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MODELLING OF GUIDED ULTRASONIC WAVE IN AIRCRAFT WIRING

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Abstract

Degradation and failure of aircraft wiring insulation results in potential flight safety critical system failure or in smoke and fire due to arcing. Therefore, there is a need to detect any defect within the physical structure of the aged wire before any malfunction takes place. There are different types of Non-Destructive Testing (NDT) techniques available for aircraft wiring inspection and one of them is the ultrasonic guided waves technique. Using guided wave ultrasonics, inspection can be carried out for a long distance from a single location. In order to understand the behaviour of guided waves in aircraft wiring, a modelling tool was used to simulate and predict the behaviour of guided wave characteristics in wires with respect to the stiffness property of the insulation. Artificial defects were introduced into the wire. Finally, the modelling results have been validated experimentally.

1. Introduction

One of the greatest concerns the aerospace industry has is ageing wiring inspection. Aircraft wires operate under constant change of operational conditions i.e. aircraft wires might operate under a cold, hot or humid environment with variations in the atmospheric pressure [1-4] . Operating in such conditions might create chafes, cracks, cuts, delamination or embrittlement in the insulation of the aircraft wires. The extreme conditions the aircraft wires operate it may cause failure if it becomes brittle or cracked [1-4] . This status of the aircraft wire is a potential fire hazard. Therefore, there is a need for an inspection technique to improve the reliability of the aircraft wiring. NDT technology can be used to inspect aircraft wires. NDT is promising the aerospace industry to reduce its maintenance costs by 70% [1] . NDT will increase the system lifetime operation. This will consequently reduce the need for new products, which gives financial gain to the aerospace industry.

Low Power Laser-Diode, Pulse Arrested Spark Discharge (PASD), Time Domain Reflectometry (TDR), Frequency Domain Reflectometry and Infrared Thermograph (FDR) [2,5-9] are NDT techniques used to inspect aircraft wires. However, some of these NDT techniques lack the ability to assess the conditions of the insulation in the wire or damages the insulation by its high power signal, while other techniques require removal of wire insulation or disconnecting wire ends. These disconnecting and connecting mechanisms would increase the risk of induced maintenance failure [2,5-9] .

This paper reports the potential of utilising ultrasonic guided waves as an NDT technique to inspect ageing aircraft wires. Guided waves use the cylindrical geometry of the wire as a wave guide to propagate through its structure[4,10,11]. Under the assumption that there is a perfect contact condition between the two materials in the wire[7,8], guided waves propagate in both the conductor and insulator of the aircraft wires. Two types of wave mode exist in the cylindrical geometry, axi-symmetrical and flexural[1,10-12]. The axi-symmetric wave mode is non-dispersive at the low frequency. Hence, this wave mode will be the focus of this paper. The axi-symmetric wave mode is in the order of a zero circumferential wave mode and can be divided into two types; the axi-radial and torsional. The axi-symmetric wave mode decreases slightly below the Rayleigh velocity as the frequency increases. The circumferential wave mode of order one is the flexural wave mode. This wave mode is highly dispersive at low frequencies. However, the velocity of this wave mode tends to approach just below the Rayleigh wave mode velocity as the frequency increases[4,10-13]. Furthermore, the velocity of both wave modes is a function of: geometry, frequency, wave mode order, and the material stiffness of the conductor and the insulator. A number of authors have reported that the flexural wave mode has a higher energy than the axi-symmetric wave mode[8,10] due to its mode of excitation[10]. While, the insulation material has a significant effect on the travelling wave modes in terms of its velocity and attenuation[10,13]. In addition, insulation has an effect on the dispersion curves, where it decreases the frequency range of the non-dispersive region.

In this paper, dispersion curves has been generated for insulated wire and used to describe the modes behaviour. Transient axi-symmetric model has been developed and confirmed the dispersion curves findings. Finally the transient model has been correlated based on experimental data.

2. Numerical Modelling

2.1 Dispersion Curves

Dispersion curves are used to describe the nature of the existing wave modes at a particular frequency with respect to its travelling velocity. Dispersion curves have been constructed for an insulated wire with the following parameters[10,12]:

Material	Brass	Heat Shrinking Tubing
Young's Modulus (GPa)	108.94	0.72
Density (kg/m^3)	8500	958
Passion's Ratio	0.35	0.46
Rayleigh Velocity, (m/s)	2036	484
Radius, (mm)	1.59	2.175

Table 1: material property and dimensions for the Brass and Heat Shrink Tubing [10,12]

The radial displacement in figure 1.a shows very little amplitude vibration taking place. On the other hand, operating at the high frequency non-dispersive region (see fig 1.b), the longitudinal wave mode L (0,1) turns its axial displacement to radial displacement. Here, most of the propagation takes place in the insulation with no displacement in the conductor's material. Furthermore, figure1.e&1.f shows that operating at the dispersive region, all the axial and the radial displacement will take place in the insulator with no propagation in the conductor's material. Therefore, in order to propagate L (0, 1) in both insulator and conductor materials, exciting longitudinal wave-mode at low frequency will be the convenient way to propagate guided waves.

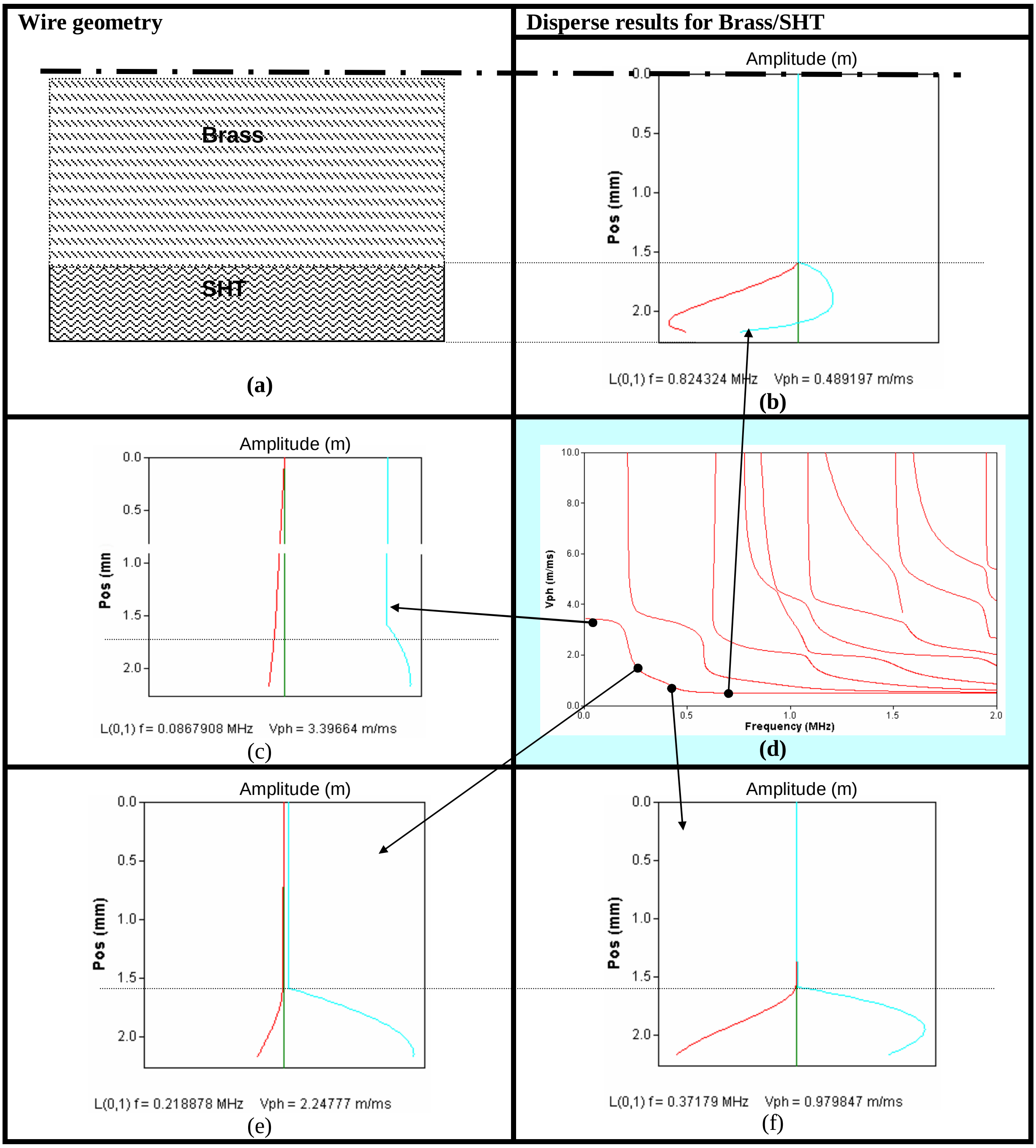

Figure 1: Shows different graphs for describing the displacement at different regions in the dispersion curves for the insulated wire: (a) representation insulated wire structure, (b) displacement of guided wave at high frequency in the non-dispersive region, (c) displacement of guided wave at low frequency in the non-dispersive region, (d) dispersion curves for insulated wires, (e) displacement of guided wave at the dispersive region at the low frequency region, (f) displacement of guided wave at the dispersive region at the high frequency region.

3. Experimental Work

In order to validate the findings of the numerical modelling carried out, it is important to carry out real physical experimentation trials. This section of the paper will look at the effect of exciting longitudinal wave mode in bare wire and insulated wire as well as looking at the optimum parameters with respect to the frequency and the number of cycles for the excited signal.

3.1 Initial Experimentation

The work is carried out to look at the effect of propagating longitudinal wave-modes in bare and insulated wire. The bare wire is made from copper, and it has been excited longitudinally with a frequency of 150 kHz. Figure 2 shows the propagation of the longitudinal wave at 150 kHz. A pulse echo technique is used to detect the reflected signals from the excited wave mode. The longitudinal wave is decaying as it propagates. This decay is the result of the dispersion effect and attenuation. According to this experimental condition, longitudinal waves can travel up to 8m in bare wire. A second test has been carried out for an insulated wire at an excitation frequency of 20 kHz. The reason for choosing this frequency is its high energy. As can be seen from figure 3, the wave in the insulated wire is highly attenuative and dispersive. According to this experimental condition, the longitudinal wave has travelled 4m in insulated wire. The longitudinal wave travels in bare wire further than in insulated wire. This is due to the presence of the soft material in the insulation, which results in signal attenuation and dispersion. These findings agree with the modelling and the literature. However, there is a need to find the optimum experimental parameters with respect to the excitation frequency and number of cycles.

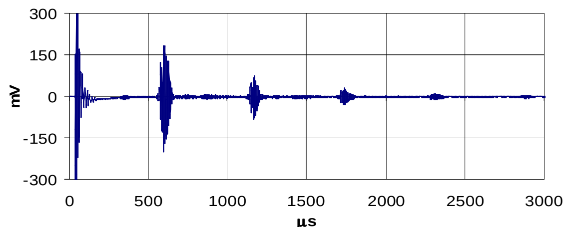

Figure 2: The propagation of longitudinal wave mode in a bare copper wire at 150 kHz

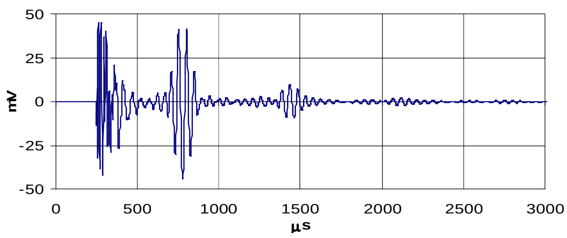

Figure 3: The propagation of longitudinal wave mode in an insulated wire at 20 kHz

3.2 Optimum Excitation Parameters

There is a need to find the optimum frequency range and number of cycles as this will have a significant effect on the nature of the excited wave, propagation distance, attenuation and dispersion. Therefore, a full study and analysis is needed to determine the parameters which satisfy these two factors. An initial experimental trial has been carried out to look into the effect of the number of cycles at different frequencies. A range of frequencies from 20 kHz up to 100 kHz with an increment of 10 kHz between each test was applied to the insulated wire.

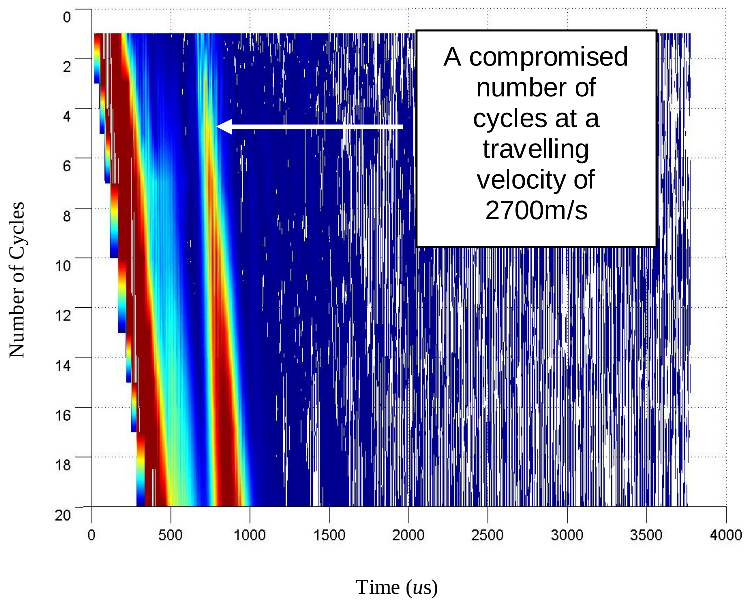

Figure 4: Experimental results for insulated wire at 60 kHz

Figure 4 shows the number of cycles (vertical axis) versus time (horizontal axis) at the excitation frequency of 60 kHz. From the figure, it shows that 5 cycles are a reasonable compromise number of cycles for the tone-burst signal to be constructed and propagated. Furthermore, the frequency range is also sufficient to propagate guided waves. The lower the frequency is, the higher energy the wave has. In contrast, the high frequency is, the lower energy the wave has, hence, higher attenuation. This attenuation is due to the presence of the insulation. At this frequency, the effect of dispersion of the output signal does not exhibit itself.

3.2 The effect of insulation in an insulated wire

To study the effect of insulation on propagating guided waves, as well as to confirm the findings in section 2.1, verification was required to confirm that there is only one wave mode present at the low frequency region. A number of experimental works were carried out for different lengths of insulation. The experiment started with a 1m insulated wire, the insulation was then gradually removed every 5cm. This is shown in figure 5, where L represents the length of the removed insulation. Throughout the experiment a 40 kHz 5cycles tone burst signal was used. The results are shown in pitch catch form in figure 6, where the x-axis shows the time of arrival for the signal, while the (y-axis) represents the insulation length. The results show that there is only one wave mode present at this structure. However, the presence of the insulation has decreased the inspection range. In addition, insulation imposes the effect of dispersion as well as increases the presence of attenuation of the wave.

Figure 5: An insulated wire with a gradual insulation removal

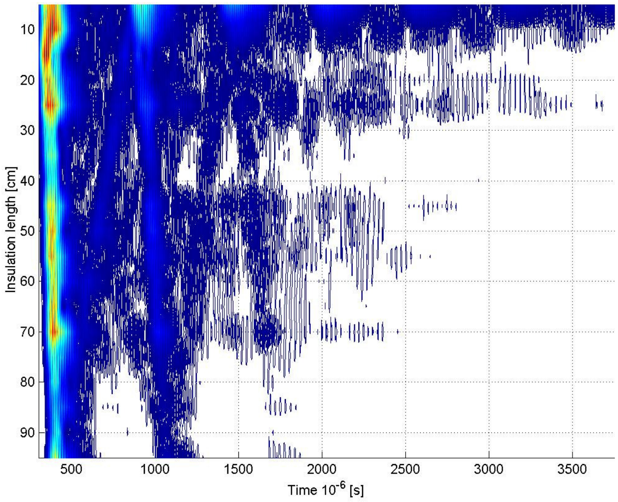

Figure 6: Wave propagation in a gradual insulation removal at a frequency of 40kHz

3.3 Correlation between Experimental and Modelling Results

In order to validate the numerical modelling and the experimental results, the received signal in both the modelling and the experimental results were correlated against each other. The correlation is done on 20 kHz and 100 kHz on an insulated wire with the presence of a defect. The amplitude of the reflected signals were normalised with respect to the 1st reflection of the wire end. Figure 7 shows the correlation between the two signals. Figure 7 shows that there is a large degree of correlation between the modelling and the experimental results. However, there is an amplitude difference between the modelling and the experimental results. In addition, there is a velocity difference by 1.8% and 2.5% for the two frequencies, 20 kHz and 100 kHz respectively. These differences are due to the attenuation existing in the experimental conditions which is not included in the model, as well as the difference in the insulation loss representation in the model. The model can be improved by including attenuation and damping, and a better description of the defect.

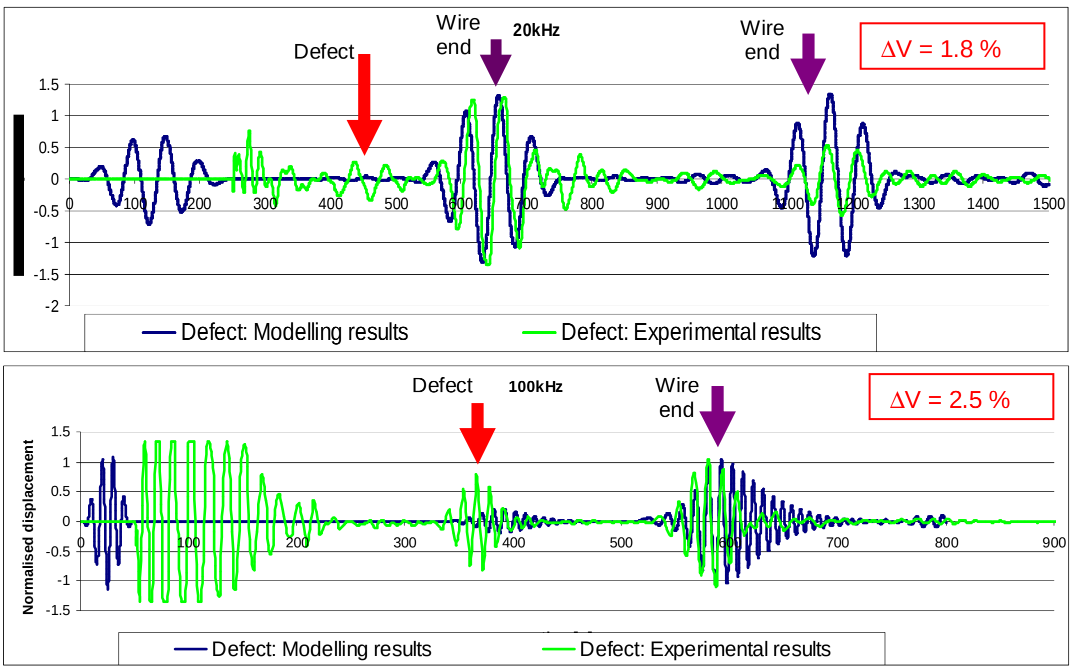

Figure 7 Correlation between experimental and modelling results at two different frequencies 20kHz and 100kHz respectively.

4. Discussion and Conclusion

Guided waves have the capability of propagating in insulated wire structures. This paper has shown the ability of guided wave to travel in insulated wire structures from a single point of access. However, this propagation depends on different parameters, which include: the number of cycles of the tone burst signal, the excitation frequency of the tone burst signal, the stiffness of the conductor material and the insulation and the form of excitation. This paper has focused on exciting insulated wires at low frequency with an axi-symmetric excitation. This excitation processed a longitudinal wave mode, type L (0, 1). This is a compression wave mode where the propagation takes place in both materials (conductive and insulation). The compression wave mode becomes a Rayleigh wave mode in which most of the displacement takes place in the insulation as the frequency increases. L (0, 1) has proved its ability to detect defects within the insulated wire structure. This wave mode has the limitation of being dispersive in nature and attenuative when an insulated material (soft material) is present. Finally, the experimentation and modelling results have shown a large degree of agreement with few variations. Some variations do occur due to attenuation and damping which have not been taken into account in the model. Improvements to the results can be made by conducting further work and integrating those factors into the model.

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