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The precise use of proportional Counters over long periods of Time

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Introduction.

It is not necessary to labour the merits of a proportional counter in determining particle energy when that energy is small. If the energy dissipation is a few MeV the variance in the pulse height distribution due to intrinsic straggling in the ionisation yield is becoming comparable with that due to amplifier noise and so there is little point in using a proportional counter. But for energies below about 1 MeV gas amplification is essential if a precise estimate of particle energy is to be made.

The chief objection to the use of a proportional counter is its lack of stability. The gas amplification A is a more-or-less rapidly increasing function of the voltage V applied to the counter. Under good conditions when A is not too high it may require V to be increased by 200 volts or so in order to double it: but if A is to be pushed to its limit it may double in 20 volts or less. Now the straggle in ionisation produced by particles up to 1 MeV is a few tenths of a percent, so for work of the highest precision A should be held constant to this order. If we take as typical a doubling of A for a 70 volt increase in V, then a variation of V by $^1/_{10}$ volt (perhaps in 1000 volts) will give a $^1/_{10}\%$ change in A. Such voltage stabilisation is impossible to achieve over a period of hours and even if it were achieved the problem would not be solved: unless a proportional counter has been violently outgassed absorption and emission of gas by the walls causes A to drift quite considerably over long periods. Such behaviour is most strongly marked in counters containing pure noble gases, but even in the presence of polyatomic molecules the trouble remains to a lesser degree.

One cannot then attain the highest precision over long periods of time by using proportional counters in the conventional way.

It is the object of this paper to show how the desired precision may be attained by deriving control of the counter from within itself, and then to discuss the operation of the machine which has been developed to analyse the pulse distribution coming from the counter.

The principle of the method is to include permanently within the counter a group of α-particles such as that of polonium. It is then arranged by a feed-back mechanism between a discriminator and the voltage V that the voltage group emerging from the amplifier should always register in the same channel of the pulse amplitude analyser. In this way an over-all stabilisation of gas and electronic amplification is achieved: leaks in the counter and drifts in the amplifier are automatically compensated for, the stability of the whole arrangement remaining better than 1%. It will be seen that this stability depends essentially on the ratio of two resistances in the stabiliser proper and a resistance-capacity time constant in the pulse amplitude analyser: no voltages need to be highly stabilised anywhere in the system.

The stabiliser.

The stabiliser operates in the following way. The output from the amplifier is fed through two discriminators. One fires at x_1 and the other, which is not so important, fires at x_2 ($x_1 > x_2$ and it is only necessary that $x_1 - x_2$ should be bigger than the width of the α-particle group used for stabilisation). The discriminators are coupled so that the one firing at x_1 passes a pulse down channel A whenever it fires, and that firing at x_2 passes a pulse down channel B only when no pulse goes down channel A. Channels A and B feed into opposite sides of a flip-flop: one of the anodes of this flip-flop is directly coupled through a large resistance to the grid of a tetrode. The tetrode derives its anode voltage through a high resistance from an unstabilised high voltage line somewhat higher in voltage than the maximum which must be applied to the counter. The counter itself receives its voltage V from the anode of the tetrode. When a pulse passes down channel A the anode potential of the flip-flop rises and with it the grid potential of the tetrode. The current through the tetrode increases and so its anode voltage — the counter voltage V — falls. Similarly a pulse down channel B causes V to rise. A large condenser is connected from anode to grid of the tetrode and this exerts a damping effect on the changes of anode potential of the tetrode and makes them linear with time. So the voltage V applied to the counter is always either rising or falling at a constant rate. If the counter leaks, the gas amplification falls, more pulses pass down channel B instructing the counter volts to rise in compensation. Similarly an increase in electronic amplification or a hardening of the counter by the absorption of gas on the walls will cause an increase in pulse height, an excess of pulses in channel A and the counter volts will fall, rectifying the situation.

It is obviously of importance to know how efficient this stabiliser is going to be. It is clear that, if the whole set-up is perfect, then the use of the stabiliser is going to make the situation worse, introducing an extra variance into the pulse height distribution. One must know how great this variance is and how the situation is affected by a non-perfect set-up. We will follow through the argument assuming that the electronic amplifier is perfect — the generalisation to a non-perfect amplifier is immediate.

Suppose the differential relation

$$\delta A = k A \, \delta V$$

between A and V; suppose also that when the volts are instructed to change they do so at the rate c volts/sec. The variation of gas amplification due to leaks or something against which stabilisation is provided is given by the relation, for constant V

$$\delta A = - b A \, \delta t$$

We assume, to perform an approximate calculation, that the stabilising group of α-particles has width an amount ω either side of a mean centred at unity corresponding to a gas amplification A_0. Now in operation A will distribute itself about some mean value which will not be A_0 because c is finite. We assume a Gaussian distribution for the probability $p(A)\delta A$ that A should lie at any instant between A and $A + \delta A$.

Thus

$$p(A) = \frac{1}{\sigma \sqrt{2\pi}} \, e^{-\frac{(A-(A_0-\delta))^2}{2\sigma^2}}$$

and if the operation of the device is to be satisfactory we must have

$$\left(\frac{\sigma}{A_0}\right)^2 \ll \omega^2$$

the extra variance introduced by the device being small compared with that intrinsically present.

If now the stabilising particles arrive at the random rate N/sec. we find

$$\delta = \frac{A_0 b \omega}{k c}$$

$$\sigma^2 = \frac{A_0^2 \omega}{N k c} (k^2 c^2 - b^2)$$

The biggest extra variance comes when $b = 0$ when the above condition for satisfactory operation becomes

$$kc \ll \omega N$$

so with typical values $k = {}^1/_{100}$, $\omega = {}^1/_{100}$ and with $c = 1$ we have satisfactory operation with a counting rate from the stabilising particles of a few per second. If now, for example, the counter leaks so that, without the use of the stabiliser, A would halve itself every hour, $b \sim 10^{-4}$ and the group shifts by a fraction of its width given by

$$\frac{\delta}{A_0\,\omega} = \frac{b}{kc} = 2 \times 10^{-2}$$

a negligible effect. With $N = 10$/sec. the intrinsic variance is increased by 10%, again a negligible effect.

The particles in which we are really interested give pulses lying below x_2 and so do not disturb the action of the stabiliser. Their number may be as great or as small as is desired.

The pulse amplitude analyser.

The stabiliser described above may, of course, be used in conjunction with any form of pulse amplitude analyser, but in general will demand the stabilisation of a high voltage line: x_1 is defined through the junction of resistances, R_1 and R_2 feeding from a positive line of voltage V_1 to ground. Thus

$$x_1 = \frac{R_2}{R_1 + R_2} V_1$$

and the stability of the stabiliser itself is determined by V_1 as well as R_1/R_2. This is undesirable and is not necessary.

The analyser to be described is particularly suitable for use in conjunction with the stabiliser as it has itself a high degree of stability over long periods. It has ninety-nine channels and is simple to make, the number of valves being much less than the number of channels.

The principle is to convert the incoming pulse of a certain height in volts into a pulse of standard height whose length in time is proportional to the height of the input pulse. This time pulse then gates a continuously-running oscillator and so produces a number of pulses proportional to the height of the input pulse. These pulses are passed into two rings of ten in series. Thus if thirty-eight pulses are generated, the eighth valve of the "units" ring will be left in an extraordinary state and the third of the "tens" ring also. These valves cause two relays to close and the relays in turn operate the appropriate telephone message register. (The fact that the registration is made directly on message registers means that the analyser is slow. A blocking circuit is, however, incorporated in the input stage so that a high input pulse rate may be tolerated). It will be realised that the only portions of the machine which require a high degree of stabilisation are the oscillator and the unit which converts the input pulse into the time pulse. Now the oscillator frequency may easily be stabilised to better than 1% so occasions no worry. The converter unit operates by charging a condenser C to the peak value of the input pulse through a diode. When the input pulse has passed away the diode is cut off and the condenser C becomes the grid-to-anode condenser of an ordinary MILLER time-base pentode. The running down of this pentode is controlled by a high resistance R connected from the positive line at voltage V_2 to the grid side of C. Thus the anode runs down at the rate V_2/RC volts/sec. The stability of the height-time conversion is then seen to reside in the stability of V_2 and RC. It is found in practice that this stability is very good, being better than 1% over a period of some months. But now if the analyser and the stabiliser are working together the height of the stabilising group is $x_1 = \frac{R_2}{R_1 + R_2} V_1$ and so the corresponding time pulse is of duration $RC \frac{R_2}{R_1 + R_2} V_1/V_2$. If now the stabiliser and analyser share the same positive line $V_1 = V_2$ and the time pulse has a duration $RC \frac{R_2}{R_1 + R_2}$ dependent only on the time constant RC and the ratio R_1/R_2 as remarked earlier. So the stabilising group always registers in the same channel though no high degree of voltage stabilisation is provided anywhere in the apparatus.

In this way a proportional counter may be used as a precision instrument even at high gas amplification and over periods of weeks if necessary.