‘Stutter timing’ for charge decay time measurement

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Abstract. The paper describes the approach of ‘stutter timing’ that has been developed to
improve the accuracy of measuring charge decay times in the presence of noise in compact and
portable charge decay test instrumentation. The approach involves starting and stopping the
timing clock as the noisy signal rises above and falls below the target threshold voltage level.

1. Introduction
Assessment of the ability of materials to dissipate electrostatic charge requires measurement of the
time for surface potentials to fall from an initial level to an end point level. The initial level is to be
either the maximum initial peak voltage achieved by the charging action or, in the case of corona
charging, may better be chosen to be a set time after the end of charging [1,2]. A delay, for example
0.1s, will mirror the time taken in tribocharging situations for the contacting surfaces to separate and
for the surface voltages created to develop electric fields that will influence items nearby. The end
point voltage level is set to be a defined fraction of the initial voltage – and the values of 1/e (37%)
and/or 10% are recommended [1,2,3].

Surface voltages in charge decay studies are preferably measured, without contact, by a ‘field mill’
type of electrostatic fieldmeter [4]. The fieldmeter signal inevitably includes some noise. This may
involve oscillatory components, related to the chopping frequency, and also quasi-random
components. Noise will affect the accuracy with which decay times can be measured. The problem
only becomes significant when dealing with materials having very long charge decay times, where the
rate of decay may slow up significantly during the progress of charge decay, and where surface
voltages are low so that signal to noise ratios are less than desirable – for instance where a high
capacitance for surface charge depresses the surface voltage to a low level.

If, for example, the noise on the fieldmeter signal has a peak amplitude of N (volts) and the
average rate of decay of surface voltage around the timing point is dV/dt (V s⁻¹) then if timing is
judged simply by the signal’s first crossing of the set voltage threshold, the end of timing will occur
too early by a time T(s):

\[ T = \frac{N}{dV/dt} \]  

(1)
In general, charge decay curves do not follow an exponential form but slow up progressively as decay proceeds. Where the rate of decay almost plateaus out towards the set threshold level, where \( \frac{dV}{dt} \) become very small, the measurement of decay time by first crossing of a target threshold level will be strongly affected by noise.

This paper is concerned with the technique of ‘stutter timing’ that was developed to overcome the problem of real time measurement of decay times in low power, self-contained, portable charge decay instrumentation suitable for use in industrial environments.

2. ‘Stutter timing’

The basic technique of ‘stutter timing’ is for the timing clock, with a suitably short basic time step, to be started and stopped repetitively as the fieldmeter analogue source signal passes below and back above the selected target voltage level until it no longer traverses this level. The accumulated clock time shows the effective time at which the voltage level was crossed. The approach is a sort of simulation of manual drawing of a ‘best fit’ line through data points.

Figures 1 and 2 show spreadsheet modelling of noisy charge decay curves and the influence of noise on the measurement of decay time. The basic decay curve for both figures used a charge decay curve form that slows up progressively with time during the progress of decay [5]. The decay curve modelled had an initial peak voltage of 100V, an initial decay time constant of 0.03s, and a rate of increase in local decay time constant with time of 2s per second. The time to 10% of the initial peak voltage was then 1.5s. The random noise added was based on a maximum peak-peak voltage of 4V. Decay curves were calculated on a spreadsheet with time steps of 0.01s.

Figure 1 shows the basic decay curve and this same curve with added noise. It shows the accumulation of time until 10% of the initial peak voltage is reached for both the smooth basic curve and for the curve with added noise until the first crossing of the 10% level. With this level of random noise the end of timing, to the first transition across the target voltage threshold, occurs around 30% too early. Equation 1, above, would suggest the end of timing would be about 0.4s too early - from the value of \( \frac{dV}{dt} \) at the threshold level which may be compared the observed 0.45s.

Figure 2 shows the same noisy decay curve as Figure 1 but with ‘stutter timing’ used to measure the decay time. The top trace shows the timing clock starting and stopping as the signal varies above and below the 10% target threshold. Calculated decay times from various tests with different random number sequences for the noise, were within 3.5% too long.

3. Applications to practical charge decay measurement

Noise levels on fieldmeter signals have two main components: first, basic noise from operation of the fieldmeter sensing system, associated preamplifier circuits and any cross talk interference signals; second, noise arising from inadequate filtering of the signals after phase sensitive detection. Noise arising from digitisation of fieldmeter signals also needs to be minimised.

The output signal from phase sensitive detection includes noise mainly at twice the source signal chopping frequency. Filtering to reduce this level of noise to a suitably small fraction of the r.m.s. output signal level needs to be chosen to avoid prejudicing the response to fast changes in the source electric field signal.

For good identification of the initial peak surface voltage the response time of the fieldmeter needs to be much shorter than the time for opening the fieldmeter view of the test surface during removal of the plate carrying the corona charging electrodes. In practical charge decay instruments (for instance JCI 155 instruments) the opening time is 15-20ms so the fieldmeter response time needs to be 5ms or less [1,2,3]. This requires a fairly high chopping frequency in the fieldmeter, for instance around 2kHz. Careful design of the output signal filtering is needed to maintain good response to the initial peak voltage signal together with good rejection of phase sensitive detection noise. Care is also needed to minimise swashplating of the field mill rotor assembly.

Two facilities can be used to improve signal to noise ratios with digital signal processing:

a) the fieldmeter output can be simultaneously recorded by digitisation at several accurately related
levels of sensitivity. The observations used in calculation of surface voltage at any time are then those from the highest sensitivity range that is not in saturation. This will give best use of the ADC resolution available.

b) the effective noise can be usefully reduced in the processing of digitised signals by averaging larger and larger numbers of data points during the progress of charge decay. This enables a fast response to be offered for short decay times with progressively reduced influence of noise as charge decay proceeds.

Stutter timing’ has been used in the processing of fieldmeter signals as follows:

1) **Initial peak:** The initial peak is determined as the maximum median (or the average) of 4 successive fieldmeter readings. The peak signal is observed as a competition between the fieldmeter reaching maximum sensitivity, as the plate is fully retracted, and the decay of already deposited charge. The ‘time zero’ and the value of the ‘initial peak voltage’ are taken 2ms after occurrence of this peak. After choosing the initial peak voltage value the time zero can be calculated with better accuracy by stutter timing after the relevant range of readings has been collected.

2) **Delayed start voltage:** The surface voltage a set time after end of charging (so corona charge decay observations match those after tribocharging [2,3]) is initially determined as the average of 2 readings before and 2 readings after that time. Time zero may then be more accurately calculated by stutter timing calculations as for the ‘Initial peak’.

3) **End of decay timing:** The end of decay time, to a set % of the initial voltage, is determined by stutter timing by starting and stopping of the timing clock as the signal and noise fall through the end point voltage level.

Application of the above approaches for decay time measurement in practical charge decay measuring instrumentation (for instance JCI 155v5 and JCI 155v6 instruments) has shown that surprisingly good performance is achieved – even with quite noisy signals and slow rates of charge decay.

An important feature of this timing method when applied to instruments using processors with limited speed and program size is that it is easy to write compact code, needing no floating point arithmetic, and using a state machine concept to allow stutter timing to several different levels “simultaneously”. There is no problem about a seamless transition between processing the initial fast changing part of a charge decay effectively offline, and the slower part of the decay when readings are taken less frequently and can be processed in available processor time as soon as the data is stored, i.e. effectively online. The method is self-optimising for different levels of noise.

It will be noted that if the noise peak level meets or exceeds the surface voltage level at which stutter timing is performed, the timing will in theory never stop. For this reason the method will not work on decay curves swamped with noise around the end of timing target level. It is not easy to determine what method could work in such a case – except perhaps off-line curve matching.

4. **Conclusions**

A method ‘stutter timing’ for measuring charge decay times has been described. This technique provides significantly better accuracy of decay time measurement in the presence of real signal noise than is achieved with measurement of decay time by first crossing of a target threshold level. The accuracy of decay time measurement may not be as high as can be achieved with curve fitting during post-processing of charge decay curve data, but it is a simple approach that provides real-time decay time measurement in low power, self-contained, portable charge decay instrumentation used to satisfy industrial test requirements for the electrostatic suitability of materials.

**References:**

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Figure 1: Model of decay timing to first crossing of target voltage threshold at 10V (10% of initial peak voltage of 100V) is 1.5s. First crossing of threshold by noise signal occurs 30% too early.

Figure 2: Model of decay timing with ‘stutter timing’.