

Aircraft Cable with Connector Fault Modeling and Diagnosis

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Abstract: The aircraft complex across multiple conn paper, set up the aircraft cable cross connector open defect mathematical model and corresponding simulation model, the time domain reflection method is used to calculate and analysis the transformation rule of characteristic impedance and reflection coefficient when the aircraft cable across one or more connector. The aircraft cable open defect with a narrow delay pulse waveform across one or more connector reflection and transmission is researched in Matlab Simulink, the aircraft cable connector fault diagnosis system is built in the industrial computer hardware platform and the LabVIEW software. The experiment result showing: simulation model in the aircraft cable open defect multiple cross connector is scalable, waveform identification level is high, at high sampling rate in the hardware platform can realize aircraft cable connector fault diagnosis and locating.

Keywords: Connector cable, time domain reflection method, Matlab Simulink, LabVIEW.

1. INTRODUCTION

Aircraft cable is an important device to provide power and control signals to the aircraft electrical and electronic systems, widely distributed in all parts of the plane. In the actual aircraft cable laying, because the body structure and signal transmission pathways, aircraft cable often connect through multiple connectors, the schematic diagram of the airplane cabin wall cable laying is showing in Fig. (1).

Since the age of growth, inadequate maintenance and other reasons, the aircraft cable connector shortening, insulation wear, cable short defects and open defects will happen, these faults lead to indicating instrument instability, manipulation of mechanical failure, abnormal signal, short defects caused fire and other consequences, threaten continuing airworthiness of aircraft, how to identify and diagnose aircraft cable fault is an urgent need to be solved.

Domestic and foreign literature data show that in the field of electrical systems, the time domain reflectometry is applied for diagnosing and locating the cable short defects and open defects and made a series of achievements. Time domain reflectometry method give the cable a high-frequency pulse or step signal, measure superimposed signal formed by incident and reflected signals, through analyzing the cable characteristic impedance changes information that come from superimposed signal to determine whether the cable is faulty or not. However, due to the aircraft cable shorter distances, connected by connectors, connector shortening and so on, based time-domain reflectometry research in aircraft cable connector shortening model, the superimposed signal

reflecting law and the related studies in the country did not see [1, 2]. Document 2 construct a time domain mathematical model of wire insulation defects, analyzes the characteristic impedance variation rules from damaged cable, but the model does not consider the phase shift constant term in conductor voltage and current differential equations, when the input waveform is high-frequency pulse wave, the superimposed signal is difficult to reflect actual pulse phase shift position, this led to the cable fault is difficult locate.

Based on time-domain reflectometry, the paper establish mathematical model of aircraft across connector cable which tail is open, through signal propagation characteristics and the characteristic impedance changes from the narrow pulse signal across one and more connectors, the simulation model is got in Matlab / SIMULINK. At the same time, the practical system for verification is built, the results show that aircraft across connector cable short defects and open defects can be checked by the characteristic impedance changes from the superimposed signal cross one and more connectors, and provide a theoretical basis for aircraft cable connector shortening fault detection.

2. AIRCRAFT CABLE CONNECTORS FAULTS AND MATHEMATICAL MODELS

2.1. Aircraft Cable Connectors Faults

With modern aircraft to more electric and all-electric direction, in order to meet the aircraft electrical and electronic systems should have the capability of lightning and HIRF protection airworthiness requirements, currently the most used aircraft cable is single line and multi-core wire with shield, connect through one or more connectors. Cable faults often appear on connectors, mostly with open defects, short

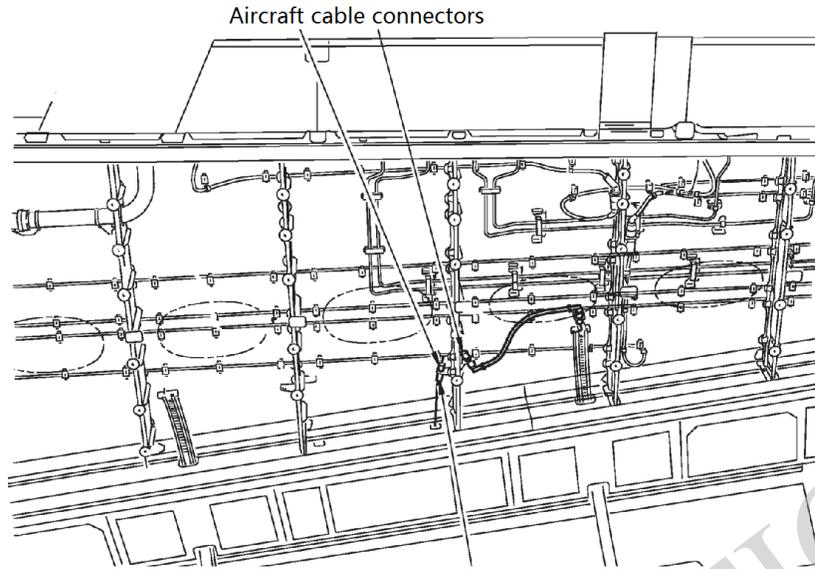


Fig. (1). The schematic diagram of the airplane cabin wall cable laying.

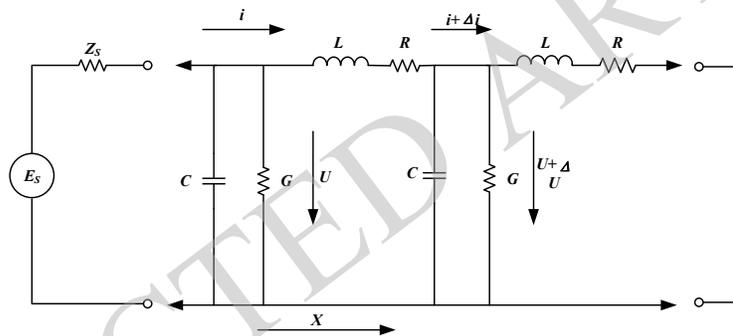


Fig. (2). The unit length of the cable equivalent circuit.

defects and connector shortening, few with external insulation abrasion, aging, corrosion and other cable phenomenon of aging [3-5].

According to the theory of transmission line, the aircraft cable faults such as cable connector shortening, open defects, short defects can be expressed as the process of changes in the characteristics impedance of cable and cable connector influence the incident electromagnetic wave, cable and connectors can be constructed in the current-voltage differential equations to explain the characteristic impedance changes of cable connector shortening, open defects and short defects.

2.2 Aircraft Cable Connectors Faults Mathematical Model Based on Time Domain Reflectometry

According to the theory of transmission line, for a good cable, cable is a distributed parameter circuit, can be constituted by the unit length of the resistance, inductance, capacitance, and conductance, the distributed parameter values related to the size of the cable, the wire material and the filled medium parameters. Unit length x of the cable equivalent circuit shown in Fig. (2).

Cable characteristics differential equation:

$$\begin{cases} -\frac{\partial u(x,t)}{\partial x} = i(x,t)R + L \frac{\partial i(x,t)}{\partial t} \\ -\frac{\partial i(x,t)}{\partial x} = u(x,t)G + C \frac{\partial u(x,t)}{\partial t} \end{cases} \quad (1)$$

Where R, L, C, G represent the distribution resistance, inductance, capacitance and conductance of cable per unit length, the negative sign indicates the transmission line voltage, the current in the positive x direction of the transfer is reduced. Solving equation (1), it is get:

$$\begin{cases} U(x,t) = A_1 e^{-\alpha x} \cos(\omega t - \beta x) + A_2 e^{\alpha x} \cos(\omega t - \beta x) \\ I(x,t) = \frac{1}{Z_0} (A_1 e^{-\alpha x} \cos(\omega t - \beta x) + A_2 e^{\alpha x} \cos(\omega t - \beta x)) \\ = A_1 e^{-\alpha x} e^{-j\beta x} + A_2 e^{j\alpha x} e^{j\beta x} \\ = \frac{A_1}{Z_0} e^{-\alpha x} e^{-j\beta x} + \frac{A_2}{Z_0} e^{j\alpha x} e^{j\beta x} \end{cases} \quad (2)$$

Table 1. Table of reflection coefficient and transmission coefficient

Type	Reflection Coefficient	Transmission Coefficient
Connector	$-1 < \rho < 1$	$-1 < \rho_1 < 1$
Open defect	$\rho = +1$	0
Short defect	$\rho = -1$	0

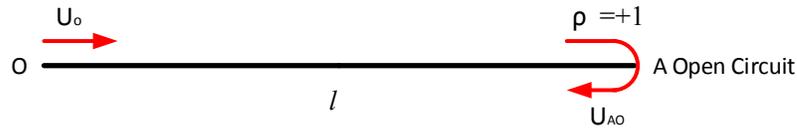


Fig. (3). Time domain waveform schematic diagram of the aircraft cable which tail is opened.

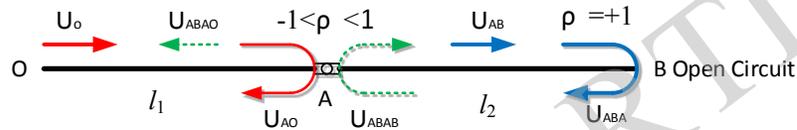


Fig. (4). Time domain waveform schematic diagram of the aircraft cable across a connector which tail is opened.

Where α is a attenuation constant, identify the amplitude attenuation of the signal waveform, β is a phase constant, identify the changes in the signal waveform phase, $Z_0 = \sqrt{L/C}$ (Characteristic impedance), they are all related to the signal frequency ω ; A_1 , A_2 are integration constant to be determined, is determined by the initial conditions. In equation 2, items containing $e^{-\alpha x}$ indicates the reflected signal, items $e^{j\alpha x}$ containing indicates the incident signal [6].

Cable characteristic impedance is defined as the incident signal voltage divided by the incident signal current, cable reflection coefficient is defined as the ratio of cable in a point reflected voltage (current) and the incident voltage (current). If the cable connect by connectors, the alloy material and the cable connector features parameters is different, the characteristic impedance changes in connectors is occurred.

According to the theory of time domain reflectometry, when the high-frequency pulse or step signal transmitted to the impedance changing area, signal is reflected and transmission, reflection coefficient and transmission coefficient in the impedance changing area is shown in Table 1.

In Table 1, ρ is reflection coefficient, $\rho_1 = 1 + \rho$ is transmission coefficient. In cable tail, the reflected signal occurs only, no transmission phenomenon happen.

Fig. (3). is a time domain waveform schematic diagram of the aircraft cable which tail is opened.

In Fig. (3), for length l aircraft cable which tail is opened, because there is no connector, input time domain signal U_0 , reflections occur at the cable end A, generate a

reflected signal U_{AO} which spread to the beginning of cable, so according to equation (2) and Table 1, the reflected signal U_{AO} at the cable end A is:

$$U_{AO} = A_1 \rho U_0 e^{-\alpha l} e^{-\beta l} = A_1 U_0 e^{-\alpha l} e^{-\beta l} \quad (3)$$

It can be seen that incident signal reflected totally, considering the attenuation coefficient and phase-shift coefficient, the reflected signal push back a certain phase, amplitude reduce.

When the cable across a connector, a time domain waveform schematic diagram of the aircraft cable which tail is opened shown in Fig. (4).

In Fig. (4), due to impedance mismatching at the connector, input time-domain signal U_0 occur reflection and transmission at the connector A, reflected signal U_{AO} return starting side O, reflection coefficient express as ρ , transmitted signal U_{AB} transfer to the end of cable B, transmission coefficient express as ρ_1 , reflected totally at the end of cable B, generate signal U_{ABA} , signal U_{ABA} transmission direction opposite to the incident signal, become the second incident signal, U_{ABA} occur reflection and transmission twice at the connector A, transmitted signal U_{ABAO} transfer to the starting side O, reflected signal U_{ABAB} return the end of cable B. At this point, the time-domain waveform signal propagate completely across a connector.

Comparing to no connector aircraft cable, due to reflection and transmission phenomena occurring on impedance mismatches connectors, the signal will continue to reciprocate repeatedly between the starting end and a connector, reflection and transmission is occurred, therefore, there are a

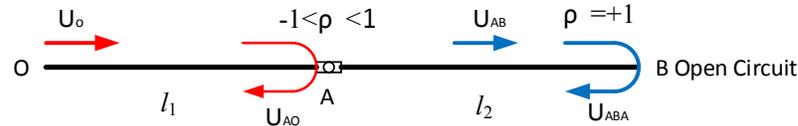


Fig. (5), Real time domain waveform schematic diagram of the aircraft cable across a connector which tail is opened.

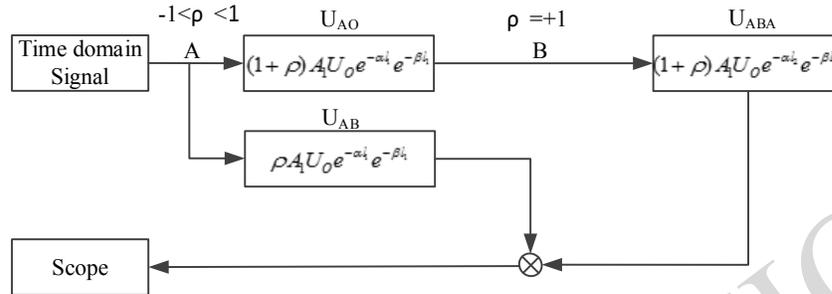


Fig. (6). Mathematical model of the aircraft cable across a connector which tail is opened.

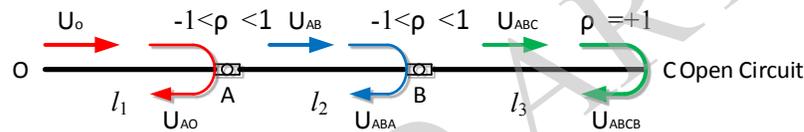


Fig. (7). Time domain waveform Schematic diagram of the aircraft cable across two connector which tail is opened.

number of weaker spaced superposed reflected signals continue to come. However, signal loss is happened during transmitting in the cable, signal amplitude is gradually reduced, and becomes more and more slowly rise. So in fact, only the first reflected signal waveform real work, cannot think the subsequent reflected signal as the connector reflected signal, that signal U_{ABAO} and U_{ABAB} disregarded. The time domain waveform real schematic diagram of the aircraft cable across a connector which tail is opened is shown in Fig. (5).

In Fig. (5), at the connector A, reflected signal U_{AO} and transmitted signal U_{AB} is got in equation 4 and equation 5, reflected signal at the end of cable B is expressed as equation 6.

$$U_{AO} = A_1 \rho U_o e^{-\alpha_1} e^{-\beta_1} \tag{4}$$

$$U_{AB} = A_1 \rho_1 U_o e^{-\alpha_1} e^{-\beta_1} = (1 + \rho) A_1 U_o e^{-\alpha_1} e^{-\beta_1} \tag{5}$$

$$U_{ABA} = (1 + \rho) \rho A_1 U_o e^{-\alpha_1} e^{-\beta_1} = (1 + \rho) A_1 U_o e^{-\alpha_1} e^{-\beta_1} \tag{6}$$

It can be seen that incident signal generate reflected signal U_{AO} and transmitted signal U_{AB} after across connector A, considering the attenuation coefficient and phase-shift coefficient, the reflected signal U_{AO} push back a certain phase, amplitude attenuate. Transmitted signal U_{AB} reflected totally at the end of cable, compare to U_{AO} , the phase of U_{ABA} push back mostly. According to the standard of aircraft cable

laying, connector pin material used alloy silver plating, the characteristic impedance of cable connector is less than cable, the energy of reflected signal U_{AO} is inevitably less than transmitted signal U_{AB} , $\rho < \rho_1 = 1 + \rho$. Mathematical model constructed is shown in Fig. (6).

In Fig. (6), U_{AO} , U_{AB} and U_{ABA} respectively calculated by the equation 4, 5, 6. When the cable connectors connect loosely and generate connector shortening, connector impedance increases, the value of it related to pin contacting area, pin material, test environment and other factors. According to the situation, the parameters A_1 , α , β can be adjusted, the model can promote to multi-connector, the time domain waveform schematic diagram of the aircraft cable across two connector which tail is opened is shown in Fig. (7), its mathematical model is shown in Fig. (8).

3. AIRCRAFT CABLE CONNECTORS FAULTS SIMULINK SIMULATION MODEL

3.1 Simulink Simulation Model Based on Time Domain Reflectometry

As the aircraft cable length is shorter, the cable resistance and conductance can be ignored in the analysis of time-domain signal propagation, the mathematical model in Fig. (6) and Fig. (8) can be simplified to the transmission delay part and transmission reflection part, the time delay part used

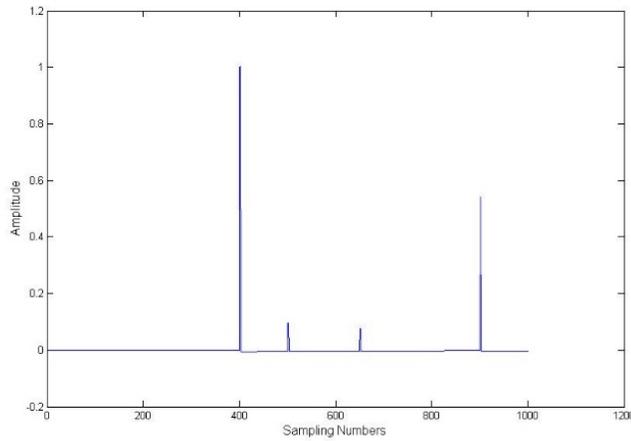


Fig. (10). Simulation results of the aircraft cable across two connector which tail is opened.

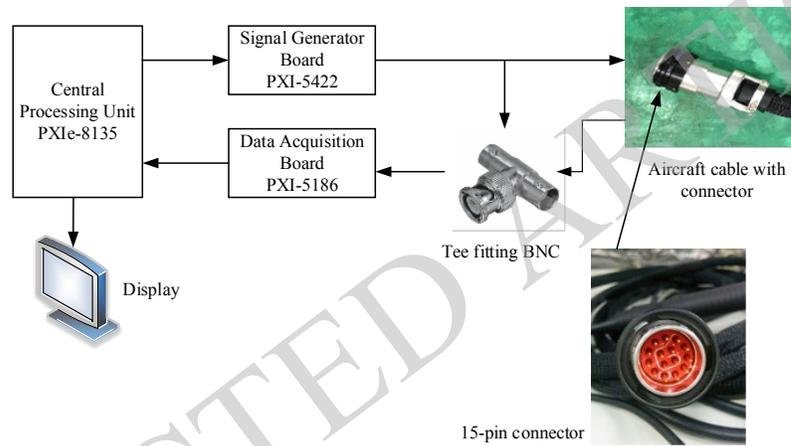


Fig. (11). The experimental platform of aircraft cable cross connector fault diagnosis system.

4. AIRCRAFT CABLE CROSS CONNECTOR FAULT DIAGNOSIS SYSTEM

4.1. The Experimental Platform

The experimental platform of aircraft cross connector cable fault diagnosis system is composed by IPC PXI, PXI-5422 signal generator board, PXI-5186 data acquisition board with bus control, the tested cables and cable connectors, diagram shown in Fig. (11). Among them, the data acquisition board synchronous sampling rate is 12.5GB/s; the tested cables is shielded single wire, cable core is silver plated copper wire, shield is double silver-plated copper braid. The tested aviation connector is 15-pin connector, male model is BACC63CBA4-15P6, female is BACC63CC14-1556, pin material is silver alloy.

Labview is used for constructing software platform, where signal generation, signal acquisition and signal operation can be achieved. 5V high frequency narrow delay pulse is generated in signal generator board, the input signal, the connectors reflected signal and the reflected signal at the end of cable is simultaneously sampled in data acquisition board. As a processing unit, IPC achieve signal wavelet denoising

processing, connector shortening fault analysis, the end of cable fault analysis. Physical platform is shown in Fig. (12).

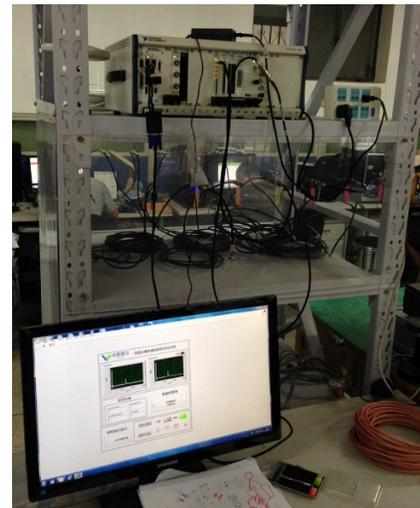
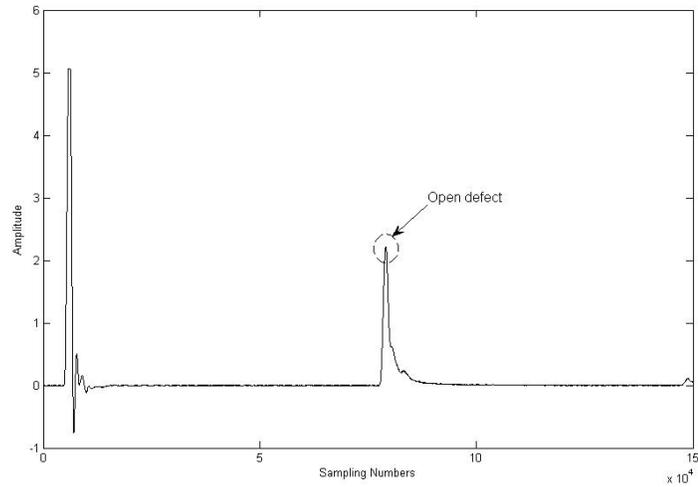
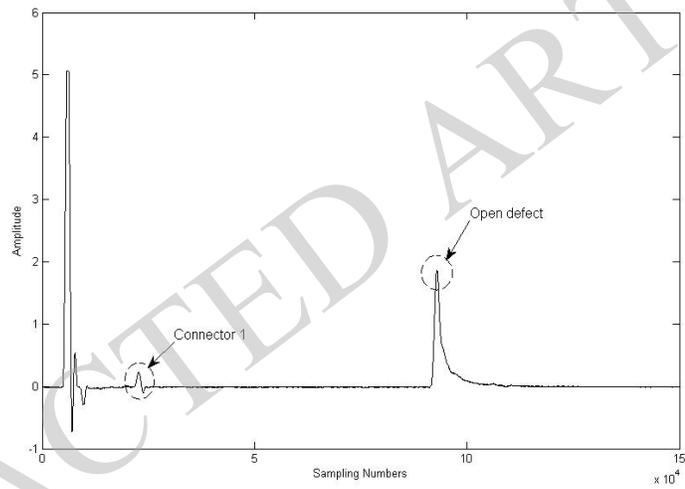


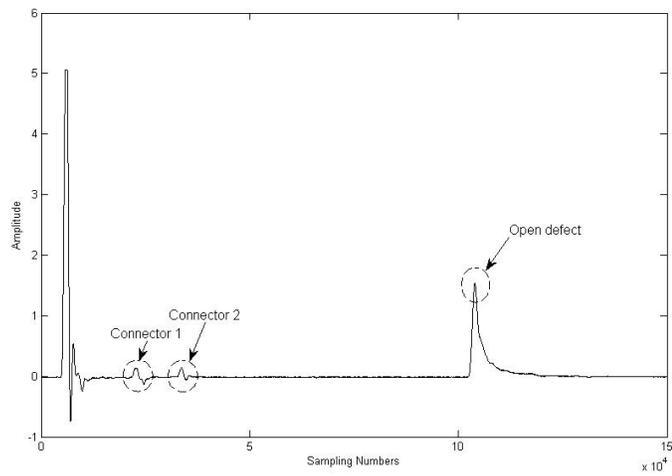
Fig. (12). Physical platform of diagnosis system.



(a) no connector

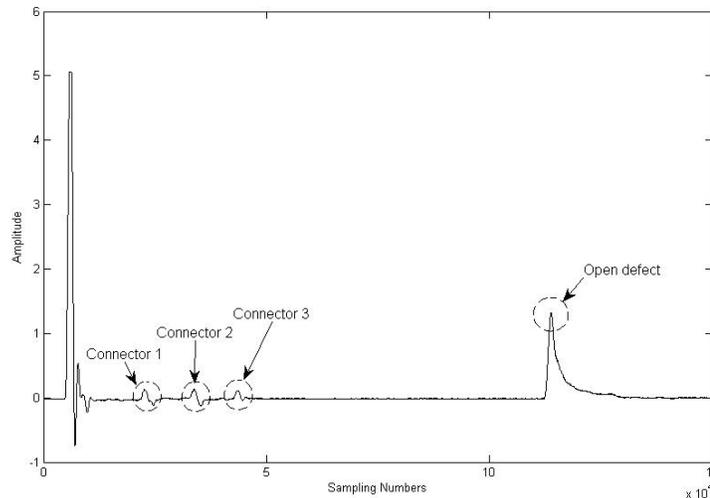


(b) one connector



(c) two connector

Fig. (13). contd...



(d) three connector

Fig. (13). The collecting time domain reflectometry waveform of cable which tail is opened.

4.2. The Experimental Results of Aircraft Cross Multiple Connector Cable Fault which Tail is Opened and the Comparative Analysis with Simulation Results

Several aircraft cables of the same length is chosen, connect with connectors, its tail is opened. The across multiple connector cable is constructed according by cross connector cable model shown in Fig. (6), due to the impedance mismatch at the connector, the number of connectors and fault condition at the end of cable can be determined by analyzing superimposed signal status composed with the input signal and the reflected signal. Fig. (13) is the collecting time domain reflectometry waveform of cable which tail is opened in diagnosis system, (a) is no connector, (b) is cross a connector, (c) is cross two connectors and (d) is cross three connectors.

As can be seen, due to cable materials, production processes and length is different, the impedance of connector pin less than cable impedance, the impedance matching point is generated at cable connectors, and according to the mathematical model constructed in Fig. (8), the transmitted signal energy is greater than the reflected signal energy at the connectors, there are obvious signal energy is reflected in the position of connectors and cable tail.

These results and the simulation results are the same, for aircraft cross multiple connector cable, in premise of ensuring incident signal rise time and sampling circuit synchronous sampling rate, if the propagation velocity and time can be determined, the position of connectors fault and cable tail fault can be sure by the position of energy appearing and signal wavelength, the fault location can be achieved.

4.3. The Analysis of Cable Connector Shortening Fault

Cable connector shortening fault is the most frequently fault in aircraft cable fault, due to changes in the contacting area of the connector pin, not full contact, impedance change inevitable, we can determine whether the connector shortening happened by analyzing the amplitude of the superimposed signal which composed with the incident and reflected

signals. In experiment, the length of connector pin is 2.5cm, take experiment by shrinking connector pin contacting area to 1cm. Fig. (14) is the collecting time domain reflectometry waveform of cable which tail is opened in diagnosis system, (a) is connector connected tightly, (b) is connector shortened 1cm.

As can be seen, when the pin contacting area shrink to 1cm, obviously impedance changes is occurred at the connector, the transmission coefficient and the reflection coefficient increases, connector energy consumed obviously, cable tail energy weaken. If the pin shrinking reduce to 0.5cm, the impedance changes of connector is obviously too.

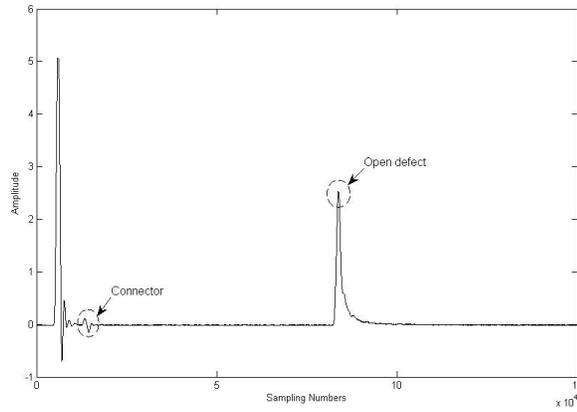
These results and the simulation results are the same, when the connector shortening happen, in premise of ensuring incident signal rise time and sampling circuit synchronous sampling rate, if the propagation velocity and time can be determined, the connector shortening fault judgment and location can be achieved, and the degree of connector shortening can be reflected by the amplitude of reflected waveform.

CONCLUSION

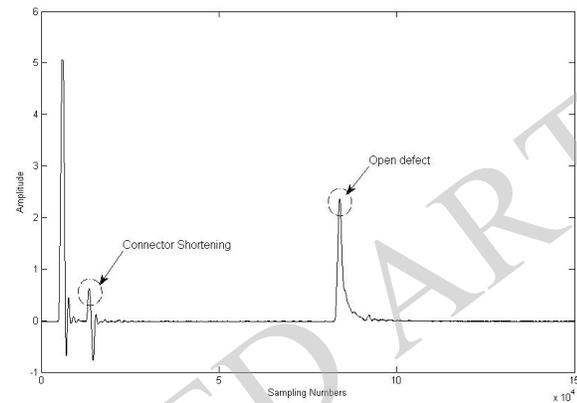
The time domain reflection method is used to calculate and analyze the transformation rule of characteristic impedance and reflection coefficient when the aircraft cable across one or multiple connectors.

The fluctuated reflection and transmission narrow delay pulse waveform is researched with Matlab Simulink to find the difference between one and multiple connectors under the situation of aircraft cable open failure. The aircraft cable connector failure diagnosis system is built by the industrial computer hardware platform and LabVIEW software.

Simulation and experimental results show that this method is accurate and effective. The simulation method provides a simulation model and theoretical basis for the future research of cable connector shortening fault locating research and analysis.



(a) tightly



(b) connector shortened

Fig. (14). The collecting time domain reflectometry waveform of cable which tail is opened.

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CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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