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PARTIAL DISCHARGE MEASUREMENTS FOR A TWISTED PAIR OF INSULATED CONDUCTORS AT LOW PRESSURES IN AIR, ARGON AND HELIUM (POSTPRINT)

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Partial discharge (PD) measurements in air, argon and helium, under pressures from 101.3 kPa (760 Torr) down to 0.27 kPa (2 Torr), have been performed for both 60 Hz ac and dc energization. The electrode arrangement is a twisted pair of insulated conductors taken from a standard aircraft wiring harness. The paper describes the physical PD test setup, the electrical connections for ac energization, and specifies the twisted pair arrangement of the insulated conductors. The results are presented in terms of PD current pulse waveforms and their analysis reflecting the effects of pressure and voltage.

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Partial Discharge Measurements for a Twisted Pair of Insulated Conductors at Low Pressures in Air, Argon and Helium

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***Abstract*- Partial discharge (PD) measurements in air, argon and helium, under pressures from 101.3 kPa (760 Torr) down to 0.27 kPa (2 Torr), have been performed for both 60 Hz ac and dc energization. The electrode arrangement is a twisted pair of insulated conductors taken from a standard aircraft wiring harness. The paper describes the physical PD test setup, the electrical connections for ac energization, and specifies the twisted pair arrangement of the insulated conductors. The results are presented in terms of PD current pulse waveforms and their analysis reflecting the effects of pressure and voltage.**

I. INTRODUCTION

The proper operation and survival of aerospace equipment must be assured by the reliable performance and normal functioning of electric power system components and subassemblies under operating conditions. A twisted pair of conductors was tested for pressures in the range from 101.3 kPa (760 Torr) down to 0.266 kPa (2 Torr). This pressure range corresponds to a range of altitudes from sea level to about 60 km (about 200 kft). Partial discharge (PD) testing is one of the methods of evaluating the integrity of electrical insulation [1].

II. DESCRIPTION OF EXPERIMENTAL SETUP

A cylindrical vacuum chamber was constructed of acrylic. Its inside diameter is 89 mm and its height is 254 mm. A molecular drag pump, backed by a diaphragm pump, was used to maintain selected gas pressures and flow rates.

For ac tests, two 60-Hz, 240-V variable transformers in cascade were used as the voltage control. The output of the second one was connected to the low-voltage side terminals of a 240-V / 7.6-kV transformer. A 27-kohm current limiting resistor was inserted into the high voltage circuit. The coupling capacitor was a 1.36 nF ceramic capacitor. Guidelines of IEC 60270 [2] were observed. For dc tests, a bipolar source with voltage up to $\pm$50 kV was used. Two variable transformers were used for the low-voltage ac-side control of the source.

A 50-ohm non-inductive current-viewing resistor was connected between the bottom electrode and ground. The source voltage (measured through a voltage divider) and the voltage across the 50-ohm viewing resistor were observed on a 350 MHz, 5 GS/s digital oscilloscope.

A photograph of the experimental setup is shown in Fig. 1. One of the conductors of the twisted pair was connected to the upper (high-voltage), rounded aluminum connector, and the other one to the grounded, bottom, rounded aluminum connector. The distance between the connectors was about 110 mm. The maximum electric stress for the insulation was in the vicinity of where the two conductors were twisted together. The length of the twisted section was about 50 mm.

The insulated conductors used for the measurements were from an aircraft wiring harness. The outside diameter of the insulation is 1.55 mm, the conductor diameter is 0.88 mm. Each conductor is composed of 19 strands of 0.19 mm diameter wire.

II. TESTS PERFORMED

A series of tests were conducted for air, argon and helium with a 60 Hz ac source voltage. The source voltage level for PD onset was determined for each gas. Then the source voltage and the PD pulse waveforms were recorded for a source voltage of 5% above onset and 20% above onset. Also, both positive PD, i.e., PD that occurred when the 60 Hz ac source voltage was positive, and negative PD, i.e., PD that occurred when the 60 Hz ac source voltage was negative, were recorded. A total of 200 PD waveforms were recorded for 5%

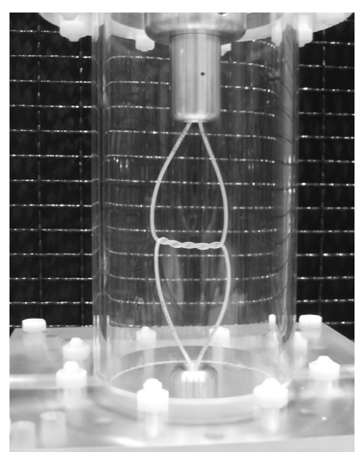

Fig. 1. Twisted-pair assembly in the vacuum chamber.

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above onset and 200 waveforms for 20% above onset. One-half of the waveforms were for positive PD, and the other half for negative PD. At each pressure, for each one of the 400 waveforms, the phase angle of the 60 Hz ac source voltage at which the PD occurred was determined and recorded by the scope. Rise time and charge content of each PD waveform were calculated during post-processing.

The tests with helium were exploratory and were done only at 20% above onset, with the number of waveforms for each polarity at 50 rather than 100.

PD results were recorded for air at pressures of: 2, 5, 10, 20, 50, 100, 200 and 760 Torr. In argon at pressures of 10 Torr and below, no PD could be recorded because connector-to-connector discharges occurred. Similarly, PD waveforms in helium could be recorded only at pressures above 10 Torr.

With the present experimental configuration, no PD was recorded with dc excitation because of full discharges between the aluminum connectors. This was the case for air, argon and helium. Whether or not PD actually initiated the discharges cannot be determined with the data acquisition method currently being used.

III. Waveforms

Fig. 2 shows representative waveforms for air. Nine waveforms were identified; they are labeled Air-1 through Air-9. Table 1 is a summary of per cent occurrence of waveforms at each recorded pressure with air. Only positive PD waveforms are shown; however, these are also representative of the negative PD waveforms. Oscillations can be observed on Air-7, 8 and 9. In general, there were no PD-waveform oscillations in air, for pressures below 5 Torr. At and above 20 Torr, many PD waveforms appeared to be oscillatory with and without overshoot (i.e., the oscillatory response changed polarity for at least one cycle of the oscillation). This was not the case for argon and helium. Though some oscillations did occur occasionally, never did these oscillations have a polarity reversal as with air.

The variations of the amplitude and rise time, respectively, of the PD waveform, at different phase angles of the 60 Hz ac source voltage at which PD occurred in air at various pressures are presented as two-variable histograms (Figs 3-4). Similar figures and histograms are available for argon and helium.

IV. Waveform Discussion

Based upon the results illustrated with Figs 2-4 and Table 1, a summary of the twisted-pair test results in air with ac excitation is given as follows:

-- Air-1 waveform shows a single peak with gradually rising front and sharp peak.

-- Some waveforms show a single peak with a gradually rising front and flatter top; see Air-2. The waveform of Air-3 has a single peak but a fast rising front.

-- Significant excursions from Air-1 waveform are shown by Air-4, 5 and 6. Air-4 and 6 show front sections which are not smooth. Air-5 illustrates a tail section with a hump.

-- Typical oscillatory waveforms are shown by Air-7 to 9. The oscillations can be compared in terms of unipolar (Air-7 and 8) vs. bipolar (Air-9), damping, cycle time and typical frequency. The typical oscillatory cycle times were in the range of 20-25 ns and are likely to be instrumentation artifacts.

-- PD pulses with waveforms Air-4 and Air-5 occurred more often on the positive half cycle than on the negative half cycle.

Table 1 provides a summary of the frequency of occurrence of each of these waveforms as a function of pressure for air. The percentages shown in the table are based on a total of 400 waveforms at each pressure; this combines both positive and negative PD and the results for 5% and 20% above PD inception. The differences between positive and negative PD waveforms were minimal and the differences between the results as a function of level of excitation were also not significant. The percentage values of the most frequently occurring waveforms are underlined in Table 1.

V. Conclusions

Aspects of evaluation of PD waveforms for twisted-pair electrodes have been reviewed. The evaluation criteria are the waveform polarity, magnitude, shape, rise time, cycle time, phase angle (temporal location) relative to the source voltage, and waveform parameter statistical distributions. Each of these features can be correlated with the pressure of the gas.

Specific conclusions for air are:

- Differences between PD current waveforms at 5% above onset and 20% above onset do not appear to be very significant. The rise times are similar. The maximum amplitude of the average pulse waveform is larger at the source voltage 20% above PD inception than at 5% above. The phase angles of the 60 Hz source at which PD occurs are slightly higher at 5% above onset compared to 20% above onset.
- The maximum amplitude of the average pulse waveform increases with increasing pressure.
- Rise times (10% to 90%) decrease with decreasing pressure.
- PD waveform duration decreases with increasing pressure.

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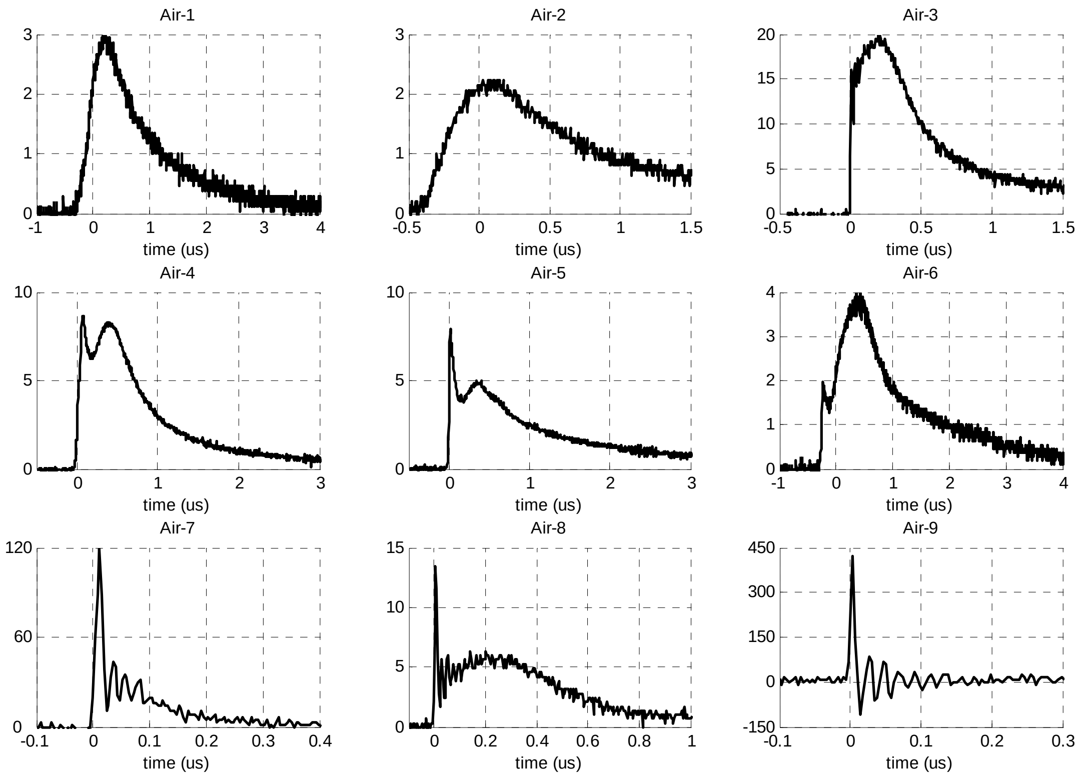
[1] D. G. Kasten, X. Liu, S. A. Sebo, D. F. Grosjean, D. L. Schweickart, "Partial discharge measurements in air and argon at low pressures with and without a dielectric barrier," *IEEE Trans. Diel. and El. Insulation*, vol. 12, April 2005, pp. 362-373.

[2] International Standard, *High Voltage Test Techniques – Partial Discharge Measurements*, IEC 60270, Third Edition, IEC, 2002.



Air-1: single peak, gradually rising front, sharp peak
Air-2: single peak, gradually rising front, flatter top
Air-3: single peak, fast rising front, flatter top
Air-4: double peak of almost equal heights, fast rising front
Air-5: double peak, first peak larger than second, fast rising front
Air-6: double peak, first peak smaller than second, gradually rising front
Air-7: oscillation without overshoot, single peak, oscillation after first major peak
Air-8: oscillation without overshoot, double peak, oscillation at the beginning of the pulse
Air-9: oscillation with overshoot, and fixed oscillation period.

Fig. 2. Representative PD waveforms for twisted-pair electrodes in air with 60 Hz source voltage.
All amplitudes are in milliamps.

TABLE 1
PERCENT OCCURRENCE OF WAVEFORMS OF FIG. 2 VS. AIR PRESSURE.
THE PERCENT FIGURES OF THE MOST FREQUENTLY OCCURRING WAVEFORMS ARE UNDERLINED.

Pressure	2 Torr	5 Torr	10 Torr	20 Torr	50 Torr	100 Torr	200 Torr	**760 Torr**
Air-1	**57.5%**	13.25%	1.5%	0.5%	--	--	--	--
Air-2	16.5%	8.75%	1.75%	1.75%	--	0.5%	--	--
Air-3	5.75%	1.0%	--	--	--	--	--	--
Air-4	6.5%	13.25%	--	--	--	--	--	--
Air-5	0.75%	**43.5%**	3.25%	--	--	--	--	--
Air-6	13.0%	18.25%	--	--	--	--	--	--
Air-7	--	1.0%	**92.5%**	**70.2%**	**49.%**	37.25%	**53.0%**	**10.5%**
Air-8	--	1.0%	1.0%	--	--	--	--	--
Air-9	--	--	--	**27.5%**	50.5%	62.25%	47.0%	89.5%

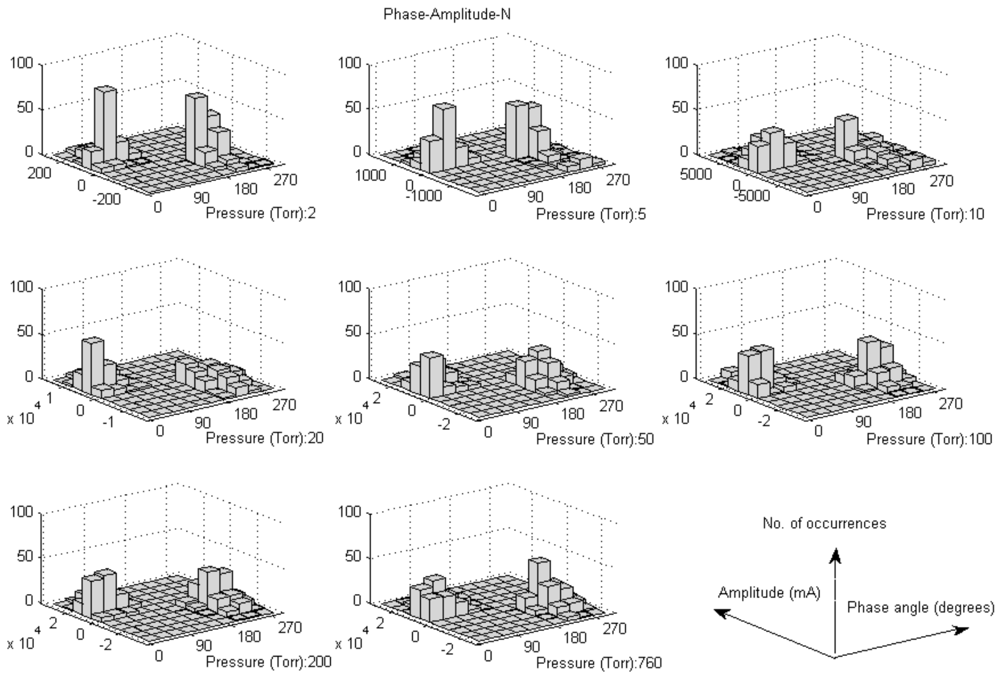


Fig. 3. Two-variable histograms for twisted-pair test results in air; number of occurrences vs. PD pulse amplitude (mA) vs. phase angle of 60 Hz ac source voltage where PD occurred.

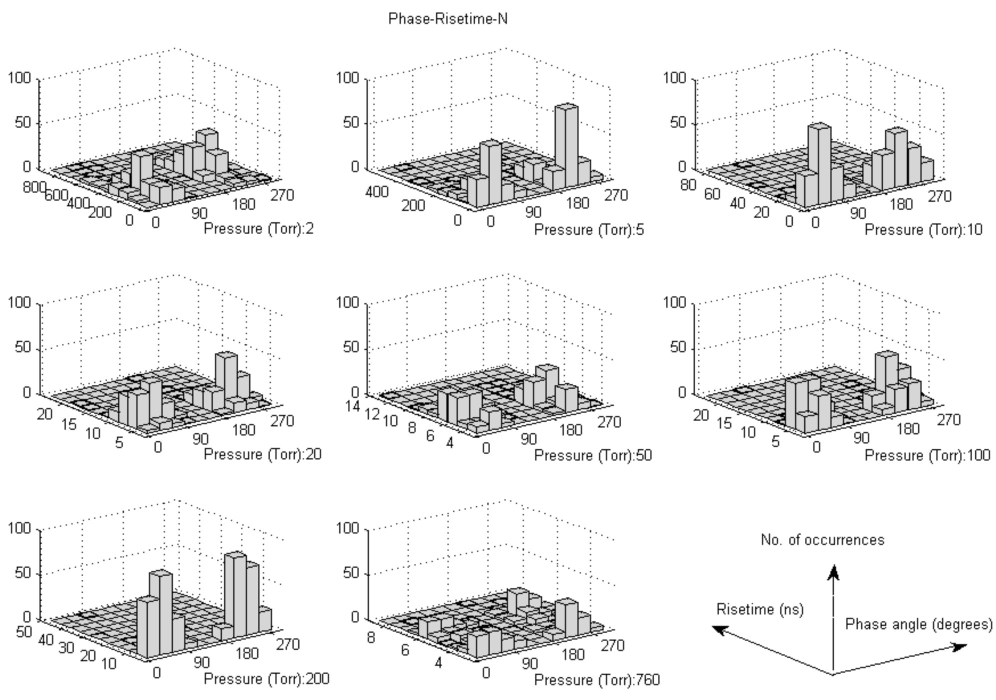


Fig. 4. Two-variable histograms for twisted-pair test results in air; number of occurrences vs. PD pulse rise-time (10% to 90%, nanosec) vs. phase angle of 60 Hz ac source voltage where PD occurred.