

INSTRUMENTATION FOR LONG TERM CONTINUOUS MEASUREMENT OF GROUND LEVEL ATMOSPHERIC ELECTRIC FIELDS

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Abstract:

The paper describes practical aspects of instrumentation for long term monitoring of atmospheric electric fields. Particular features discussed include the separation gaps needed between sensing surface components, the use of charge sensitive amplifiers to minimise the influence of water over insulation surfaces, avoidance of the need for earthing of the rotating chopper and the use of continuous ‘operational health’ monitoring to confirm continuity of measurement performance. Comments are included on features for simultaneous and separate observation of atmospheric and power line electric fields and on the use and interpretation of pole mounted fieldmeters.

1. INTRODUCTION

Rotating chopper (‘field mill’) type electrostatic fieldmeters provide a simple and direct way to measure electric fields. They can offer wide dynamic range, stable sensitivity, good signal to noise ratio and fast response [1,2]. They also offer immunity to charge flow in the local atmosphere [1,2]. With appropriate design and construction they can operate and make reliable measurements in adverse environmental conditions – for example in the presence of rain, dust and dirt [3,4].

The aim of this paper is to outline some of the features of the instrumentation that has been developed over the years for measuring electric fields in adverse conditions [3]. In particular this capability has found application in measurement of atmospheric electric fields with confidence in the values measured and in the immunity to environmental conditions as needed for long term continuous observations [4,5].

2. BASIC APPROACHES

There are two main ways available to use electrostatic fieldmeters for direct measurement of atmospheric electric fields: a fieldmeter mounted with its sensing aperture flush with a large plane conducting surface at ground level or a fieldmeter mounted at the top of a pole.

The ground level fieldmeter appears to be a simple arrangement but has two main drawbacks:

- the fieldmeter structure needs mounting under a large plane surface at the level of the surrounding ground. This presents problems with hard, rocky and uneven ground.
- the fieldmeter is exposed to wind blown surface dust and dirt and to a variety of insects.

The pole mounting arrangement uses an earthed fieldmeter as a probe of the local potential [6]. This way of using a fieldmeter as a probe of local potential has been used extensively in studies of potential distributions in the cargo tanks of large crude oil tankers during tank washing operation [6,7]. The presence of the earthed fieldmeter perturbs the overall potential distribution locally around its structure and creates an electric field which, at

the end of the probe, creates an electric field directly proportional to the potential that was at the tip of the probe before it was introduced. The electric field at the fieldmeter sensing aperture is close to: $E = V/d$ – where V is the local potential and d its diameter. This sensitivity for measurement of local potential can easily be checked by applying a potential to the fieldmeter and its mounting structure to achieve zero electric field at the fieldmeter sensing aperture. Atmospheric electric field values are then derived from the values of local potential, derived from electric field measurements, and the height of the fieldmeter sensing aperture above ground. This arrangement provides good immunity to ground level dust, dirt and insects, is easier to mount and is less influenced by local unevenness of the ground surface.

3. INSTRUMENT DESIGN FEATURES

Design features for ‘field mill’ type electrostatic fieldmeters suitable for long term continuous measurements have been described [1,2,3]. A particular design that has been developed and used for many years in JCI instruments has avoided the need for earthing of the rotating chopper. This is basically to have two fieldmeter sensing systems mounted on a common insulated drive. One assembly observes signals arising solely from the influence of charge on the combined rotor assembly, the other observes the combination of this signal and the influence of the external electric field. Appropriate subtraction between these signals provides a difference signal independent of any charge present on the rotor assembly. The main advantage this offers in the present context is long operational life - by avoiding wear of an earthing brush. Operational life is limited by the life of the motor bearings.

Immunity to rain, dust, dirt and insects requires that separation gaps between all active surfaces in the fieldmeter sensing region are more than 5mm. (The 5mm separation requirement arises from the gap needed to avoid water bridging between horizontal surfaces). There is also the requirement that insulators mounting the sensing surfaces have good long tracking paths and that the motor and all the electronic signal processing circuits cannot be accessed by moisture. Figure 1 shows the arrangement of the rotor assembly and the sensing surfaces and Figure 2 shows an overview of the JCI 131 fieldmeter with the cover removed to show the mounting of the circuit boards. To accommodate the surface separation gaps needed and provide good sensitivity and stability the overall outside diameter of the JCI 131 is about 100mm.

It is advantageous that measurement of the signals from the sensing surfaces are made using virtual earth charge measurement circuits. This minimizes the risk of degradation of signals by charge leakage across the insulators mounting the sensing surfaces because the sensing surfaces remain at earth potential.

For reliable and stable sensitivity it is important that the geometry of the chopper and sensing surfaces remains constant. In particular this requires that the chopper drive arrangement achieves rotation with no end float. In the JCI 131 fieldmeter this is achieved by mounting the chopper assembly on a high quality rigid insulator tube (alumina or machinable glass) directly from the shaft of an electronically commutated motor with bearings that are spring loaded to take out all end float.

If measurements of atmospheric electric fields are to be made in the presence of power line alternating electric fields it is important that the chopping frequency is chosen and controlled to avoid low frequency beating that would pass through output stage filtering. A chopping frequency of 275Hz is chosen for the JCI 131 fieldmeter as appropriately between the fifth and sixth harmonic of 50Hz power line frequencies and between the fourth and fifth harmonics of 60Hz frequencies.

In any practical measurement system exposed to adverse environmental conditions there is always the question of how one can be sure the signals observed are a true reflection of the electrostatic conditions measured. This problem was first tackled with fieldmeters built for

measuring electrostatic conditions during washing of the cargo tanks of large crude oil tankers with high pressure water jets [6]. In development of the JCI 501 Lightning Warning System [5] a system was included that enabled the ‘operational health’ of the fieldmeter (and also the radio observations) to be continuously monitored and reported. The system was based on modulation of the voltage of the whole fieldmeter system by a 50V p-p quasi-square wave signal. The signal was not a true square wave in that the rise and fall times were made long enough to avoid generation of signals that would interfere with the low frequency end of the 2-200kHz radio observations. The 50V voltage swing modulated the observed electric field signal and the amplitude of modulation was compared to the level expected to indicate the level of the operational health. The operational health is thus equivalent to a continuous measurement of the fieldmeter sensitivity. This system demonstrated its worth during pre-installation testing when a 30% reduction in the operational health signal was found to be due to a spider’s web across the sensing aperture! More recently a facility has been developed using an additional shield mounted around the earthed casing of the JCI 131 fieldmeter sensing head. The arrangement is shown in Figure 3. The shield is driven by a sinewave voltage source withing the sensing head relative to earth at a frequency that is phase locked to the chopper rotation signal. The amplitude of the sine wave is automatically switched between 2.2V, 22V and 220V r.m.s. according to the operating range of sensitivity of the fieldmeter. Observations of both the amplitude of the drive signal and the related signal through the fieldmeter and comparison to the values expected show the operational health status and help identify the nature of any diminution in performance. The levels of the health drive signal can be expected to remain very stable with time, unless there is serious contamination of the shield mounting. The health signal may vary by a few % in normal operation. This variation may well be due to rainwater droplets on the primary sensing surface changing the effective spacing between the electrodes slightly.

Particular anxiety in long term operation can be felt regarding the entry of insects into the sensing region. Pole mounting reduces the risk, but does not eliminate it. Experience with a JCI 131 that had operated on Benbecula (in the Outer Hebrides) for several months was that even though there was a thick layer (perhaps 20mm deep) of midges in the base of the sensing region the performance and sensitivity were unaffected. Even if these had become wet and bridged the lengths of the insulators supporting the sensing surfaces the influence can be expected to be negligible because of the use of virtual earth charge sensing amplifiers keeps the voltages on the connections at zero. Careful design of instruments can allow the casing around the sensing region to be removed for inspection and internal cleaning without changing the operational performance.

4. INTERPRETATION OF OBSERVATIONS

Atmospheric electric field E_a may be measured using the fieldmeter mounted on a support tube at a mounting height, h (m), with the fieldmeter earthed - as shown in Figure 3. In this mode the fieldmeter is operating as a potential probe [6,8]. The atmospheric electric field $E_a = V/h$ - where V is the local voltage (kV) and h the height (m) above ground level. The sensitivity of a fieldmeter mounted well clear of nearby surfaces is close to $V = E_f d$ - where E_f is the fieldmeter reading ($kV m^{-1}$) and d the effective sensing head diameter (m). Hence the ambient electric field is obtained from measurement of the electric field at the fieldmeter sensing aperture as:

$$E_a = E_f d / h$$

There will be a contribution to the electric field measured dependent on the alignment of the sensing aperture relative to the ambient electric field. If for example the two field

components are in directions to add (e.g. the fieldmeter looks upwards on the top of the mounting pole), then the atmospheric field can be derived as:

$$E_a = E_f d / (h (1-d/h))$$

As d/h is normally small (typically 0.05) this effect is small.

Ideally the fieldmeter should be pole mounted within a large-scale area of flat ground and well clear of any buildings or earthy projections. This may not be feasible in practice. In this case it will be necessary to interpret electric field measurements in relation to the geometric arrangement of the surroundings. This can be done with computer modelling calculations - but this is not easy and may lack conviction in complex three dimensional arrangements. One approach to tackle this problem is to normalize readings in relation to short term measurements of ambient atmospheric electric field values made in an area that is flat over a large area and is nearby. Such normalizing measurements may conveniently be made using a handheld fieldmeter (for instance a JCI 140 Static Monitor) held at arm's length above the head. It will be best to match observations between the two instruments at the same time in clear blue sky conditions and with the reference site not too far away.

The concept of using a fieldmeter to measure the difference in potential between the instrument and its local surroundings provides an appropriate basis for measuring atmospheric electric fields at altitude – for example with balloon borne instrumentation. The approach here would be to have sensors spaced vertically apart with a common zero volt line. The local atmospheric electric field would then be the difference in local potential divided by the vertical separation distance.

5. OPERATIONAL EXPERIENCE

Experience from operation of a good number of instruments has been very good. Instruments installed on St Kilda have operated for over 10 years with the only maintenance needed being replacement of drive motors because the motor bearings had failed! A JCI 504 Lightning Warning System (that includes a JCI 131 fieldmeter) operated for many months at home in Cheltenham showed no problems while operating during periods of very heavy rain.

An example of signal variations (from operation of the JCI 504 system) is shown in Figure 4. It will be noted that the variations of electric field during bursts of heavy rain can be on quite a short timescale. These are genuine variations of electric field – and are not affected by any current flows to the fieldmeter that may be associated with air ions or charged rain drops. This is because signals from such currents are in quadrature to the electric field induced charge signals and so eliminated in phase sensitive detection [1,2].

6. CONCLUSIONS

Electrostatic fieldmeter instruments can provide the capability for long term continuous measurement of atmospheric electric fields at ground level. Features are described that enable reliable measurements to be made even through periods of heavy rain and with good immunity to dust, dirt and insects. In particular reference is made to the operational health facility that has been developed to ensure continuing confidence in measurement performance.

References:

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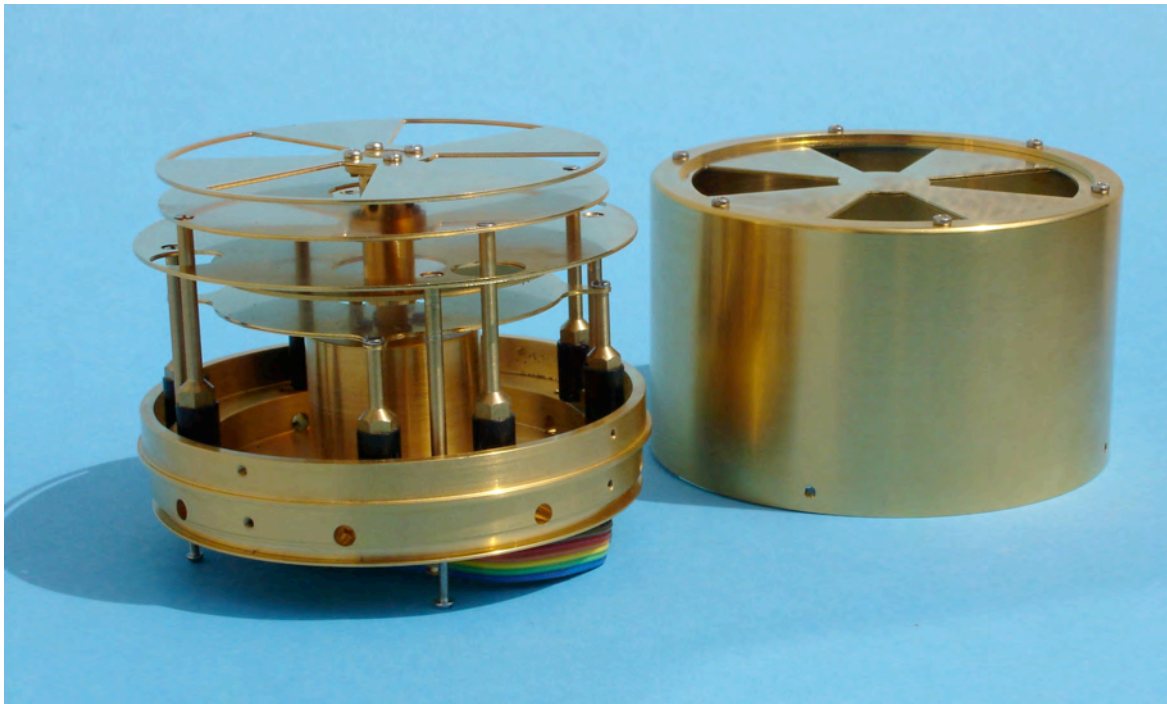


Figure 1: Rotor and sensing surface assembly and outer cover with sectored sensing aperture of JCI 131 fieldmeter



Figure 2: Assembly of JCI 131 fieldmeter - with rear casing removed to show mounting of fieldmeter, operational health and power supply circuit boards



Figure 3: JCI 131 fieldmeter on mounting pole with operational health shield fitted

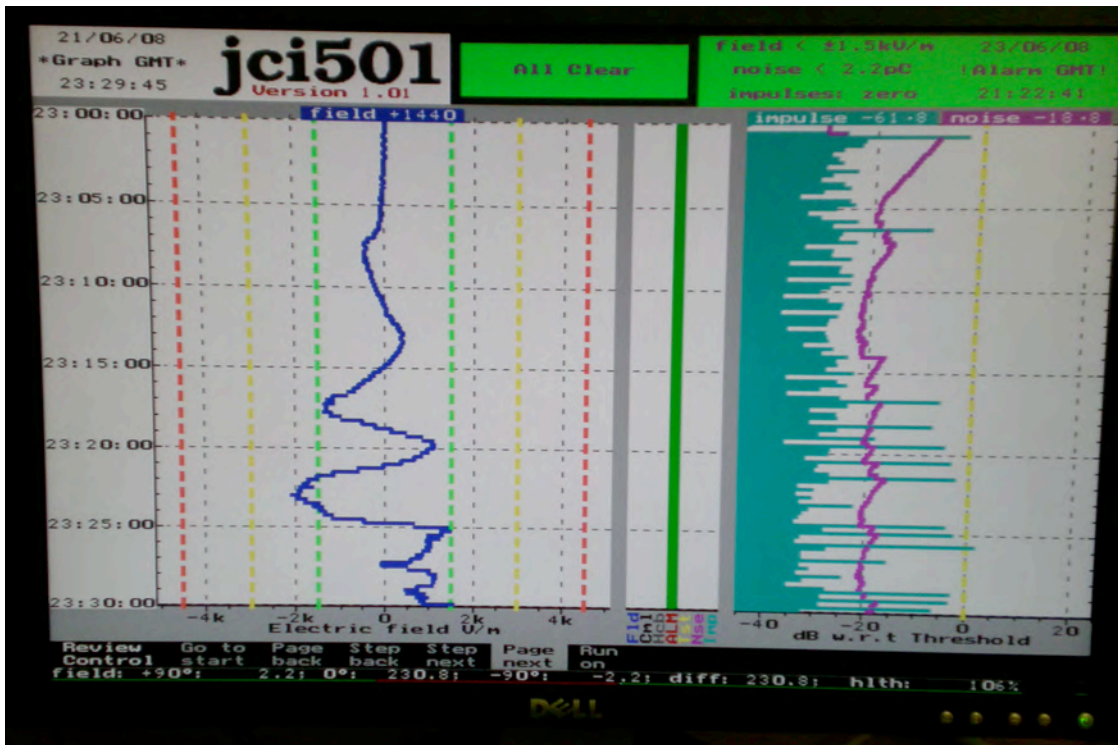


Figure 4: Example of electric field variations during a period of bursts of heavy rain observed with a JCI 504 Lightning Warning System