ISTITUTO NAZIONALE DI FISICA NUCLEARE
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19 Maggio 1986

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A COMPUTER CONTROLLED SYSTEM FOR TESTING LARGE QUANTITIES OF PHOTOMULTIPLIER TUBES

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A COMPUTER CONTROLLED SYSTEM FOR TESTING LARGE QUANTITIES OF PHOTOMULTIPLIER TUBES

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1. INTRODUCTION

Photomultiplier tubes, traditionally widely useful in cases where light to charge conversion is required, are major components of the detectors used in high energy physics. Today's experiments at big accelerators, and in underground laboratories, make use of ever increasing numbers of photomultipliers and recent detectors employ up to a few thousand separate channels.

However, in spite of the relative antiquity of this device and the copious amount of literature produced over the years concerning their behaviour under wide ranges of operating conditions, each new experiment generally requires performances in a peculiar regime. Consequently, a careful study of performance characteristics and a careful selection of a suitable type from the many different photomultipliers that are usually on the market at any given time, are generally necessary whenever one desires to instrument a new experiment.

Moreover, dealing with such a large number of channels, it is important to reduce the spread of the characteristics. A test and a selection of each single photomultiplier is generally necessary to preserve the designed performances of the detector. To make the situation even more complicated, certain performance characteristics in a single given photomultiplier vary as a function of time and history. For example, it is well known that the gain of a photomultiplier depends not only on the interdynode potentials, but also on many factors involved in the its previous history. For thousands of photomultipliers the test and the selection of each single device under working conditions similar to the experimental situation, is very demanding.

This note describes a CAMAC interfaced and computer controlled system designed to facilitate a completely automated simultaneous study of a large number of photomultipliers. This system consists of a HV power supply for the photomultipliers, an LED and associated CAMAC controlled pulse generators, a box stabilized in temperature which houses the photomultipliers, the appropriate electronics for triggering logic and ADC CAMAC read-out. Both on-line monitoring and data acquisition are handled by a CAVIAR microcomputer, while the storage of data is performed by an on-line link to a VAX 11/780. The equipment allowed a test of 24 PMT's simultaneously; however, the upgrading to larger amount of phototubes would be straightforward. The modularity of the hardware and the software provided for data acquisition and off-line analysis makes it suitable for a large range of tests including aging, gain determination, long term stability , linearity, "rate effect" measurements, measurements of short term instabilities following brief high current shocks, recovery time, single electron response, *etc.*

This system was used to study and select $\sim$ 1500 photomultipliers for the E687 experiment at FNAL [1].

2. OVERVIEW OF THE PROBLEM AND PROCEDURE

2.1 Purpose of photomultipliers and selection

About 1500 high quality photomultiplier tubes (PMT's) were needed to instrument a new, high-resolution electromagnetic calorimeter developed at Frascati to detect photons and electrons in the final states originated from the decay of charmed and beauty hadrons, produced with a new multi-hundred GeV photon beam at the Fermilab Tevatron (Fermilab experiment E687).

The calorimeter consists of 30 alternating $X-Y$ layers of lead and acrylic scintillator strips, each layer being about 0.5 radiation lengths thick and running in a plane perpendicular to the beam direction. High transverse position resolution was achieved with the use of 33 mm wide strips. Longitudinal segmentation included also an U (45°) view and a V (135°) view, to disuntangle the ambiguities in $X-Y$ coupling. In general, each PMT received light from five strips of different layers, bringing the total number of channels to near 1500.

Overall requirements for the choice of the photomultiplier type were: a compact focused structure, a diameter well fitting the size (33 mm) of the scintillating strips, gain $10^5 - 10^6$ at $900 - 1600\,V$, high bialkali spectral response. The designed energy resolution of the detector put very stringent performance requirements on the phototubes, particularly in the areas of linearity and gain stability. As is well known, only in a first approximation does the output of a PMT depend solely on the input and applied high voltage. Numerous other factors affect the gain and output shape such as the age of the phototube, its detailed history, the mean anode current ($< I_a >$), the repetition rate, the temporal proximity to large bursts of current, *etc.* Specific tests for some specimens of the suitable PMT available were performed to determine aging characteristics, behavior of gain as a function of voltage, long term stability with various anode currents, "rate effect" and associated instability at high anode current and short term instabilities following brief bursts of high current. These tests were performed under conditions that mimicked actual Tevatron operating conditions as closely as possible, and are described in overview in § 3 below. The EMI 9902 PMT with linear-focused dynode and enhanced anode pulse current capability was selected. Nevertheless, due to the severe requirements, each photomultiplier delivered was tested and those failing to meet specifications were rejected.

2.2 Description of Specific Tests for the Selection

A) Aging and stability

All PMT's were "burned in" at low voltage for at least 20 hours, before being subjected to any of the tests. After this, the voltage was increased to 80% of the maximum allowed, by steps of $100\ V$ with a $\sim 0.5 \mu A$ current flowing on the anode. Stability was then monitored for an 8 hour period; the light pulse was 20 ns and number of photoelectrons on the cathode was about 2000.

B) Gain as a function of voltage

If this stability was satisfactory (better than 2%), the voltage was lowered to $500\,V$ and then increased in $20V$ steps, output being recorded by an ADC for each step. Between changes, a period of stable voltage was programmed for as long as the phototube took to become satisfactorily stable.

C) "Rate effect" and instability at high average anode current

It is well known that under conditions of high repetition rate and/or high average anode current the gain of a PMT typically differs from its "normal" value, at a given high voltage. The causes of these effects are not well understood yet, although they appear to be due to temporary changes in the dynodes themselves [2]. Such effects became very important for photomultipliers used at modern high energy accelerators because such accelerators usually operate with high incident intensity "switching on and off."

The Tevatron cycle consists of a 10 seconds long spill period, and a 40 second long recovery period. The spill was simulated by means of a sequence of $\sim 30\,ns$ wide light pulses. Both amplitudes and frequencies can be varied in the range 75 photoelectrons to 10^3 photoelectrons and $100\ Hz$ to $33 \cdot 10^3\ Hz$ respectively. Nevertheless, because of the substancial ignorance on the rate effect, we decided to investigate the PMT's behaviour during periods of shock longer than the Tevatron spill. Therefore, we have studied the rate effect in (so called) short-term pulsed mode, medium-term pulsed mode, long-term mode.

The short-term pulsed mode is the simulation of the Tevatron cycle. The rate effect is characterized by a very short excitation time ($\sim 1ms$): it is thus necessary to measure the anode charge (namely, reading the ADC's) immediately after the start of the burst. To do this, the external trigger driving the light source (LED's) must be properly delayed, to permit the CAMAC electronics to read the very first pulses after the start of the burst. Because of the very small RAM memory in CAVIAR, it is necessary to spend $\sim 500ms$ between ADC measurements, for the transfer of the data to the mass memory (*i.e.* VAX or floppy-disc). This bound is overcome by repeating the $10s$-sampling, shifting (fig.1a) each time the

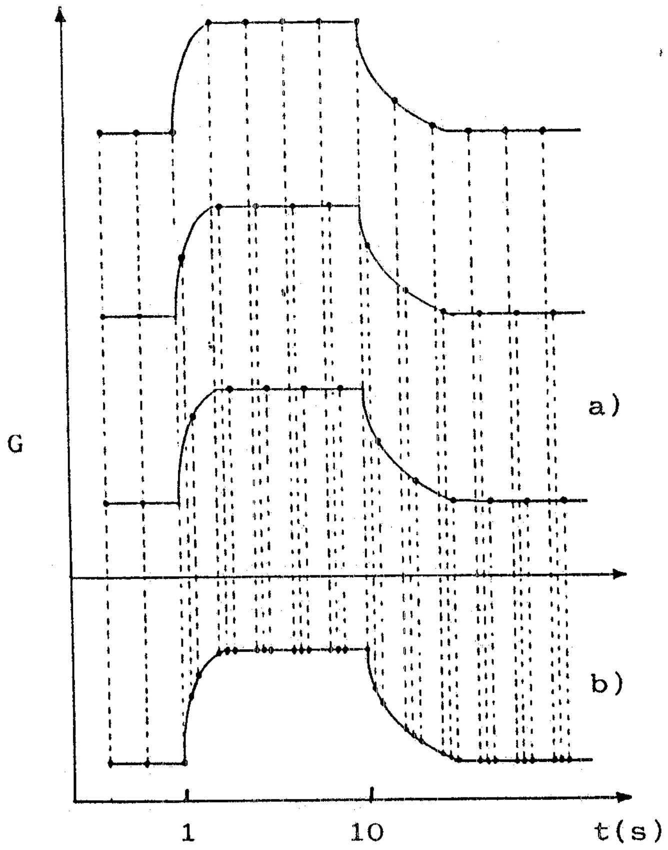

Fig. 1 The time-shift mechanism in the excitation cycle for short-term rate effect. Measurements are iterated by setting an increasing delay each time [1a)]. The final gain variation is obtained by the overlapping of every measurement [1b)].

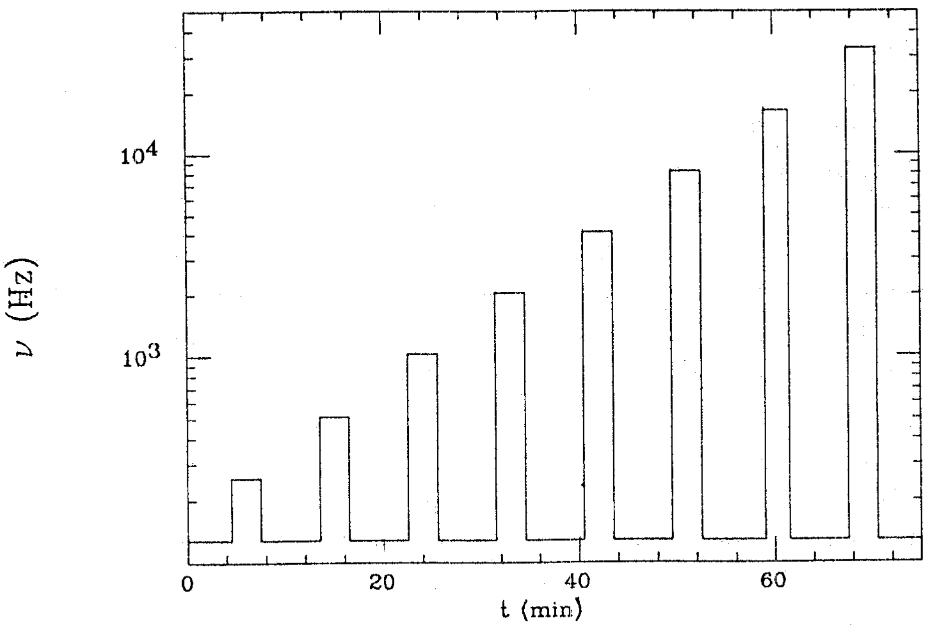

Fig. 2 The excitation cycle for the study of medium-term rate effect. High-current bursts are achieved by doubling the fundamental pulse frequency from $128\,Hz$ to $33\,KHz$, at a given Q_a.

hardware-generated delay described in § 3. The measurements collected are overimposed in the off-line analysis, and the definitive curve $\Delta G\ vs\ t$ is obtained (fig.1b).

The measurement cycle in the medium-term pulsed mode (fig.2) is composed of a set of excitations ($\sim 3min$) and disexcitations ($\sim 7min$), doubling each time the mean anode current. This mode is much easier and faster to handle than the short-term mode, for what concerns DAQ on a large sample of PMT's, and it provides significative results about the PMT's behaviour under rate effect.

The study of the long-term mode is performed by carrying the PMT from a state in which pulses frequency and anode currents are very low, to a very high-current ($\lesssim 100\mu A$) state: PMT's gain is monitored for a long period ($\sim 3h$), during the shock, and after the shock is turned off.

3. THE APPARATUS

The experimental apparatus (fig.3) is composed of a box containing 20 PMT's optically coupled to the LED's light source (fig.4), a HV power supply, a LED pulse generator, a trigger logic and read-out electronics.

The box and the room are indipendently conditioned: the environmental temperature is kept constant within $\pm 1°\ C$, while the temperature in the box is within $\pm 0.5°\ C$. An electronic termometer monitors the temperature in the box, and its output is digitized and sent to the ADC.

PMT's and LED's are powered by a CAMAC-compatibile HV system[3]. Voltages are set both by computer and manually with a precision of 0.2%: the $F(0)$ CAMAC function provides the setting value. A 10-dynodes voltage divider with grounded-anode is used (fig.5). The voltage drops increase starting from the $4th$ stage: this arrangement provides a better gain linearity, because the strongest field between the last dynodes raises the threshold electronic current at which the space charge saturation is established. The current flowing in the divider is $I_d = 1.5mA$ at $1500V$.

The pulse generator[4] flashes a set of HP5082-4956 green LED's, emitting at a wavelenght $\lambda = 565nm$. The pulses typical rise time is $\sim 2ns$, the $FWHM \sim 2ns$ and the fall time is $3 \sim 4\,ns$. The LED's output has a risetime $\sim 5ns$ and a fall time $\sim 30ns$: this is a realistic simulation of the light pulses in organic scintillators after $100m$ of LEMO cable, namely in the experimental conditions at Fermilab. LED's are assembled outside the box housing the PMT's, and they are matched to the photocatodes by optical fibers. Two different bunches of LED's are used. The former bunch ("BLED") is used to change, in the "switching on-off" structure, the mean anode current $< I_a > \propto Q_a \cdot \nu$, by means of the anode charge Q_a and/or the pulses frequency ν. Frequency and charge were varied, in order to disuntangle rate and peak current effects on PMT's gain at the same $< I_a >$. The reference LED ("RLED") is continuously pulsed at low frequency ($\sim 100\ Hz$), monitoring PMT's gain variations before, during, and after the current burst simulated by the BLED. The bunch of RLED's is triggered by a pulse generator external to the CAMAC, to avoid fixed phase relations with the BLED.

A reference PMT is optically matched to the RLED only, and monitors the LED's gain. The reference PMT is always powered at the same high voltage: the long-term gain stability over the test period is of the order of $\sim 2\%$.

A variable delay circuit (fig.6) is used when studying the rate effect in short-term pulsed mode (see

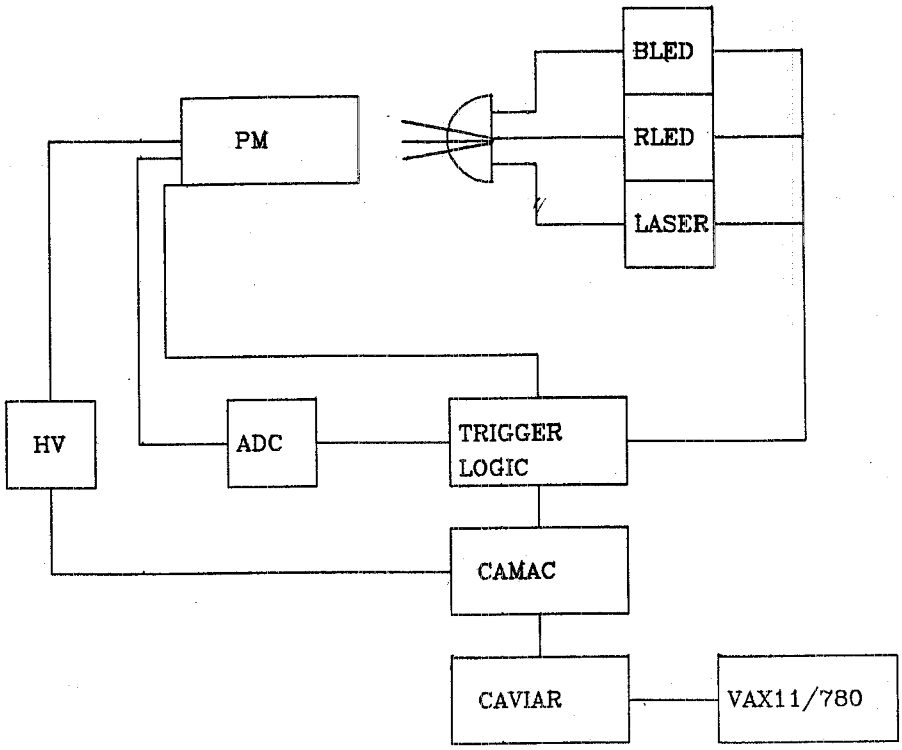

Fig. 3 The experimental apparatus used for the tests.

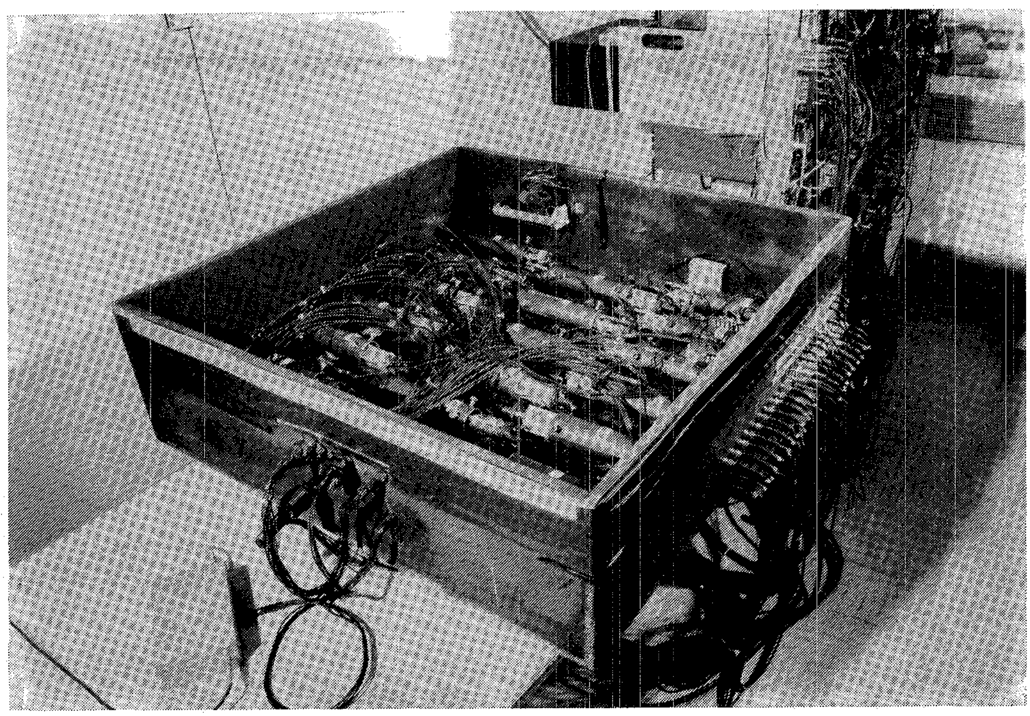

Fig. 4 The box housing 20 PMT's at a time, coupled to LED's via optical fibers.

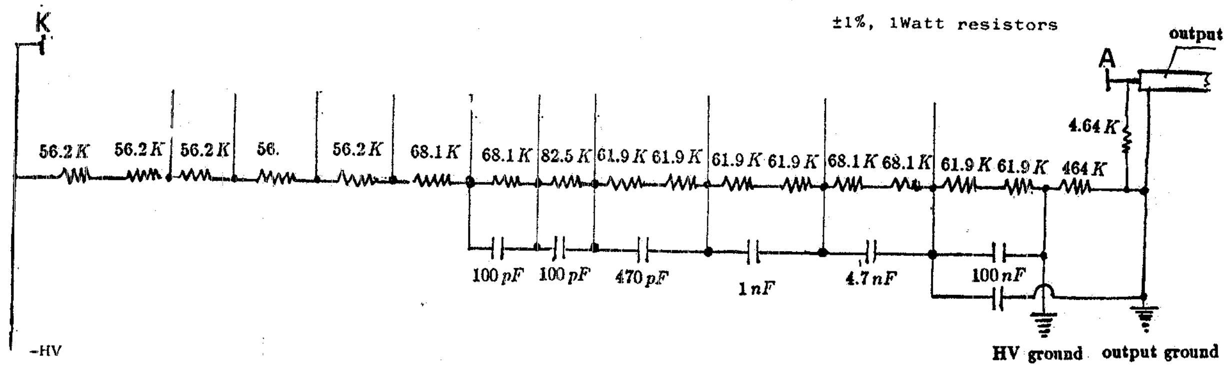

Fig. 5 The high-linearity voltage divider.

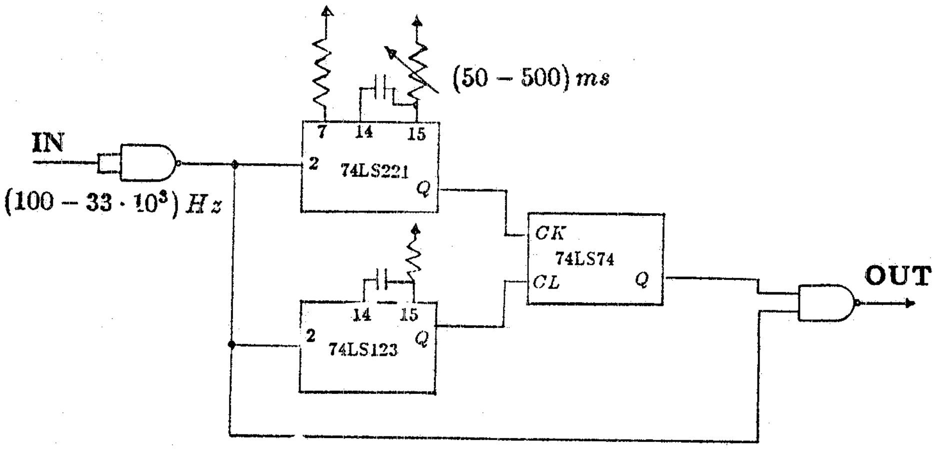

Fig. 6 The variable delay circuit permitting the time-shift mechanism.

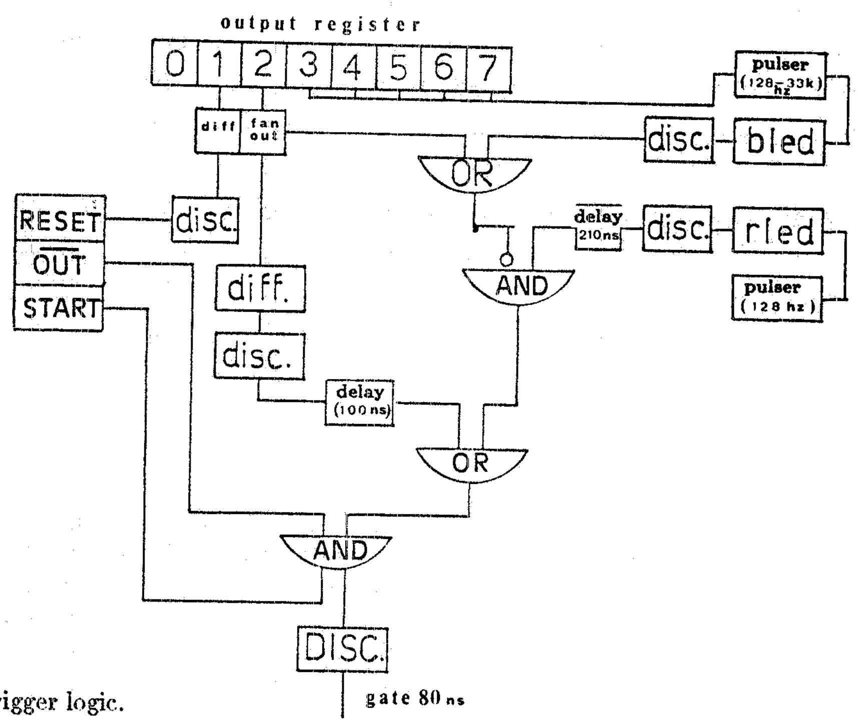

Fig. 7 The trigger logic.

§ 2). The circuit permits to delay from 50 to 500 ms the external trigger driving the BLED; the ADC read-out immediately after the start of the high-current burst is thus possible.

The trigger logic enables to control via computer the pulses frequency from the BLED and the ADC gate (fig.7): the gate is released if no overlapping of light pulses from the two LED's is present.

ADC's pedestals are measured by setting the *3rd* and the *2nd* least significant bits of the Output Register. The remaining 5 bits are used to vary the pulses frequency: the fundamental frequency (32768 Hz) is divided 9 times by 2, to get the frequencies $128 \cdot 2^n$, where $n = 0, 8$.

The anode charge is measured by two 11-bits, 12-inputs LRS-2249W Analog-to-Digital Converters: the conversion slope is $0.250\,pC/channel$, and the max integral deviation from linearity is $< 0.25\%$.

The CAVIAR microcomputer[5] is used for DAQ, on-line monitor and measurements management. It is based on the 6800 8-bits processor, and it is provided with CAMAC and graphic software. An IEEE-488 interface controls a line printer and a 5"1/4 single-face, single-density floppy-disc; an RS-232 interface and a data communication protocol allow to link CAVIAR to a host computer (in our case a VAX11/780).

The apparatus is completed by a timing unit and a scaler, acting as a high-precision clock.

4. DAQ AND ON LINE MONITOR SOFTWARE

The test program CVTEST is written in semi-compiled BASIC-BAMBI language, a CERN version of Hewlett-Packard BASIC.

CVTEST performs the test of 20 PMT's at a time: it controls the flowing of the measurements, prints tabs on the line printer and histograms on the graphic display, checks if anode currents and HV's are within safe limits, reads ADC's with pedestal subtraction, computes statistical quantities for the distributions of the anode charge and stores the data either on floppy-disc or on VAX.

CVTEST is basically structured in an initialization and a loop on "phases" [fig.8 a),b)]. The initialization is necessary to define the number of PMT's under test, their characteristics, the number of phases, the required histograms, *etc*; CAMAC addresses are defined as well, and files on floppy and VAX are opened.

A "phase" is a portion of test characterized by 7 operations: setting PMT's HV, setting LED's HV, pedestal measurements,setting a delay after the ADC measurement, number of ADC measurements and setting the BLED's frequency.

In the following, each subroutine appearing in the flow-chart is described.

Initialization routines

CINPM

The variables containing informations about the PMT's in each ADC channel are initialized. $NPMAX$ contains the number of ADC channels to be managed in the run ($NPMAX \leq 24$). The array $IDPM(4,24)$ is filled, for each Ith PMT, with the type number, the maximum high voltage, the maximum peak and mean currents; if the high voltage of the Ith channel is required not to be changed by the computer, set $IDPM(1 \leq K \leq 4, I) = 0$. The array $XNUM(24)$ contains the serial numbers, while the total charge attenuation factor on the Ith ADC channel is stored in $ATT(24)$.

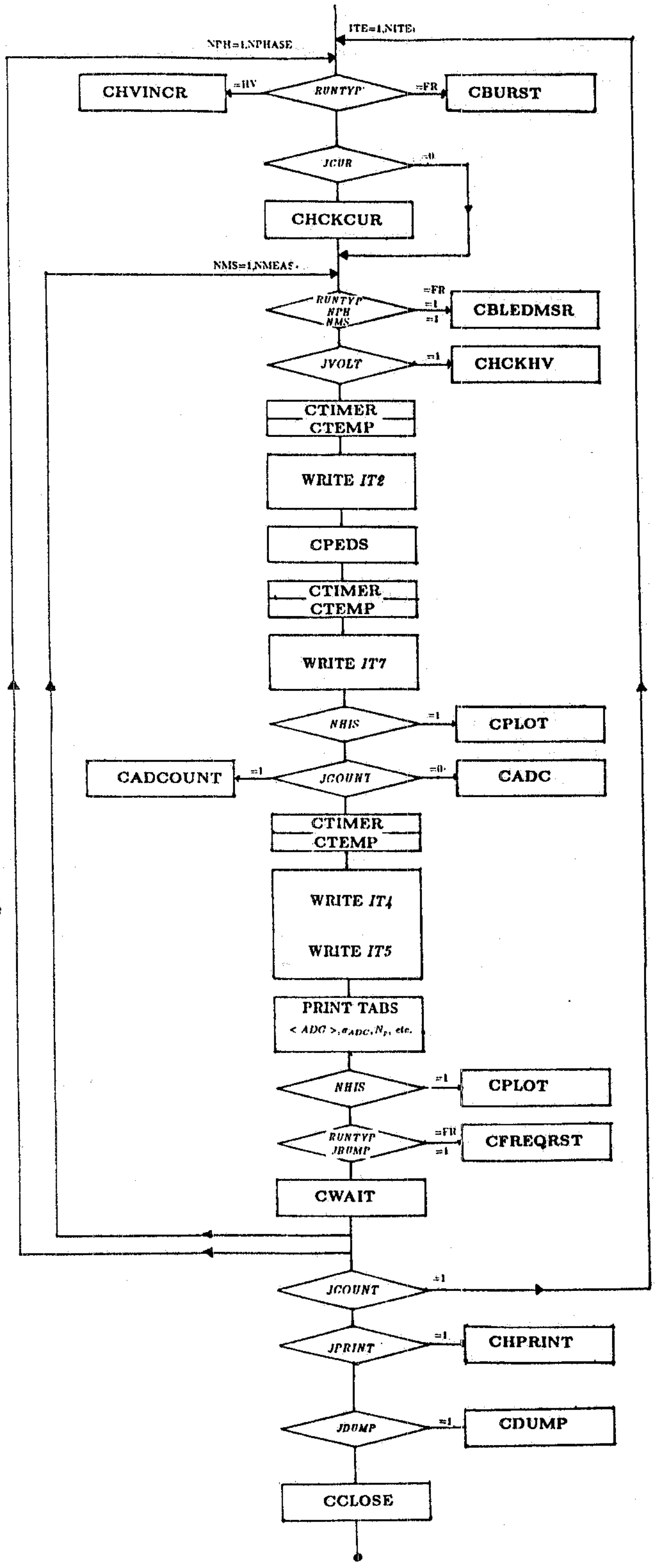

Fig. 8b) CVTEST: the loop on phases.

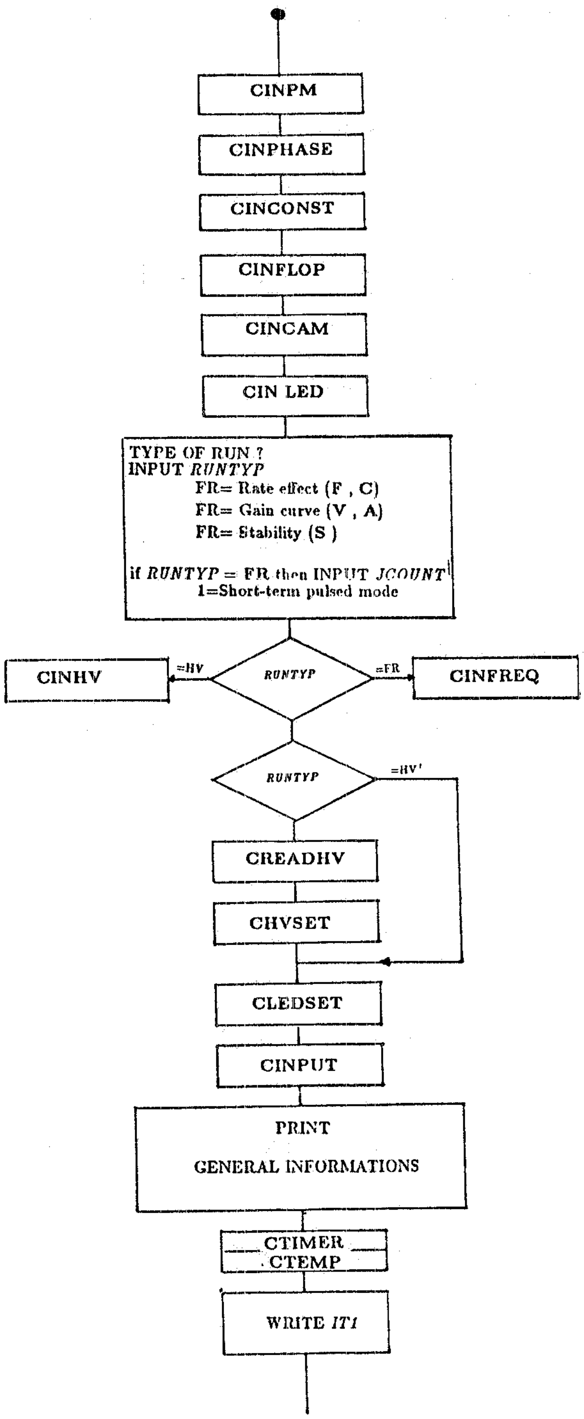

Fig. 8a) CVTEST: flow chart of the initialization section.

CINPHASE

The number of phases, and the operations to be performed in each phase, are defined by means of the array $IPHASE(7,20)$.

CINCONST

Various constants and flags are set.

CINFLOP

Floppy-discs are initialized and data files are open: a DOS resident on CAVIAR permits the dialogue with the discs, back and forth through the IEEE-488 interface.

CINCAM

The CAMAC electronic is reset, and the addresses of the modules are defined as well.

CINLED

Reads the values of the LED's high voltage supply.

CINHV

This is called if the run is dedicated to the measurement of the PMT's gain ($RUNTYP = "HV"$), and reads the voltages to set phase after phase.

CREADHV

Reads the PMT's voltages in those runs where they are not required to be varied.

CHVSET

Sets the voltages read in **CREADHV**.

CINFREQ

This is called in runs studying rate effect ($RUNTYP = "FR"$); it initializes the BLED's frequencies of each phase.

CLEDSET

LED's high voltages requested in **CINLED** are set. A failure flag is also returned.

CINPUT

General informations are input (date, number of the run), and it is also possible to modify interactively the variables initialized in **CINPM**.

The phases loop

CHVINCR

It is called on "HV" runs. In the $NPHth$ phase, the voltage can be increased by either a fixed quantity DHV at a time, or a variable step according to $RINCHV(NPH)$.

CBURST

It is called on "FR" runs. If a high-current shock is required, the frequency of the BLED is set by modifying the 4 most significant bits of the Output Register.

CHCKCUR

Performs a check on mean and peak currents: these quantities are measured, and if they are found to exceed the allowed values, the PMT is switched off and the error condition is output.

CHCKHV

Reads the high voltages supplied to each PMT, and checks if they do not differ more than 1% from the values of setting.

CTIMER

Returns the daytime in the variable TIM, in the format $HHMMSS$.

CTEMP

Returns the output from the electronic termometer (digitized and sent to the ADC), in the variable TEM.

CPEDS

ADC's pedestals are measured, and the mean values $DMP(24)$ of the distributions are returned. The histograms of the pedestals distributions are also filled.

CPLOT

This is a histogramming routine. It is possible to plot on the graphic display and/or the line printer, the histograms of the ADC distributions (pedestals or LED's output). It is also possible to store the mean values of such distributions, and to plot them as a function of time.

CADC

ADC's are read and the quantities related to the charge distributions are computed, on a sample of $NEVT$ readings: mean value, RMS, photoelectrons, anode currents. Histograms of the charge distribution and plots of the anode current as a function of time are also filled.

CADCOUNT

It is called instead of **CADC** when studying the rate effect in short- term pulsed mode. **CADCOUNT** performs the same operations that **CADC**, but includes the iterative time-shift mechanism necessary to collect a sample of measurements, suitable for the study of rise and fall times.

CFREQRST

In "FR" runs, this subroutine resets the high-current burst.

CWAIT

Supplies an interval time between two measurements.

CHPRINT

Prints the plots of the quantities collected in the run (*i.e.* $< ADC >$) as a function of time.

CDUMP

Types on terminal's screen the content of the data file on floppy.

CCLOSE

Performs various operations of end run, closing files, resetting CAMAC, *etc.*

5. THE CAVIAR VAX LINK

CVX[6] is a FORTRAN program running on VAX11/780 which performs the file exchange from and to CAVIAR microcomputers. It is possible to SAVE program files written in standard BAMBI from the CAVIAR RAM to VAX, and to LOAD BAMBI files from VAX to CAVIAR.

A tipical working session could be as follows:

$\$\,TMODE < RET >< RET >$	login VAX
$\$\ @CAVASS$	setting some privileges and assigning suitable I/O logical units
$\$\,RUN\quad CVX$	copying to VAX the program file existing in the CAVIAR RAM, with the name P.M.BMB
$VAX\quad READY > SAVE\quad PM.BMB$	
IOT	
11928 9830 1233 B	end of copy
$< CTRL\_Y >$	stopping CVX

The option OPEN allows to use VAX just like an output logical unit, which accepts records by means of the BAMBI statement $PRINT\#6, ARRAY$: therefore, it is possible both the on-line saving of large amounts of data, and the saving of data temporarily stored on the floppy-discs.

Data are written in a free format, and each record is terminated by a control character $(< CR >)$. This forces to modify the final file to make its reading possible, by the FORTRAN statement

$$READ(LUN, *)ARRAY\,.$$

CONCAVAX is a FORTRAN program running on VAX11/780 which converts free-format data files loaded from CAVIAR to VAX in a file that can be read by the statement $READ(LUN, *)$. CONCAVAX simply reads each input file and substitutes the last control character of each record $(< CR >)$ with a comma (,).

A tipical session with CONCAVAX, converting FILE.RAW (not FORTRAN-readable) to FILE.OUT (FORTRAN-readable) could be as follows

```
$ RUN   CONCAVAX
ENTER  INPUT  FILENAME:
FILE.RAW
ENTER  OUTPUT  FILENAME
FILE.OUT
END  OF  CONVERSION - RECORDS  WRITTEN = 25
$
```

6. DATA STRUCTURE

Data are stored on floppy and VAX as ASCII strings with variable format. The informations are shared in 7 kinds of records (see "COM"BLOCKS): the initial record $IT1$ has a lenght of 440 bytes, while records $IT2 \rightarrow IT7$ have a lenght of 110 bytes each.

Record IT1

- $IT1$ record identifier.
- $NR1$ sequential number of the record.
- $IDATE(5)$ day,month,year,hour,minute of the run.
- $NRUN$ number of the run.
- $NPMAX$ number of HV and ADC channels to be considered in run $NRUN$ (≤ 24).
- $NPHASE$ phases in run $NRUN$.
- $FREQ$ initial pulses frequency.
- $IDPM(4, 24)$ model, max HV, max peak current (mA) and max mean current (μA) for the PMT in Ith channel $(1 \leq I \leq 24)$. These quantities are set to 0 if the channel is empty.
- $ATT(24)$ attenuation factor inserted on the channel of each PMT.
- $XNUM(24)$ serial number of the PMT in channel Ith ($XNUM(I)$=0 on empty channel).

Records $IT2 \rightarrow IT7$

- ITn, NRn see above.
- TMn daytime (HHMMSS) when the record NRn was output.
- IEn error condition.
- $ARRAY(24)$ array containing the informations. Namely:
    - $HV(I)$ High Voltages set at the Ith channel.
    - $IADC(I)$ single reading of the Ith ADC channel.
    - $DM(I)$ mean value of the anodic charge distribution of the Ith channel.
    - $SIGMA(I)$ R.M.S of the anodic charge distribution.
    - $IPED(I)$ single reading of the Ith pedestal.
    - $DMP(I)$ mean value of the distribution of ADC pedestals.

Once on VAX, data files are named following the code

P*nnnn*R.TYP

The 4-digits number of the run is coded in *nnnn*. R is the kind of run: it is **"A"** for aging runs, **"V"** for runs in which the gain vs. HV curve is determined, **"F"** for rate effect runs and **"C"** for runs with storage of each ADC reading.
TYP is **"RAW"** for files not converted by CONCAVAX yet (see prev.par), and **"OUT"** for converted files. Only **"OUT"** files are suitable for being read on VAX.

7. DATA ANALYSIS AND RESULTS OF THE TEST

About 800 over 1500 PMT's have been tested until December 85.

We describe here the results of the selection test, while a detailed study of the rate effect will be reported in a forthcoming paper[8].

Once on VAX, data files are processed by standard FORTRAN77 programs, and for each PMT the tests are summarized in a data sheet (fig.9).

Plot a) shows the gain versus the applied voltage. The gain $G(V)$ of a photomultiplier is defined as

$$G(V) = \frac{< Q_a(V) >}{N_p \cdot e} \quad (1)$$

where N_p is the number of photoelectrons, e the electronic charge,

$$< Q_a(V) > = < ADC(V) > \cdot 0.250$$

the mean value in pC of the anodic charge when the photomultiplier is operated at a voltage V.

If a direct measurement of N_p is not available, the number of photoelectrons can be evaluated using the approximation [7]

$$n_p \sim \left(\frac{< Q_a >}{\sigma_{Q_a}} \right)^2 \quad (2).$$

Moreover, the relationship (2) is affected by large statistical errors. We fit the dependence of G *vs* the applied voltage V and, separately, the absolute value of the gain. The fitting function [7] is

$$G = aV^b \quad (3).$$

Let

$$\frac{G}{G_0} = \left(\frac{V}{V_0} \right)^b = \left(\frac{< Q_a(V) >}{< Q_a(V_0) >} \right)^b \quad (4).$$

By fitting (4) to the experimental data, we get b with a tipical error $\sim 1\,\%$.

The best evaluation of the parameter a is then obtained by the relationship

$$< a > = \frac{1}{N} \sum_{i=1}^{N} \left(\frac{G(V_i)}{V^b{}_i} \right) = \frac{1}{N} \sum_{i=1}^{N} \left(\frac{< Q_a(V_i) >}{(n_p)_i \cdot e \cdot V_i{}^b} \right) \quad (5).$$

Because the estimation of n_p from (2) at low $< ADC >$ is strongly dominated by large fluctuations of σ_{Q_a}, the mean is performed on those i measurements where $< Q_a >$ is large enough ($>$ 100 ADC channels). Usually $N \sim 50 - 70$.

Fig. 9a) shows the function G=G(V) obtained following this procedure (solid line). The evaluated parameter b and $< a >$ are reported. Also the $< n_p >$ performed on the measurament at voltage greater then 1000 volts is indicated. Stars show the ADC outputs in gain's units. Round circles show the evaluation of gain G for each measurement obtained from the expression (1) using the approximation (2).

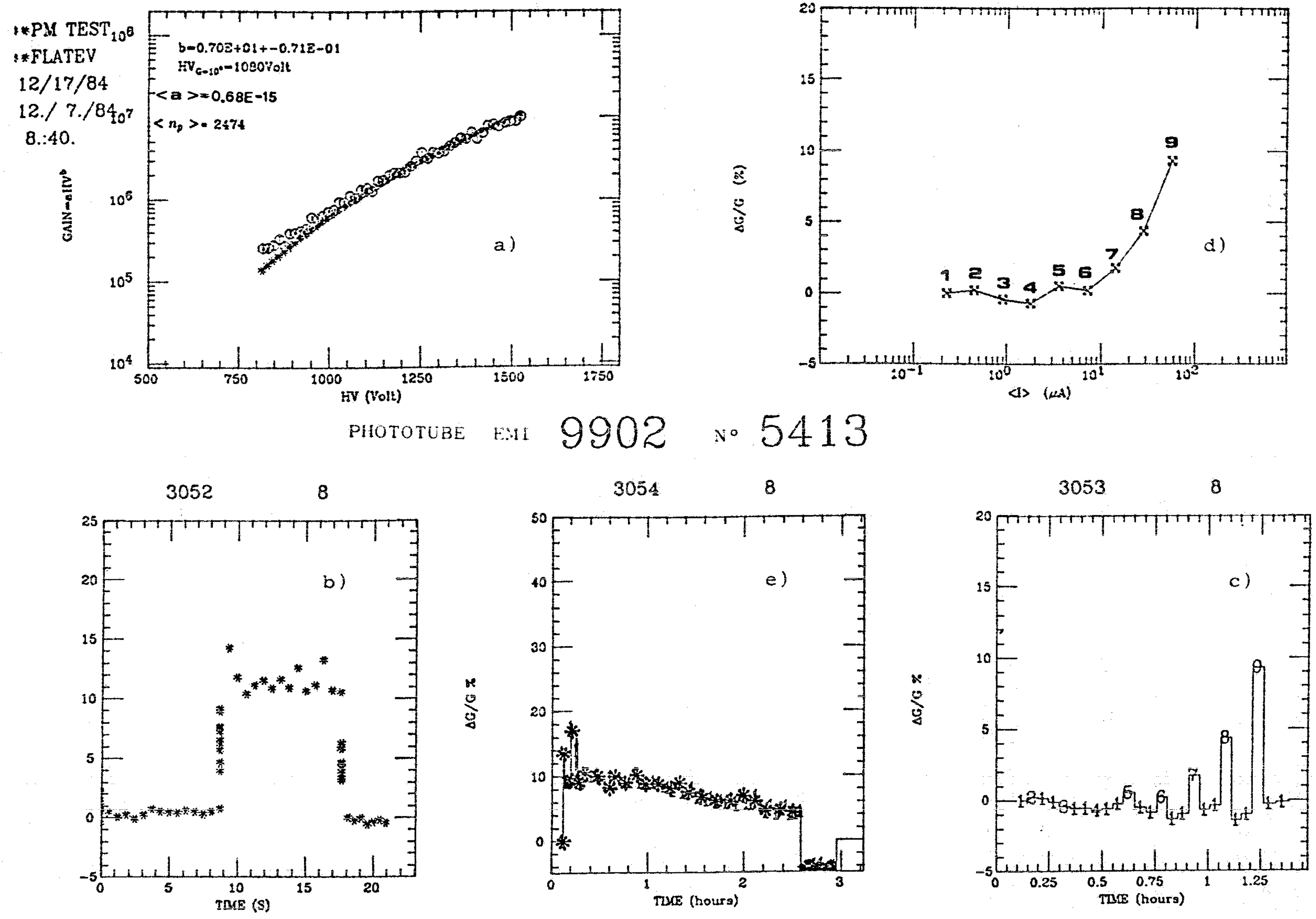

Fig. 9 The plot summarizing the results of tests on a PMT.

In conclusion the agreement between the functional dependence G=G(V^b) of the gain and experimental data, rappresented by the the error in the evaluation of the parameter b, is very good, while the absolute gain is known with an error $\sim 7\%$ due to the use of the approximation (2).

Both plots c) and d) in fig.9 show the PMT's behaviour in medium-term pulsed mode,*i.e.* according to the pulse cycle in fig.2. Plot c) is used to detect, if any, hysteresis effect in the period between the high-current bursts. The gain variation is plotted as a function of time; increasing numbers identify the pulses frequency used to produce the high-current burst, according to the cycle in fig.2. Plot d) reports the same gain variation that in plot c), but as a function of $< I_a >$: the relative gain variation is calculated with respect to the gain in conditions with a very low mean anode current ($< I_a > \sim 100\, nA$).

The measurement of the short-term gain variation due to rate effect is shown in plot b) of fig.9. The gain variation is measured during high-current bursts with an $< I_a >$ equal to the higher value of $< I_a >$ injected in the photomultiplier (it corresponds to the step 9 of fig.*c*) and *d*)). Each point in the plot is the average of 10 measurements, and the mechanism of time-shift described in §2 is used.

The long-term rate effect has been also investigated. The behaviour of PMT's is reported in the plot 9c). A current shock is injected in the photomultiplier from low current regime ($< I_a >$ less then 100 nA) to a very high value corresponding to $< I_a >$ of step 9 in fig. *c*). This shock is mantained for 2.5 hours. The gain variation are checked during this time and also in the 30 minutes following the reset of the current shock.

The acceptance value for the gain in the sample of PMT's already tested has been fixed as $G = 1 \cdot 10^6$ at a voltage between 950 and 1300 V. The distribution of the voltage for $G = 1 \cdot 10^6$ is reported in fig.10: about 10% of the PMT's tested have been returned as not matching the voltage range requested.

Furthermore, PMT's gain is requested not to exceed a variation due to medium-term rate effect of 7%, at $< I_a >= 30\, \mu A$. Fig.11 shows the distribution of the gain variation at $30\, \mu A$: approximately 15% of the PMT's have been returned for this specification.

8.CONCLUSIONS

We have designed and installed a computer-controlled, CAMAC-interfaced system which allows the test of large quantities of photomultiplier tubes.

This system is currently used for the selection of $\sim$ 1500 PMT's for the Outer Electromagnetic calorimeter of the E687 experiment at FNAL. So far, $\sim$ 10% of the PMT's supplied have been returned as not matching the required specifications for what concerns gain, and $\sim$ 15% for rate effect.

With this system, due to the versatility and modularity of both hardware and software, we were able to investigate in depth the PMT's physical behaviour, under high-intensity, on-off current conditions.

In a forthcoming paper [8] we shall report the results of this study, namely for what concerns rate effect, gain variation's hysteresis after the end of the high-current burst, gain variation's rise and fall time, *etc.*

We would like to thank David H. Kaplan (University of Colorado at Boulder) for having spent part of his time in useful discussions, while prepairing this paper.

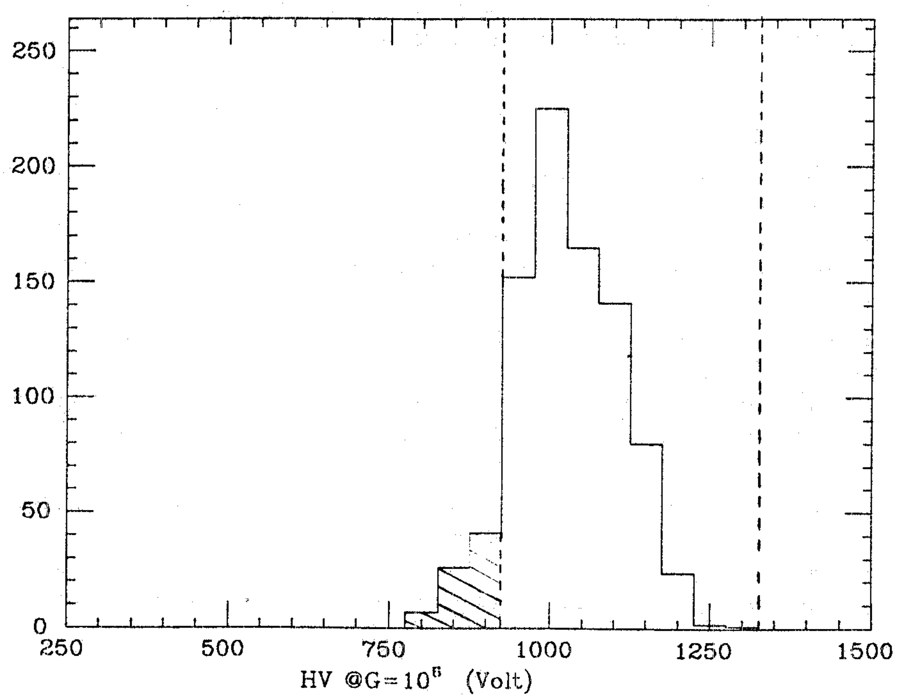

Fig. 10 The distribution of the voltage supply requested to get the gain $1 \cdot 10^6$ for the PMT's tested. The fraction of PMT's rejected is shown in the shaded area.

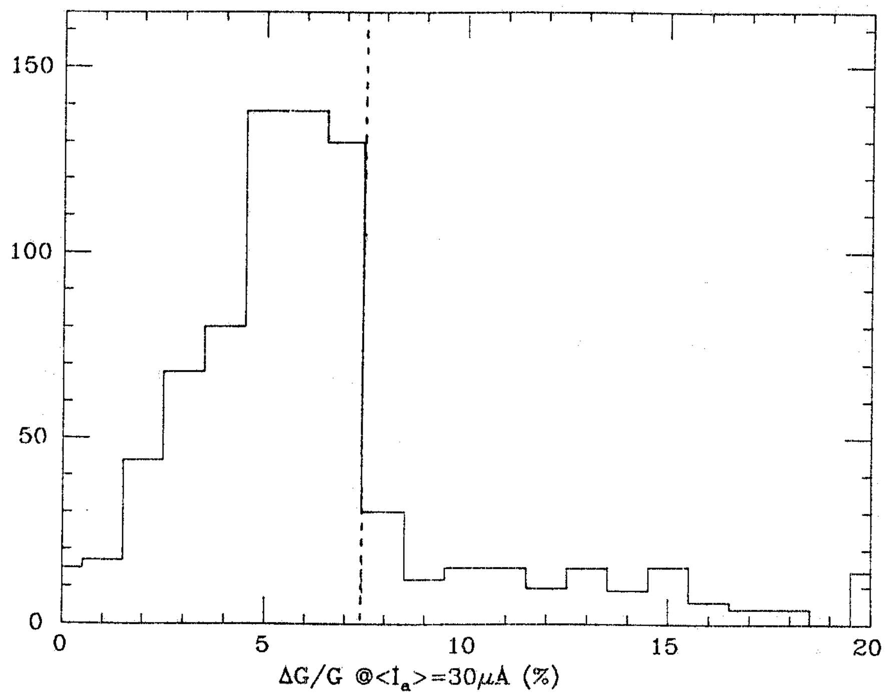

Fig. 11 The gain variation at $< I_a >= 30\,\mu A$, for the tested sample. The fraction of PMT's rejected is shown in the shaded area.

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