Pulse Arrested Spark Discharge (PASD) Wiring Diagnostic**

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Pulse Arrested Spark Discharge (PASD), a non-destructive wiring diagnostic, was developed by Sandia National Laboratories and has been refined for application to aircraft wiring systems under a Federal Aviation Administration contract. PASD employs a low energy arrested-arc concept and time domain reflectometry to produce a well-defined reflection from an insulation defect site. The PASD diagnostic can detect and locate a range of electrical insulation damage in cable/wire bundles with non-uniform impedance profiles. This paper will discuss the PASD concept and results of laboratory and aircraft-type wiring system measurements.

I. Background

The Department of Energy (DOE), the U.S. Navy, and the Federal Aviation Administration (FAA) have funded research and development at Sandia National Laboratories in a novel wiring system diagnostic called Pulsed Arrested Spark Discharge (PASD). The PASD concept and technique was first demonstrated on electrical wiring systems in 1996 under a DOE sponsored Nuclear Energy program. Sandia's success during initial development of PASD for the DOE led to a contract with the U.S. Navy to explore the use of this concept for complex wiring in control and power systems. This work, completed in August 2001, demonstrated the ability of this technique to identify and locate gross defects and very difficult small-volume dielectric defects in a laboratory environment (ref. 1). This foundational work with PASD led to a three-year FAA program beginning in October 2002 with a focus on commercial aircraft wiring systems, a reduction to practice of the PASD technique, and near-term commercialization. This work is drawing to closure ahead of schedule. PASD has demonstrated great potential to locate aircraft wiring flaws relevant to aging processes, manufacturing defects, and installation damage.

II. Introduction

Fig. 1 shows the PASD diagnostic concept. The PASD technique uses a high-voltage, low-energy (few mJ), short pulse to induce an electrical spark discharge at the site of an insulation defect. The discharge occurs from the conductor in the wire under test to an adjacent return path (another wire or ground plane). The arc impedance collapse, which occurs within a few nanoseconds, produces a momentary short circuit which reflects energy back to the sensors at the injection point. Conventional Time Domain Reflectometry (TDR) techniques are used to accurately locate the defect site. This technique is a direct test of the dielectric strength of the insulation system. Since the PASD voltage is insufficient to breakdown any significant amount of bulk insulation, only defects which expose the center conductor are affected.

The PASD technique begins by characterizing the impedance of the wire under test, much like a conventional TDR technique, using the PASD pulse at a low voltage setting (hundreds of volts). This establishes an impedance

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baseline which is critical to PASD's ability to perform in non-uniform impedance wiring systems. The pulser voltage is then raised until a change is seen in the baseline waveform caused by the breakdown at a defect site.

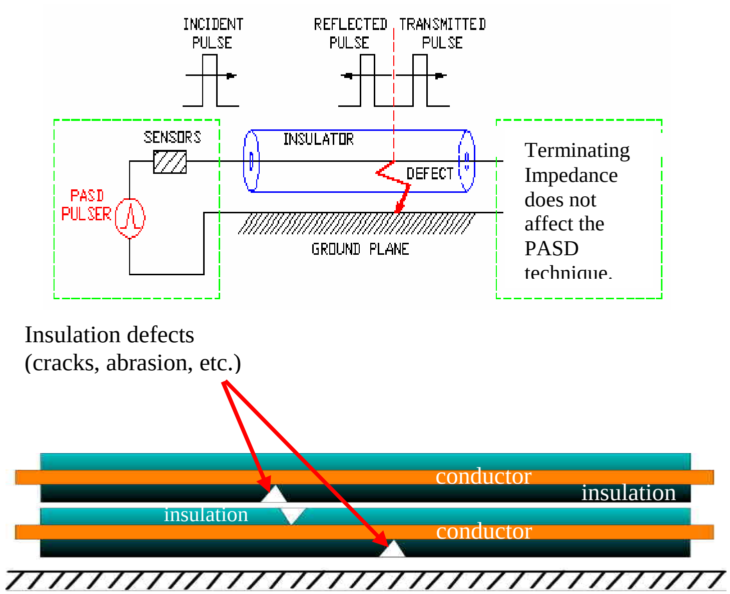

Figure 1. (Top) PASD diagnostic concept for locating defects in electrical wiring systems. A single conductor is shown under test. The ground plane can be an adjacent insulated conductor or metallic plane such as an aluminum aircraft shell. An electrical breakdown occurs due to an injected, low energy, high voltage pulse. (Bottom) The breakdown can occur between two adjacent conductors with insulation damage, or from a conductor to ground plane such as braided shielding or a metal plane.

Fig. 2 shows example waveforms derived from tests on a coaxial cable with a 0.7 mm hole punched through the dielectric and a damaged twisted shielded pair cable. The location of the change in the two sensor voltage versus time waveforms describes the physical location of the defect sites. A simple differencing algorithm can easily locate the change between the two waveforms. PASD can be applied using several different techniques, including the use of multiple pulse injection to improve PASD's response in long lines. PASD has been effectively demonstrated in wire harnesses up to 100 foot in length with injection from one end.

III. Non-Destructive Nature of PASD

As effective as PASD can be, it would not be a viable diagnostic if it were destructive or degraded the properties of the wiring or connectors under test. A series of experiments were conducted to carefully quantify PASD's impact on typical aircraft wiring insulation including Teflon, polypropylene, celluloid, and Mylar (ref. 2). Fig. 3 shows the test fixture used during these experiments. Several types of experiments were conducted to evaluate the impact of a PASD breakdown on insulator surfaces. They included: (1) exposing the sample to a series of PASD pulse breakdowns to evaluate whether the breakdown voltage decreased with subsequent pulsing; (2) performing a slowly rising DC breakdown test, applying a PASD pulse, then repeating the DC breakdown test; and (3) effect of high energy discharges on low energy voltage breakdown strength.

Fig. 4 shows data from the repeated application of a PASD pulse sufficient to breakdown the sample. The variation in breakdown voltages are statistical in nature. Fig. 5 shows DC breakdown testing of a set of 21 insulation samples before and after the application of a PASD pulse. PASD did not reduce the surface flashover strength of any of the materials tested. The PASD arc breakdown process occurs very rapidly. The impedance of the arc channel falls to 10% of its initial value in approximately 3 nanoseconds. This is an important characteristic as it improves the location accuracy of the PASD technique. Fig. 6 shows typical breakdown curves for insulation samples.

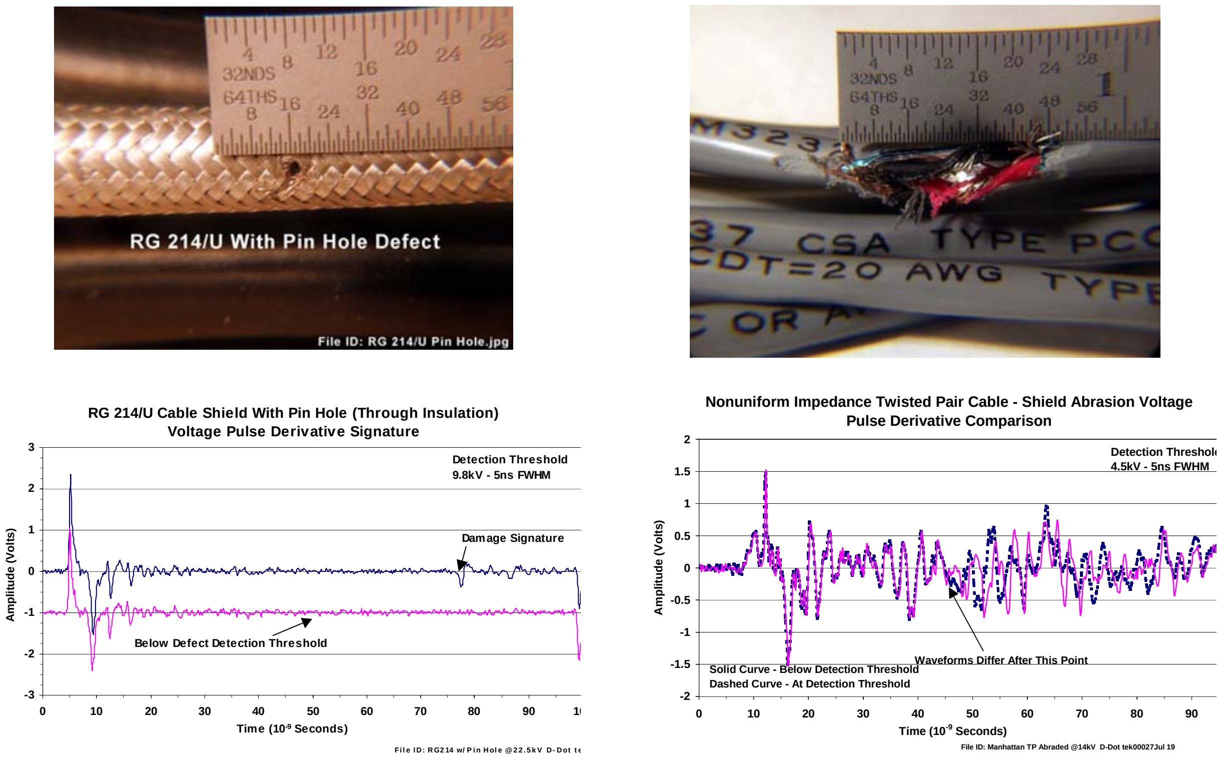

Figure 2. (Left) PASD waveforms from a test of a coaxial cable with damage to the outer shield braid and internal insulation. The inner conductor and outer shield remain fully conductive. The two waveforms deviate at the location of the defect, 78 nanoseconds down the line. In this example, the peak PASD pulse was 9.8 kV at a pulse width of 5ns. The amplitude scale is the voltage measured at the sensor.

(Right) PASD waveforms from a test of a twisted shielded pair cable. Insulation on the wire pairs has been abraided, but the inner conductors remain intact. The impedance of this cable is highly non-uniform, as evident by the multiple reflection in the PASD baseline (solid line). The dashed line is the normalized PASD pulse (4.5kV) which creates a breakdown at this defect site. The two waveforms separate at approximately 45ns, accurately indicating the location of the defect.

IV. The Ability of PASD to Locate Aircraft Wiring Defects

The PASD diagnostic has demonstrated that it can detect and locate chafing, breached wires and pin-hole wire defects under laboratory conditions and during testing at the FAA's Airworthiness Assurance NDC Validation Center (AANC) in Albuquerque, New Mexico (ref. 3). These types of defects are documented in the ATSRAC publications *Intrusive Inspection Final Report*, December 2000 (ref. 4), and *Aging Transport Systems Task 1 and 2 Final Report*, August 2000 (ref. 5), which were comprehensive joint government-manufacturer-operator (industry) studies sponsored by the FAA.

Several types of defects were tested using the AANC test bed enclosure, which is a mockup of aircraft wiring harnesses attached to aircraft-type panels. Fig. 7 shows the results on a DT1 insulation chafe on a 10 foot wiring harness in the modular testbed. Fig. 8 shows PASD waveforms from tests on a 100 foot pair of wires using a multipulse approach. An insulation defect was present with a 1.0 mm air gap between two conductors with a small amount of insulation stripped away.

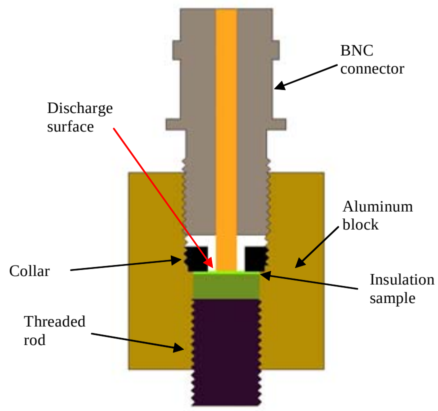

Figure 3. Test fixture used during flashover experiments. 8 mm diameter insulation samples were inserted into the center of the figure.

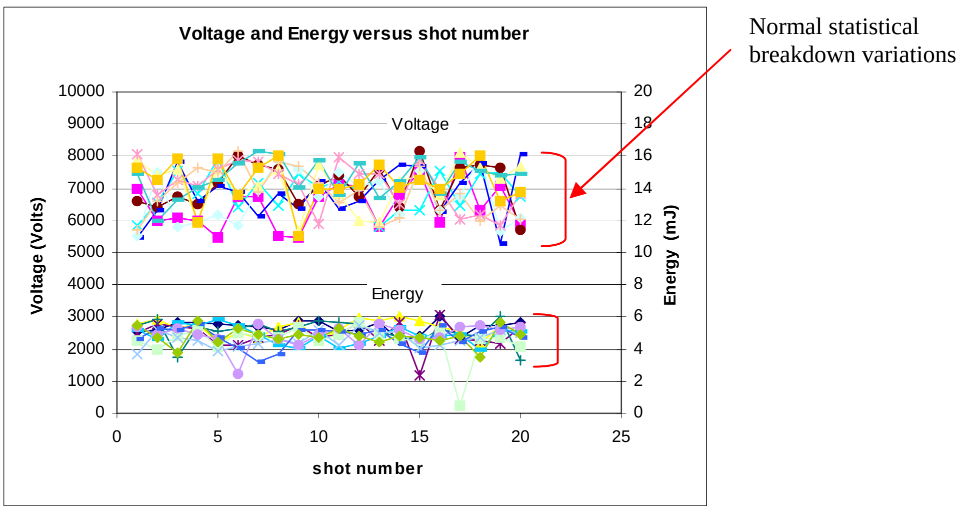

Figure 4. Typical breakdown results for an insulation sample exposed to repeated PASD breakdowns. Eight samples of the same dielectric material were exposed to 20 consecutive PASD breakdowns. The breakdown voltage of the samples did not trend lower. The average energy dissipated at the breakdown site was approximately 5 mJ per shot.

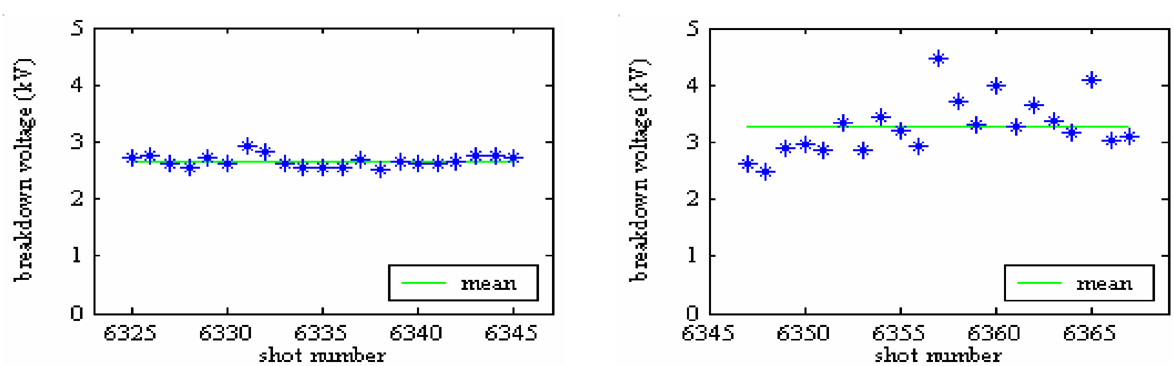

Figure 5. (Left) Example slow rising, low energy, DC breakdown voltages for multiple insulation samples. The samples broke down at an average of 2.8 kV+/- 0.2 kV. (Right) When exposed to slowly rising DC after the application of the PASD pulse, the average breakdown voltages remained the same or actually increased. This is a common high voltage conditioning phenomenon.

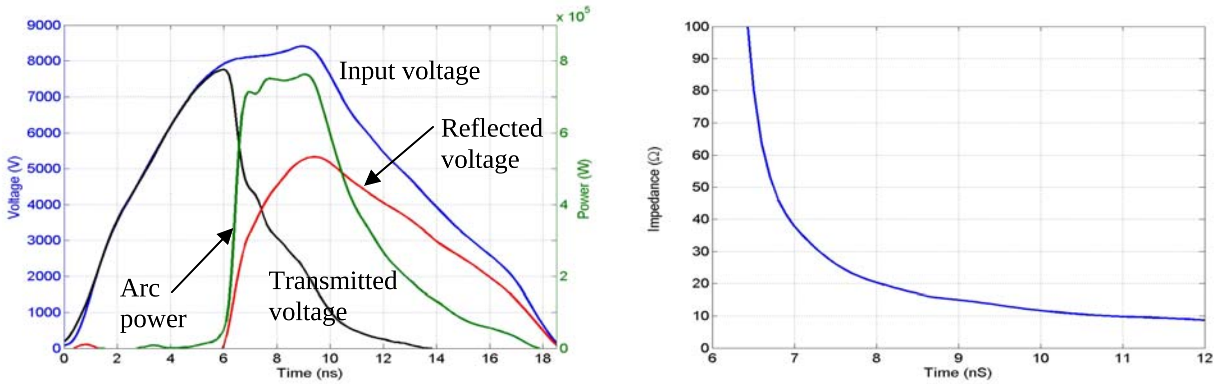

Figure 6. (Left) Arc impedance history. The power in the arc rises very rapidly (< 2ns), creating a fast rising reflected voltage waveform. It is this waveform that sets the location accuracy of PASD. (Right) Typical arc impedance as a function of time.

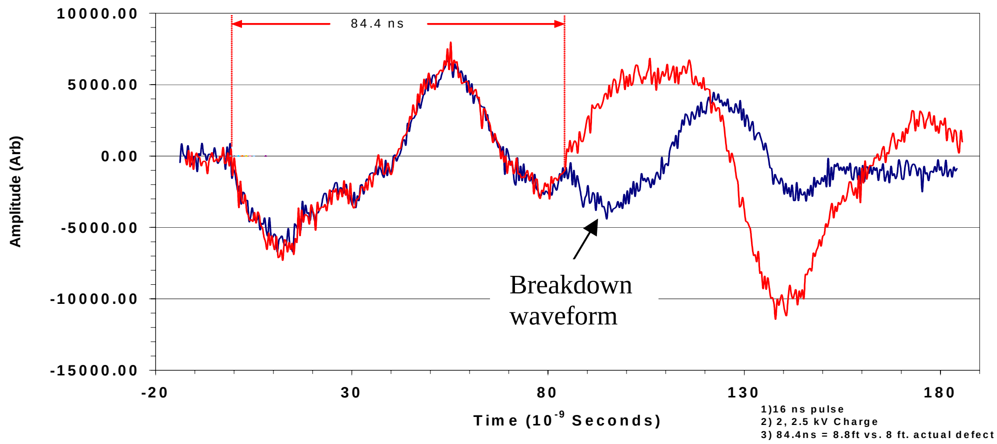

Figure7. PASD probe waveforms for an insulation chafe defect (DT1). The PASD waveforms separate at 84.4 ns. This implies that the defect was located at approximately 8.8 feet from the injection end of the harness. The actual location of the defect was at 8.0 feet.

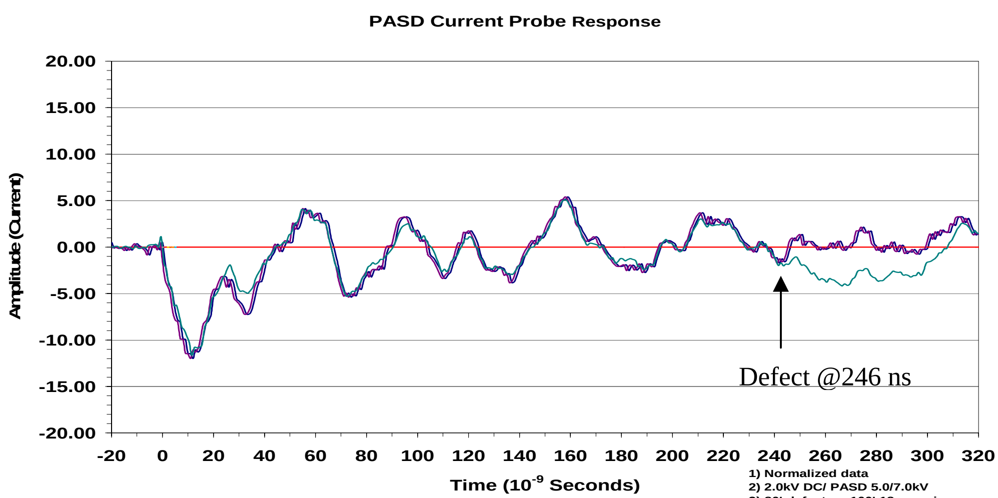

Figure 8. PASD waveforms from a test of a 100 foot wire harness with an insulation defect at 80 feet. The two waveforms deviate at the location of the defect, 246 nanoseconds down the line. The variations in the waveforms are caused by a varying impedance profile down the harness. The nature of impedance variations are not important since PASD uses a differencing technique to locate the defect.

A summary of testing at the AANC wiring test bed is shown in Table 1.

Gap spacing	QTY	DEFECTS DETECTED	DEFECTS UNDETECTED
DT-1 **Insulation chafe defect**			
1mm gap	**7**	**7**	**0**
3mm gap	**5**	**3**	**2**
DT-2 **Insulation breach defect**			
1mm gap	**2**	**2**	**0**
3mm gap	**6**	**3**	**3**
DT-3 **Cracked insulation defect**			
1mm gap	**6**	**3**	**3**
3mm gap	**1**	**0**	**1**
TOTAL	**29**	**17**	**12**

Table 1. Test results at the FAA's AANC wiring test bed. The gap spacing refers to the physical air gap from the exposed wire conductor to the nearest ground plane or adjacent grounded conductor. With a 1 mm air gap, PASD found 12 out of 15 defects present, including challenging cracked insulator defects. PASD was 100% effective in locating chaff and breach defects with air gaps up to 1 mm.

Conclusion

PASD is effective at detecting and locating a variety of insulation defects in complex wiring geometries. It is highly immune to line impedance variations, an important property in aircraft wiring systems, and has been shown to be nondestructive to electrical insulation materials. Due to the simplicity of the PASD concept, the low energy PASD pulser and diagnostics can be readily implemented into a portable diagnostic system. PASD shows great promise as an effective diagnostic to find difficult to locate insulation defects such as breached insulation, chaffing, and physically small insulation cracks. Although the PASD technique will likely evolve as it enters into field applications (pulse shape, testing strategy, etc.) it is capable of making a near-term impact on the ability of inspection and maintenance organizations to detect and locate potentially hazardous insulation defects.

Acknowledgments

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