Translated to English from paper in Japanese, originally published in: Gijutsu Houkoku, Vol.41, No.1 (No.112), 8–13, 2001 with permission of the authors.

Preliminary Test for Atmospheric Electricity Measurement Using an Electrostatic Sensor

by

Nobuaki SHIGENO, Tomoaki TAKIZAWA, Nobukazu ITOH, Megumi YOKOYAMA and Takeshi OWADA

1. Introduction

For Observing atmospheric electric potential gradient, two methods are generally known: One is the atmospheric electricity measurement; the potential difference between a point on the ground surface and a point in the atmosphere is measured and the average electric field present between these two points is calculated.

The other is the inductive charge measurement; The inductive charge occurring in conductors due to the electric field present in the atmosphere is measured to verify the intensity of the electric field.

In the case of the atmospheric electricity measurement method, it takes time to collect current, i.e. it takes time for the potential of a conductor used in a sensor to become equal to the potential of the surrounding atmosphere. Therefore for continuous observations, the time must be reduced by using a radioactive collector or a water-dropper collector. At the Kakioka Magnetic Observatory, observations are made using the combination of a water-dropper collector and a Benndorf's self recording electrometer.

The Benndorf's self recording electrometer is an electricity tester and analog recorder integrated. At Kakioka observatory, records by this electrometer were digitized by a digitizer and the data were averaged and reported as hourly values. Reports of one-minute digital data have become a hot issue.

Electric field mills, which are widely used as instruments using the inductive charge measurement, Kakioka Magnetic Observatory has observed the atmospheric electric potential gradient using the electric field mill since 1972. Electric field mills have mechanical troubles more often than other types of measuring devices since it works by rotating a insulated shielding plate at high speeds. In addition, it was discovered through the researches conducted by our colleagues that if the potential difference between the cover plate and the ground is reduced to 0 for the sensitivity measurement, the degree of fluctuation of output signals is equivalent to the degree of potential gradient on calm days, raising concern over the stability of absolute values. Considering this situation, we have been making observations at this observatory based on the idea that the values measured by the electric field mill are dealt with data on the disturbed conditions of atmospheric electricity.

To acquire stable digital one-minute data, we conducted a preliminary atmospheric electricity measurement test using the water-dropper collector in combination with a noncontact electrostatic sensor instead of the Benndorf's self-recording electrometer. This paper describes the results of this test.

2. Specifications of the Electrostatic Sensor

We could use a high-performance electrostatic sensor through the courtesy of Keyence Corporation, and conducted a comparative test using this sensor. The atmospheric electricity measurement method requires that the sensor be insulated completely. The sensor used in the present test is a noncontact sensor that can measure potential difference, and does not need to contact with an object to measure.

This sensor uses the Voltage Scanning Search (V.S.S.) method. This method works by a voltage being applied to a surface potential sensor built into the sensor head, the voltage applied is changed in a stepwise pattern within a specified range. As each voltage is applied, the surface potential sensor generates signals proportional to the potential difference between a target object and the sensor. Based on the signals output from the surface potential sensor, a point where the potential difference between a target object and the surface potential sensor becomes 0 V is computed by a microcomputer.

Sampling interval is 0.1 second. The result of sampling is displayed in units of one volt on the controller, and the average number of samples can be specified. A hundredth of the measured value is also output from the analog output terminal as a monitor signal. In the case of the electrostatic sensor, the analog output value become smoother if a larger average number of samples is specified; it is inferred from this that this sensor first averages A/D converted signals, and then D/A-converts and outputs them. Although a detailed survey was not conducted as the sensor was owned by Keyence, we presume that if the sensor is adopted for routine measurement system, it is need to be modified to output the analog signals before data are introduced to the internal arithmetic process.

Table 1 shows the specifications of the electrostatic sensor.

Table 1 Specifications of the high-performance electrostatic sensor

Model	Sensor head	SK-030	
	Controller	SK-200	
Measurement method		V.S.S. method	
Measurement mode		High accuracy mode	Wide range mode
Measurement range		0 to ±5 kV	0 to ±30 kV
Measurement accuracy		±10 V *1	±5% of F.S. *2
Analog Voltage output	Output voltage	±5 V	±3 V
	Output impedance	100 Ω	
Sampling time		0.1 s	
Control input		Program, timing, hold reset	
	Signal	NPN open collector or dry contact signal	
Control output	Tolerance judgment output	HI, GO, LO NPN open collector 100 mA maximum (40 V or less) N.O.	
	Alarm output	NPN open collector 100 mA maximum (40 V or less) N.C.	
	Response time	0.2 second (if the average number of times is one)	
Rating	Source voltage	DC 24 V ±10%	
	Consumption current	600 mA or less	
Environmental resistance	Ambient temperature	0 to +50°C	
	Ambient humidity	35 to 85%RH (there can be no condensation)	
Material		Sensor head: Special polycarbonate	
Weight		Sensor head: About 330 g (including the weight of the cord (3 m)), controller: about 900 g	
Main functions		Feedback to the antistatic blower (SJ-F020), switching between measurement modes, setting of the average number of samples, various holds, setting of upper and lower limits, panel lock, program switching	

*1 When measured at a distance of 8 to 12 mm and at a voltage of ±100 V or less
10% of a reading when measured at ±100 V to ±5 kV.

*2 When measured at a distance of 68 to 72 mm

3. Comparing the Data Measured by Electrostatic Sensor and by the Benndorf's self-recording Electrometer

In the present test, the electrostatic sensor was set at a point about 10 mm from the water tank of the water-dropper collector, and the potential difference between surface of the water tank and ground surface was measured in high-accuracy measurement mode.

The analog output signal of the electrostatic sensor was connected to a pen recorder and a DR-M3a digital data recorder made by TEAC. In this setup, the 0.1-second value data, which is not subjected to average computations, was digitally recorded, but then the average of ten 0.1-second values was computed and defined as a one-second value. This one-second value was compared with the analog records taken by the Benndorf's self-recording electrometer and the digital data (one-second values) taken by the electric field mill.

We first noted, as explained earlier, that the output voltage of the electric field mill installed at Kakioka fluctuates widely when 0 V is applied during sensitivity measurement. Since this fluctuation is directly added to measured values, it was thought that the accuracy of absolute values becomes unstable. To compare this state of fluctuation with that of the water dropping collection, 0 V was also applied to the water-dropper collector and the stability of measurements was examined.

At Kakioka, water is supplied twice a day (UT00h, 12 h) through a magnetic valve to replenish the water-dropper collector with water. The water supplied this way should cause the potential difference between the water-dropper collector and ground surface to become zero. Fluctuations in the values given by the electrostatic sensor were examined when water was added. In Figure 1, values given by the electrostatic sensor when 0 V is applied to the water-dropper collector are also shown; this application of voltage is equivalent to the sensitivity measurement made by the recording part of the Benndorf's self-recording electrometer. Values shown in Figure 1 were obtained by subjecting the values output from the electrostatic sensor to sensitivity calibration, specifically by multiplying them by the planar calibration value 1.3 presently used at Kakioka and converting the values obtained by this multiplication to potential gradient values. A solid circle indicates the value when water is supplied, and a filled square indicates the value when 0 V is applied. Data shown at these points, where the potential difference becomes zero, are one-minute values. (The solid line is drawn by connecting average one-minute values measured when water is supplied.).

Three voltages 0 V, +200 V and −200 V as one set were applied to measure the sensitivity. In Figure 1, only the data obtained with the applied voltage of 0 V is shown. In Figure 2, the data for all three voltages are shown.

In Figure 2, the relative difference is obtained by subtracting the value with the applied voltage of −200 V from the value with the applied voltage of +200 V. It is apparent from Figure 2 that relative values are stable although absolute values are incorrect. In addition, fluctuations in one-minute values become notable on the 17th and subsequent days in Figure 1, and the relative difference becomes small after the 19th in Figure 2. Causes

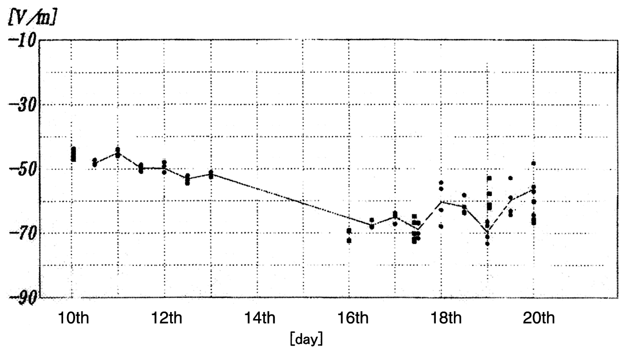

Fig. 1 Change in the output when water is supplied (●) and 0 V is applied (■)

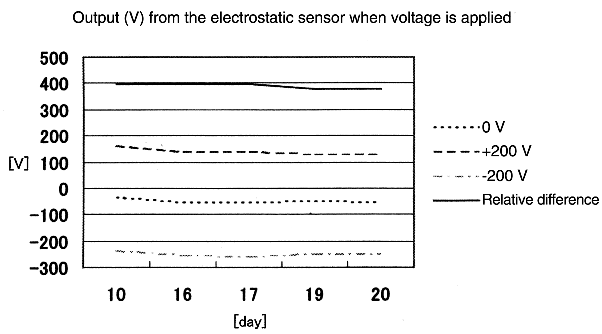

Fig. 2 Values output from the electrostatic sensor when voltage is applied From Aug. 10 to Aug. 20

of these phenomena, however, are not identified.

In the case of the electric field mill, the circuit offset at the main body can be measured by periodically short-circuiting input signals at the main body. It is difficult, however, to automatically obtain the offset value of a potential gradient to be measured. In the case of the water-dropper collector, it is simple. Measured value when the measurement system is connected to the ground can be used to obtain the offset value.

Figure 3 shows the hourly values based on the measurements obtained by the Benndorf's self-recording electrometer and by the electrostatic sensor we used in this test. The records measured by the Benndorf's self-recording electrometer were read by a digitizer and the data was multiplied by the sensitivity of the recording part and the planar calibration values of the measurement system in order to obtain the hourly values. In calculating the hourly values based on the measurements taken by the electrostatic sensor, the output value when 0 V was applied to the water-dropper collector was used as the offset value. The output values by the electrostatic sensor with applied voltage of +200 V and −200 V were used for sensitivity calibrations, and the sensitivity-calibrated values were multiplied by the planar calibration value used at Kakioka observatory. We did not make corrections to outliers recorded when a calibration voltage was applied or when water was supplied.

In Figure 3, the divisions on the right vertical scale show the differences between the hourly values by the electrostatic sensor and those by the Benndorf's self-recording electrometer. The differences are approximately within ±20 V/m on calm days. We attribute the differences to the difference in the response times of the recorders, read errors of the digitizer, potential conversion errors due to leaks, and other factors.

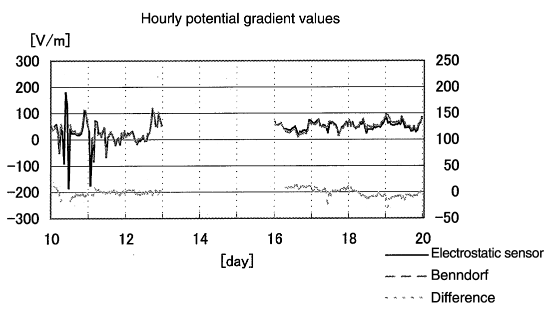

Fig. 3 Comparison between hourly values by the electrostatic sensor and those by the Benndorf's self-recording electrometer

4. Comparison between Electrostatic Sensor and Electric Field Mill Data

In the present test, we also compared data given by the electrostatic sensor with data given by the electric field mill. The distance from a building and installation conditions for the electric field mill were different from those for the water-dropper collector. The principle of measurement of the water-dropper collector is vastly different from that of the electric field mill, as described in the introduction. Therefore, there is a marked difference between the response time of the water-dropper collector (time that it takes to collect current) or the time to assimilate itself to the surrounding electric field and that of the electric field mill. Furthermore, since an output filter is set in the electric field mill system, we think it is not so meaningful to make a precise comparison between the data by water-dropper collector and that by the electric field mill. In the present test, therefore, we only show comparative data and graphs in this section.

Figure 4 shows the provisional one-second values given by the water-dropper collector with electrostatic sensor and the provisional one-second values given by the electric field mill (not sensitivity- or offset-corrected) during the period

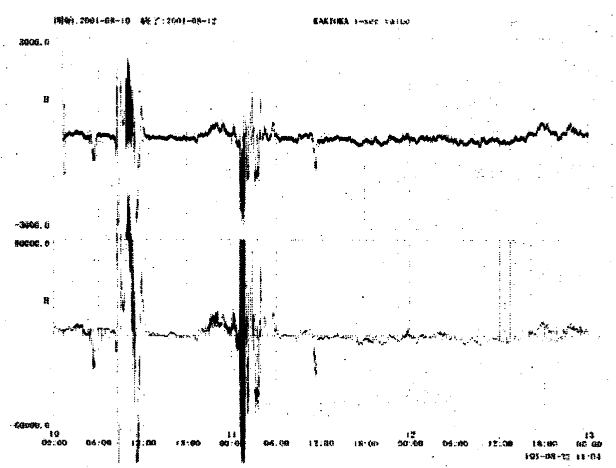

Fig. 4 Provisional one-second values given by the electrostatic sensor (top) and those given by the electric field mill (bottom) from Aug. 10 to Aug. 12

of Aug. 10 to Aug. 12. The unit is a digit at the time of recording, and the digit value is not converted to any physical quantity.

Figure 5 shows a comparison between the hourly values from the electrostatic sensor and the hourly values from the electric field mill; the hourly values from the electric field mill were processed using proper sensitivity calibration values to reduce the difference in measurements between the water-dropper collector and the electric field mill (offset corrections were not made). In Figure 5, the divisions of the right vertical scale shows the differences, as with in Figure 3.

5. Conclusion

We think that results of the test suggest a possibility of using the electrostatic sensor made by Keyence Corporation in stead of the Benndorf's self-recording electrometer which is used at Kakioka. Some problems have remained to adopt the electrostatic sensor as a device for the routine continuous measurement system. It has difficult points; determinations of planar calibration values, measurements of sensitivity based on known electric fields, and insulation tests.

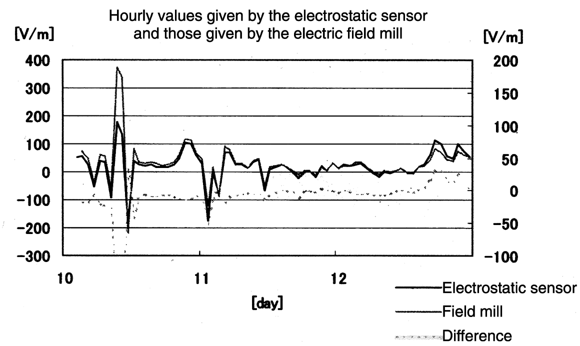

Fig. 5 Hourly values given by the electrostatic sensor and those given by the electric field mill, and the differences in them from Aug. 10 to Aug. 12

Observations now being made at Kakioka are operated on the assumption that the planar calibration value has remained since the time when the radioactive collectors were used. By using this electrostatic sensor with a small size water-dropper collector, we will be able to measure potential gradients in a neighboring uniform open space and obtain approximate planar and sensitivity calibration values by comparing the measured potential gradient values.

Concerning insulation tests, although a measurement and a routinary maintenance of the insulation can be conducted, it is indispensable to develop methods for feeding the results of the insulation tests back to measured values.

Whether the water-dropper collector can be installed in cold-latitude climate, for example at Memambetsu Magnetic Observatory, Hokkaido, Japan is a is another remained issue.

Acknowledgments

In conducting this test, we received useful advice from the senior researchers Mr. Nakaya and Mr. Yamada and also gained the cooperation of the colleagues of the Observations Division. We would like to take this opportunity to extend our sincere appreciation to these people.

References

Hatakeyama, H., and M. Kawano, *Meteorological Electricity,* Iwanami Zensho, Iwanami Shoten, 1955 (in Japanese).

Kakioka Magnetic Observatory, "Atmospheric electricity part II" in Gijutsu Houkoku No. 34 (special issue) of Observation Guideline, 1994 (in Japanese).

Keyence Corporation, "Technical guide to measuring instruments and equipment for observation of magnified images" (in Japanese).

Kitagawa, N., *Atmospheric Electricity,* Tokai University Press, 1996 (in Japanese).