SIGNAL PROCESSING FOR CHARGE DECAY MEASUREMENT

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Abstract: The paper describes the approach of 'stutter timing' that has been developed to improve the accuracy of measuring the 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 level.

Keywords: electrostatic assessment of materials; stutter timing; corona charge decay; electrostatic measurement

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 be chosen to be a set time after the end of charging [1,2]. The delay chosen (for example 0.1s) aims to mirror the time taken in tribocharging situations for the contacting surfaces to separate and for the surface voltages created to create electric fields that have influence on 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].

Surface voltages in charge decay studies are preferably measured, without contact, by a 'field mill' type of electrostatic fieldmeter. Such instruments provide the ability to make reliable measurements for charge decay times from below 0.05s to many days [3]. Induction probe instruments may be useful for decay times up to perhaps several tens of seconds, but their operation may be prejudiced by the influence of residual air ionisation.

The signals of fieldmeter measuring surface voltage inevitably include some noise. This noise may have oscillatory components relating to the chopping frequency and also quasi-random components. Noise will affect the accuracy with which decay times can be measured. The problem may not seem likely to be too significant where signals have large signal to noise ratios and decay times are short and/or good precision is not expected. However, they do become significant where signal to noise ratios are not as high as desirable and, in particular, when dealing with materials having very long charge decay times and where the rate of decay slows up significantly during the progress of charge decay.

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 first crossing of the signal across the set voltage threshold, the end of timing will occur too early by a time T(s):

$$T = N/(dV/dt) \qquad (1)$$

For example, with a decay time constant of 10^4s at around the timing point and a noise peak level of say 2V, the measured time will be judged too early by about 200s at a surface voltage of 100V.

In general, charge decay curves do not follow an exponential form but slow up progressively as decay proceeds. The form of the early part of decay curves is not predictable at present but the form of the tail has been found to be more predictable [4]. Where the rate of decay almost plateaus around the end of timing voltage level the approach to the end point may be very gentle and measurement of decay time by first crossing of a target threshold level will be strongly affected by noise.

Where charge decay curves can be input to an external microcomputer the above problem of noise affecting decay time measurement can be overcome by the use of curve fitting software. This is not so easy if the form of the curve is not known. This paper is concerned with the technique of ‘stutter timing’ that has been 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. Within these requirements it is not practical to expect to use fancy curve fitting software. The method of timing described is simple and can be applied with analogue signal processing as well as with digital processing of fieldmeter signals. For timing analogue signals this is achieved by starting and stopping the accumulation of clock pulses.

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 curves for both figures were based on a charge decay curve form that slows up progressively with time during the progress of decay. This general practical experience [4]. The basic decay curve used involved an initial peak voltage of 100V, a initial decay time constant of 0.03s, a rate of increase in local decay time constant with time of 2s per second and a time to 10% of 1.5s. The random noise added was based on a maximum peak voltage of 2V. The decay curves were calculated with time steps of 0.01s.

Figure 1 shows the basic decay curve and this curve with added noise. It shows the accumulation of time until 10% of the initial peak voltage is reached for the smooth basic curve and until the first crossing of the 10% level is achieved for the curve with added noise. With this level of random noise the end of timing, from the first transition across the target voltage threshold, the decay time ends around 20% too early. The analysis giving equation 1 above would expect the end of timing might be 0.66s too early instead of the observed about 0.45s. The difference is mainly due to the rate of change in the local decay time constant just before the threshold target is reached.

Figure 2 shows the same 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. In this instance the decay time measured was about 3.5% too long.

The error in decay time measurement depends, with both first crossing of a threshold and with stutter timing, on the phasing of the rate of decay and the noise signal pattern. The error is very much smaller with stutter timing.

Figure 3 shows an example of an actual decay curve voltage decay curve with Figure 4 showing detail of the same decay curve around the end of timing point and real fluctuation with time of a digitised fieldmeter signal. For this particular decay curve the end of timing by first crossing of the target voltage threshold would have occurred about 0.05s earlier than the time reported by stutter timing (a difference of about 2.6%). This error is small because the voltage level at the end of timing is quite large so the signal to noise ratio is quite good.

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. 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, where the plate carrying corona discharge points is removed in about 20ms, the response time of the fieldmeter needs to be 5ms or less [1,2]. This requires a fairly high chopping frequency, for instance around 2kHz, which may be achieved using a multi bladed chopper and a high motor speed. Careful design of the output signal filtering (for example using Salen and Key filter circuits) 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 in the design and construction of the fieldmeter to keep variations of signals at low multiples of the chopper rotation time (for instance due to swashplating and similar irregularities) to a suitably low level.

Where fieldmeter signals are transferred into a computer for software analysis the signals are sampled by an analogue to digital converter (ADC). The bit resolution of the conversion adds an additional source of noise to the sampled signals. For low digitization noise an ADC with at least 10 bit resolution is needed. A point to be borne in mind is the avoidance of beating between the chopping frequency and the frequency of taking ADC samples.

As illustrated in Figure 1, the output signal level dependent noise puts a limit on the precision of decay time measurement when timing measurements are determined simply by first crossing of a set voltage threshold level.

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

a) the fieldmeter output can be simultaneously recorded at several accurately related levels of sensitivity – the least sensitive determined by the maximum surface voltage likely to arise in use of the instrument. 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 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 decay time gets longer. This averaging can easily be done ‘on the fly’ – which provides the added advantage of reducing the number of readings recorded and hence the data storage space required.

Stutter timing’ can be used in the digital processing of fieldmeter signals as follows:

1) **Initial peak:** The initial peak voltage is determined as the maximum of the median or average of 4 successive fieldmeter readings. Time zero for the start of decay timing is taken as 2ms after occurrence of this peak. This is a deliberate choice. The peak occurs as a competition between the fast rising signal as the plate carrying the corona charging electrodes completes its movement to open the test aperture to full fieldmeter view and the signal variation that is just the decay part of the curve. The voltage level at this time is the average of 2 readings before and two reading after that time.
   The time zero at this start of decay timing can be calculated with better accuracy by stutter timing in signal processing after the relevant range of readings has been collected
2) **Delayed start voltage:** the surface voltage a set time after end of charging is

initially determined as the average of 2 readings before and 2 readings after that time.
The time zero for decay timing may be more accurately calculated (as for the ‘Initial peak’) by stutter timing calculations after the relevant data has been collected.

3) **End of decay timing:** The end of point time is determined by stutter timing as the time obtained with the starting and stopping of the timing clock as the signal and noise fall through the target voltage level.

Application of the above approaches to control noise in practical charge decay measuring instrumentation has shown that surprisingly good performance is achieved – even with quite noisy signals and slow rates of charge decay. An example of stutter timing on a practical charge decay curve is shown in Figures 3 and 4.

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 level on 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. Curve fitting could be used [4] but this would require appreciable computational effort.

4. CONCLUSIONS

A method for measuring charge decay times by a technique of ‘stutter timing’ 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 by stutter timing may not be as good as can be achieved with curve fitting during post-processing of charge decay curve data. It is however simple and can provide real time decay time measurement in low power, self-contained, portable charge decay instrumentation suitable for use in industrial environments.

References:

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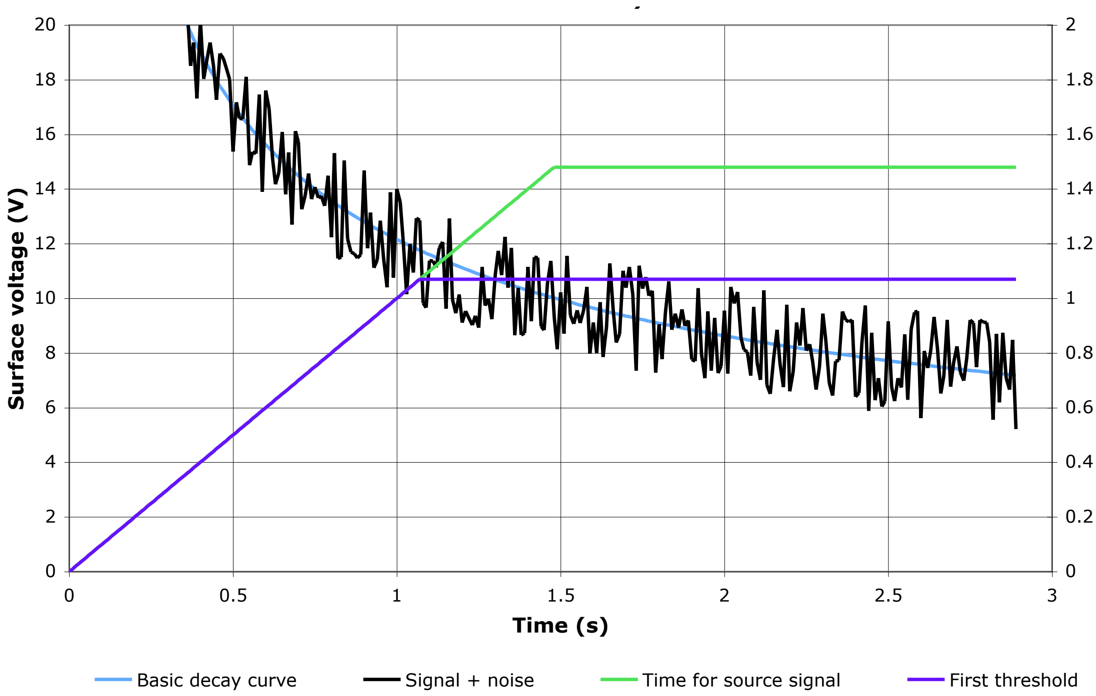

Figure 1: Model of decay timing to initial crossing of target voltage threshold. Decay from an initial peak voltage of 100V with a 2V peak superimposed random noise signal. Local decay time constant increasing with time and with added random noise. Decay to 10% of source signal is 1.5. First crossing of threshold occurs 26% too early.

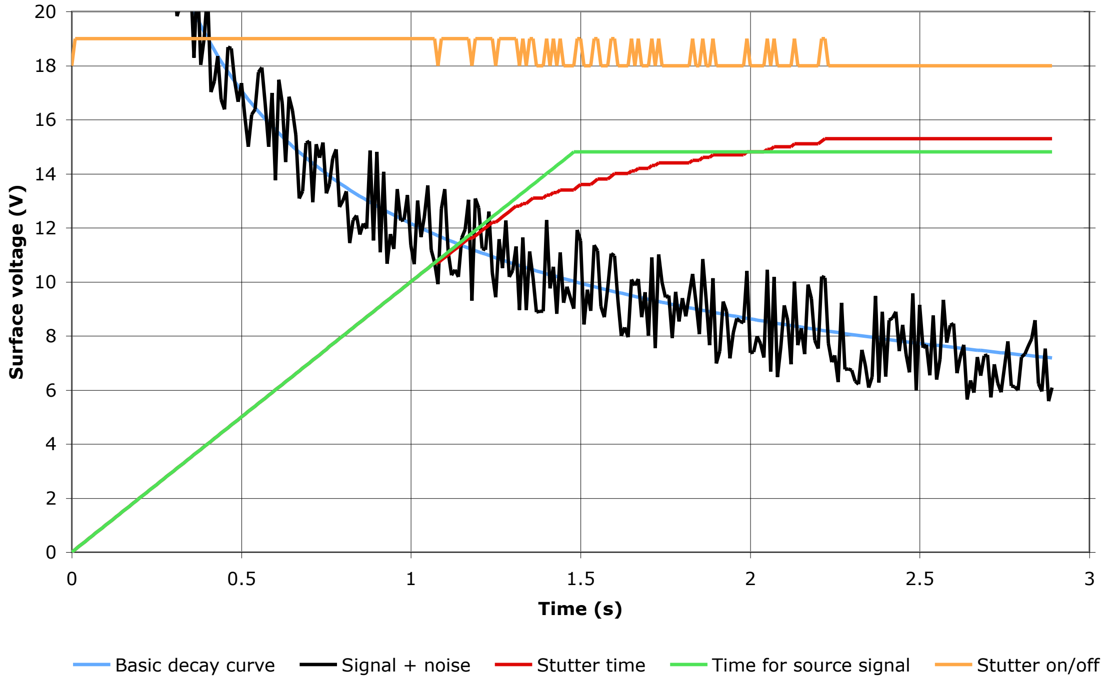

Figure 2: Model of decay timing to target voltage threshold with 'stutter timing'. Decay from an initial peak voltage of 100V with a 2V peak superimposed random noise signal. Local decay time constant increasing with time. Decay to 10% of source signal is 1.5. Decay time by 'stutter timing' is about 3.5% too long.

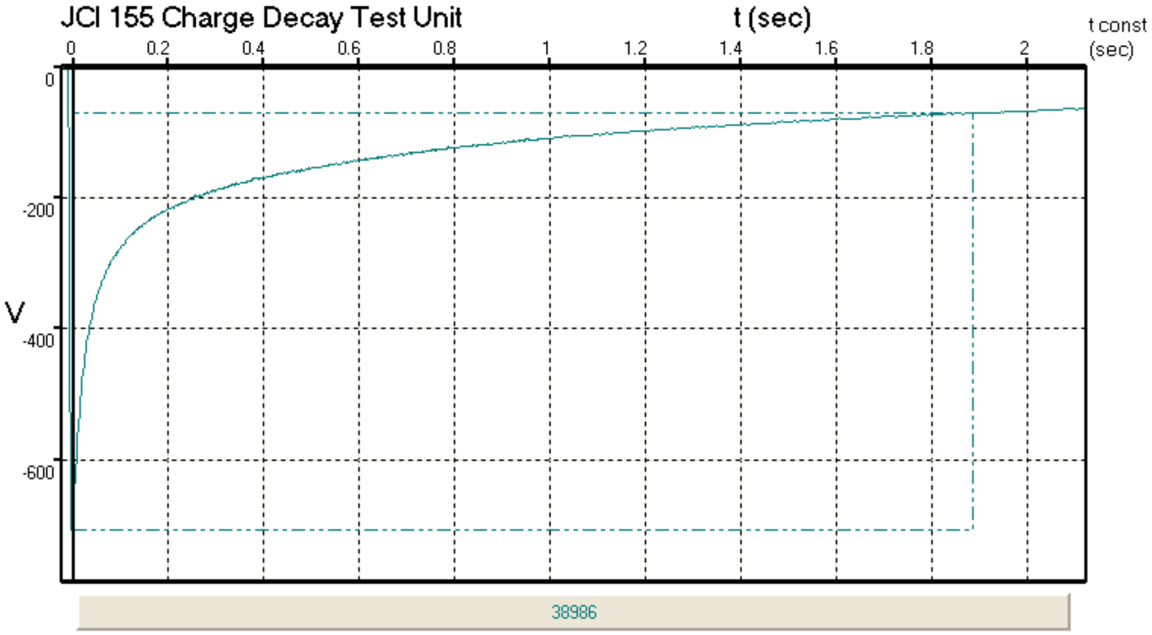

Figure 3: Example of practical charge decay curve showing of rate of decay slowing up during the progress of decay as the local decay time constant increases.

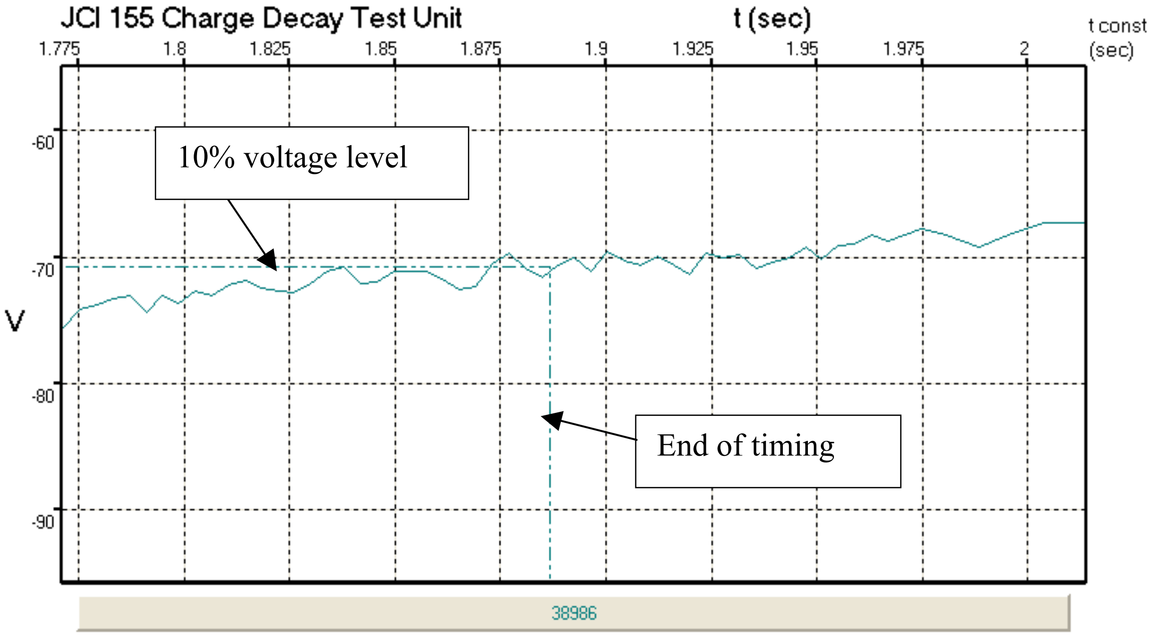

Figure 4: Detail of decay curve in Figure 2 around end of timing point