Enhanced TDR Technique for fault detection in Electrical Wires and Cables

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Abstract. Degradation and failure of aircraft wiring insulation is of particular interest which could lead to smoke and fire due to arcing. With two recent major air accidents and hundreds of major incidents over the past twenty years, health monitoring and sustainment of wiring, particularly for aging aircraft is a major concern. The results of a technique based on TDR, using trains of successive pulses is presented in this paper for detection of partial damage to insulation in electrical wires and cables.

Introduction

Electrical wiring and cables used in many applications occasionally suffer damage. In many cases the damage only affects wire insulation and cannot be detected through routine tests and inspection. In aircraft the degradation of wires are generated because the wiring is subjected to heat, cold, moisture and vibration, which can eventually cause the wire insulation and even the wire conductor to fail. In most cases these environmental and operational conditions are modest, but in some cases these conditions are extreme and can cause the insulation to become brittle and crack. There are a range of factors that result in wire degradation and damage. These include vibration, which can result in insulation damage through rubbing on other wires or structural parts of the aircraft, hardening of wires, loosening of connections or terminations. Exposure to moisture and hydrolysis could lead to cracking and breakdown of insulation. Elevated temperatures or repeated thermal cycles can increase ageing rate. Exact wire position can also vary slightly from one aircraft to the next resulting in changes in bend radius, wire position relative to structural parts, clamping of wires and similar problems during maintenance. If this is not conducted correctly, it can result in the wire or insulation degradation, cracking and damage through the introduction of foreign bodies, such as metal shavings. Chemical Contamination, exposure to hydraulic fluid, fuel, battery electrolytes, waste system chemicals, cleaning solvents and agents, de-icing fluids, paints and soft drinks can also contribute to wire degradation. Time Domain Reflectometry is often used in many fields from ecology to fault detection in microelectronic circuits, but present systems developed so far are unable to detect minor faults resulting from insulation damage and partial degradation of electrical wires. Many other techniques have been investigated for finding faults in aircraft harnesses [1-3], communication lines [4] and power cables [5]. These mostly involve considerable change in localised impedance. A number of advanced techniques have also been developed for detection and characterisation of defects in wires and cables [6-9]. The detection of small impedance irregularities associated with chafes and frays are still very hard to detect [10]. Similar defects to those considered here were previously reported using ultrawide-band (UWB) signals for shorter lengths of cables [11-12]. Recent work also includes investigations in complex wired networks using distributed reflectometry [13-14]. The work described in this paper was carried out in order to investigate the development of a technique for the detection of small faults over long lengths of wires and cables, which would require sharp rise and fall times, as well as higher pulse spans of up to around 10 nanoseconds.

1. Measurements

1.1 Experimental Setup

An Agilent arbitrary pattern generator (81134A 3.35 GHz) was used to generate and launch the successive pulses into the cables. The reflected waveforms were then captured using an Agilent 4 GHz, 20GS/s Infiniium oscilloscope (MSO9404A). The Agilent pattern generator and oscilloscope were used in conjunction with a PC workstation in order to demonstrate this technique for the detection and locating damage to insulation and braiding in a coaxial cable. The insulation damage was created at an arbitrary position along the wire. The fault consisted of a 1.0 cm (10 mm) cut created on the insulation and braiding of an RG59 coaxial cable of a total length of six metres. This fault was created on one side of the cable in a position between the centre and the end of the cable. The central core conductor of the coaxial cable remained undamaged. This flaw which was created at around two thirds of the way down from the beginning of the cable was successfully detected using the ETDR technique.

1.2 Test Procedure

The technique uses injection of successive pulses with sharp rise and fall times into the cable. A large number of pulses are currently used at the demonstration stage for the technique. A similar number of pulses are also required for the original pulse conditions for representation of the no fault conditions. The time required for the flight and capture of a single pulse is around 200 ns. So, one full set of measurement results should be obtained well within 100 μs. For the demonstration purposes, a PC workstation was used for control and synchronisation of the Agilent pattern generator and the scope, as well as processing and analysis of the results. This PC was networked through a hub for connection with the pulse generator and oscilloscope. The generation of the pulses through the pulse generator and capture of the reflection signals through the scope was automated using dedicated Agilent software operated through Matlab. As a consequence of communication through the router, control of the constituent parts of the system and processing of the measurements through the PC, long delays are expected. The final system should be able to provide fault detection within a few minutes. The processing of the results is presently done using Microsoft Excel, and Matlab, which will return a single file. this can then be displayed graphically where start and the end of the cable together with the fault are identified.

Figure 1 shows the experimental setup used in the measurements, Agilent 81134A 3.35 GHz Pattern Generator and Agilent 4 GHz, 20GS/s Infiniium oscilloscope (MSO9404A). An Agilent 81150A 120 MHz arbitrary waveform generator (the instrument on the top right in figure 1) was initially used to synchronise the 3.35 GHz generator and the 4GHz Infiniium scope with each other, and was not used in the measurements. Figure 2 shows the selected position (marked by brown tape on the floor), for creation of the arbitrary Fault which was chosen to be at around two meters from the end of the six meter long cable under test.

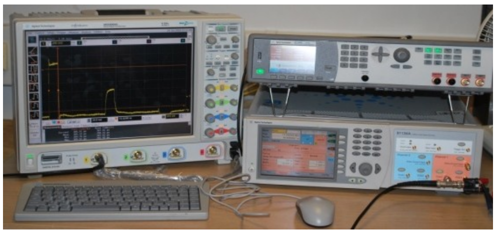

Figure 1. The experimental setup, Agilent Pattern Generators and Infiniium oscilloscope.

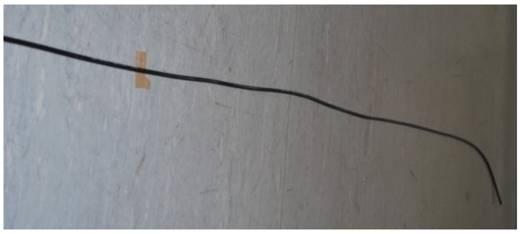

Figure 2. The selected position for the creation of the fault at two meters from the end of the six meter long cable.

Figures 3 and 4 show the position, shape and size of the 10 mm fault created in an RG59 coaxial cable of an overall length of six metres. This defect was created on the insulation and braiding on one side of the cable. The central core conductor of the coaxial cable remained unaffected.

Figure 3. Fault created at around two meters from end of the six meter long cable (the position shown in Figure 2).

Figure 4. Shape and size of the 10 mm fault created on the insulation and braiding of an RG59 coaxial cable.

2. Results

As mentioned, the technique involves injection of a large number of pulses of varying size into the cable under test which span over 5, and in some cases 10 nanoseconds. The analysis of these pulses is then carried out which will provide the anomalies due to the defects to be detected. Figure 5 shows the reflection trace for a test pulse, observed on the Agilent 4 GHz, 20GS/s Infiniium oscilloscope, with rise and fall times of around 132 and 121 picoseconds respectively. A positive reflection from the end of the cable is also seen, which was an open circuit in this case.

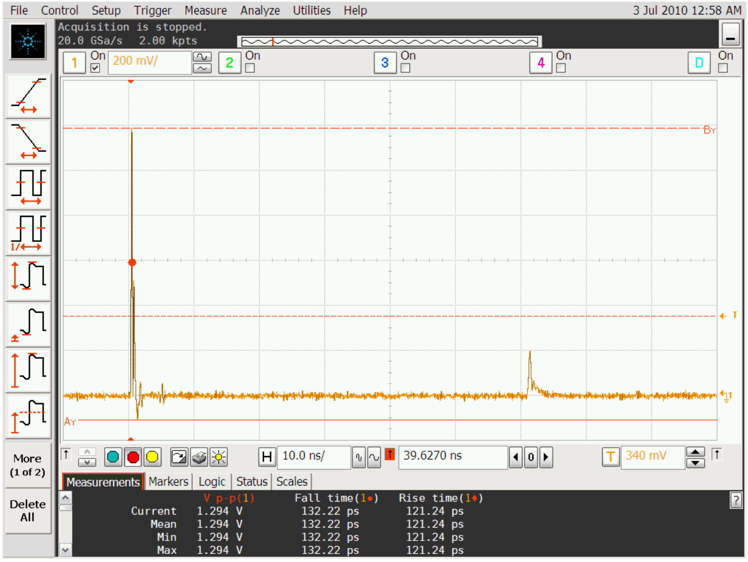

Figure 5. Captured image of a test pulse with rise and fall times of around 132 and 121 picoseconds respectively showing a positive reflection from the end of the cable (which is open circuit in this case).

Figure 6 shows analysis of the results obtained for the six metre long RG49 coaxial cable with a 10 mm fault created on the insulation and shielding screen of at around two thirds of the distance from the beginning of the cable where TDR pulses were being injected into the cable.

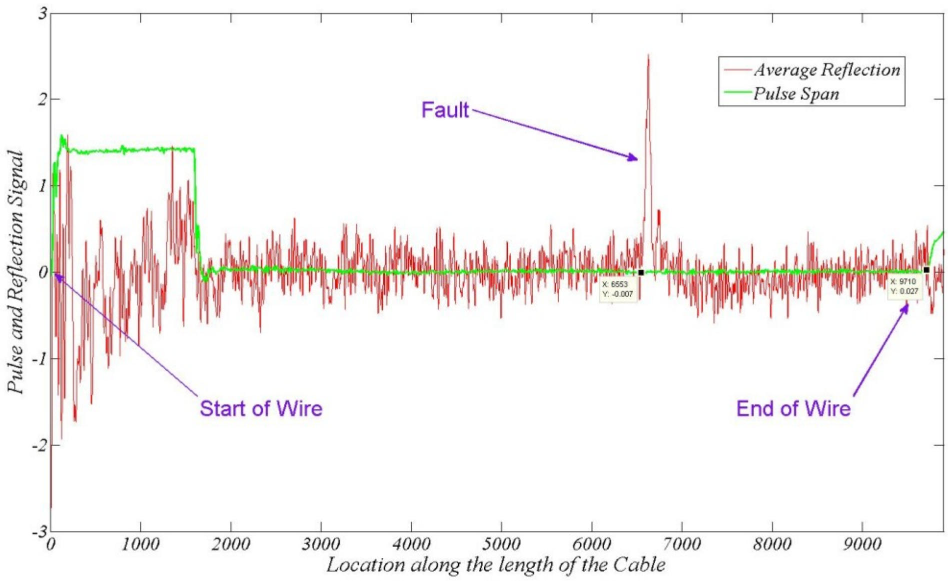

Figure 6. Analysed results for the detection of a 10 mm fault created on the insulation and shielding screen at two thirds of the distance down a six metre long coaxial cable. The large spike in the trace is due to the fault.

The figure shows the analysed reflected signals from the cable, which starts from point zero on the horizontal axis, as indicated in the figure, coinciding with the rise of the green trace, representing the pulse span. The pulse span describes the width within which all injected pulses are contained. The end of the cable can also be determined by the rise of the pulse span trace when the pulses are reflected from the end of the cable, which was an open circuit in this case. In real terms, the TDR traces show a distance equivalent to that of twice the time of flight to the end of the cable, since the measurements are carried out at one end of the cable under test, and the time taken for the reflection signal to reach the detector would have to cover the length of the cable, and its return back to the detector. The pulse span itself, in this case, is the period of time where multiple pulse lengths are launched into the cable and hence cannot be included in the measurements. A 10 ns time span is generally the time of flight in around one metre for most of the wires and cables. In this case the fault was created at around four metres down from the start of the cable. The position of the fault is shown as indicated in the figure, as a large spike. This spike is clearly seen to be well above the measurement noise along the axis.

3. Work in progress

Smaller 5 mm defects were also investigated in shielded twisted pair cables as well as the above mentioned RG59 cable, which are currently being analysed. Computer models of these cables are also currently under examination, using both finite element and finite difference techniques.

4. Conclusions

An experimental technique has been developed for detection of small faults over long lengths of wires and cables. The technique uses injection of successive pulses with sharp rise and fall times, and with higher pulse spans of up to around 10 nanoseconds into the cable, in order to detect small faults over longer distances. The technique has been used to accurately detect the position of a 10 mm fault created on the insulation and braiding on one side of a six metre long coaxial cable.

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