STUDY OF THE PERFORMANCE OF A LARGE SAMPLE
OF PHILIPS PHOTOMULTIPLIERS TYPE XP2972

Geneva - Glasgow - Liverpool - Milan - Neuchatel Collaboration.

CM-P00062972

M. Bonesini⁴⁾, E. Bonvin⁵⁾, P.S.L. Booth³⁾, L.J. Carroll³⁾,
D. Cavalli⁴⁾, G. Cecchet^{4,a)}, G. Costa⁴⁾, P.A. Dorsaz¹⁾,
D.N. Edwards³⁾, J.R. Fischer¹⁾, L. Fluri⁵⁾, D. Frame²⁾,
S. Jack²⁾, J.N. Jackson³⁾, M. Kelly³⁾, M.N. Kienzle-Focacci¹⁾,
R. Lucock²⁾, J.G. Lynch²⁾, E. Macavero⁴⁾, L. Mandelli⁴⁾,
M. Martin¹⁾, L. Mathys¹⁾, A. Maxwell²⁾, M. Mazzanti⁴⁾,
J.J. Myerscough³⁾, P.J. Negus²⁾, S. Pensotti-Rancoita⁴⁾,
L. Perini^{4,6)}, D. Perrin⁵⁾, W.H. Range³⁾, J. Rutschmann¹⁾,
L. Rosselet¹⁾, S.W. Snow³⁾, M. Tamborini⁴⁾, A.S. Thompson²⁾,
R.M. Turnbull²⁾, J. Wells²⁾, M. Werlen¹⁾.

- 1) University of Geneva, D.P.N.C. CH-1221 Geneva, Switzerland.
- 2) University of Glasgow, Dept. of Physics and Astronomy,
Glasgow G12 8QQ, U.K.
- 3) University of Liverpool, Dept. of Physics,
Liverpool L69 3BX, U.K.
- 4) Dipartimento di Fisica dell'Universita' e Sezione INFN Milano,
I-20133 Milano, Italy.
- 5) University of Neuchatel, Institut de Physique,
CH-2000 Neuchatel, Switzerland.
- 6) C.E.R.N., CH-1211 Geneva, Switzerland

Abstract

The gain of the Philips XP2972 phototube was measured as a function of time and anode current using 3456 tubes in conditions simulating the experimental situation at the CERN SPS. After an initial ageing period of 35 hours, the mean gain variation was measured to be 0.7% with an r.m.s. of 0.5% over 12 hours at constant anode current ($I_a=1.6\mu A$).

At an approximately constant gain of $2.2 \cdot 10^5$, the majority (88%) of the tubes show an increase in gain with an average of 1.6 % and an r.m.s. of 1.1% when the anode current rises from about 10nA to 1.6 μA . These characteristics were used to select and distribute the tubes on the electromagnetic calorimeter of the CERN WA70 experiment. Short term instability and photocathode homogeneity were studied on a reduced sample.

1. Introduction

Many high energy experiments make use of large area calorimeters [1] to measure the energy of interaction products. Either scintillator or lead glass is often used as the active element and coupled to a number of photomultipliers typically in the range of 1000 to 10000. The charge at the anode of the photomultiplier is proportional to the energy deposited in the calorimeter. Consequently the response stability of the photomultipliers under varying working conditions is one of the parameters determining the energy resolution.

In the present paper we describe the tests performed and the response of the XP2972 photomultiplier tubes, specially manufactured according to our specifications by Philips, to be used on the electromagnetic calorimeter of the CERN WA70 experiment [2].

Some photomultiplier characteristics [3] relevant to the present note are listed in table 1. The tubes were operated with a type B [3] voltage divider at a constant gain of $2.2 \cdot 10^5$ ($\pm 35\%$).

After ageing for 35 hours all tubes were tested for gain stability versus time (over 12 h) and versus anode current. Tests and results are described in section 2. The short term stability (gain variation inside the 2s beam spill time typical of the CERN SPS) was studied on a small sample of tubes and is described in section 3. The measurements of the relative gain and its dependence on the voltage is described in section 4.

The uniformity of the photocathode efficiency was assessed on a limited sample. The method and results are described in section 5.

2. Long term stability tests

It is known [4, 5, 6] that the gain of a photomultiplier (PM) is a function both of the anode current and of time. Due to the complicated nature of the processes involved (change in dynode surface structure, change in the photocathode response, redistribution of the dynode potentials etc.) different types of behaviour are found, not only between different types of tubes, but also between tubes of the same type.

The measurement of gain stability at constant anode current and of gain dependence with the anode current were performed with a semi-automatic computer controlled test bench similar to the one used by the UA2 Collaboration [7]. Fig. 1 shows a sketch of the apparatus. A mean anode current was provided by the light of a constant current incandescent lamp (IL) filtered by a blue filter (B). Different anode currents were obtained by positioning different neutral filters (F) with transmission factors 1., 0.5, 0.25, 0. in front of the light guide (LG) (by means of a stepping motor (SM1)). Tubes were tested at a gain of $2.2 \cdot 10^5$ compatible with subsequent conditions on the calorimeter. The signals used to monitor the PM gain were supplied by 24 LEDs (L) (green type HP 5082-4950 GaP). The pulse width was ~ 60 ns and the amplitude fluctuations were 2% (FWHM). The CERN SPS duty cycle, consisting of a 2s spill every 14s, was simulated by a rotating slit (S) placed between the lamp and the filters and driven by a second stepping motor (SM2). All test conditions were controlled by a Caviar computer [8] via Camac modules; the only manual operation was the initial H.V. setting. Up to 49 tubes could be measured simultaneously. The anode of each photomultiplier was directly coupled to a 12 bit charge ADC (LeCroy 2282E) with an integration time of 200 ns. Four stable tubes were left on the apparatus

during many successive batches and used to monitor the stability of the system. The temperature was continuously registered and remained stable to better than 3 C° during a three day run.

Table 2 summarises the measurement cycle to which the PMs were submitted. After an ageing period (period 1) of 35 hours at a mean anode current of 3 μ A (no SPS duty cycle) all 3456 PMs were subjected to a stability test over 12 hours (period 2) in conditions simulating the SPS cycle (pulsed mode). The mean anode current during the spill was $\langle I_a \rangle_{\text{spill}} = 1.6\mu\text{A}$. The PMs were subjected to periods of darkness (periods 3, 5, 7) ($\langle I_a \rangle_{\text{spill}} \sim 10\text{nA}$) alternated with periods at anode currents of 0.8, 1.6, 0.8 μA (periods 4, 6, 8). During each period measurements were performed at regular intervals. The mean values and, less frequently, standard deviations were computed on line for each ADC channel and written on a floppy disk for subsequent analyses. The number of events in each group of measurements as well as their frequency are presented in table 2. Pedestals were computed for each series of measurements and software subtracted from the corresponding ADC mean values.

The ratio of the mean ADC value normalized to the mean value in period 2 ($\langle \text{ADC}(2) \rangle$) is plotted in Fig. 2 as a function of the sequence number of the measurement for three PMs showing different typical behaviour. In the following, ADC values normalized to the mean in period 2 are referred to as relative gain (g).

Photomultipliers were grouped in 5 classes (Table 3) according to the instabilities measured as a function of time and mean anode current. Class 5 PMs (4 out of 3456) were rejected. The distribution of the absolute value of the maximum gain variation from the average during period 2 is shown in Fig. 3.

The mean variation is 0.7% with an r.m.s. of 0.5%.

The relative gain variation between period 2 ($\langle I_a \rangle_{\text{spill}} = 1.6 \mu\text{A}$) and period 3 ($\langle I_a \rangle_{\text{spill}} \approx 10 \text{nA}$), $\Delta g_{23} = (\langle g \rangle_2 - \langle g \rangle_3) / \min(\langle g \rangle_2, \langle g \rangle_3)$, is shown in Fig. 4. The large majority of tubes show an increase in the gain as a function of the anode current. These tubes have a mean variation of 1.7% with an r.m.s. of 1.3% for the above quoted $\langle I_a \rangle_{\text{spill}}$ variation. The tubes with a negative gain variation (12%) have a mean gain change of 0.7% with an r.m.s. of 0.5%.

Class 1,2 tubes have a mean gain variation of 1.2% with an r.m.s. of 0.7%, while class 3,4 tubes have a mean of 2.8% and an r.m.s. of 1.6%.

The gain variation due to the voltage redistribution between dynodes has been computed for the present voltage divider and accounts for a $\Delta g/g = +0.6\%$ for a $\langle I_a \rangle_{\text{spill}}$ variation between $0 \mu\text{A}$ and $1.6 \mu\text{A}$. The residual relative variation of 1.1% indicates that other mechanisms contribute to the phenomenon.

Comparison of the mean gain between period 2 and 6 ($\langle I_a \rangle_{\text{spill}} = 1.6 \mu\text{A}$) indicates the reproducibility of the gain after modification of the working conditions (hysteresis). The relative gain variation $\Delta g_{26} = (\langle g \rangle_2 - \langle g \rangle_6) / \min(\langle g \rangle_2, \langle g \rangle_6)$, is shown in Fig. 5. The mean gain variation is 0.3% with an r.m.s. of 1.1%.

3. Short term stability

The short term stability of the photomultipliers, i.e. the time needed to reach the new gain value after a sharp change in anode current was studied on a limited sample of tubes in special runs using a modified set up.

Due to the need for precise timing the mean current during

the spill time was simulated by LEDs. During the 2s spill the first 5 measurements were performed every 40 ms, the others every 80 ms. In the interburst 14s period the first 5 measurements were performed every 40 ms, the others every 300 ms.

The mean of many bursts of the ADC values normalized to the mean in the interburst period $ADC / \langle ADC \rangle_{\text{spill}}$ is shown in Fig. 6 as a function of time and $\langle I_a \rangle_{\text{spill}}$ for a class 1 (Fig. 6a) and a class 3 (Fig. 6b) tube. The gain shows a rapid rise and usually the plateau value is reached in less than 100 ms. Only the most unstable tubes at very high currents take as long as 250ms to reach the plateau value.

The plateau gain variation versus $\langle I_a \rangle_{\text{spill}}$ is shown in Fig.7 for four different tubes. The dependence is of the type:

$$\Delta g / g_0 = A \langle I \rangle_{\text{spill}}^b \quad (1)$$

where g_0 is the gain at very small $\langle I_a \rangle_{\text{spill}}$ and A and b constants. b is approximately the same for all tubes ($b \approx 0.7$) while A (the relative tube gain variation at 1 μA) is tube dependent.

The mean gain variation measured between periods 2 and 3 ($I_a = 0.03 - 1.6 \mu\text{A}$) gives $A = 0.009$ and $A = 0.02$ for class 1,2 and class 3,4 tubes respectively. Since in the experiment the monitoring of the gain is usually done outside the burst, to minimize the gain variation in and out of the burst, the most stable PMs (class 1,2) were used in the calorimeter regions around the beam, where $\langle I_a \rangle_{\text{spill}}$ up to 5 μA were measured. The remaining PMs were used in the outer part of the calorimeter. In each sample the tubes were ordered by increasing gain starting from the beam region to minimize the effect due to the voltage divider. Furthermore the

gain variation during the burst has been computed during data taking by measuring laser pulses inside and outside the spill.

The gain variation relative to the interburst interval has been computed and the data subsequently software corrected. As an example the gain variations observed in a series of adjacent tubes in the calorimeter at a typical beam intensity of $2 \cdot 10^7$ particles per burst in the 2s spill is shown in Fig.8. A maximum variation of 2.7% is measured. (The arrow indicates the beam position). Open circles show the variation expected from relation (1) with class 1,2 PMs using the measured currents. The agreement is satisfactory.

4. Gain dependence from the High Voltage

The photomultiplier gain is expressed as a function of the voltage by the relation:

$$G = \beta K V^\alpha \quad (2)$$

where G is the absolute gain, K the relative gain (ADC counts) at 1.0 Kv, α the dependence on the voltage V (Kvolts). The constant β (≈ 100) relating the absolute to the relative gain was determined from the data supplied by the manufacturer (the high voltage V_0 for which the gain is $3 \cdot 10^5$). α and K were measured for each PM at the end of the stability control run by varying the H.V. between 1.2 and 1.8 KV.

Fig. 9 shows the K and α distribution and their correlation. The relative gain K varies by more than a factor 40 with a most probable value of ~ 80 ($G = 8 \cdot 10^3$) at 1KV while α has a mean value of $\alpha = 7.3$ with a r.m.s. of 0.27. The K and α values of each PM and the relation (2) were subsequently used in the equalization procedure of the calorimeter [9].

5. Photocathode anisotropy

Since on the calorimeter each PM looks at either 10 or 20 light guides collecting light from 5 different longitudinal sampling layers [2] good uniformity of the photocathode efficiency is required to maintain the energy resolution. For this reason the focussing and first dynode stages were specially designed by the manufacturer.

The photocathode uniformity was assessed on a 5% sample of photomultipliers. Batches of 10 PMs were illuminated in a light tight box with light sources originating from LEDs fitted on one end of a 500 mm long, 4 mm diameter teflon tube filled with mineral oil simulating a calorimeter light guide. The light guides were moved across the photocathode at a distance of about 0.5 mm above the surface. The PMs could be rotated around their axis so that any diameter could be scanned. Usually the scan was performed on diameters corresponding to the two (rectangular) dynode axes (0° ; 90°). Fig. 10a shows the typical pattern of a scan across various diameters. Large deviations from the central value are present. Fig. 11 shows the maximum variation over the mean value between ± 10.5 mm from the centre for scans across 0° and 90° . PMs showing a maximum variation greater than 25% were rejected.

In the calorimeter the use of light mixers in front of each PM greatly decreases the consequences of photocathode anisotropy. Fig. 10b illustrates the effect of the light mixer on the same PM. Response inhomogeneity is reduced by about one order of magnitude.

6. Conclusion

Measurements on 3456 Philips XP2972 photomultiplier tubes, for use on a large electromagnetic calorimeter, have produced statistical information on the gain variation versus time and anode current in conditions simulating the CERN SPS duty cycle.

The mean gain variation was measured to be 0.7% with an rms of 0.5% over 12 hours at constant anode current ($I_A = 1.6 \mu A$).

The dependence of the gain on anode current is found to be of the form $\Delta g/g = A \langle I_a \rangle^b$ with $b \approx 0.7$ and A varying from tube to tube with a mean value of 0.011.

Tubes were classified according to quality and then distributed over the calorimeter in a way to optimize the energy resolution.

References

- 1) C. W. Fabjan and T. Ludlam Ann. Rev. Nucl. Part. Sci. 32 (1982) 335.
- 2) Bachmann et al., CERN/SPSC/80-61; Bachmann et al., Nucl. Instr. and Methods 206 (1983) 85.
- 3) Philips Data Handbook. Electron tubes Part 9 1980.
- 4) G.A. Akopolzhanov et al., Nucl. Instr. and Methods 161 (1979) 247.
- 5) RTC. Photomultiplicateurs.
- 6) M. De Vincenzi et al., Nucl. Instr. and Methods 225 (1984) 104.
- 7) A. Beer et al., Nucl. Instr. and Methods 224 (1984) 360.
- 8) S. Cittolin, G.B. Taylor. CERN/Pre 78-095 (1978).
- 9) M. Bonesini et al., Calibration of an Electromagnetic Calorimeter for Direct Photon Physics, submitted to Nucl. Instr. and Methods.

Table captions

Table 1. Characteristics of the photomultiplier type XP2972.

Table 2. Sequence and characteristics of the measurements performed to measure gain stability versus time and anode current.

Table 3. Distribution of PMs into quality classes.

Table 1

Photocathode type	bi-alkaline type D (Sb K Cs)
Useful photocathode diameter	23 mm.
Number of stages	10
Dynode material	CuBeO

Table 2

Period	Duration (hr)	$\langle I_a \rangle_{\text{spill}}$ μA	No. of meas.	Events/ meas.	Interval between measurements (minutes)	RMS (1)
1	35	3.0	4	100	0	Y
		3.0	18	540	120	N
2	12	1.6	2	540	30	N
		1.6	48	490	10	Y
3	0.17	0.0	2	490	0	N
4	3	0.8	5	540	0	Y
		0.8	16	490	5	N
5	0.5	0.0	5	490	1	N
6	2.5	1.6	5	540	0	Y
		1.6	16	540	5	N
7	1	0.0	5	540	0	N
8	3	0.8	5	540	0	Y
		0.8	16	490	5	N

(1) Indicates whether or not the r.m.s. of the measurements was computed.

Table 3

Class	1	2	3	4	5
Max. deviation from average in period 2 (%)	2.5 and	5 or 2.5 and and	5 and	5 and	>5 or
Max. variation between periods 3-4,5-6,7-8 (%)	2 and	2 and	10 and	10	>10
Max. variation between periods 2-6 and 4-8 (%) (hysteresis)	2	2	2	--	--
Fraction of PMs (%)	48.9	20.1	18.9	10.13	0.015

Figure captions

- Fig. 1 Layout of the apparatus to measure gain stability and gain dependence on anode current and voltage.
- Fig. 2 ADC values normalized to mean value in period 2 (see text) versus measurement number for 3 different PMs. At the bottom is shown the measurement number the period number and the mean current $\langle I_a \rangle_{\text{spill}}$ in the period. Full lines divide different periods.
- Fig. 3 Distribution of the maximum gain variation from the mean in period 2. $\Delta g_{22} = \text{Max} |(g_2 - \langle g \rangle_2) / \langle g \rangle_2|$.
- Fig. 4 Distribution of the relative variation between periods 2 and 3. $\Delta g_{23} = (\langle g \rangle_2 - \langle g \rangle_3) / \min(\langle g \rangle_2, \langle g \rangle_3)$.
- Fig. 5 Distribution of the relative gain variation between periods 2 and 6. $\Delta g_{26} = (\langle g \rangle_2 - \langle g \rangle_6) / \min(\langle g \rangle_2, \langle g \rangle_6)$.
- Fig. 6 Short term instability. The mean ADC value over many bursts is shown for two PMs as a function of time and $\langle I_a \rangle_{\text{spill}}$. The normalization is the mean ADC value in the interburst period. a) PM class 1 b) PM class 3.
- Fig. 7 Gain variation between end and start of burst (%) versus $\langle I_a \rangle_{\text{spill}} (\mu\text{A})$ for different tubes.
- Fig. 8 Mean gain variation inside and outside the spill time measured during the WA70 experiment for a series of adjacent tubes in the calorimeter. The arrow indicates the beam position. Open circles show the variation expected from (1) and the measured currents.
- Fig. 9 a) Distribution of relative gain (K) vs α (see text).
b) Relative gain distribution. c) α distribution.

- Fig. 10 a-d) Response of a photocathode as a function of the light position along various diameters.
- e) Sketch of the photocathode, dynodes and the diameters used for scanning.
- f-i) Response of the same tube when a light mixer is placed in front of the photocathode.
- j) Sketch of the light mixer.

- Fig. 11 Distribution of the maximum variation of a photocathode response (no mixer) from the mean a) 0° diameter; b) 90° diameter.

Acknowledgements

The authors thank S.O. Flyckt, A. Mattei, J. Roland from Philips and D. Vallat from RTC for their cooperation and application support. They also wish to thank M. Cighetti, and B. Monticelli for great help in the construction of the test system and in the measurements.

Fig. 1

Period	1	2	3	4	5	6	7	8
$\langle I \rangle_{\text{spill}} \mu\text{A}$	3	1.6	0	0.8	0	1.6	0	0.8

Fig. 2

Fig. 3 $\Delta 922$

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10

Fig.11