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PHOTOMULTIPLIER WITH IMPROVED LINEARITY ON THE BASE OF FEU-115

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Abstract

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Measurement results of the output current linearity, quantum efficiency, uniformity of the cathode sensitivity and other parameters of FEU-115 M are presented. The results obtained with FEU-115 M are compared with those for other types of photomultipliers.

Аннотация

Белянченко С.А. и др. Фотоумножитель с улучшенной линейностью на базе ФЭУ-115: Препринт ИФВЭ 95-12. – Протвино, 1995. – 8 с., 7 рис., библиогр.: 3.

В настоящей работе представлены результаты исследований линейности выходного тока, квантовой эффективности, однородности фотокатода и некоторых других параметров фотоумножителя ФЭУ-115 М, дается сравнение характеристик данного ФЭУ с характеристиками некоторых других типов ФЭУ.

1. INTRODUCTION

The goal of this work is to study a possibility to use a new modification of the photomultiplier (PM) FEU-115 in calorimeters of modern collider setups. One of the main requirements to small-size PMs employed in such calorimeters is a high output current linearity. As has already been stated in [1] home-made small-size PMs cannot compete in this parameter with such PMs as XP2081 (Phillips).

There are some characteristics which satisfy the main specific requirements for the PMs of related calorimeters:

1. The quantum efficiency maximum for blue-green region (450 - 490 nm) is more than 5%.
2. Nonuniformity of the quantum efficiency is less than 10% along the photocathode.
3. Nonlinearity of the output signal is less than 5% for the output current up to 100 mA.
4. The duration of output signals is not more than 15 ns for 0.1 level.
5. The gain is of the order of $10^5 - 10^6$.
6. High long-term stability of the above parameters at a variable light loading.

Here the characteristics (1-5) for FEU-115 M as compared with those of PM FEU-84 widely used in calorimeters are presented.

2. DESIGN FEATURES OF PM FEU-115 M

The PM FEU-115 was designed more than 20 years ago. This PM had an 11-stage Al-Mg alloy linear focused dynode system and a semitransparent Sb-K-Na-Cs photocathode placed on a radiation resistant entrace window (C96-1 glass).

The cathode camera configuration and that of the multiplier system are the same as for the well-known FEU-85 widely used in spectrometry.

Mainly due to two drawbacks FEU-115 has not found its application in calorimeters:

1) the anode configuration did not provide a high output current linearity;

2) the photocathode production technique did not allow one to get a high quantum efficiency for 400-500 nm wavelength range [2].

With the aim of removing these drawbacks PM FEU-115 was modernized. Simulations of the anode reflector unit permitted to get an optimal configuration (Fig.1). A high output pulse linearity limit (up to 100 mA) was provided due to a small distance between the grid flat anode and the last (12-th) flat Cu-Be dynode.

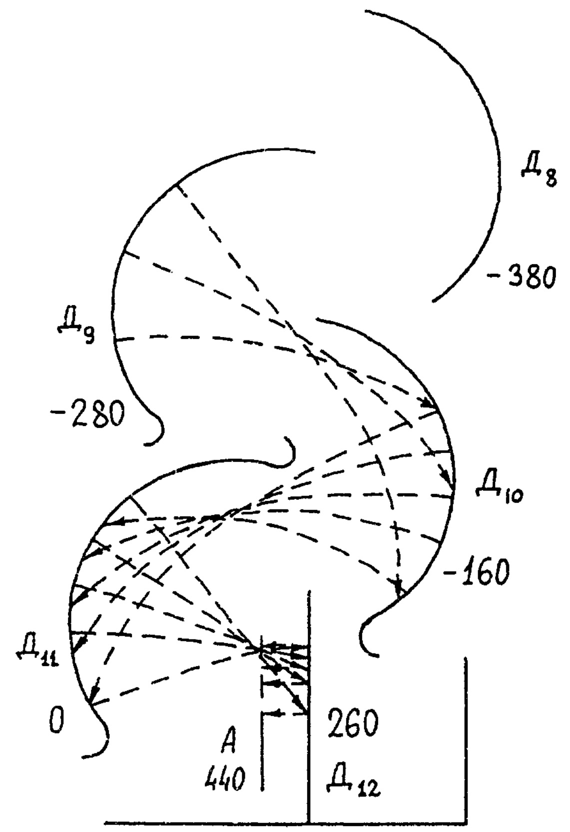

Fig. 1. Configuration of anode assembly for FEU-115M.

The fitted voltage divider allowed one, alongside with high linearity of the current, to improve the energy resolution of the PM due to a better electron collection efficiency on the second dynode.

For the PM FEU-115 M the following voltage divider is optimal: $R_1 = 3R$; $R_2 = 2R$; $R_3 \div R_9 = R$; $R_{10} = 1.6R$; $R_{11} = 2R$; $R_{13} = 3.3R$; $R_{13} = 3R$.

All the results discussed in this paper have been obtained with such voltage divider.

An improvement of pumping and activating techniques (the sequence of operation and thickness of antimony layers, temperature conditions for alkaline metal treatment and so on) allowed one to get an average quantum efficiency of the photocathode more than 12% for the wavelength range 400-500 nm. It is also possible to fit the photocathode sensitivity for different radiation spectra in 410 $\div$ 530 nm range when manufacturing.

For the improvement of the long-time stability (more than ten thousand hours) an alkaline absorber was incorporated in the PM.

The attained technology ensures nonuniformity of the photocathode less than 10% in the central part (10 mm in diameter). But this value is worse for ⌀=25 mm. This parameter is under elaboration now. It is possible to produce this PM with a thick-film divider and a magnetic shield as well.

The output pulse width is about 10 ns at the base level and about 10^6 gain for these PMs.

3. METHODS AND RESULTS OF PM CHARACTERISTICS MEASUREMENTS

The following two methods were used to study the PM linearity:

1. The tested PM was illuminated by a light emitting diode (LED) source simultaneously with a reference PM, a high-stable PM FEU-143 with the first phosphide-gallium dynode having the secondary emission coefficient more than 10. It almost eliminates the dynode system effect on the signal amplitude distribution width. A gray filter with the attenuation of about two orders was placed before the reference PM. The number of photoelectrons for this PM was defined from the amplitude spectra width and was less than 100. The dependence of the number of photoelectrons on the ADC channel (Fig.2) for the reference PM is a linear function with the accuracy of about 1% within the region considered. That permitted this PM to be used in these relative light flux measurements.

The tested PMs FEU-115 M were placed near the reference one, but without an attenuation filter. The average values for the amplitude spectra were detected for different pulse amplitudes applied to LED. At the same time the second ADC was used for recording the signal from the reference PM. It allowed one to get the information on the light signal value. Then the ratio of the average values of the amplitude spectra to the light signal values versus the anode current in pulse was determined (Fig.3). This ratio is a characteristic of the tested PM linearity.

2. The other way to measure nonlinearity was to illuminate the tested PM with two pulses with different amplitudes A_1 and A_2. The ratio of amplitudes remained the same during the measurement cycle and was ~ 2. The PM output signals for pulses A_1 and A_2 were sent to ADC and then the dependence of their ratio for different anode pulse currents was drawn up (Fig.4). This ratio was used to determine the other characteristic for the nonlinearity of the tested PMs.

For Green quantum efficiency measurements (GQE) a LED with the wavelength 480 nm in the spectra maximum working in single electron mode was used. At first the PM FEU-85 with the known quantum efficiency for the required wavelength region was placed in front of the LED to define the counting efficiency. Afterwards this PM was replaced by the tested ones and their counting efficiencies were determined. The measurement results are presented in Fig.5 as a histogram.

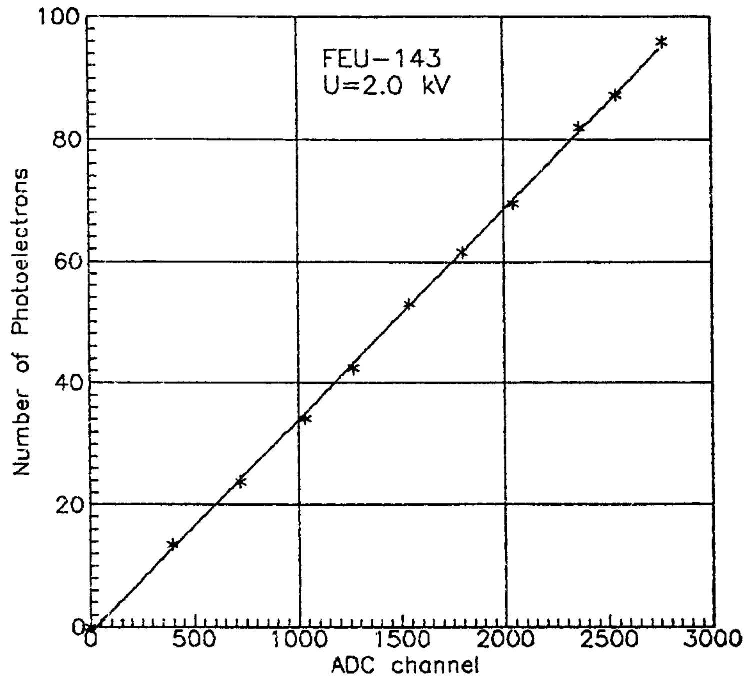

Fig. 2. The output signal linearity for the reference photomultiplier.

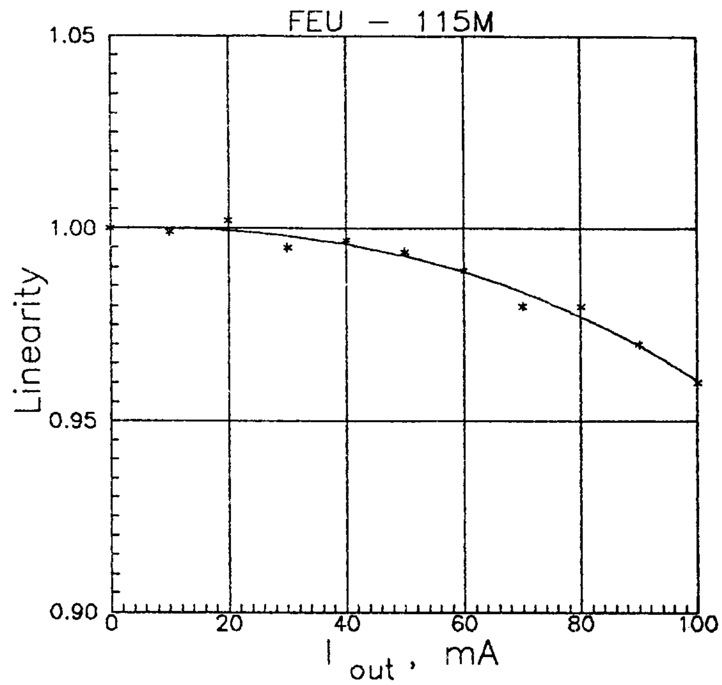

Fig. 3. A normalized to 1 ratio dependence of an average amplitude spectra for the tested photomultiplier to the number of photoelectrons from the reference PM versus the output cutrrent.

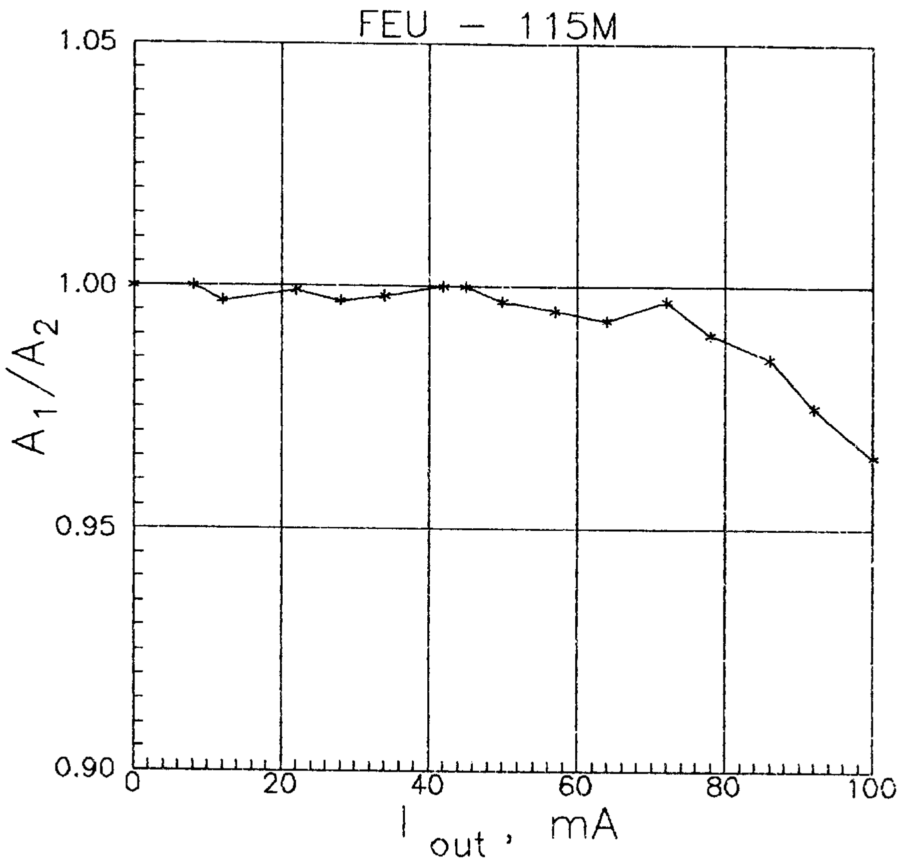

Fig. 4. A normalized to 1 ratio dependence of an average value amplitude spectra means for two different (A_1; A_2) amplitudes of a signal applied to LED, versus the output current.

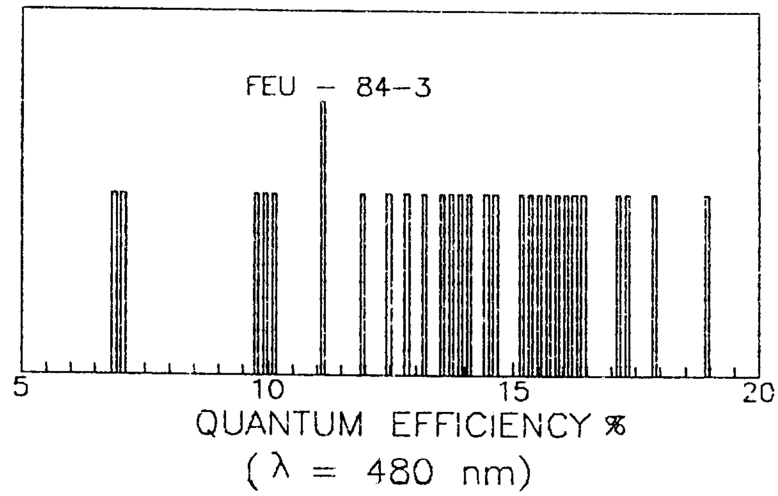

Fig. 5. Quantum efficiency of the photocathodes for FEU-115 M (λ_{max}=480 nm).

At the same time the photocurrents of FEU-115 M and FEU-84, were measured both for the LED and for the 490 nm wavelength shifting fiber excited by an ultraviolet lamp. For these measurements twenty samples of PMs FEU-115 M and six PMs FEU-84-3 samples were used. The average values of photocurrent for measurements with the LED are 17±3 nA and 13±2 nA, respectively, which is in a good agreement with the spectral measurements for this LED. The average values for the WLS measurements are 25±8 nA and 20±6 nA, respectively. Besides, spectral characteristics for these PMs were measured using a spectrophotometer [3]. Average dependencies (seven FEU-115 M and four FEU-84-3 were tested) for these spectra are shown on Fig.6.

The nonuniformity of the photocathode sensitivity for twenty PMs FEU-115 M was also tested. The photocathode surfaces photocathode were scanned with a fiber of 1mm diameter with 3 mm step in two perpendicular directions. The measurement results are presented in Fig.7.

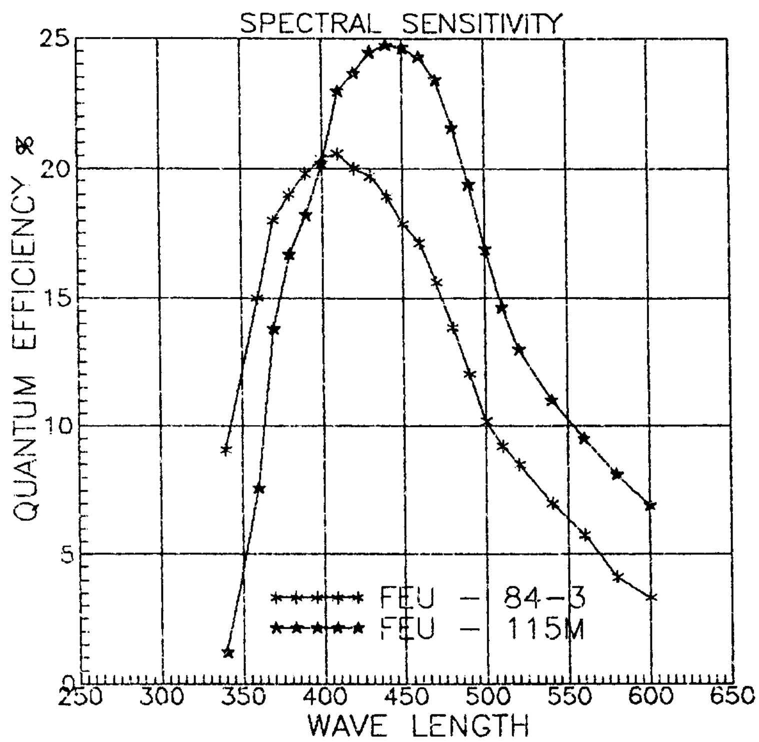

Fig. 6. Spectral dependencies of the quantum efficiency for FEU-115 M and FEU-84-3.

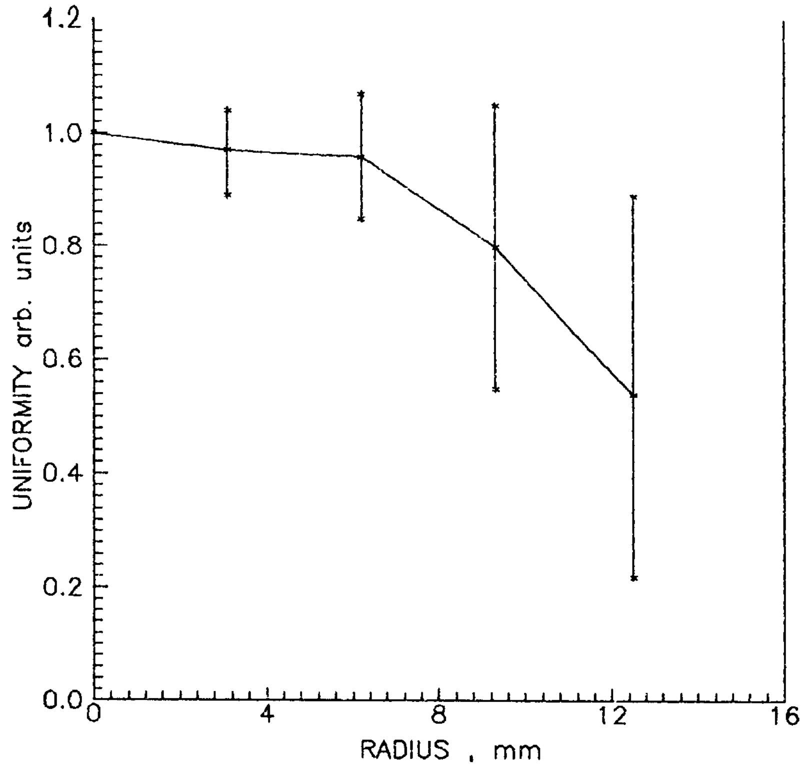

Fig. 7. The average uniformity of the photocathode sensitivity along the radius (vertical segments define the dispersion of uniformity).

CONCLUSION

1. The output current nonlinearity for FEU-115 M is 3-5% for the currents up to 100 mA (this value is less than 1% for one third of the PMs) and increases up to 10-13% for the currents up to 200 mA.

2. The quantum efficiency for FEU-115 M is about 14-16% for the wavelength 480 nm which is 1.5 times higher as for FEU-84-3 with 100 μA/L photocathode sensitivity.

3. The nonuniformity of the photocathode sensitivity is less than 15% within the 12 mm diameter spot placed in the photocathode center and increases up to 40% at the photocathode edge.

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