rectifiers, have a 4 mA and 12·5 kV capability. Due to the high-frequency operation mode, the capacitance required to filter the output is much reduced. With loads as low as 10 kΩ, 1 μF gives a smooth response. The voltage drop across the variable resistor R_F is used for current feedback. This resistor is a series of wirewound 10 kΩ resistors, one of which is a multiturn potentiometer to allow for small adjustments. A standard resistor connected in series with the transference cell supplies a voltage drop, which is read in a DVM, providing an accurate current measurement.

Figure 3 shows the control circuit diagram: A waveform generator, the RS305–804 (equivalent to 8038CC), is used to produce a stable sinewave output of 5 kHz, 1 V peak-to-peak. This signal is fed to an electronic attenuator, the MC3340, goes through an isolation stage and is then supplied to the power amplifier. A power driver, the ICL 8063† is used to drive the pair of output transistors, a 2N3055 and a 2N3789. The output of the power amplifier is fed to the step-up ferrite transformer, which supplies the high voltage side of the apparatus. The current feedback, after a buffer stage, is compared with a reference voltage derived from the temperature-compensated Zener 1N827. The amplified error signal controls the output of the sinewave going through the electronic attenuator.

3 Limiting factors and performance

As far as output capability is concerned, the current and voltage ratings can be changed using rectifiers, capacitors and transformers of suitable ratings. The output capability of the power amplifier used in the apparatus is about 50 W.

Some components in the circuit play an important role in keeping a highly stable current. The critical elements with respect to temperature and time drifts are the voltage reference Zener, the differential amplifier and associated resistors, and the current feedback resistors and buffer amplifier. The voltage reference diode, the 1N827, has a temperature coefficient of 0·001 %/°C. The current feedback and differential amplifier resistors are of the wirewound type having a temperature coefficient of 0·002 %/°C. The differential and buffer amplifiers use the low-cost 741, whose offset characteristics are reasonable for the purpose. Some improvement may be expected using very low-drift amplifiers such as the AD510 or AD517.

The system has been operating satisfactorily for several months, presenting a warming-up time of about 15 min and a current change of less than 0·1 %, when the load changes from 1 MΩ to 10 kΩ. In experiments lasting up to 12 h, the maximum overall drift observed did not exceed 0·015 %. The regulator described presents a low-cost solution, the total cost of components being around £100, for a high-voltage current regulator. With small modifications this type of circuit can satisfy different requirements.

References

Graeme J G 1973 *Applications of Operational Amplifiers: Third Generation Techniques* (New York: McGraw-Hill)

Gwyther J R 1972 A high voltage capability galvanostat *J. Phys. E: Sci. Instrum.* **5** 979

Lima M C P 1977 Transference number studies by the direct moving boundary method *PhD Thesis* University of London

Notley J M and Spiro M 1966 Transference numbers and conductances in formamide at 25°C *J. Phys. Chem.* **70** 1502–10

† Intersil, Inc., Cupertino, California.

J. Phys. E: Sci. Instrum., Vol. 13, 1980. Printed in Great Britain

Influence of position-sensitive detector discrete structure on accuracy of coordinates determination

M A Gruntman
Space Research Institute, Academy of Sciences, Profsojusnaja 88, 117810 Moscow, USSR

Received 5 March 1979, in final form 1 October 1979

Abstract The source of the error of coordinates determination for position-sensitive detector on microchannel plates is considered for the case of axisymmetric flux being detected. Simple procedure of the error evaluation is presented. Numerical examples show that error due to detector discrete structure may be significant.

The purpose of this work is to investigate the limiting accuracy of the intensity radial (angular) dependence $I(R)$ determination for the axisymmetric flux registered by a position-sensitive detector (PSD). Such characteristics are required for treating a number of problems, particularly in measurements of differential scattering cross-sections using electron, ion or neutral particle beams and gaseous targets (e.g. Wijnaendts van Resandt *et al* 1976). A PSD consisting of two microchannel plates (MCP) installed in tandem fashion was able to determine the coordinates of the centroid of the electron avalanche created by a detected particle (Kellog *et al* 1976). The centroid coordinates correspond to the centre of the first MCP channel the particle enters, regardless of the exact location of the entering point. The PSD can therefore determine only the coordinates of the centre of the first MCP channel which the particle enters but not those of the exact point of entrance. Such a discrete structure PSD differs from the ideal detector which establishes a one-to-one correspondence between the coordinates determined and those of the point where the particle enters the detector. The PSD spatial resolution is not expected to be better than the MCP channel radius r when a flux with arbitrary intensity distribution is detected, and this was observed in the measurements by Kellog *et al* (1976). However in the case of axisymmetric flux PSD will provide better spatial resolution because particles at a fixed distance R_0 from the axis are detected by a number of channels (figure 1). ϕ is the diameter of the channel and a the distance between the centres of the channels. It will be shown that even in the case of axisymmetric flux the limiting accuracy of $I(R)$ determination results from the PSD discrete structure.

MCP channels are known to be strictly fixed, forming a net of equilateral triangles (Washington *et al* 1971) (figure 1). The crucial point in the determination of the limits of accuracy is an assumption about the behaviour of the particles impinging on the space between the channels of the first MCP. In this connection it should be noted that not only are the MCP surfaces coated with metal but the channel walls themselves are metallised to a depth of the order of ϕ. This results in the elimination of the trapping potential exerted on secondary electrons. In the vicinity of the MCP surface an electric potential gradient is sometimes created to push out secondary electrons.

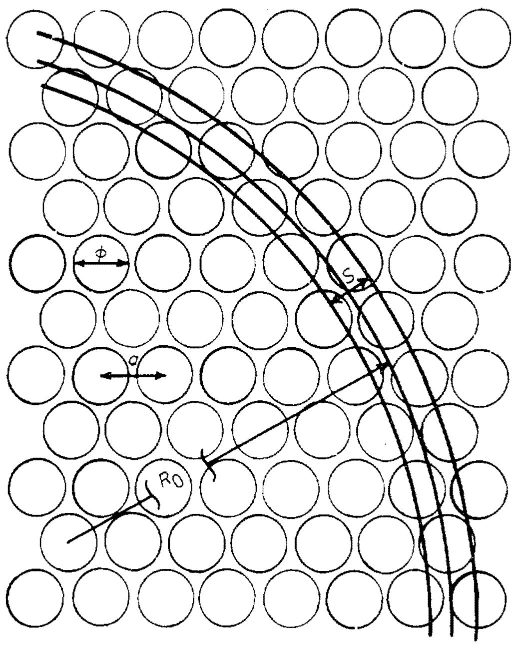

Figure 1 Geometry of microchannel plates.

For these reasons it is assumed that all particles impinging on the first MCP in the interchannel space are not detected.

Let us consider now the case when an infinitely thinan nular flux of radius R_0 is registered. The ideal detector output would be

$$I(R) = A\,.\,\delta(R - R_0)$$

where A is a constant and δ is the delta-function. The MCP has a definite structure but if the radius R is large enough $(R \gg \phi)$ the distribution of distances between the circumference of this radius and the centres of the channels crossing it may be regarded as uniform. If an infinite number of channels crosses such a circumference then for an infinite number of detected particles

$$I(R) = \begin{cases} C(1 - ((R - R_0)/r)^2)^{1/2}, & |R - R_0| < r \\ 0\quad, & |R - R_0| \geqslant r \end{cases}$$

where C is a constant. The mathematical expectation of R equals R_0 and the standard deviation $\sigma_0 = 0{\cdot}5\ r$. If the numbers of channels and detected particles are limited the mathematical expectation of R will differ from R_0 by a standard deviation

$$\sigma = \sigma_0(1/N_p + 1/N_c)^{1/2}$$

where N_p is the number of detected particles and N_c the number of channels crossing circumference of radius R_0.

In real measurements (Wijnaendts van Resandt, Champion and Los 1976) the variation range of R is divided into intervals. For simplicity they are assumed to be equal. The value of I in the point R is the number of particles coming into the interval from $R - S/2$ to $R + S/2$ (figure 1). Of special interest is the case with high radial resolution, i.e. $S < \phi$.

An ideal detector establishes a one-to-one correspondence between the determined cordinates and the entrance point. When uniform flux is registered, i.e. there exists a constant illumination of the ideal detector, the ratio of the intensity $I(R)$ (being equivalent to the number of particles coming into the annulus of width S) to this annulus radius $I(R)/R$ will be constant. For a discrete structure PSD the number of detected particles entering the annulus S (i.e. registered intensity $I^*(R)$)

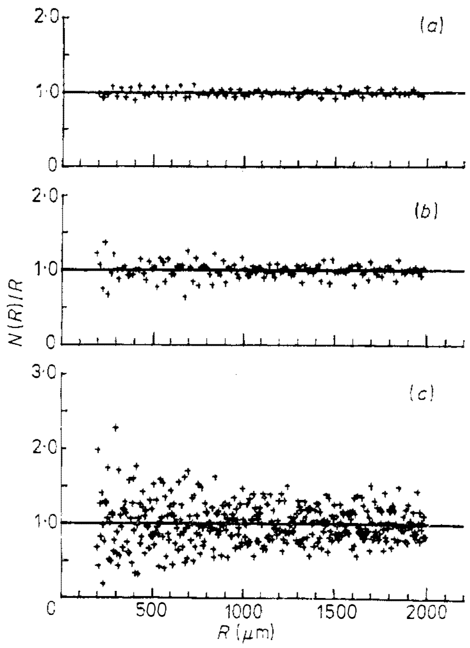

Figure 2 Computer-calculated normalised dependences of $N(R)/R$ on R for different values of S. (*a*) 25 μm, (*b*) 15 μm, (*c*) 5 μm.

is proportional to the number of channels $N(R)$ with their centres within this annulus. So, unlike an ideal detector, the ratio $I^*(R)/R$, being proportional to $N(R)/R$, is not constant and depends on R in a very non-systematic way. In figure 2 the computer-calculated normalised dependences $N(R)/R$ as a function of R are shown for different values of S, the centre of the circle of radius R being concentric with the centre of one of the MCP channels. The MCP characteristics are: $\phi = 25$ μm, $a = 29$ μm. Calculations were performed simply by counting the number of MCP channel centres situated at the annulus with a certain radius R, the net of MCP channels being first created in the computer memory. The scatter in the number of effectively acting channels $N(R)$ is the error source in $I(R)$ determination by the PSD method, the error being due only to the MCP discrete structure. The error may be determined by numerical evaluation of this scatter.

All calculations were performed for $R > 200$ μm. There would be a larger scatter in $N(R)$ for smaller values of R. With an increase of either R or S, as may be anticipated, the scatter decreases. The number of the channels with centres in the annulus of width S changes with the small displacement of axis of the flux to be detected, the radius R being fixed but the random behaviour of the dependences of figure 2 and the scatter remain the same. For this reason it is impossible to remove this scatter by calibration in real experiments. As an example, for an MCP with $\phi = 19$ μm, $S = 5$ μm and $R = 1$ mm, a flux axis displacement of only 2 μm may result in a 10% change in $N(R)$. Calculations performed show that when a PSD with discrete structure is used for axisymmetric flux detection an attempt to improve radial resolution gives rise to an increased error in determination of $I(R)$. This note describes a simple procedure for evaluation of the error due to the MCP discrete structure and gives the opportunity of using a PSD in a proper way, especially in choosing reasonable values of interval width S.

To conclude I would like to acknowledge Professor V B Leonas, Professor J Los and Dr A P Kalinin for fruitful discussions clarifying the problem.

References

Kellog B, Henry P, Murray S, van Speybroeck L and Bjorcholm P 1976 High-resolution imaging X-ray detector *Rev. Sci. Instrum.* **47** 282–90

Washington D, Duchenois V, Polaert R and Beesly R M 1971 Technology of channel plate manufacture *Acta Electronica* **14** 201–24

Wijnaendts van Resandt R W, Champion R L and Los J 1976 Diffraction effects in the differential scattering of Li^+ by rare gases *Chem. Phys.* **17** 297–302

Wijnaendts van Resandt R W, den Harink H C and Los J 1976 A position-dependent particle counter using microchannel plates *J. Phys. E: Sci. Instrum.* **9** 503–9

J. Phys. E: Sci. Instrum., Vol. 13, 1980. Printed in Great Britain

A water-wave height probe with calibration stabilised for changes in water conductivity

H Altmann
Royal Military College of Science, Shrivenham, Swindon, Wilts SN6 8LA, UK

Received 17 September 1979, in final form 21 November 1979

Abstract A twin-wire wave height probe with calibration stabilised for changes in water conductivity has been produced. A conductivity cell driven by a constant current signal is used to monitor the water conductivity. Use of the cell voltage as a signal source for the wave height probe eliminates the need for frequent probe calibration. Experimental verification proves the system to be extremely accurate.

1 Introduction

Wave height probes are frequently used to measure the surface condition in water channels, towing tanks and wave tanks. A number of probe designs are reported in the literature (Fryer and Thomas 1975, Sancholuz 1978). Of these the twin-wire resistance probe has found favour because of its ease of manufacture and good dynamic performance. Its application is, however, generally limited to fresh-water tanks where the water conductivity is quite low. In practice two parallel vertical wires are partly immersed in water and supplied with a constant voltage. If the depth of immersion is sufficiently large, the end effect will be negligible and the electrical conductance between the wires will be proportional to the depth of immersion and the water conductivity. Provided that the conductivity does not change, the electrical current flowing between the wires will be a measure of the water surface elevation. Problems such as nonlinearity from long supply cables have been solved by suitable feedback methods (Fryer and Thomas 1975). Polarisation around the wires is avoided by driving the probes with an AC signal, and unwanted common-mode signals are eliminated by driving the two wires with anti-phase signals and measuring the differential current between them.

One problem which still exists is the sensitivity of the probe to changes in water conductivity. The amplitude of the driving voltage is normally kept constant and changes in conductivity, due to impurities or temperature variations, then alter the probe current and upset the depth calibration. Frequent calibration of these probes is consequently required.

The solution to this problem lies in altering the driving voltage so that it varies in inverse proportion to the water conductivity. This is easily achieved by fitting a separate, fully submerged conductivity cell in the water tank and driving it with a constant-current AC signal. A change in water conductivity results in an inverse change in the voltage across the cell. This cell voltage, via a suitable high-input-impedance buffer, is used to drive the wave height probe. This may be illustrated as follows:

If V_p is the wave probe voltage, I_p the wave probe current, V_c the conductivity cell voltage, I_c the conductivity cell current, k the water conductivity and h the depth of wave probe immersion