Tips on the Use of Photomultipliers

RCA

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Maximum Ratings

The maximum ratings specified for photomultiplier tubes are limiting values above which the serviceability of the tube can be impaired from the viewpoint of life and satisfactory performance. In order not to exceed these absolute ratings, the user has the responsibility of setting the tube operating values below each absolute rating by an amount such that the absolute values will never be exceeded under any unusual condition of supply-voltage variation. load variation, light input, or manufacturing variation in the equipment itself.

Voltage and Current Ratings. The maximum voltage ratings are established primarily to prevent degradation of tube performance and damage to the tube itself due to possible field emission, and in some cases, to limit leakage currents between leads at the base of the tube. The maximum current rating is established primarily to prevent dynode fatigue and subsequent loss in tube gain.

Temperature Ratings. The maximum temperature rating should not be exceeded because too high a temperature may cause alkali metals, used to activate the cathode surface and dynode surfaces, to migrate with consequent decrease in sensitivity and life of the tube. A minimum temperature limit is established for some tube types because of phase transformations of metals employed within the tube and to prevent an undue increase in photocathode resistivity which limits photocurrent to an abnormally low value.

Mechanical Considerations

Handling. Most photomultipliers employ glass envelopes. Accordingly, the tubes should be handled with care to avoid damage to the tube's seals and other parts. This caution is especially important for tube types having graded-seal envelope construction. The pins or leads of the tube should also be treated with care.

Storage. Photomultipliers should be stored in the dark. Storage of tubes in areas where light is incident on the tube results temporarily in a higher than normal dark–current level when the tubes are placed in operation. This increase in dark current is primarily due to phosphorescence of the glass and can persist for about 24 hours. Additionally, storage of tubes designed for operation in the near IR region of the spectrum (above 700 nm) in illuminated areas may decrease the "red" sensitivity of the tube.

The phototube should never be stored or operated in areas where concentrations of helium exist because helium readily permeates glass. The composition of the bulb material is a major factor governing the rate of helium permeation. As the silica content in the glass is reduced, the rate of permeation decreases. Accordingly, the rate of permeation is greatest for fused silica and decreases to a minimum in lime glass. It is also to be noted that the rate of permeation is proportional to temperature and varies directly with pressure.

Terminal Connections. RCA photomultipliers are supplied with either semiflexible leads, semiflexible leads attached to temporary bases, permanently attached bases, or stiff leads.

Semiflexible leads may be soldered, resistance (spot) welded, or crimp connected into the associated circuitry. When soldering or welding is employed for such connections, care should be taken to prevent tube destruction due to thermal stress of the seals at the stem. A heat sink placed in contact with the semiflexible leads and the point being soldered, or welded, and the tube seals is recommended. If soldering is employed, only a soft solder (e.g., 60% Sn, 40% Pb) should be used. Heat should be applied only long enough to permit the solder to flow freely. By semiflexible leads, we imply that excessive bending may break the leads, most commonly at the stem surface. Some photomultipliers are supplied with insulating wafers attached to the stem to prevent such an occurrence. The semiflexible leads are normally made of stainless steel, dumet, or Kovar and are usually plated to facilitate soldering.

Photomultipliers supplied with permanently attached bases or stiff leads should use only high-grade, low-leakage sockets to minimize leakage currents between adjacent electrode terminals. Teflon and mica-filled sockets should be used.

Mounting and Support. Photomultipliers having permanently attached bases normally require no special mounting arrangements. However, when special mounting arrangements are employed, the bulb, especially that region near the photocathode, must be maintained at cathode potential. Care should be also be taken so that tube performance is not affected by extraneous electrostatic or magnetic fields.

Side-on photomultipliers should be mounted to allow rotation of the tube about its major axis to obtain maximum anode current for a given direction of incident radiation. An angular tolerance with respect to incident light direction is normally specified in tube data sheets.

Direct clamping, with non-resilient materials, to the envelope of tubes not having permanently attached bases is not recommended nor should clamping be made to any metal flanges employed in the construction of a tube. Such flanges, if employed, are part of the tube's vacuum enclosure and any undue force or stress applied to the flanges can damage the seals and destroy the tube.

The use of resilient potting compounds or rubber washers is recommended when clamp-mounting photomultipliers. If a potting compound is used, its characteristics — over the temperature range in which the tube is to to operated — must be such that its resilience is maintained at low temperature and its expansion, in confined space, is not excessive at high temperature.

The electrical insulation properties of any materials supporting or shielding the photomultiplier should be considered. If such materials come into contact with high voltage with respect to photocathode, minute leakage currents can flow through the material and the tube envelope to the photocathode. Not only does this condition introduce excessive noise at the tube output but it can also permanently damage the photocathode sensitivity of the tube due to electrolysis of the glass envelope. This caution is only true when the tube is operated at high negative potential with respect to ground. Under this operating condition, a decrease in sensitivity can occur if the faceplate of the tube comes into contact with ground. Cathode sensitivity does not recover after such an occurrence. Photocathode "poisoning" due to envelope electrolysis can destroy the usefulness of a photomultiplier in a very short time. Therefore, the insulating property of materials supporting the tube should be such that leakage current to the tube envelope is limited to 1×10^{-12} ampere, or less.

Shielding. Electrostatic and/or magnetic shielding of most photomultipliers is usually required. When such shields are used and are in contact with the tube envelope, they must always be connected to photocathode potential.

In applications where the DC component of the signal output is of importance, the cathode is normally operated at high negative voltage with respect to ground. As a result, the shield is at high negative voltage and precautions must be taken to avoid shorts to ground and to prevent shock hazard to personnel. A 200-megohm resistor should be placed between the negative high voltage and shields to avoid such hazards.

In scintillation counting applications, it is recommended that the photocathode be operated at ground potential. In this case, the shields should be operated at ground potential.

Magnetic shielding of most photomultipliers is highly desirable. Characteristic curves showing the effects of magnetic fields on anode current are contained in many data sheets.

Operating Considerations

Operating Temperature. For optimum tube performance it is recommended that the photomultiplier be operated at or below room temperature. In no case should either the minimum or maximum rated tube temperature specified in data sheets for a given tube type be exceeded. **Warning.** The use of teflon sockets with certain photomultipliers at temperatures below -50°C may break the lead seals and destroy the tube.

Anode Current Stability. The use of an average anode current well below the maximum rated value is recommended when stability of operation is important. When a tube is operated at high average values of anode current, a drop in sensitivity (called fatigue) may be expected. The extent of the drop below the tabulated sensitivity values depends on the severity of the operating conditions. After a period of idleness, the tube may recover a substantial percentage of such loss in sensitivity.

Anode Dark Current. A very small anode current is observed when voltage is applied to the electrodes of a photomultiplier in darkness. Among the components contributing to this dark current are pulses produced by thermionic emission, ohmic leakage between the anode and adjacent elements, secondary electrons released by ionic bombardment of the photocathode, cold emission from the electrodes, and light feedback to the photocathode. Other conditions contributing to anode dark current include external leakage caused by condensation on the tube base and/or socket when conditions of high humidity exist and contamination of the tube base and/or socket by handling.

Moisture condensation can be minimized by potting the tube socket assembly in silicone rubber compounds such as RTV-11, or equivalent.

It is recommended that if a tube is suspected to have high ohmic leakage as a result of handling that it and its socket be washed with a solution of alkaline cleaner such as Alconox*, or equivalent, and de-ionized or distilled water having a temperature not exceeding 60°C. The base or the socket should then be thoroughly rinsed in de-ionized or distilled water (60°C) and then air-blown dry.

A temporary increase in anode dark current by as much as three orders of magnitude may occur if the tube is exposed momentarily to high-intensity ultraviolet radiation from sources such as fluorescent room lighting even though voltage is not applied to the tube during such exposure. This increase in dark current is due to phosphorescence of the glass and may persist for a period up to 24 hours after such irradiation. Typically, a tube with voltage applied in

*Distributed by Arthur H. Thomas Company, Vine Street and 3rd, Philadelphia, PA 19105.

darkness for a period of about 24 hours exhibits a lower value of anode dark current than the values specified in data sheets for the tube type.

Range of Sensitivity. A range of sensitivity is normally specified for a photomultiplier tube. The range of sensitivity values depends on the respective amplifications of each dynode stage. The overall amplification of the photomultiplier is nearly equal to the average amplification per stage raised to the nth power, where n is the number of stages. Thus very small variations in amplification per stage produce large changes in overall tube amplification.

Because overall amplification changes are large for small changes in voltage, it is advisable for equipment designers to provide adequate adjustment of the overall supply voltage to insure adjustment of the amplification of individual tubes to the desired design value.

Current Amplification and Dynode Modulation. Current amplification may be controlled, or the output signal may be modulated, by varying the overall voltage, or the voltage on one or more of the dynodes with the voltages on the other stages held constant. Usually one of the central dynodes of the tube is selected to perform this control or modulation. A greater latitude in control of current amplification may be obtained by varying the voltages that are applied to two or more successive central dynodes. In gated operation, however, it is sometimes advisable to gate the first dynode for cutoff because of the lower inter-electrode capacitance.

Equivalent Anode-Dark-Current Input. A practical measure of relative dark current is the equivalent anode-dark-current input characteristic. Specified values for this characteristic are obtained by dividing the value of the dark current obtained at a given luminous or radiant sensitivity value by the sensitivity value. Optimum operation of a photomultiplier with respect to dark current and signal-to-noise ratio is usually near the minimum value of this characteristic. As voltage and sensitivity are increased, a point is eventually reached where instability occurs due to regenerative effects.

Operating Voltages

Voltage Distributions. In general, the operating potential between successive dynodes should not be less than 30 to 40 volts per stage. The voltage distributions specified in data sheets are suggested distributions for obtaining a good compromise between output current and time and energy resolution. Care should be exercised when modifying the suggested distributions to make sure that the maximum rated electrode voltages are not exceeded.

A complete discussion of all phases of voltage-divider design is contained in the RCA Photomultiplier Manual, PT-61. A few salient considerations are described below.

Interstage voltages for the tube electrodes may be supplied by individual sources but are usually obtained from resistive voltage-divider networks placed across the high-voltage supply. The power ratings of the individual resistors making up the network should be approximately twice that of the calculated dissipation values for circuit safety reasons. Resistors having tolerances of about 5% are satisfactory in most systems for circular-cage and focused in-line photomultipliers. Resistors having 10% tolerances may be used with venetian-blind tubes.

The voltage-divider arrangement should be located so that it will not affect tube operating temperature. Head-on type photomultipliers sometimes use zener diodes between cathode and dynode No. 1 to provide constant voltage when tube sensitivity is varied by adjustment of supply voltage.

An important consideration is that the voltage-divider current should be maintained at a value of at least 10 times that of the expected average value of anode current. If this consideration is not observed, deviation from linearity and limitations on anode-current response to pulsed light may occur. The latter effect may be reduced to connecting capacitors between the tube socket terminals for the last 3 or 4 dynode stages and anode return. The values of the capacitors will depend upon the shape and the amplitude of the anode-current pulse, and the time duration of the pulse, or train of pulses. When the output pulse is assumed to the rectangular in shape, the following formula applies:

$$C = 100 \frac{i \cdot t}{V}$$

where C is in farads, i is the amplitude of the anode current in amperes, V is the voltage across the capacitor in volts, and t is the time duration of the pulse in seconds.

This formula applies for the anode-to-final dynode capacitor. The factor 100 is used to limit the voltage change across the capacitor to 1% maximum during a pulse. Capacitor values for preceding stages should take into account the smaller values of dynode currents in these stages. Conservatively, a factor of approximately 2 per stage is used. Capacitors are not required across those dynode stages where the dynode current is less than 1/10 of the current through the voltage-divider network.