ON THE MILL TYPE ELECTRIC FIELD METER

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Summary

A mill type electric field meter with high time response has been constructed to measure the electric field change due to lightning discharge. Alternating voltage proportional to the field is produced by the mill consisted of sixty inductive electrodes and a rotary disc. The voltage is amplified and then fed into three recorders. These are a camera system to photograph the field change displayed by cathode-ray-tube, a magnetic tape recorder, and an ink writing ammeter. It has been found that the meter has two major defects which seem to be inevitabe to this type of field meters. The first of them is the reduction of sensitivity when the meter is used in the natural electric field as compared with that when it is calibrated in artificial electric field, and the second is the surplus voltage from the field mill when it is shielded from the field.

I. Introduction.

A mill type field meter has been constructed to measure the electrostatic field change accompanied by a lightning discharge. Although the meter of this type has already been reported by many other investigators[1], the one described in the paper has been subjected to some improvements that it can operate with high time response and give the simultaneous recordings in three ways.

The principle of the field meter is as follows. When the electrode earthed through a resistor is repeatedly exposed to electric field and then shielded from it, the alternating voltage proportional to the field is produced on the resistor. The voltage, amplified then, is recorded in three ways.

It has been confirmed through the experiment that the meter has three defects which seem to be fatal to this type of field meter.

II. Construction of the meter.

The construction of the meter is shown in Fig. 1. The alternating voltage proportional to electric field is produced by the field mill. After amplification of the voltage, it is fed into three parts of the recorder system. The first of them is a cathode-ray-tube with a circuit operating it, the second is a magnetic tape recorder, and the third a synchronous rectifier connected to an ink writing d. c. ammeter.

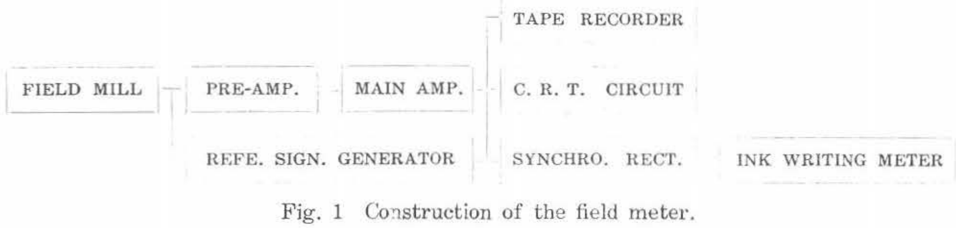


Fig. 1 Construction of the field meter.

III. The field mill.

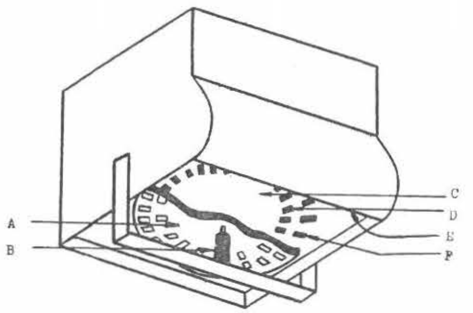


Fig. 2 Construction of the field mill.
(A) Rotary disc
(B) Mercury pool
(C) Ebonite plate
(D) Reference electrode
(E) Intake of air stream
(F) Inductive electrode

The construction of the field mill is shown in Fig. 2. Two groups of brass electrodes, each consisting of sixty pieces, are ranged in two cocentric circles on an ebonite plate. The inner group produces the reference signal to the synchronous rectifier and the outer one the alternating voltage proportional to the field. Electrodes in each group are connected into one with a copper wire inside the ebonite plate. The earthed metal disc rotating on these electodes has two groups of holes, each of which is ranged in a cocentric circle. The outer holes correspond with the outer electrodes and the inner holes with every other inner electrode. Hereafter we shall term the inner group reference electrodes, and the outer group inductive electrodes to avoid ambiguity. As the frequency of alternating voltage produced on the inductive electrodes determines the time response of the meter, the highest possible frequency is recommended. The increase of frequency, however, results in the increase of the electrode number, which means the increase in the disc diameter, and in the rotary speed of it. As a result, the mechanical vibration of the mill will increase. This must be avoided for the sake of stable recordings, and the attainable frequency is limited by the reasons. The disc diameter of the mill is 36 cm and the rotary speed is 3000 r. p. m. at 50 c/s power mains and 3600 r. p. m. at 60 s/c. The inductive electrodes are earthed through a 200 kΩ resistor, and the capacity between the earth and the electrodes is 220 pF when it is exposed to the electric field by rotary disc, and 320 pF in shielded state. As the theory on the mechanism of the mill has already been described by many investigators[1)2)], it will not be discussed in the paper. In constructing the mill, it is important to take precautions against the mechanical vibration of it as well as the electrical disturbances in it. The vibration of electrodes produces the noise voltage, and in some case, this makes it impossible to measure the electric field. After the electrodes are fixed with screws to the ebonite plate, they are further fixed with insulating paint. The ebonite plate is fixed through rubber cushions onto a steel fame. Through this technique, the noise voltage caused by the vibration has been reduced to a negligible degree.

The motor continuously driven usually for a long time is cooled with air stream produced by motion of disc. In the preliminary stage of experiment, the rotary disc was earthed by contacting earthed metal brush with the motor shaft that is connected with the rotary disc. This method was not suited for a long run operation, as it was impossible to drive the meter for a long time owing to the wear of the metal brush. To improve this point a brass needle fixed to the lower end of the motor shaft has been dipped in earthed mercury pool. Since the improvement, the meter has been operated without any trouble.

Several points concerning the performance of the mill shall be described. If the mill is shielded from the electric field, the alternating voltage must theoretically be expected to reduce to zero. In actuality, however, some voltage appears in this case in spite of the zero condition of the field, and the output value of the mill reaches 10^{-4} V. The sense of this voltage is always identical to that of the voltage produced by positive field. We have found through some qualitative experiments the following facts which seem to explain the phenomenon.

1. There is no direct correlation between the surplus voltage and the atmospheric moisture, but when water drops are sprinkled on the surface of the mill, the decrease of the voltage is observed.
2. If the surface of the mill is covered with parafine or dust, an increase of the voltage results.
3. Although a metal disc with no perforation is fixed on the rotary disc and rotated together, the voltoge does not disappear again, but if the latter disc is removed, and only the former is rotated above electrodes, then the voltage does not appear contrary to the previous case.
4. The voltage is independent of the rotary speed of the disc.

It is obvious from these facts that the surplus voltage is concerned with the boundary surface phenomena of the mill and with the rotation of perforated rotary disc. The surplus voltage may result from the modulation, by the perforated rotary disc, of the field due to some charge accumulated on the surface of the mill. Several investigators have reported some probable causes of the voltage[1].

These surplus voltage may be removed independent of the cause of it by adopting the following method. The phase of voltage produced by one mill exposed to an electric field is shifted as much as 180 deg. relative to that of the other voltage produced by the other identical one always shielded from the electric field, and both these voltages are mixed. This will cancel objectional voltages.

Concerning the second item in the following, unfortunately we do not know of any available report discussing a way to overcome it. When the mill is calibrated in the artificial uniform electric field between two parallel plates subjected to some voltage, the sensitivity is higher than that measured in the natural electric field. This may be caused by an ionic cloud produced by disc rotation over the mill surface. When the sensitivity is measured in the artificial field, the ionic cloud thus produced will spread out between two parallel plates, hence the field does not decrease in this case. The natural field, on the other hand, will be partially shielded by the ionic cloud existing over the mill surface. The effect seems to be substantial for all types of high speed rotative mill.

The third point is the distortion of the output wave form from the mill. It is likely that this correlates to the surface condition of the mill, to electric field strength, and to geometrical factors of the inductive electrode arrangement. As the distortion varies with the sense of electric field, it is reported by some investigators that the distortion can be used as a criterion for discrimination of the field sense, but it is not certain whether or not the distortion is always identical for any surface condition of the mill and for any field strength with the same sense.

These points shall be discussed further in detail. The apparent sensitivity of the mill for a natural field is only 5×10^{-8} V/v/m as the result of what is described above.

IV. The amplifier.

The mill is placed in outdoors and the remaining parts indoors. The mill and the remaining parts are connected with a cable 25 m in length. A pre-amplifier is placed near the mill to connect the cable to the 200 kΩ resistor earthing the inductive electrodes and to change the high impedance of the resistor circuit into low. It is suspended with springs from the wooden frame to avid mechanical vibrations. The half of a triode tube 12AU7 is used as a cothode follower and forms the pre-amplifier. The alternating voltage from it is fed into main amplifier through an attenuator, which can reduce the input voltage down to 80 db. in 10 db. step. The main amplifier consists of three triodes, that is 1/2 12AX7, 1/2 12AU7, and 6C4. All heaters of these tubes are connected in series, and heated with direct current to avoid the 50 or 60 c/s hum induction from heaters. The first and second tubes are sustained in the respective cushion sockets to prevent the microphonic noise. The voltage amplified from the main amplifier is fed into three parts of the recorder system as described in section 2.

V. Cathode-ray-tube and relating circuit.

The atmospherics radiated from a lightning discharge is received in the wave form recorder with trigger method[3], and the recorder forms one element part of a composite apparatus to observe the lightning discharge. The recording method of the wave form is to photograph the display of the wave form on the screen of a cathode-ray-tube on a frame of 35 mm cine film. The spot of the cathode-ray-tube is swept in horizontal direction when the wave form recorder receives an atmospheric. The sweep duration is adjusted to 20 ms and the spot is deflected simultaneously by the voltage proportinal to the input wave form in

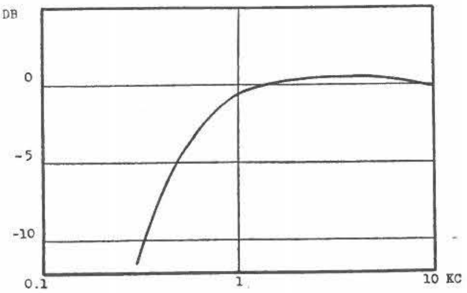


Fig. 3 Frequency characteristic of the apparatus from the pre-amplifier to the cathode-ray-tube.

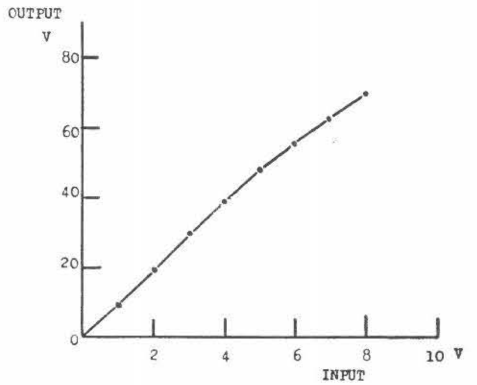


Fig. 4 The amplification characteristic of the apparatus from the pre-amplifier to the cathode-ray-tube when an input voltage is reduced to 80 db by the attenuator.

the vertical direction. The electric field change is also recorded by same mechanism as the wave form recorder, and the two records are simultaneously triggered by the input to the wave form recorder. After the phase of the output voltage from the main amplifier is inverted by triode 6J5, the voltage is further amplified through a push-pull arrangement using twin triode 6SN7. This output deflects the spot of the cathode-ray-tube. A small portion of the voltage is utilized to operate a small cathode-ray-tube as monitor. The frequency characteristic of the apparatus from pre-amplifier to cathode-ray-tube is shown in Fig. 3. The amplification is cut down from 1 kc/s to lower side to avoid the inductive action of the power mains. The carrier frequency of this field meter is 3 kc/s at 50 c/s power mains and 3.6 kc/s at 60 c/s. The output voltage is not distorted up to about 5 V input voltage as shown in Fig. 4. The sensitivity of the mill to natural field is 5×10^{-8} V/v/m and the voltage appearing on the mill when it is shielded from external electric field, is 10^{-4} V, so that we need not further consider the linearlity of the amplifier.

VI. The magnetic tape recorder circuit.

The alternating voltage from the main amplifier is separated and fed into a magnetic tape recorder to obtain a long run record of the rapid field changes inexpensively. The frame number of the wave form record described in the above section and the mark representing the time when the spot of the cathode-ray-tube is swept, are simultaneously recorded in the tape recorder to assure the correspondence of these two. On the occasion when lightning discharges occur frequently, the atmospheric wave forms can continuously be recorded on 16 mm film for a few minute, and the marks above described are also recoded on it. As a lightning discharge often continues itself no less than one second, the continuous record of field changes on magnetic tape and that of atmospherics on 16 mm film are highly suited for the observation of violent thunderstorms. The records of field changes obtained with camera or with magnetic tape recorder can not in itself distinguish the sense of electric field, but it can be done by comparing them with the corresponding records of ink writing ammeter.

VII. The circuit of ink writing ammeter.

The third alternating voltage output separated from the main amplifier is synchronously rectified and the voltage rectified drives the ammeter. The recording speed of the ammeter employed on electrically calm conditions is 7 cm/hour and that in the case of thunder storms is 7 mm/min. The behavior of field recovery following a field change produced by a lightning discharge can be recorded by the latter speed. The circuit of the synchronous rectifier is shown in Fig. 5. The reference signal for the rectification is produced in the mill. The inner group of electrodes on the mill, i. e. reference electrodes, is utilized to produce the reference signal. A change of capacity

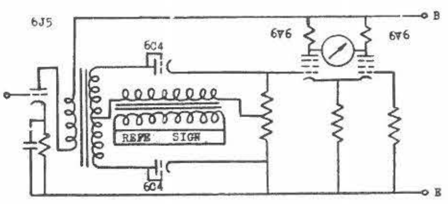
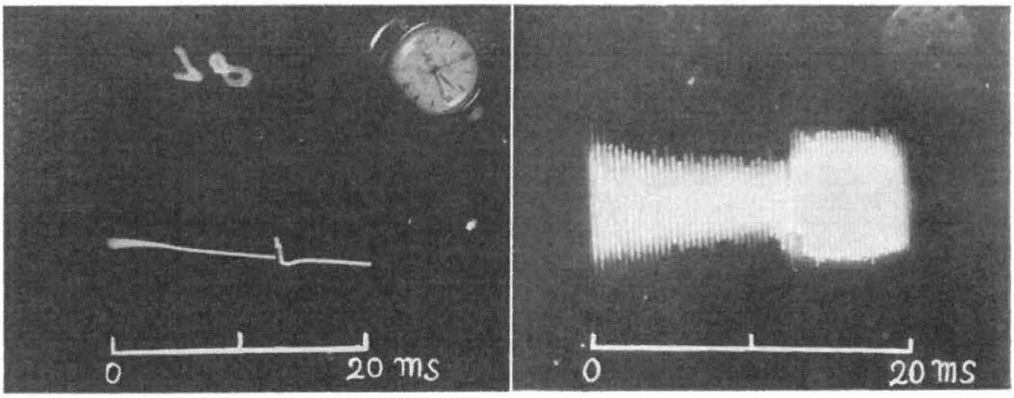


Fig. 5 Synchronous rectifier

between reference electrodes and the earth synchronizes with the phase of the alternating voltage produced by the external field on the inductive electrodes. The capacity of reference electrodes is 130 pF when both groups of electrodes are exposed, and 140 pF when shielded. The difference of the capacity, 10 pF, is converted into an alternating voltage by Inoue-circuit[1)] and then is fed into the synchronous rectifier.

VIII. Examples of records.

Simultaneous records of atmospheric wave form and electric field change due to a lightning discharge, both photographed on each frame of 35 mm cine film, are shown in Fig. 6. The duration of each sweep is 20 ms. The record of the electric field change obtained with a tape recorder is shown in Fig. 7, and that with an ink writing ammeter in Fig. 8.



(A) Record of atmospheric wave form. (B) Record of electric field change.

Fig. 6 Simultaneous records of atmospheric wave form and electric field change.

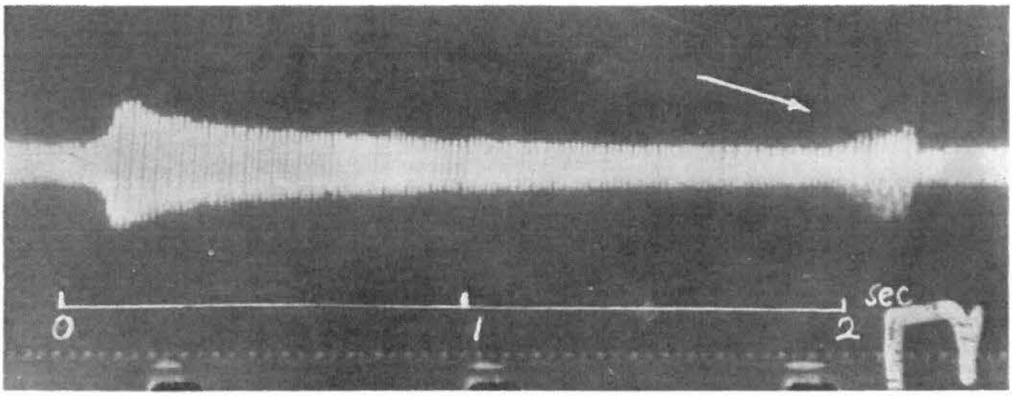


Fig. 7 Record of electric field change obtained with the tape recorder. The arrow denotes a frame number.

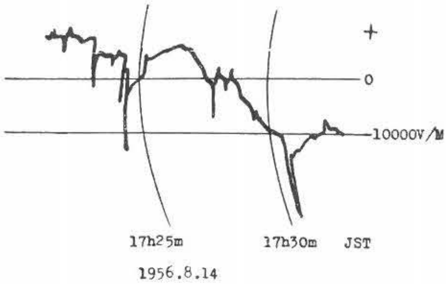


Fig. 8 Record of electric field change with the ink writing ammeter.

IX. Conclusion.

This field meter has been employed to observe the lightning discharge for the last few years and has gradually been improved. The meter can be divided into several small parts to transport it with ease. Major defects of the meter are the decrease of sensitivity in the natural electric field and the presence of surplus voltage when the mill is shieded. We are now inquiring the cause of these troublesome defects.

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