ON THE MEASUREMENT OF STATIONARY ELECTRIC FIELDS IN AIR

Harold Kirkham

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91109

Abstract

Applications and measurement methods for field measurements are reviewed. Recent developments using optical technology are examined. The various methods are compared. It is concluded that the best general purpose instrument is the isolated cylindrical field mill, but MEMS technology could furnish better instruments in the future.

Historical Review

The atmospheric electric field has been studied for centuries. As instruments have improved beyond a key on a string, measurements have been made both near the ground and at altitude in the study of weather in general, as well as of weather phenomena such as lightning storms. There is evidence that dust devils have electric fields [1] as do volcanoes [2]. Electric fields affect the way falling snow lands [3]. The sun is a prodigious source of ions; the charging of spacecraft in earth orbit is one result.

In addition to these natural effects, there are technologies that depend on understanding and controlling electric fields: insulation systems for dc lines are an example. Semiconductor fabrication and assembly rely on the avoidance of electrostatic discharge (ESD). Power lines are associated with both electric and magnetic fields. It has been alleged that there are health effects caused by one or both fields.

The measurement of stationary or slowly varying electric fields is thus widely important.

Measurement Methods

The first successful device for measuring atmospheric fields was the field mill. In the example shown in Figure 1, the field induces a charge on the upper surfaces of the device. Because the sensing electrode is alternately exposed to and shielded from this charge, an alternating current flows in the output circuit.

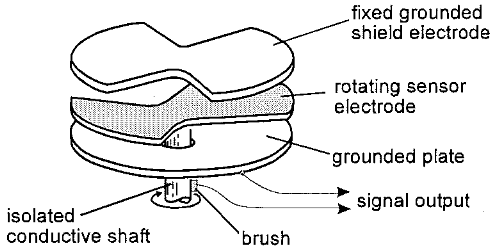

Figure 1. The basic field mill

The magnitude of the current is related to the charge (and hence the field) as well as the speed of rotation. No information is available about the direction of the field, which is forced to be normal to the instrument since it is conducting.

Miniature versions of this instrument have been made for ESD work. Here the interest is in the *voltage* producing the field. Although it responds to the field in air, the meter is calibrated to read voltage, on the assumption that it is being held a certain distance from a charged object.

A variation of this method is the vibrating plate field meter. In this instrument, the external field induces a charge on the upper surfaces, as before, but now the capacitances between the electrodes are changing, as the central plate is moved up and down. A feedback mechanism is used to drive the output signal toward zero – the feedback is then a measure of the induced charge, ie, the field.

Yet another design is the cylindrical mill, where rotation of the device (usually about a horizontal axis) gives rise to a current between electrodes.

The Langmuir probe is essentially a voltage measuring device that works by measuring the potential between two points coupled by ion sources to the atmosphere. It is the only approach based on a direct voltage measurement. It finds application on spinning spacecraft during the launch phase, and is of use in high altitude work.

Recent developments

An optically isolated version of the cylindrical field mill was developed at the Jet Propulsion Laboratory in the late 1980s as part of an effort by the US DOE to understand health effects of power lines [4]. A cutaway view is shown in Figure 2.

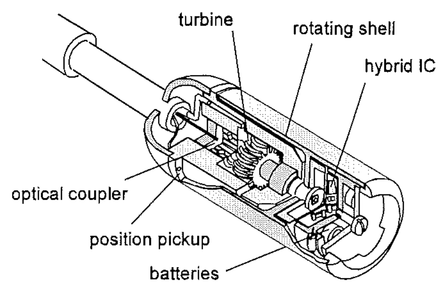

Figure 2. JPL's isolated field mill

One problem with the isolated probe approach is the difficulty of providing adequate isolation. The solution implemented at JPL was to add a small radioactive source to the probe. Provided the support structure was reasonably high resistance (>10^{10} Ω, say), the leakage current would be supplied by the space charge created, and the probe would be maintained at the local space potential.

A synchronous detector was used to resolve the field into components in two orthogonal directions, making this the first field meter to provide direction information.

A non-rotating probe was made by Cecelja, Bordovsky and Balachandran [5]. These workers used the Pockels effect in $LiNbO_3$ because the crystal has a relaxation time of several months, and it was felt that rotation would not be necessary.

A new measurement method may be enabled by micro-electro-mechanical systems technology (MEMS). A design for a vibrating plate meter might be only a few mm on a side is shown in Figure 3.

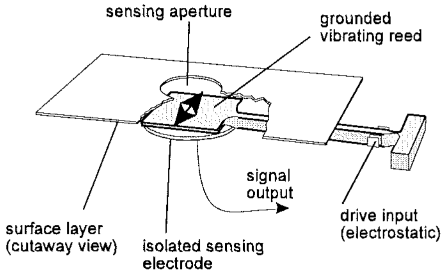

Figure 3. Possible MEMS vibrating plate field mill

Assessment of the methods

In our discussion so far, the effect of ion current has been neglected. In most ordinary atmospheric conditions there will be some ions present; in some situations there will be many. The ions drift down the field lines under the influence of the field and the wind.

This ion current produces a reading in a grounded mill. To distinguish the effect of current from the effect of the field, a double mill can be used [6], though the apparatus tends to be large and cumbersome. Alternatively, the *isolated* field mill solves the problem of ion current. Ions impinge on the probe only until it is charged to the extent that field lines no longer terminate on it.

The cylindrical mill will not read the self-charge, as it is symmetrically distributed about the axis of rotation. There will be no error in the reading unless the probe is quite near to a grounded conductor.

Other meter types, if grounded, will respond to ion current. If isolated, they will read self-charge.

For example, the non-rotating crystal approach is rendered useless by ions. The scale factor can change by up to a factor of 10 depending on the number and polarity of the ions.

ESD instruments are compact, but would require re-calibration for use as field instrumentation. It may even be possible to adapt such a meter for battery operation, and to isolate it. The field vector could be obtained with 3 such mills.

The MEMs approach is untried at present. A sphere, say 5 or 10 cm in diameter, with MEMS sensors embedded in the surface, may be capable of responding both to dc and relatively broadband ac fields (up to a few hundred Hz). While the sphere itself could be isolated, the sensors would still respond to self charge. However, by having sensors in pairs on opposite sides of the sphere, it should be possible to calculate the self charge, and remove its contribution to the measured field.

Conclusions

If the full vector field must be measured, an isolated cylindrical mill has the advantage that ions have no effect on the reading. Unless there is some known symmetry (as in a power line), two mills are needed, since an on axis field is not measurable.

Even if the field direction can be assumed, if the instrument is grounded attention must be paid to the effect of ions.

The isolated non-rotating crystal approach has problems in the presence of ions.

The isolated cylindrical mill is probably the best general purpose instrument at present.

The best hope for future field instrumentation may be a MEMS-studded sphere.

References

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Acknowledgments

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