (AP2), undergo significant variations as a function of the total charge collection. First an up-drift trend of the gain, up to about 1500 C and 2300 C for the STD and SBA PMTs respectively, there was a steep decrease in the gain, corresponding to the down-drift model, to the value of total charge collection of about 1800 C and 2500 C for the STD and SBA PMTs, respectively. The up-drift phase shows an increase of the gain of about 10% and the following down drift phase shows a faster diminution of the gain of about 30%. The final value of the gain is still suitable for the use of the two PMT and can be easily recovered to the initial value acting on the PMTs power supply. Other parameters that were measured do not have substantial changes. One of the characteristic parameter of PMTs that must be take into consideration is the percentage of AP2, a parameter that may affect the timing properties of the PMTs. The validity of the observations depends, however, on the dispersion of the PMT properties due to the production procedures.

7. References

[1] http://nemoweb.lns.infn.it
[2] http://antares.in2p3.fr
[3] J.M. Schonkeren, Photomultipliers, Kater and Thompson, 1970
[4] B. Leskovar, Photomultiplier characteristics considerations for the deep underwater muon and neutrino detection systems, February 1980 Presented at the Deep Underwater Muon and Neutrino Detection Signal Processing Workshop, DUHAND Hawaii Center, University of Hawaii, Honolulu, February 11-16, 1980
[5] http://www.hamamatsu.com
[6] S. Aiello, E. Leonora, D. Lo Presti et alter, Procedures and results of the measurements on large area photomultipliers for the NEMO project, Nucl. Instr. Meth. Phys. Res. A, Vol. 614, 2, 206-212