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PHOTOMULTIPLIER TUBE
TESTING AND ANALYSIS

Technological Spinoff Report

J. L. Bowers, Project Leader

Project Team:
T. E. Allen

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**Kansas City
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Project Leader:
J. L. Bowers
Department 844

Project Team:
T. E. Allen

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PHOTOMULTIPLIER TUBE TESTING AND ANALYSIS

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Prepared by J. L. Bowers, D/844

An investigation was conducted to determine the effect of a wide operational temperature range on the output of a small photomultiplier tube (PMT). This PMT is similar to the RCA 8571 miniature PMT. A calculator based instrumentation system is described including programming techniques used to reduce and display data. Also described is a Light Instrumentation System with specially designed fiber optic light guides which supplies light to the PMT to allow measurement of the PMT output with respect to temperature.

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SUMMARY

The spectral response and pulsed output of a small, nine-stage photomultiplier tube (PMT) are analyzed to determine how these characteristics vary over a wide operational temperature range (-70°C to $+100^{\circ}\text{C}$).

Two instrumentation systems were used in conjunction to acquire and process data. The calculator based instrumentation system was used to process and display data in graphic form. The Light Instrumentation System was used to supply light to the PMT via specially designed fiber optic light guides. These two instrumentation systems were interfaced to determine the calibration of the light source.

Results of this investigation indicate that this photomultiplier tube (PMT) exhibits a shift in peak spectral response wavelength to the shorter wavelengths and an increase in radiant sensitivity with an increase in applied high voltage. The peak spectral response wavelength does not vary significantly with changing temperature and the radiant sensitivity decreases with increasing temperature. The pulsed response data from the PMT indicated a greater relative decrease in sensitivity with increasing temperature than the radiant sensitivity due to the spectral range of the light emitting diode (LED) used as a pulsed light source.

DISCUSSION

SCOPE AND PURPOSE

The analysis of the PMT (similar to RCA Type 8571) was initiated as part of a project to determine the temperature characteristics of an electro-optical assembly. By knowing how the outputs of the assembly components shift with respect to temperature, temperature compensation techniques may be employed which would allow the electro-optical assembly to function over an extended temperature range. This will enable more efficient calibration and economical production of the electro-optical assembly. The PMT has an S-4 response (peak response wavelength ≈ 400 nm) and the cathode material is cesium antimony (Cs-Sb).^{1 2}

PRIOR WORK

Prior work has consisted of the fabrication of a test fixture for the PMT. Fiber optic light guides were designed at Bendix and fabricated at Bausch & Lomb. Two types of fiber optic light guides were designed and built: single bundle with circular cross-section ends, and single bundle with a rectangular cross-section at one end.

All light guides were non-coherent (do not preserve the image). The single-bundle light guide with rectangular cross-section at one end is used with the light source/monochromator to transmit light from the light source to the PMT through a hostile environment. The rectangular cross-section end is designed to couple the maximum amount of light from the exit slit of the light source/monochromator.

ACTIVITY

Instrumentation System

Calculator-Based Instrumentation System

The Calculator-Based Instrumentation System consists of the following:

- Hewlett Packard 9810A Programmable Calculator
- Hewlett Packard 2570A Coupler Controller
- Hewlett Packard 9862A Calculator Plotter
- Hewlett Packard 3480B Digital Voltmeter

This system configuration (Figure 1) was programmed to minimize manual data and information recording. Figure 2 is a flow diagram of the program used to collect and process data from the Light Instrumentation System and PMT test fixture.

The Calculator System collects, processes, and records the data. The complete calculator program consists of a print program and a magnetic memory card containing calibration data of the PMT test fixture obtained using the EG&G Model 580/585 Spectroradiometer and Model 590 Tungsten standard lamp system (Figure 2). A general purpose plotting program was used to make the final plot of the temperature data on each PMT (Figure 3).

Light Instrumentation System

The Light Instrumentation System was used as a calibrated light source for the PMT testing. The following is a list of the major system components. Figure 4 illustrates the system configuration.

- Fiber Optic Cables.
- OCLI (Optical Coatings Laboratories Inc.) Circular Variable Neutral Density Filter (Optical Density 1.0 to 4.0).
- Light Source Consisting of
 1. EG&G 590 Standard Source Power Supply.
 2. B&L Tungsten Lamp Light Source.
 3. B&L 33-86-76 Monochromator Grating With Housing (300 nm to 800 nm).
- PMT Test Fixture and Monitor Box.
- Fluke 412B High Voltage Power Supply.

Instrumentation System Interface

All data transferred to the Calculator System was in analog form. The anode current was monitored using a 1.0 k Ω current viewing resistor (CVR). The HP 3480B digital voltmeter (DVM) was used to monitor the voltage developed across the Dynode CVR. This voltage is directly proportional to the Dynode current from the PMT. Pulse signals were monitored with an oscilloscope (Figure 5) using a 1.0 k Ω load resistance as shown in the PMT bias network schematic (Figure 6).

Figure 1. Calculator Based Instrumentation System

Figure 2. Program Flow Diagram

Figure 2 continued. Program Flow Diagram

Figure 2 continued. Program Flow Diagram

Figure 3. Plot Program Flow Diagram

Figure 3 continued. Plot Program Flow Diagram

Figure 4. Light Instrumentation System

Figure 5. PMT Pulse Test System

Figure 6. PMT Bias Network Diagram

Instrumentation System Calibration

The calibration of the light instrumentation system is based on calibration of the EG&G 580/585 spectroradiometer, which is National Bureau of Standards (NBS) traceable.

The Light Instrumentation System was calibrated in total power (watts) at the diffuser of the PMT test fixture. This calibration was done with the variable neutral density filter (VNDF) set for maximum transmission of light. The VNDF was calibrated with respect to the attenuation it presented, thus controlling the optical power present at the diffuser. The diffuser optical power was attenuated when the PMT anode current approached 20.0 μ A, the specified maximum anode current.

After calibration of the light source at 10-nm intervals from 300 nm to 800 nm, reference points were chosen to reset the calibration of the system. These calibration reference points were checked during PMT testing with the EG&G 585-66 high sensitivity detector and fiber optics probe. All PMT data is in terms of optical power at the PMT test fixture diffuser surface. The diffuser is made from Corning fused silica with a 60-grit finish, has an area of 0.21 in.² (135 mm²) and is located approximately 0.5 inch (1.3 cm) from the photocathode of the PMT. The diffuser was rotated around the PMT and located at the angle of maximum response prior to testing each tube.

The same diffuser was also coupled to a light emitting diode (LED) via a 24-inch (61-cm) fiber optic light guide and calibrated at a diode current of 50.0 ma. Calibration was accomplished by integrating the spectrum of the LED at the diffuser using the EG&G 580/585 spectroradiometer. This data was used to compute the peak output power at the diffuser by using 1.0-A diode current pulses 6.0 microseconds wide with a 1.0 percent duty cycle.³ The PMT pulse test system (Figure 5) was used to determine how the PMT pulse characteristics changed with temperature.

Photomultiplier Tube Testing

Three PMT's were chosen at random from a lot of 400 devices. These tubes were tested at five temperatures (-70, -40, +25, +60, and +100°C). Steady state spectral response was plotted and tube pulse characteristics were analyzed. Some of the test data is shown in the Appendix. The data from these tests established three areas of interest in the electro-optical assembly application.

- The shift of the peak spectral response wavelength with temperature and applied high voltage.

- The shift in magnitude of the PMT radiant sensitivity with temperature.
- The change in the PMT pulse response with temperature using the output of a pulsed LED as a light source.

The envelope of the PMT is coated with a conductive graphite-loaded coating (AQUADAG) to eliminate static charge buildup on the PMT envelope which would distort the electric field within the tube. Such a static charge creates unstable PMT sensitivity to incoming light.^{2 4}

The spectral response of the PMT was plotted from 380 nm to 700 nm. Investigation at wavelengths below 380 nm indicated that the spectral response of the PMT decreased rapidly. It was found that below 380 nm, the low transmission of the fiber optic cables used to couple light to the PMT did not allow accurate light source calibration. In addition, the glass tube envelope is a limiting factor to PMT spectral response in the near ultraviolet (UV) region (≈ 350 nm).^{1 4 5 6} This was not a serious limitation in determining how the PMT characteristics changed with temperature.

To prevent moisture from condensing on the surface of the PMT window and test fixture diffuser, dry nitrogen was introduced into the PMT test fixture and a slight positive pressure was maintained during all testing.

Test System Configuration

The two instrumentation systems (Figures 1, 4, and 5) were used in conjunction to perform all tests. The schematic of the PMT test fixture shows how the tube was biased during testing (Figure 6).

All spectral response data was taken by monitoring the anode current of the PMT. The pulse response of the tube was monitored at another point which would produce a positive output pulse corresponding to the bias scheme used in the application of the PMT in the electro-optical assembly (Figure 6).⁷

Data Analysis and Summary

The data observed in this investigation are reinforced by the literature that was searched.^{4 8 9} The purpose of the investigation was to verify and determine the magnitude of the change in the radiant sensitivity of this PMT. Analysis of the data yields the following results.

- The PMT exhibits a coefficient of radiant sensitivity of -0.42 percent/°C from -70 to +25°C and a coefficient of -0.60 percent/°C from +25 to +100°C as evidenced by the typical spectral sensitivity plot in Figure A-1.
- The pulse amplitude response of the PMT has a coefficient of -0.5 percent/°C from -70 to +25°C and a coefficient of -0.8 percent/°C from +25 to +100°C.

Conclusions

The response of the PMT is reasonably predictable over a wide temperature range. It must be kept in mind that each photomultiplier tube is an individual device with respect to the absolute radiant sensitivity, but data from this investigation indicates that this PMT may be characterized as to the relative change of the PMT radiant sensitivity as a function of temperature. The shift in the peak spectral response wavelength to lower wavelengths was primarily a function of the high voltage applied to the PMT. However, this shift was more pronounced at lower temperatures. The loss of radiant sensitivity at -70°C is due to the semiconductor properties of the cesium-antimony (Cs-Sb) which is used in this PMT^{4 8 9} and the lack of accurate spectral data below 380 nm due to the fiber optic cable transmission losses.

The literature also predicted that the radiant sensitivity of the Cs-Sb will decrease more rapidly over the temperature range at longer wavelengths (in the LED spectrum), while the sensitivity to the shorter wavelengths will increase with temperature due to the shift in peak spectral response wavelength. This effect could cause an increase in response (at wavelengths near 400 nm) within the electro-optical assembly, while producing a corresponding drop in sensitivity at longer wavelengths.

Operation of this PMT with the graphite-loaded coating (AQUADAG) on the PMT envelope at cathode potential will produce a significant reduction in random data. Operation without some type of electrostatic shielding is not recommended for applications requiring stable PMT sensitivity.

ACCOMPLISHMENTS

Three photomultiplier tubes (PMT's) were analyzed to determine how the output of each tube changed over a broad operational temperature range. In addition to the testing and analysis of the three PMT's, the capability to perform tests on PMT's in the future was established.

FUTURE WORK

Future work will consist of analyzing the transmission characteristics of the optical coupling medium of the electro-optical assembly.⁷ An assembly will be analyzed and the effect each component parameter has on the overall function of the electro-optical assembly will be ascertained. With this information, suitable compensation techniques will be investigated that will allow efficient calibration of the electro-optical assembly.

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Appendix
TEST DATA

Figure A-1. PMT Radiant Sensitivity Versus Temperature for Tube Number 0775

Figure A-2. PMT Pulse Output Versus Temperature for Tube Number 0775

Figure A-3. Spectral Response Versus Temperature for PMT Number 0775 at 750 Volts

Figure A-4. Spectral Response Versus Temperature for PMT Number 0775 at 1000 Volts

Figure A-5. Spectral Response Versus Temperature for PMT Number 0775 at 1250 Volts