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Calibration of the Stabilisation Servo Equation for a Gas Microstrip Detector

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Abstract

It is demonstrated that two sets of simple measurements of the gain of a Gas Microstrip Detector (GMSD) are sufficient to generate a servo control function which can thereafter be used to stabilise the gain of a flow-gas counter against ambient (pressure and temperature) fluctuations, using either manual or automatic methods. Gain stabilisation to the level of 0.62% RMS is demonstrated.

1. Introduction

The operation of gas counters (and Gas Microstrip Detectors (GMSD) in particular) with flowing gas is required to prolong the detector lifetime when they are used in intense beams. It is also a pre-requisite when flexibility is required in the gas filling. Both these conditions are encountered in typical applications on Synchroton Radiation Source (SRS) beamlines such as various forms of EXAFS experiment [1,2,3]. The access of the counter volume to the atmosphere makes the gas density (and therefore the electron mean free path in the gas) dependent on the ambient conditions of pressure (*P*) and temperature (*T*) and this causes gain drifts of the order of 10% over typical ambient excursions. It has been shown elsewhere [4] that a simple model of the gain process in gas counters predicts that the gain is dependent on the variable *P/T* (*q*) making a simple servo relation possible which, in turn permits the gain to be stabilised by small adjustments in the detector bias potential (V_c).

The GMSD [5] is a gas counter formed by the etching of fine metallic tracks on a glass substrate. While it functions very well as a typical gas avalanche counter which can be accurately compensated for ambient variations [4] the temperature-dependent dark current drawn by the glass substrate can introduce a separate, powerful temperature sensitivity to the gain as a result of ohmic voltage drops in the EHT bias resistors. It is usually possible to make this effect negligible by suitable choice of the bias resistors. The analysis given in this report depends on this precaution having been taken.

2. The Mathematical Model

It has been shown elsewhere [4] that the gas gain of a GMSD can be represented accurately by the function:

$$\ln M = \frac{V_c}{A}\exp\left\{-\frac{\left(\alpha\frac{P}{T}+\beta\right)}{V_c}\right\} \qquad (1)$$

where V_c is the anode-cathode potential and A, α and β are constants for a given counter geometry and gas filling. The quantity *P/T* is usually represented by the variable *q*.

Equation (1) shows that M is a function of V_c and *q* so that an excursion in *M* is given by :

$$dM = \frac{\partial M}{\partial V_c}dV_c + \frac{\partial M}{\partial q}dq \qquad (2)$$

Since the term on the left of equation (1) is ln *M*, it is more appropriate to write (2) as:

$$\frac{dM}{M} = \frac{1}{M}\frac{\partial M}{\partial V_c}dV_c + \frac{1}{M}\frac{\partial M}{\partial q}dq \qquad (3)$$

The servo condition for using V_c to stabilise the changes in q is:

$$\frac{dM}{M} = 0 \qquad (4)$$

Or :

$$\frac{1}{M}\frac{\partial M}{\partial V_c} dV_c = -\frac{1}{M}\frac{\partial M}{\partial q} dq \qquad (5)$$

giving us the differential equation :

$$\frac{dV_c}{dq} = -\frac{\frac{1}{M}\frac{\partial M}{\partial q}}{\frac{1}{M}\frac{\partial M}{\partial V_c}} \qquad (6)$$

For convenience we write :

$$S = -\frac{\frac{1}{M}\frac{\partial M}{\partial q}}{\frac{1}{M}\frac{\partial M}{\partial V_c}} \qquad (7)$$

And so integrating equation (6) we get the servo relation :

$$V_c = V_0 + S(q - q_0) \qquad (8)$$

Where V_0 and q_0 are operating bias and ambient conditions to which we wish to servo the gain. This is a particularly simple (linear) correction function provided the function S is effectively constant over the range of V_c and q met with in practice. The following analysis shows that this is in fact the case and experiment confirms it also.

Differentiating equation (1) with respect to q gives :

$$\frac{1}{M}\frac{\partial M}{\partial q} = -\frac{\alpha}{V_c}\ln M \qquad (9)$$

and with respect to V_c gives :

$$\frac{1}{M}\frac{\partial M}{\partial V_c} = \ln M\left(\frac{1}{V_c} + \frac{(\alpha q + \beta)}{V_c^{\,2}}\right) \qquad (10)$$

Substituting relations (9) and (10) into (7) yields :

$$S = \frac{\alpha}{\left(1 + \frac{B}{V_c}\right)} \qquad (11)$$

where $B = \alpha q + \beta$. In order to evaluate S an actual case must be considered. Operating at a gas gain of M = 1080, the Wide Angle X-ray Scattering (WAXS) detector [6] (gas: 17% dimethylether (DME) in argon) has V_c = 500V and B = 174V. Since $B/V_c < 1$ the effect of changes in q and V_c are attenuated and, further, the sense of change of V_c in the servo process follows that of q (and therefore of B) so minimising any change in S throughout the parameter range required by the servo process.

Thus, the simple linear relation of equation (8) can be used to perform the stabilisation of the gain against the effect of changes in ambient conditions, using only a single constant S, which can be evaluated by a simple calibration (as described below) in conjunction with the single environmental variable q (P/T).

3. Calibration of the WAXS Detector

The WAXS detector is specially designed for Wide Angle X-ray Scattering experiments [6] with long (50mm) anode electrodes which point at the scattering sample. There are 256 active detector strips with a mean width of 0.45mm, each individually instrumented with readout electronics.

It has a considerable active area (approaching 100cm^2) which leads in turn to a large substrate dark current of several μA. In order to avoid this current dominating the temperature dependence of the gain it was found necessary to restrict the series resistance in the EHT feed to ≈200kΩ. The counter is operated with a gas mixture of argon plus 17% DME.

For the purposes of the calibration process eight detector strips are commoned and connected to a readout electronic chain consisting of an Ortec 142 charge preamplifier, Ortec 575A shaping amplifier (CR-RC shaping of 1μs) and an Ortec PC-based PHA with Maestro software. Charge (and hence gain) calibration was provided by an Ortec 480 precision pulser. The ambient pressure and temperature were measured by a Prosser Weathertrend digital barometer (1mbar resolution) and a digital thermometer (0.1C resolution). The detector was biased by an RAL type 344 EHT supply.

Mn (K_α,K_β) x-rays from a ^{55}Fe radioactive source are introduced into the active region of the eight strips via a small hole in the drift electrode of the detector. The centroid of a log-normal fit [7] to the x-ray peak in the PHA is used as a measure of the avalanche gain which is derived from the charge calibration using a mean energy per ion pair of 27eV for the conversion of the 5900eV of the x-ray into electrons in the gas.

In order to evaluate the key servo parameter *S* it is necessary to evaluate the two parameters $\frac{1}{M}\frac{\partial M}{\partial q}$ and $\frac{1}{M}\frac{\partial M}{\partial V_c}$ near the desired operating point q_0, V_0. The simplest way to do this is to note that if a fit of the form $M = a\ exp(bx)$ is made to any gain function *M(x)* then $\frac{1}{M}\frac{\partial M}{\partial x}$ is simply the parameter *b* in the exponential fit. In view of the approximate constancy of *S*, it is not necessary to be excessively precise about the reference values of the second variable in each data set. It is also clear that in measuring *b*, the units of the ordinate are immaterial and there is no need to calibrate the gain. However, when working directly in PHA channels it is important to ensure that any digital offset has been measured and removed from the peak channel data.

Figure 1 shows the gain as a function of *q* (measured over several days as the ambient conditions changed) with V_c = 500V.

Similarly figure 2 shows the gain versus V_c curve at q = 3.40mB/K.

The b parameters of the fits allow us to evaluate *S* = 0.767/0.0189 = 40.58VK/mB and a servo function of:

$$V_c = 490 + 40.58(q - 3.411)\text{V} \qquad (12)$$

Where q_0 is set arbitrarily to *P* = 1000mb and *T* = 20C.

Figure 3 shows how the counter gain (circles) is controlled against changes in the ambient variable (*q*) when this condition is applied. The RMS error on the mean gas gain of 754.56 is 4.64 giving a fractional error of 0.62%. This is achieved over a range of q corresponding to 986<*P*<1017mbar and 16.4<*T*<26.4C. The unstabilised gain (squares) at V_c=490V is also shown for comparison.

Figure 4 shows the same data plotted as a function of time over the period of three weeks which it took to acquire the data. The ambient variable *q* is also plotted .

4. The Errors

The measurement systems used in this work each contribute their own error to the calibration process. It is useful to briefly check the magnitudes of these contributions so that any outstandingly large error can be identified and corrected. In the ideal case all the errors should be comparable in magnitude.

- Measurement of *P* and *T*: The errors (approximate standard deviations) in *P* and *T* are 0.5mbar and 0.05C. At 1000mbar and 20C this causes a 0.053% error in *q*. As will be seen this is negligible compared to most other errors. However, there is an unseen (and unquantifiable) error in possible lags and offsets between the thermometer temperature and that of the gas within the counter. It is difficult to ensure that the counter gas is in thermal equilibrium with the containment vessel, to which the thermometer is usually attached.

Different barometers regularly display systematic variations in absolute sensitivity. This is not important for present purposes provided the same device is used for both the calibration and servo measurements since we are working over a restricted pressure range. The resistive pressure drop in the gas outlet pipe can introduce an offset in the pressure in the counter relative to the measured ambient pressure, which is flow dependent. To avoid this it is important to keep the flow rates low and any small bore waste pipe as short as possible.

- Electronic Chain Stability: The electronic chain: preamplifier, amplifier and PHA is subject to temperature drifts (in gain and pedestal) which are not negligible over the 10C temperature range experienced in the laboratory. During the calibration period, PHA spectra were collected of the precision pulser set at values of 10^5 and $2x10^5$ electrons. Normal curves were fitted to the PHA peaks and the centroid values plotted against the ambient temperature. A shift of ≈-1channel was observed over the temperature range 16C to 26C. A formal calibration procedure revealed a temperature coefficient: *1/M dM/dT* of $3.53x10^{-4}$/C for the x-ray peak at 20C. Over the 10C range this gives an error of ≈0.18% (S.D.).

- EHT Stability: The gain of any GMSD is a sensitive function of V_c. Figure 2 shows that in the present case $1/MdM/dV_c$ is 1.9%/V. The temperature coefficient of the EHT divider chain sets a limit to the stability of V_c. In the present case we estimate that the error in V_c over the 10C operating range is of the order of 0.1V, leading to an error in the x-ray peak pulse height of 0.19%.

- Evaluation of *S*: The key to the calibration process is the evaluation of *S*. This process automatically incorporates all the measurement errors discussed above, and as figure 1 shows, the precision of the measurement of *1/MdM/dq* is relatively poor (0.0674/0.767 = 8.8%). The measurement of $1/MdM/dV_c$ is on the other hand much better ($1.47x10^{-4}$/0.0189 = 0.778%). Using the above equations appropriately, one can show that an error δS in *S* results in a finite slope in the plot of gain versus q with a coefficient:

$$\langle \frac{1}{M}\frac{dM}{dq} \rangle = \frac{1}{M}\frac{dM}{dq}\frac{\delta S}{S}. \quad (13)$$

Inserting the measured values: *1/MdM/dq* = 0.767 and $\delta S/S$ = 0.088 gives <*1/MdM/dq*> = 0.0674. Fitting an exponential function to the stabilised gain versus *q* (figure 3) gives <*1/MdM/dq*> (*b*) = 0.086. This value is comparable with the estimate from equation (13) showing that the systematic error in *S* from the calibration process is the most likely source of the non-stochastic error in the stabilised gas gain.

Removal of the systematic slope from the stabilised gain data in figure 3 results in a residual stochastic error of 3.71/754.6 = 0.49%. Since the quantifiable temperature-dependent errors discussed above sum to ≈0.3%, we can conclude that the unquantifiable errors due to temperature and pressure lags and other long term effects such as the stability of the gas mixing rig contribute a comparable error.

5. Conclusions

It has been shown that two simple measurements, a plot of the peak channel of an x-ray line against the ambient variable q at the chosen operating anode-cathode potential (V_0) and a plot of the peak channel versus V_c near the desired reference value of q (q_0) produce the necessary slope parameter (S) for the gain stabilising servo equation (8). When the servo equation is used to bias the GMSD using the current value of q, the result is long-term stabilisation of the GMSD gain to a level of order 0.62%RMS while the unstabilised gain fluctuates between +7.4% and –4.6% of the stabilised value.

While the stabilised gain shows a small residual dependence on q, the remaining errors are chiefly stochastic, as figure 3 shows. As noted above, the small slope of the stabilised gain in figure 3 is almost certainly due to the measurement error in S. Correction of this by longer term monitoring would leave only random errors, implying that no single part of the control loop is dominant and that the random contribution to the error of 3.71 in 754.6 or 0.49% represents the ultimate level of gain stability achievable with this technology. Fortunately, this is adequate for all foreseen applications of GMSDs.

Work is in hand to design a hardware system which will automatically adjust V_c according to the servo equation and so remove the need for manual setting of the EHT.

References

1. A.D. Smith, J.E. Bateman, G.E. Derbyshire, D.M. Duxbury, J.D. Lipp, E.J. Spill, R. Stephenson, Nucl. Instr. and Method **A 467-468** (2001) 1136-1139

2. J.E. Bateman, G.E. Derbyshire, E. Dudzik, G. van der Laan, J.D. Lipp, A.D. Smith and R. Stephenson, J. Synchrotron Rad. (2001), **8**, 1157-1161

3. T.R. Rayment, S.L.M. Schroeder, G.D. Moggridge, J.E. Bateman, G.E. Derbyshire, and R. Stephenson, Rev. Sci. Instr. (2000) **71**, 3640-3645

4. J.E. Bateman, Rutherford Appleton Laboratory report: RAL-TR-1998-044

5. A. Oed, Nucl. Instr. and Method **A 263** (1988) 351-359

6. J.E. Bateman, J.F. Connolly, G.E. Derbyshire, D.M. Duxbury, J. Lipp, J.A. Mir, R. Stephenson, J.E. Simmons, E.J. Spill, B.R. Dobson, R.C. Farrow, W.I. Helsby, R. Mutikainen and I. Suni, Rutherford Appleton Laboratory report, RAL-TR-1998-073, to be published in Nucl. Instr. and Method A.

7. J.E. Bateman, Rutherford Appleton Laboratory report, RAL-TR-2000-023, submitted to Nucl. Instr. and Method A.

Figure Captions

1. A plot of the gas gain as estimated from the peak channel of the PHA distribution of the 5.9keV x-ray line from ^{55}Fe in the WAXS detector as a function of the ambient variable q.

2. A plot of the gas gain of the WAXS detector as a function of the cathode bias potential (anode at earth) at an ambient point near the desired reference point q_0 (P = 1000mB, T = 20C).

3. A plot of gas gain of the detector as estimated from the peak channel of the PHA distribution of the 5.9keV x-ray line from ^{55}Fe as a function of the ambient variable q (squares) with the same parameter (circles) when V_c is controlled by the servo relation, $-V_c = 490 + 40.58(q-3.411)$V.

4. A plot of the unstabilised gain,the stabilised gain and the ambient variable q over a period of three weeks.

FIGURE 1

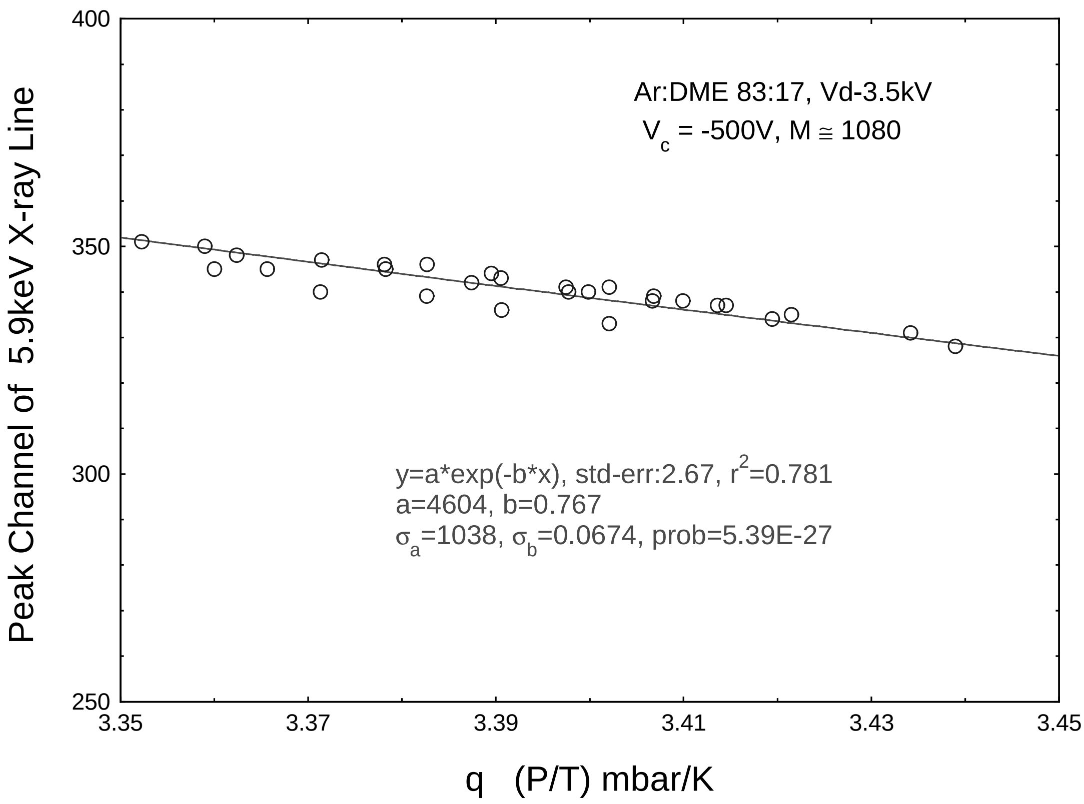

FIGURE 2

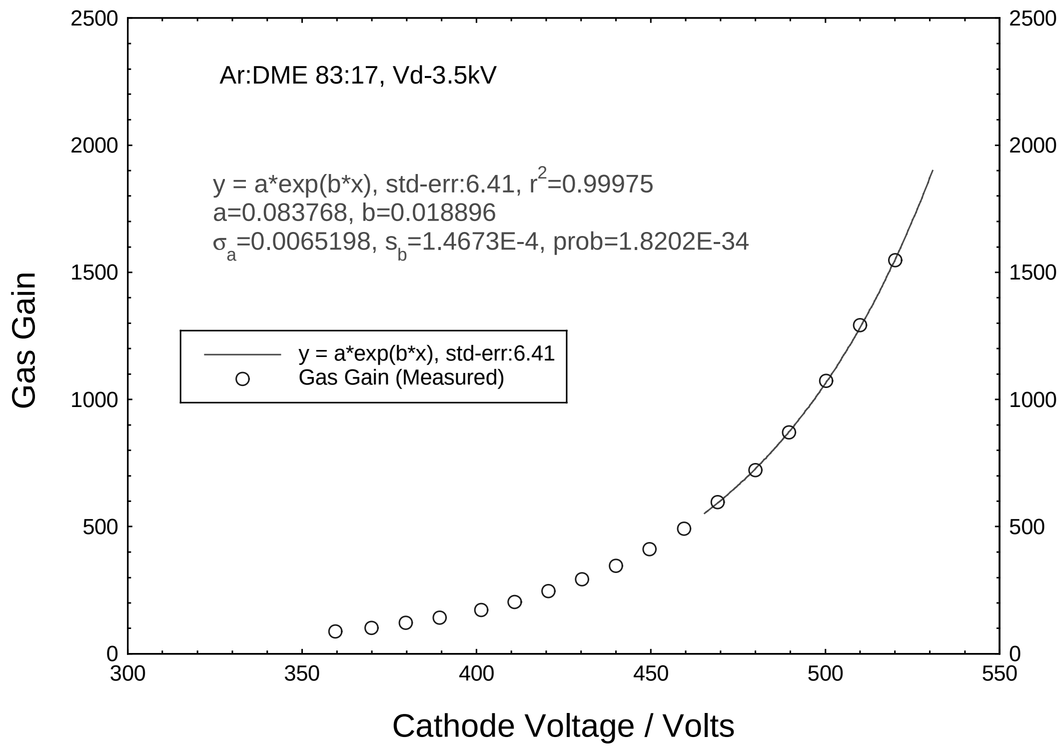

FIGURE 3

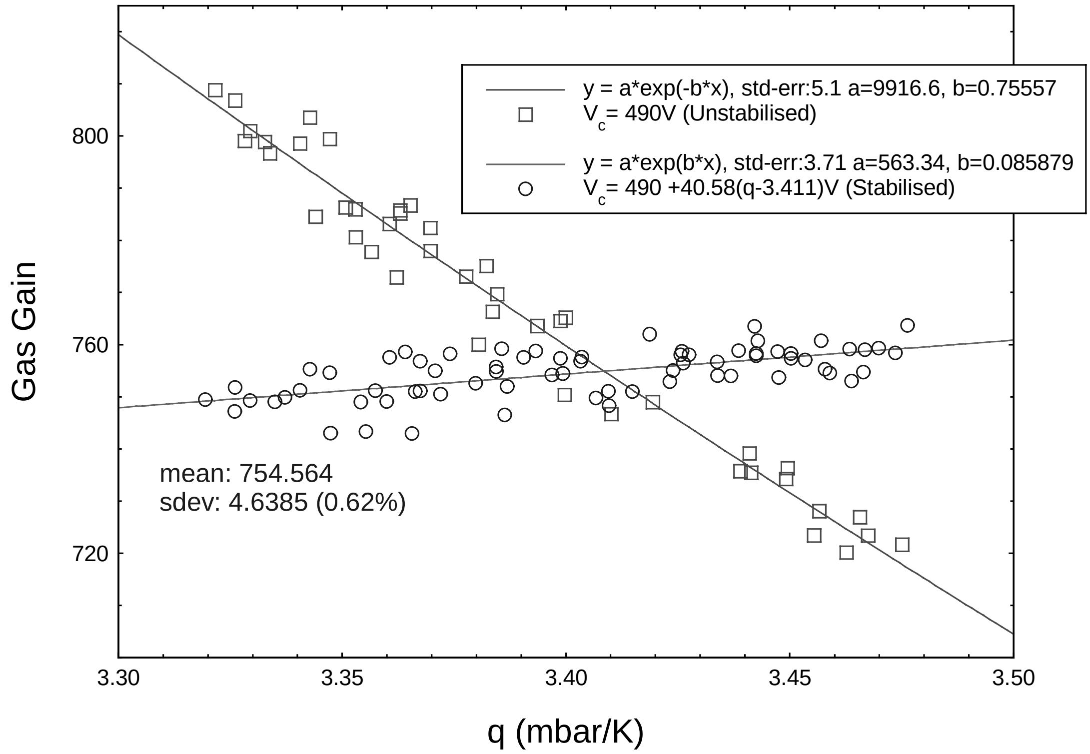

FIGURE 4