A test of the linearity of a photomultiplier used for reflectivity measurement

By R. Phillips and P. M. D. Bradshaw

Department of Geology, University of Durham

Summary. A test of the linearity of a photomultiplier has been made using crossed polars as an optical attenuator. An expression is derived that allows for the measurable transmission of a polarizing filter in directions other than the permitted vibration direction. The linearity is shown to be adequate for accurate reflectivity measurement.

RECENT attempts to obtain accurate measurements of the reflectivities of opaque minerals have led to the development of more sensitive types of measuring apparatus than have formerly been available. The most sensitive device at present is the photomultiplier—examples of its use have been given by Jones (1962) and by Nichol and Phillips (1965). A check of the linearity of the photomultiplier used by the last named authors was carried out by Nichol (1962) using a series of neutral density filters of varying transmission and it was concluded that the device showed adequate linearity. More recently, in discussion and personal communications, some doubts have been expressed as to the adequacy of the linear response so it was decided that this should be tested more thoroughly. It seemed that the simplest method for producing accurately known ratios of light intensity would be to insert a pair of polarizing filters into a light beam and vary the angle of uncrossing.

It is easily shown that after passing through two perfect polars, the intensity of the resultant plane polarized beam is proportional to $\sin^2\theta$, where θ is the angle of uncrossing, that is, the complement of the angle between the permitted vibration directions. The use of a simple optical attenuator based on this principle is complicated by the fact that a polarizing filter is not a perfect polar—there is a measurable transmission of light vibrating in directions other than the permitted vibration direction. An expression for the resultant intensity can be derived by considering the transmission in terms of two components vibrating respectively parallel and at right angles to the permitted vibration

directions, and allowing for a phase difference between the components caused by the birefringence of the filter. Because of the large difference in the amplitudes of the two components, the resulting ellipticity will be small. In addition to $\sin^2\theta$, the expression contains a term in $\sin 2\theta$ and a constant.

It is also necessary to consider the effect of experimental error in determining the exact crossed position of the polars, from which θ is measured. Such an error is almost unavoidable, since in addition to the error in measuring the low light intensity, the rate of change of intensity with angle of uncrossing decreases as the crossed position is reached, giving a very flat curve. If the photomultiplier output current is linear with respect to light intensity and the voltage developed across a resistance in the anode circuit is measured, it can be shown that $\overline{V} = a \sin^2E + b|\sin 2E| + c$, where a, b, c are constants, E is the angle of rotation from the assumed crossed position, and $\overline{V}$ is the mean of the voltages (corrected for photomultiplier dark current) measured at angles $+E$ and $-E$. Thus even with a perfectly linear photomultiplier response, a plot of $\overline{V}$ against $\sin^2\theta$ will not give the straight line suggested by the usual theoretical treatment.

The eleven stage photomultiplier used by Nichol (1962) was tested for linearity using essentially the same experimental arrangements as in the earlier work. The light source was supplied from an electronically stabilized power unit instead of the heavy duty accumulators originally used. After passing through a continuous-band interference-filter monochromator, the light beam traversed a polaroid screen held on a microscope stage, then a fixed polaroid before entering the photomultiplier. The galvanometer originally used was replaced by a 15 000-ohm resistor and the voltage developed across this was measured with an accurate potentiometer.

When the results were fitted to the above equation by the method of least squares, a standard deviation of 0·008 volt for readings between 0·012 and 0·340 volt was obtained. In attempting to reduce this level of error, the circuit was checked in detail and it was found that an internal short circuit had developed in the photomultiplier between two of the dynodes due to sagging of one of the internal elements. The photomultiplier was thus acting as a nine stage device with an attendant loss of stability and gain. This experience suggests that careful checking is required for photomultipliers that have been in use for an extended period if measurements of high accuracy are required, since there was no obvious change in the characteristics of the circuit

when used for routine measurements. The damage to the apparatus had almost certainly occurred during movement to a new location some time after the original work of Nichol (1962). A replacement photo-multiplier of the same type was obtained and the opportunity was taken to alter the characteristics of the dynode chain to further improve stability. The 1 megohm resistors of the original circuit were replaced by 0·2 megohm resistors and the 4 megohm anode resistor by 1 megohm. This last change was possible because a high-impedance digital volt-meter was now available in place of the low-resistance galvanometer originally used.

For light of 589 mμ measurements were made at 10° intervals of E for two complete rotations of the movable polaroid. The averaged results fitted to the equation by a least squares computer programme gave a 16·2, b 0·59, c —0·05. Thus, although the major contribution is from the $\sin^2\theta$ term, the effect of the $\sin 2\theta$ term cannot be ignored in accurate measurements.

For an intensity ratio of 20 : 1 with the photomultiplier anode current limited to 10 micro-amps as recommended by the manufacturers for highest stability, the maximum deviation from the regression was 0·53 %. Considering the reading errors in the voltage and the setting of the microscope stage, this is within the limits of error of the present experiment and there is therefore no detectable departure from linearity of response in the photomultiplier.

References

JONES (J. M.), 1962. Econ. Geol., vol. 57, p. 42.
NICHOL (I.), 1962. Unpublished Ph.D. thesis, Durham.
—— and PHILLIPS (R.), 1965. Min. Mag., vol. 35, p. 200.