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**Humidity Response of the Eberline Model
PAC-7 Alpha Instrument**

University of California

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HUMIDITY RESPONSE OF THE EBERLINE MODEL PAC-7 ALPHA INSTRUMENT

by

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ABSTRACT

Response of the Eberline Model PAC-7 alpha instrument under varying relative humidity (RH) and temperature conditions was studied in an environmental chamber. Electric discharges resulting in spurious counts or in instrument paralysis occurred at 35 to 50% RH. Improvement in the RH level tolerated by the PAC-7 alpha instrument was obtained by conformal coating of the high-voltage region of the printed circuit (PC) board. Following this treatment, electric discharges occurred only at relatively high humidity levels and then as a result of high-voltage breakdown within the AC-24C probe rather than within the PC board.

I. INTRODUCTION

Experiments were undertaken to determine the source of unsatisfactory operation of the Eberline Model PAC 7 alpha instrument in high humidity. These portable survey instruments operate satisfactorily in clear, dry weather, but in high humidity they typically exhibit severe spontaneous discharges or total lack of response to radiation. The instrument's detector probe and electronics circuits were studied in an environmental chamber with temperature and relative humidity (RH) closely controlled.

II. PROCEDURE

Initially, we thought that the thin-line design of the Eberline AC-24C air proportional probe was responsible for the instrument's breakdown in high humidity. Therefore, this detector probe, which normally is attached to the PAC 7, was placed inside the environmental chamber and connected to an external high-voltage power supply and scaler. An electrostatic voltmeter monitored the potential applied to the probe. With a ^{239}Pu alpha check source, response curves were obtained

as the applied potential was varied in 25-V increments from 1650 to 1900 V. Similar curves were obtained at 10, 20, 30, and 40°C as the RH was varied from 50 to 90% in 10% increments. These curves showed no significant electric breakdown in the probe until extreme humidity and temperature (>90% RH and >40°C) were reached.

For comparison, two other AC-24C probes, an Eberline AC-1 air proportional probe and a Los Alamos National Laboratory CMR-7 alpha probe, were tested. However, in these tests, chamber temperature and applied potential were held constant while the RH was increased slowly to 93%. Observations of partial and complete high-voltage discharges in the probes were made. Partial discharges were characterized by increased count rates; complete discharges resulted in a rapid high voltage decrease and count paralysis. Each probe experienced significant high-voltage discharge beginning at 59 to 85% RH. Attempts to determine the source of the humidity response variation among the three probes were unsuccessful.

In additional experiments, the PAC-7 electronics were placed in the environmental chamber and were exposed

to varying RH at 25°C. In this case, the AC-24C probe was connected to the PAC-7 instrument, and both were placed in the environmental chamber. A voltmeter monitored the potential applied to the probe, and an oscilloscope monitored the output signal from the PAC-7 amplifier circuit. As the RH was gradually increased above about 50%, spontaneous electric discharges from the amplifier occurred; as the RH was increased still more, there followed a rapidly falling high-voltage output. Discharges of increasing severity continued through the highest humidity test conditions. These conditions persisted even when no probe was attached to the instrument.

We hypothesized that these conditions were caused by high-voltage leakage across the printed circuit (PC) board. To correct this situation, successive conformal coatings of Krylon acrylic spray or Conothane CE-1155 Type UR polyurethane were applied to the high-voltage regions of the PC board. With the Krylon acrylic, both sides of the PC board were sprayed and were allowed to dry between applications of one to four coatings. With polyurethane, both sides of the PC board were brushed liberally. When the instruments were resubjected to the humidity testing, they showed a significant increase in their ability to withstand the effects of increased moisture.

III. RESULTS

Tables I-V show the count rate as a function of potential applied to AC-24C probe 1 for various combinations of temperature and RH. These same data are illustrated in Figs. 1-9, which show that when temperature is held constant, higher humidity leads to a slightly lower count rate. When humidity is held constant, higher temperature leads to an increased count rate. In most test conditions, probe 1 did not begin to continually discharge until about 1900 V were applied. The only exceptions were at 90% RH and at 30 or 40°C, when partial discharges were observed at about 1650 V.

Unfortunately, these results could not be duplicated when two other AC-24C probes were subjected to humidity test conditions. With the high voltage set at 1800 V and at 25°C, probe 2 exhibited partial discharge at 59% RH and complete discharge at 67% RH, whereas similar values for AC-24C probe 3 were 73 and 85% RH. Slight increases in resistance to humidity were observed when voltages of probes 2 and 3 were lowered to 1500 and 1650 V, respectively.

TABLE I

VOLTAGE RESPONSE CURVES OF AC-24C AIR PROPORTIONAL PROBE 1 AT 50% RH

CPS ^a ± 1%				
V	10°C	20°C	30°C	40°C
1650	69.4	94.3	123.4	142.9
75	121.9	151.5	185.2	217.4
1700	172.4	212.8	250.0	270.2
25	238.1	277.8	312.5	322.6
50	312.5	344.8	357.1	370.4
75	357.1	384.6	400.0	400.0
1800	400.0	400.0	416.7	416.7
25	416.7	416.7	434.8	434.8
50	434.8	434.8	434.8	454.5
75	434.8	454.5	CD	CD
1900	CD ^b	CD	CD	CD

^aCounts per second.

^bContinuous discharge.

TABLE II

VOLTAGE RESPONSE CURVES OF AC-24C AIR PROPORTIONAL PROBE 1 AT 60% RH

CPS ± 1%				
V	10°C	20°C	30°C	40°C
1650	62.5	98.0	111.1	128.2
75	113.6	163.9	178.6	200.0
1700	161.6	212.8	236.2	250.0
25	232.6	277.8	294.1	312.5
50	294.1	333.3	357.1	344.8
75	344.8	370.3	384.6	384.6
1800	400.0	416.7	416.7	400.0
25	416.7	434.8	416.7	416.7
50	434.8	434.8	434.8	434.8
75	434.8	CD	CD	CD
1900	CD	CD	CD	CD

TABLE III

VOLTAGE RESPONSE CURVES OF AC-24C
AIR PROPORTIONAL PROBE 1 AT 70% RH

CPS $\pm$ 1%				
V	10°C	20°C	30°C	40°C
1650	61.3	88.5	103.1	102.0
75	116.3	147.1	166.7	169.5
1700	169.5	208.3	227.3	222.2
25	232.6	277.8	294.1	294.1
50	303.0	333.0	344.8	333.3
75	357.1	370.4	370.4	357.1
1800	400.0	400.0	400.0	384.6
25	416.7	416.7	416.7	400.0
50	434.8	434.8	416.7	416.7
75	434.8	454.5	434.8	454.5
1900	CD	CD	CD	CD

TABLE IV

VOLTAGE RESPONSE CURVES OF AC-24C
AIR PROPORTIONAL PROBE 1 AT 80% RH

CPS $\pm$ 1%				
V	10°C	20°C	30°C	40°C
1650	53.8	82.6	100.0	87.0
75	104.2	138.9	163.9	147.1
1700	149.3	200.0	222.2	204.1
25	217.4	263.2	285.7	263.1
50	285.7	333.0	333.3	307.7
75	333.3	370.4	370.4	333.0
1800	384.6	400.0	400.0	363.6
25	400.0	416.7	416.7	384.6
50	416.7	434.8	434.8	400.0
75	434.8	434.8	434.8	434.8
1900	454.5	CD	CD	CD

TABLE V

VOLTAGE RESPONSE CURVES OF AC-24C
AIR PROPORTIONAL PROBE 1 AT 90% RH

CPS $\pm$ 1%				
V	10°C	20°C	30°C	40°C
1650	52.1	68.0	88.5	243.9
75	98.0	123.4	181.8	333.3
1700	147.1	175.4	250.0	434.8
25	212.8	243.9	588.2	588.2
50	285.7	303.0	625.0	CD
75	333.3	344.8	909.0	CD
1800	384.6	384.6	CD	CD
25	400.0	400.0	CD	CD
50	416.6	416.6	CD	CD
75	434.8	434.8	CD	CD
1900	CD	CD	CD	CD

Fig. 1.
Voltage response of AC-24C air proportional probe 1 at 50% RH.

Fig. 2.

Voltage response of AC-24C air proportional probe I at 60% RH.

Fig. 4.

Voltage response of AC-24C air proportional probe I at 80% RH.

Fig. 3.

Voltage response of AC-24C air proportional probe I at 70% RH.

Fig. 5.

Voltage response of AC-24C air proportional probe I at 90% RH.

Fig. 6.
Voltage response of AC-24C air proportional probe 1 at 10°C.

Fig. 7.
Voltage response of AC-24C air proportional probe 1 at 20°C.

Fig. 8.
Voltage response of AC-24C air proportional probe 1 at 30°C.

Fig. 9.

Voltage response of AC-24C air proportional probe 1 at 40°C.

Eberline's AC-1 probe showed partial discharge at 85% RH with no evidence of complete discharge up to 93% RH. The Los Alamos CMR-7 experienced partial discharge at 80% RH with no continuous discharge up to 93% RH. Results of the probe testing are summarized in Table VI and in Fig. 10.

Three PAC-7 instruments were tested in the chamber for humidity effects before conformal coatings were applied to the PC boards. AC-24C probe 1, stable at >90% RH, was used for these tests. In each test, the instruments behaved similarly though not identically. Instruments 1 and 2 operated satisfactorily up to 52% RH; instrument 3 operated satisfactorily only <35% RH. At these breakpoint humidities and higher, the instruments exhibited partial discharges resulting in increased count rates. Also, the high-voltage output of the PAC-7 decreased rapidly to zero as the humidity was raised further. As this occurred, the instruments exhibited complete discharge, resulting in total paralysis of the counting mechanism. Similar results were obtained with and without the check source and with and without the probe attached to the PAC-7. (See Table VII.)

TABLE VI

RH AT WHICH DISCHARGES OF ALPHA
AIR PROPORTIONAL PROBES OCCUR;
TEMPERATURE CONSTANT AT 25°C

Instrument		Partial Discharge at RH	Continuous Discharge at RH
I (1800 V)		Not observed < 90%	Not observed < 90%
	(1500 V)	Not observed < 90%	Not observed < 90%
Eberline AC 24C	2 (1800 V)	59%	67%
	(1500 V)	63%	75%
3 (1800 V)		73%	85%
	(1650 V)	80%	92%
Eberline AC 1	4 (2100 V)	85%	Not observed < 93%
CMR 7	5 (2100 V)	80%	Not observed < 93%

Fig. 10.

RH at which high-voltage discharges of air proportional probes occur; temperature constant at 25°C. (*No discharges were observed at maximum humidity tested.)

Instrument 1 was sprayed with four light layers of Krylon acrylic and was retested for humidity response after the second and fourth applications. The instrument's ability to withstand humidity improved significantly with each coat of Krylon. After four coats, the instrument operated normally up to 70% RH.

Instrument 2 was sprayed with two heavy coats of Krylon, then was retested for humidity response. In this case, the instrument operated satisfactorily at >90% RH.

The PC board of instrument 3 was brushed liberally with Conothane polyurethane. Again, this conformal coating greatly improved the instrument's operation in high humidity. No discharge or high-voltage breakdown was observed up to 93% RH.

IV. CONCLUSIONS

On the basis of these experiments, we concluded that high-voltage leakage between electrical components across the PC boards of the PAC-7 was primarily responsible for the instrument's unsatisfactory operation in high humidity. High-voltage leakage and discharge also were observed in the AC-24C air proportional probe, but generally occurred at significantly higher humidity than did the PC board leakage.

Two PAC-7 instruments that originally discharged at 35% RH and at 52% RH were made to withstand

humidity >90% by sealing their PC boards with Krylon or Conathane conformal coatings. Although both materials protected the electronics from humidity, the Conathane required only one application. Also, the Conathane was brushed rather than sprayed onto the boards, thereby avoiding unsealed electrical components that might be damaged by the spray. On the other hand, Krylon dried very quickly, whereas the Conathane had to be cured for 1 h at 100°C.

After the PC boards had been coated, the air proportional probes became the components limiting the instrument's use in high humidity. Different probes showed considerable variability and ranged from fair to good in humidity resistance. One AC-24C probe exhibited no high voltage breakdown up to 93% RH, whereas another showed partial discharges as low as 60% RH. To determine the source of these differences, the probes were dismantled and carefully examined under magnification. No visible differences were observed. The Mylar cover plates of these two probes were exchanged and then completely removed with no observable effect. We concluded that the most likely cause of the different responses was variation in the tension under which the anode wires were stretched. Apparently, more loosely stretched wires sagged slightly at high voltages, thereby reducing the resistance of the probe against electric discharge.

TABLE VII
RH AT WHICH PERFORMANCE OF THE EBERLINE MODEL
PAC 7 ALPHA INSTRUMENT IS ALTERED

Instrument	Coating	Normal Operation at RH	Count Rate Increased at RH	High Voltage Decreased at RH
1	None	<52%	>52%	>52%
	Two light coats of Krylon	<60%	>60%	>62%
	Four light coats of Krylon	<70%	>70%	>70%
2	None	<52%	>52%	>63%
	Two heavy coats of Krylon	>90%	Not observed up to 90%	Not observed up to 90%
3	None	<35%	>35%	>50%
	One heavy coat of Conothane	>93%	Not observed up to 93%	Not observed up to 93%