ANALYSIS OF CORROSION OF AIRCRAFT FLUID PRESSURE LINES USING EDDY CURRENT

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Master of Science

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Dissertation submitted in partial fulfillment of the requirements for the Master of Science Degree

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Declaration

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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Name of the supervisor:

Signature of the Supervisor: Date:

Acknowledgement

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Abstract

The metal tubes are often used in aircraft to convey fluids to one or more destinations as they are capable of withstanding high levels of internal pressure and hoop stresses. The internal surfaces of fluid carrying metal tubes are frequently corroded once the inner walls are contacted with stagnated fluid for a long period of time. Once corroded, the fluid lines are to be replaced as they become unairworthy. The detection is difficult as there is no method developed for the corrosion detection of small diameter Aluminium metal tubes. This study is to carry out eddy current inspections on small diameter metal tubes and to carry out a qualitative analyze on eddy current impedance plane displays, building up a relationship on the resultant signals. It is also to distinguish the different characteristics of impedance plane displays of internal corrosion and crack signals. A qualitative analysis is the objective in this study as detection of corrosion is the prime objective for the aircraft fluid pressure lines. Since, neither the aircraft manufacturer nor pressure lines manufacturer has given any tolerances for corrosion, irrespective of the depth and the spread of corrosion, the fluid lines are to be replaced with new lines, if the corrosion is detected. Therefore, this study is limited only for a qualitative analysis and will be an eye opener for another study for a quantitative analysis.

Key Words: Hoop stress, eddy current, impedance plane display, unairworthy, quantitative analysis

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LIST OF ABBREVIATIONS

Abbreviation	**Description**
SLAF	Sri Lanka Air Force
ID	Internal Diameter
NDT	Non Destructive Testing
NDI	Non Destructive Inspection
DBTT	Ductile to Brittle Transition Temperature
AC	Alternating Current
DC	Direct Current
ILI	In Line Inspection
MFL	Magnetic Flux Leakage
RFET	Remote Field Eddy Current Technique
PET	Pulsed Eddy Current Testing
SLOFEC	Saturated Low Frequency Eddy Current
PT-6	Primary Trainer-6
IACS	International Annealed Copper Standard

1. INTRODUCTION

1.1 General

The high pressure fluid carrying lines are used on the aircraft to convey working fluids, either pneumatics or hydraulics, in order to transmit forces and to reduce the pilots' fatigue during the aircraft operation. The fluid carrying lines of different aircraft had been faced frequent failures during the recent past. Some external cracks have been observed during the inspections and few of them have been blasted in flight and on ground, creating unsafe conditions. At the destructive inspections carried out during the accident investigations, on analysis of microstructure, the investigators have found that most of the failures had been occurred due to the corrosion on internal surfaces of metal tubes. The corrosion on the tubes is formed due to contamination of moisture with hydraulics or pneumatics. As the fluid is stagnated over a period of time, when the system is not in use, the corrosion is aggravated and tiny pits are created on the internal surfaces.

The detection of corrosion on the fluid lines has shown an utmost importance since the manufacturer has not given a tolerance for the corroded metal lines. Therefore, the existing lines are to be replaced with new ones, once the corrosion is detected and it ensures the optimum safety standards. The metal lines are generally replaced during the aircraft overhaul. The overhaul life is specified by the manufacturer, considering the general environmental and operating conditions of aircraft. But, certain special inspections might be required to be performed on certain areas of aircraft, prior to the overhaul, if they are operated in the extreme environmental and operational conditions. Prior to the overhaul, the thin, semi rigid pressure lines are tested externally for damages and corrosive attacks but their internal surfaces are not tested by most of aircraft operators due to unavailability of resources and required technical knowledge. It is therefore necessary to develop a suitable method to analyze the corrosion existence, area of spread, depth and type. The metal fluid lines have a small internal diameter, around 5.2mm and the fluid carrying plumbing system contains complex shapes and connections in which it is difficult to insert an inspection probe (ID Probe) for the inspection purposes. The boroscopic/ fiberscopic inspections can be conducted up to a certain extent but the entire system cannot be inspected without a complete disassembly.

The industry does not provide such ID probes for the very small diameter tubes. Therefore, the development of a method for the internal inspection of metal lines, with the fabrication of a suitable ID probe would provide more advantages. The eddy current inspection can be carried out with a partial disassembling of the system which further reduce the inspection time and periodicity of inspections. The thickness of metal walls is such that, performing an ultrasound testing to detect corrosion would be more difficult than performing an eddy current testing. Eddy current testing on metal tubes possesses certain advantages over other inspection methods which will be discussed in this paper.

1.2 Objectives

The following objectives are expected to be achieved through this research.

- To detect the existing corrosion on fluid lines after inspecting their internal surfaces.
- To design and fabricate a suitable internal diameter eddy current probe.
- To identify the places which have been corroded and the area in which the corrosion has been spreaded.

2. LITERATURE SURVEY

The corrosion is the deterioration of the metallic materials by chemical or electrochemical attack. Corrosion is normally caused by the environment (most often humidity), and sometimes by another materials. The products generated by corrosion are not electrically conductive, so that the thinning of material can be measured by a Non Destructive Inspection (NDI) such as eddy current inspection. An eddy current instrument and probe can be used for the corrosion detection and using a specific procedure, it is often possible to perform a quantitative measurement of corrosion. Different types of corrosion can exist on the aircraft materials (usually Aluminium alloys). The most common types are as follows;

a. Uniform corrosion that spreads evenly on the entire metal surface
b. Pitting corrosion that is uneven and has smaller deep pits
c. Exfoliation corrosion that forms along layers of elongated grains
d. Intergranular corrosion that forms along the grain boundaries which weaken the boundaries [1].

In most of the situations, particularly in the aviation and aerospace industry, the manufacturing material and hence the materials under inspection will be a type of Aluminium alloy. The eddy current technique is often used for the detection of corrosion on aircraft Aluminium alloys, especially on the aircraft wings and fuel tanks. The methods developed for corrosion detection on larger diameter steel tubes are also available and have a better commercial demand in specific industries. There are some exceptional cases such as the use of the reflection remote field technique, mostly for tubing inspection which facilitate the steel corrosion detection using eddy currents.

Most of the aircraft fluid lines have also been manufactured using Alluminium alloys. The Aluminium alloys are used in aircraft applications due to their desirable properties. They are light in mass, have a higher strength to weight ratios, soft and ductile, highly resistant to corrosion, no coloured salts are formed, offer good electrical and thermal conductivities. The most desirable properties of Aluminium alloys are their strength to weight ratio and corrosion resistance which offers more suitability in aircraft applications. It offers comparatively low Ductile to Brittle Transition Temperature (DBTT) and has a gradual transition unlike steel which the aircraft designers are mostly focused into.

2.1 The eddy current testing technique

Eddy current testing technique has gained worldwide acceptance over the past 50 years in the fields of aviation, aerospace, automotive, petrochemical and nuclear industries, including a diverse array of manufacturing, quality, and integrity assurance applications. In principle, the eddy current technique is typically conducted when an eddy current probe is placed in the close proximity to the surface of an electrically conductive material [2].

Either an Alternating Current (AC) or Direct Current (DC) is applied to the coil, which produces a varying magnetic field corresponding to the applied current. This varying magnetic field induces eddy currents in the material under test, as the material attempts to counter the coil's primary magnetic field. The formed eddy currents are closed loops of current that circulate in a plane perpendicular to the direction of magnetic flux. Their normal direction of propagation is parallel to the coil windings and formed in parallel to the surface of the test material which extends into the subsurface of the material.

This eddy current, produces a secondary magnetic field that in turn interacts and opposes with the primary magnetic field of the coil, which changes the test coil impedance. When the coil is scanned over a discontinuity, flaw such as surface-breaking crack, the secondary magnetic field is significantly distorted, essentially changing the load on the test coil. A change in the load of the coil directly affects the coil impedance. As the coil impedance is continually monitored by the instrument, any factor in the material that influences the eddy currents can be detected hence the output is displayed in order to detect the flaw in the material. The field of eddy current which is induced at the test material surface has a specific magnitude and phase as a function of time. Discontinuities, cracks, and material properties disturb the flow-path of the eddy current field and, in turn, affect the magnitude and phase of the induced current. As the impedance of the coil changes, both the circuit resistance and the inductive reactance of the coil also are affected. These changes in both resistance and inductive reactance do not occur at the same time and has a phase difference. Therefore they cannot be simply added together to determine the impedance of the circuit. The vector addition must be done using automated vector analysis, algorithms. The eddy current instruments can rapidly determine the magnitude and phase angle associated with the actual impedance at that particular point in the scan [3].

The eddy current density decreses exponentially with depth. The depth measured from the surface is known as the skin depth (x). The skin depth (x) is affected by the frequency (f) of the exitation current and the electrical conductivity (σ) and magnetic permeability (μ) of the speciman. The decreasing eddy current density from outer surface is shown below (See Figure 2.1).

Figure 2.1: The decreasing eddy current density from outer surface [3]

Source: [3].

According to the American Society for Testing and Materials (ASTM 1997), the eddy current density at a given depth, x is given by

$$J_x = J_0 e^{-x\sqrt{\pi f \mu \sigma}} \qquad 2.1$$

Where; J_0 = current density at the surface in amps/m^2

f = frequency in Hertz

μ = magnetic permeability

x = depth from surface in m, known as skin depth

σ = electrical conductivity in siemens per meter (S/m)

The eddy current depth of penetration is always affected by the frequency of the excitation current and the affect of frequency and the variation of depth of penetration due to change in frequency is shown in the following figure (See Figures 2.2 and 2.3).

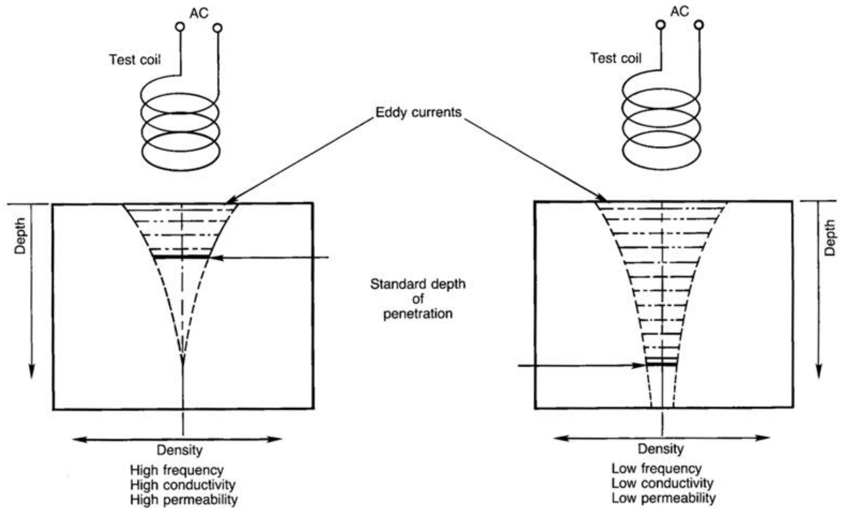


Figure 2.2: Relative Effect of Frequency, Conductivity, and Permeability on the Depth of Penetration for a Typical Single-Coil ET Probe

Source: [2]

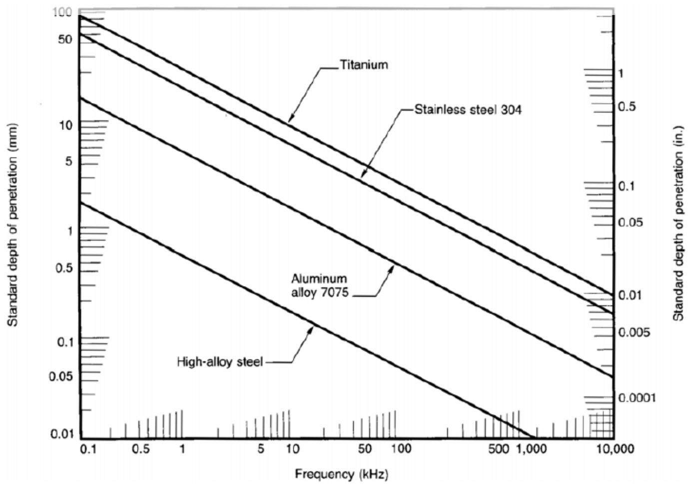


Figure 2.3: Eddy Current Testing Standard Depth of Penetration for Assorted Materials of Varying Conductivity as a Function of Frequency

Source: [2]

The depth at which eddy current density has decreased to $\frac{1}{e}$ or about 37% of the surface density is called the standard depth of penetration (δ). The relationship between standard depth of penetration (δ), frequency of the exitation current (f), electrical conductivity (σ) and relative permeability of the speciman material (μ_r) is given by equation 2.1 below.

$$\delta = 50\sqrt{\frac{172.41}{\sigma\mu_r f}} \qquad 2.2$$

2.2 Applications of eddy current testing

Eddy current testing is presently used for a wide variety of applications such as the detection of cracks, measurement of metal thickness, detection of metal thinning due to corrosion and erosion, determination of coating thickness, and the measurement of electrical conductivity and magnetic permeability. In this study, the eddy current testing data were collected and analyzed in order to measure the reduction of metal thickness or thinning due to corrosion and erosion.

The researchers have focused on the eddy current inspections of large diameter metal pipes in order to find their metal thinning due to corrosion, whereas they are mainly the inspection on steel or cast pipe lines used in different industries. The large diameter metal pipes are inspected either internally or externally using ID or OD probes respectively.

2.3 Different industrial techniques used for inspection of tubes

The in-line inspection (ILI) industry has seen the birth and demise of many different inspections technologies. From the current perspective it seems that Magnetic Flux Leakage (MFL) and Ultrasonic inspection have achieved a status of “standard applications”. Over the recent years also Electro-Magnetic Acoustic Transducer Technology has found its way in the ILI industry and it seems that it will persist, as it addresses problems that have been outside of the technical feasibility of ILI so far. When comparing ILI applications with other areas of non-destructive testing (NDT) it becomes apparent that eddy current inspection technology, that is found almost everywhere else, does not seem to have a suitable place in the ILI world. There are three main eddy current techniques used to inspect metal tubes, usually larger diameter steel tubes used in different industries;

- Remote field eddy current testing
- Pulsed eddy current technique
- Saturated low frequency eddy current technique
- Magnetic Biased eddy current testing

2.3.1 Remote Field Eddy Current Technique (RFET)

The Remote Field Eddy Current inspection is a method to inspect the ferromagnetic pipes using a variation of eddy current send-receive probe technique. The differential and absolute modes are being used in this technique and the differential mode is capable for the detection of localized while the absolute mode offering its capability for detection of gradual defects [4].

The detector coils are generally separated by a distance equivalent to two or three times the tube diameter. Then the receiving coils sense the flux lines that form cross the tube wall twice. Remote field has an equal sensitivity to internal and external indications while the phase shift is directly proportional to wall loss. The signal phase and signal amplitude are used to identify the defect depth and defect volume respectively. The receiver coil receives in the remote area, the remaining energy path field lines passing through the wall over distance. Although these field lines are of low strength, dedicated amplifiers used allow the analysis of the received induction very well. The technique allows the designing of probes for u-bend inspection, which are generally possible for running u-bends with the radius from 1 to 15 times inner tube diameter. The principle of Remote Field Eddy Current technique and the resultant signals obtained from the inspection are shown below (See Figure 2.4) [5].

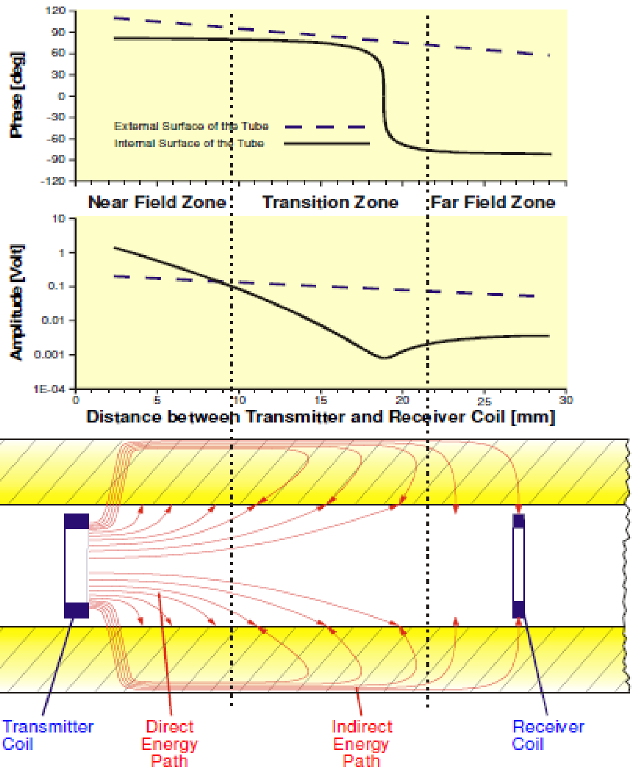


Figure 2.4: Principle of Remote Field Eddy Current Technique

Source: [4]

As the Remote Field principle works in low frequencies (typically 10Hz -1kHz), the inspection speed is therefore limited and it limits the much widely employment for in-line inspection. However, remote field eddy current method offers the advantages of more forgiving with respect to the lift-off/ fill factor characteristics and changes in diameter of pipes. The RFET tools have been used for the inspection of heat exchanger and pressure tubes and have been proposed to inspect pipelines for stress corrosion cracking. They have also been used to inspect the casing of oil and gas wells but the application in the oil and gas industry is restricted mainly due to the limitations in speed.

2.3.2 Pulsed Eddy Current Technique (PET)

The principle of pulsed eddy current technique is to use a signal pulse in the inspection. The propagation of such a pulse in a conductive material can be described as a diffusion process with a certain propagation speed. At the rear wall the reaction of the conductive layer suddenly stops. Measuring the diffusion speed to the rear wall allows for a quantitative wall thickness calculation. The accuracy of an ultrasonic probe is not being reached by this method, but being an electromagnetic method, it does not require a couplant which can be regarded as an advantage over ultrasonic method. The coil arrangement and the formation of eddy current with respect to the magnetic field are shown below (See Figure 2.5) [6].

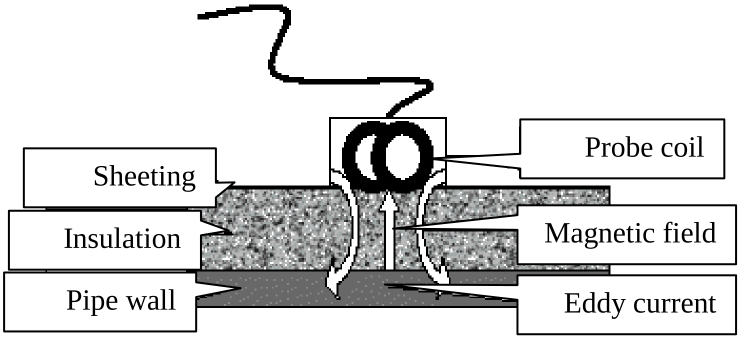


Figure 2.5: Operating principle of PET

Source: [4]

The operating principle of PET varies from system to system. A pulsed magnetic field is sent by the probe coil. This penetrates through any non-magnetic material such as insulation materials kept between the probe and the object under inspection. The varying magnetic field will induce eddy currents on the object surface. The diffusive behavior of these eddy currents is related to the material properties and the wall thickness of the object. The detected eddy current signal is processed and compared to a reference signal. The material properties are eliminated and a reading for the average wall thickness within magnetic field area results. One reading takes a couple of seconds. The signal is logged and can be retrieved for later comparison in a monitoring approach [7].

2.3.3 Saturated Low Frequency Eddy Current Technique

The SLOFEC inspection technique uses the eddy current principle in combination with a magnetic field. It is to use an eddy current coil on ferromagnetic material and to magnetize the section of pipe at the same time. It utilizes superimposed Direct Current magnetization, the depth of penetration of the eddy current field lines in the ferromagnetic material. In the case of a defect in the material, the magnetic field lines have a higher density in the remaining wall thickness, which consequently changes the relative permeability in the area, which again changes the eddy current field lines [8].

The magnetization has several different effects. It changes the permeability of the material thereby increasing the depth of penetration. Further, the changes in permeability due to different flux distribution become significant. Along with these effects, the far side defects can be picked-up with eddy current sensors. As only moderate levels of magnetization are required in this process, the method is used for the pipes with higher wall thicknesses or through several millimeters of coating thickness. The principle is shown below as Figure 2.6.

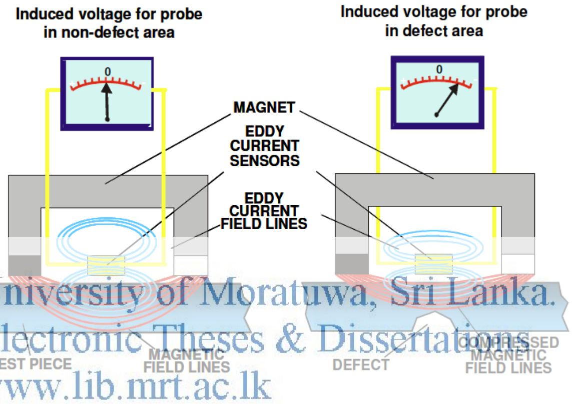


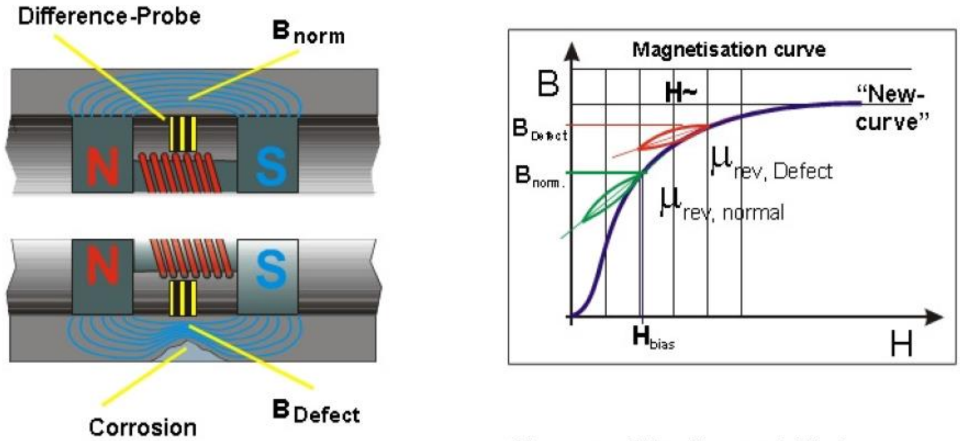
Figure 2.6: Principle of Saturated Low Frequency Eddy Current Technique

Source: [4]

2.3.4 Magnetic Biased Eddy Current Testing

The Magnetic Biased Eddy Current technique is a combination of applied Direct Current (DC) field lines and Eddy Current field lines. In this method, both coil systems are combined in a single probe. The technique is being used for the inspection of heat exchanger and boiler tubes of ferromagnetic material. The electromagnetic coil for DC field induction is adjustable for the magnetic field strength suitable to the material and wall thickness. The eddy current coils based between the electromagnetic systems can be applied with the eddy current frequency required for the inspection [9].

The basis of the technique is the principle that in the case of defect, the magnetic field lines are running higher compressed in the remaining tube wall, which causes a permeability change in the tube wall and consequently changes the induced eddy current field in the tube wall. The principle of magnetic biased eddy current technique is shown below as Figure 2.7.



Measurement of Permeability changes by eddy current

Changes of the Permeability by increased magnetic field line density

Figure 2.7: Principle of the magnetic biased eddy current technique

Source: [4]

The eddy current signal then displays the defect severity in amplitude. The difference in the eddy current field line changes as well as the chance changing the DC field lines shows the differentiation between external to internal defects.

2.4 Eddy current nondestructive testing device using an oscilloscope to identify and locate irregularities in a test piece

A slightly different study has been previously carried out to identify and locate irregularities in a test piece using eddy current and has been offered the US patent for the study.

In brief, the invention comprises first and second inductive coils placed on a probe in fixed relation to each other, the probe being adapted to traverse the surface of the material under test. The coils are excited by an oscillator. A signal is generated representative of the difference in current flowing in the two coils. As the probe traverses an irregularity in the specimen under test, the difference signal, changing with probe position, is representative of the complex impedance characteristic of the irregularity as a function of probe location. Output signal for generating quadrature reference signals and `detection of the reference signal. A phase shifting Means are provided responsive to the oscillator circuit is provided to align the noise signal due to probe wobble with one of the quadrature reference signals. The detected signals are then applied to the horizontal and vertical deflection plates of an oscilloscope, whereby the locus of the spot on the oscilloscope screen displays the complex impedance characteristic of the irregularity being traversed. Alternatively, the detected signals may be recorded on a dual channel recorder from which the complex impedance characteristic is computed in the form of a vector or phase diagram. Flaws are not only uniquely identified by means of the complex impedance characteristic but in addition, they are more accurately located for example, from the display pattern of the complex impedance characteristic on the oscilloscope screen (See Figures 2.8 and 2.9) [10].

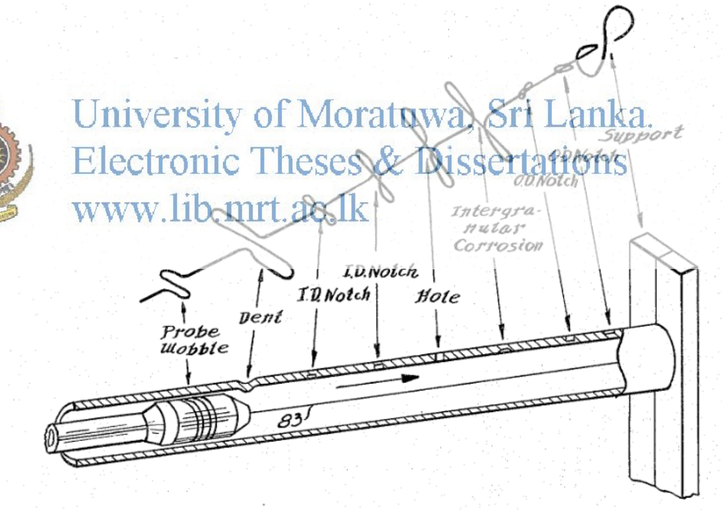


Figure 2.8: Various display patterns obtained with the designed device for irregularities in a test specimen

Source: [10]

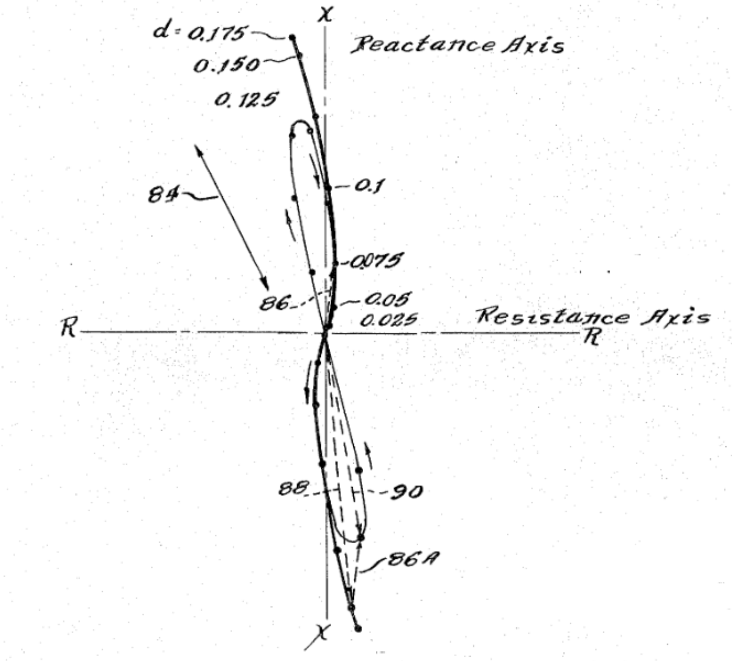


Figure 2.9: Graphical construction of the figure eight display pattern obtained with the device.

Source: [10]

2.5 The metal tubes testing using ID probes

This is the most common method of inspecting cracks on the internal surfaces of metal tubes. The current carrying conductor is wound around a core and the core is inserted to the metal tube. The eddy currents will be formed due to disturbance of primary magnetic field of the coil by the internal surface of tube. The flaws (if available) on surface or sub surface will change the coil impedance and that change will be displayed on the equipment. The industrial probes are available in the market in different diameters according to the inner diameter of the tube to be tested. The principle of an Internal Diameter (ID) probe is as follows (See Figure 2.10) [19].

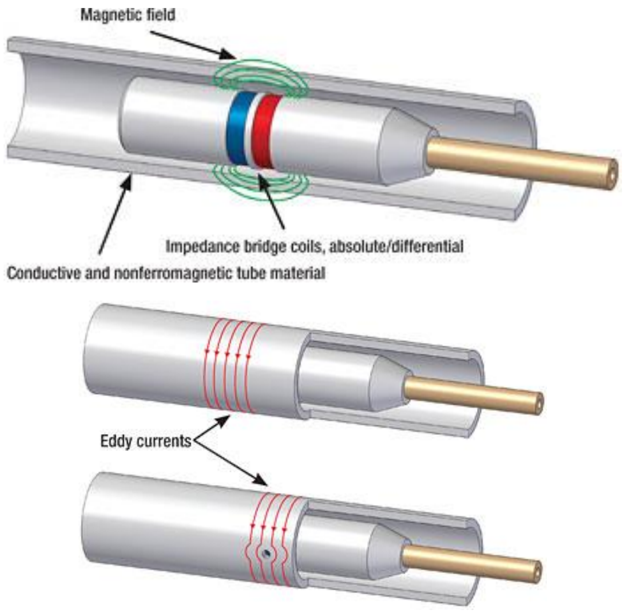


Figure 2.10: The principle of an internal diameter probe

Source: [3]

The terms used to describe any space between the test piece and the coil are “lift off” and “fill factor”. Lift off is applicable for surface coils while the fill factor is applicable for internal coils and encircling coils which are used in ID and OD probes respectively. Both the fill factor and lift off will weaker the eddy current, hence are to be minimized. For the tube testing technique, the fill factor is given by the relationship given in the equation 2.2.

$$\eta = \left(\frac{D_1}{D_2}\right)^2 \qquad 2.2$$

Where;

For internal coils – D_1 is the probe diameter

For internal coils – D_1 is the probe diameter

η is always < 1

Small variations in lift-off or fill-factor can significantly change the impedance and make the indications. The closer the probe coil is to the surface the greater will be the effect on that coil. A reduction in sensitivity occurs as the coil to material spacing increases. The lift off signal is obtained as the probe is moved on and off the surface. Therefore, to obtain a signal with improved sensitivity, the diameter of the coil should be in such that it must be very close to the internal diameter of the tube.

Apart from the aforementioned previous research efforts, with respect to the eddy current inspection of tubes, there are various studies on eddy current testing on the inspection of metal tubes. However, the comprehensive analysis of corrosion on the small diameter Aluminium metal tubes using eddy current is very few. A similar research had been carried out by Forster Friedrich M O and has obtained the US patent as well. In brief, his study is as follows;

2.5.1 Eddy current system for testing tubes for defects, eccentricity and wall thickness

The devices are known in which one or more eddy current probes rotate, either in contact with or spaced by a certain distance, about an axially moving cylindrical work piece. A helical scanning of the work piece is thus effected. Probes running in close proximity to the surface of the work piece comprise coil arrangements, with or without a ferromagnetic core, energized by alternating current. The alternating magnetic fields extending from the rotating coils produce eddy currents in the surface of the work piece, and such eddy currents, in turn, act upon the rotating coils.

In the event of a crack is disposed underneath an eddy current probe, a variation of the eddy current flow is present compared to another portion of the work piece in which there is no crack. The effect of the eddy current variation caused by a crack on the eddy current probe then serves to indicate the presence of such a defect. The eddy current system with rotating probes provides good defect detection for such defects as are disposed immediately at the surface or very close to the surface of the work piece. On the other hand, this system is not suited for the detection of defects on the inside of a tube or of subsurface defects occurring beyond a certain depth beneath the outside surface in thick walled tubes [11].

2.5.2 Selection of frequency for eddy current tube testing

Eddy-current testing can be used to detect faults in metal tubes by passing the tube through a pair of short solenoidal coils which are energized by an alternating current. The decrease in density of the induced eddy-currents from the outer surface is determined by the frequency of the energizing current and by the electrical properties and dimensions of the tube. Since the eddy-currents flow in a circumferential direction, their distribution is not, as often assumed in the past, the same as when current flows in the direction of the axis. The distribution of eddy-currents flowing circumferentially is given in general terms for non-magnetic tubes and the results can be used in conjunction with a nomogram to determine suitable frequencies for many practical applications [12].

METHODOLOGY

3.1 Chemical analysis to check the material composition

The eddy current testing for pipe line inspection is mainly carried out with ferrous metals and used for larger diameter pipes. The Aluminium tube testing using eddy current is rather uncommon and is rare in practice. The exact material composition of the manufacturing material is required to be found by a chemical analysis. The metal samples were taken from two different types of aircraft for this study. Samples were prepared using the failed hydraulic lines of Isrial manufactured Kfir C-7 aircraft and the failed pneumatic lines of Chinese PT-6 aicraft.

A chemical analysis was carried out to check the exact composition of materials and the following results were obtained (See Table 3.1). It was proven by the chemical analysis that the material is an Aluminium alloy which is alloyed with 8 other alloying elements.

Table 3.1: Material composition of aircraft fluid pressure line sample

S/No	Element	% By Mass
1	Aluminium (Al)	96.55%
2	Magnesium (Mg)	2.84%
3	Manganus (Mn)	0.25%
4	Ferrous (Fe)	0.16%
5	Nickel (Ni)	0.04%
6	Silicon (Si)	0.09%
7	Chromium (Cr)	0.01%
8	Titanium (Ti)	0.04%
9	Molibdinum (Mo)	0.02%

3.2 Sample preparation

The samples were first subjected to artificial corrosion after exposing them to a 4M NaCl solution (58.44g of NaCl was dissolved in 250ml of water). Only a half of the length of each prepared sample was exposed to the NaCl medium and was allowed to remain in the same position for different periods to create different levels of corrosion. The details were recorded as Table 3.2.

Table 3.2: Different periods of exposure for samples to 4M NaCl solution

Sample No	L (mm)	l_e (mm)	d_i (mm)	d_o (mm)	t (mm)	t_e (Days)	t_r (Days)	Level of Corrosion Expected
1	10	5	6.14	8.00	1.86	3	60	Level 1
2	10	5	6.17	8.00	1.83	7	60	Level 2
3	10	5	6.18	8.00	1.82	14	60	Level 3
4	10	5	6.16	8.00	1.84	-	-	No Corrosion

Where;

l - Total length of sample
l_e - Exposed length to NaCl
d_i - Inner diameter
d_o - Outer diameter
t - Average wall thickness
t_e - Exposed time to NaCl
t_r - Retention time to allow corrosion to be formed

The study was divided into two main parts as priliminary study and secondary study. During the priliminary study, an eddy current testing was carried out on test samples using a specially prepared Internal Diameter (ID) probe. The resultant eddy current impedence plane signals of each sample were recorded and saved for further analysis. The intention was to do a comparison on the eddy current impedence plane signals with the microscopic examination results and to build up a relationship between the two results. The prepared samples and the eddy current testing machine are shown in the Figure 3.1 and Figure 3.2 respectively.

Figure 3.1: Samples prepared for eddy current inspection

Figure 3.2: “Phasec 2D” eddy current testing machine

3.3 Preparation of an eddy current probe for smaller diameters

The Internal Diameter (ID) probes or Outer Diameter (OD) probes were not available in house for the eddy current inspection of metal tubes. Therefore, an eddy current probe was designed and fabricated to inspect the internal surface of samples. A small Carbon rod was selected and its diameter was reduced to 5.5 mm (to just fit into the metal tube). The rod was wound with 25 turns using a copper wire Gauge 40. The number of turns was made to 25 to obtain the frequency of 300 kHz. Then the wound coil was properly covered using a flexible casing. The casing was selected in such a way that it must travel freely inside the small diameter metal tube and the end coil must touch the inner surface of tube so that fill factor will be as very closer to 1. The principal of absolute surface probe was used to fabricate the test probe. It was expected to inspect the inner metal surface and to find the thinning of metal tube due to corrosion. The coil arrangement of an ID probe available at the market is shown below as figure 3.3.

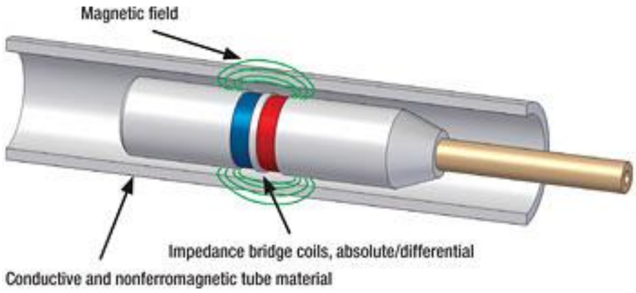


Figure 3.3: The arrangement of an existing ID probe available in the market

Source: [3]

The coil will produce a primary magnetic field and the primary magnetic field will be disturbed by the inner metal surface of the tube forming eddy currents on the inner surface. The formed eddy currents will create a secondary magnetic field thereby reducing the primary magnetic field thus to increase the coil impedance. Presence of crack or corrosion means the formation of eddy currents is disturbed and the coil impedance is reduced. The variation of coil impedance is analyzed in this study to check the formation of corrosion and the thinning of metal. The arrangement of the prepared probe is as follows (see figure 3.4).

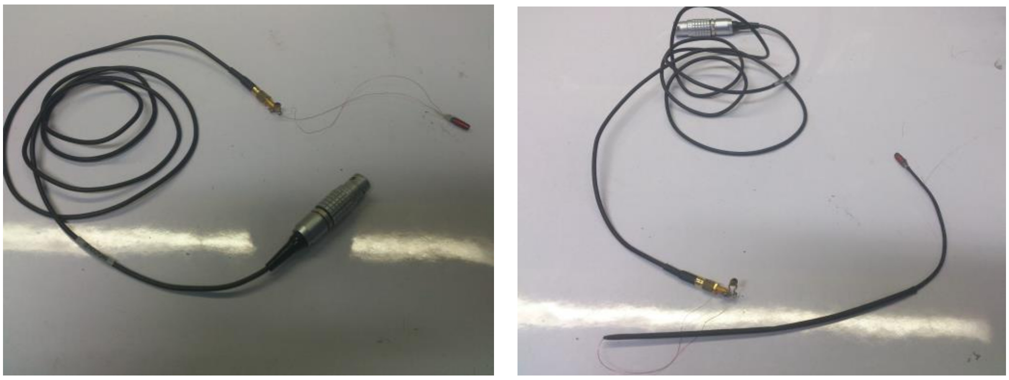


Figure 3.4: Fabricated ID Eddy current probe

3.3.1 The standard depth of penetration of prepared eddy current probe

The standard depth of penetration of the prepared ID probe was calculated using the relationship of $\delta = 50\sqrt{\frac{172.41}{\sigma\mu_r f}}$. The eddy current probe was prepared for frequency of 300 kHz. The conductivity of material was found by an eddy current inspection as 28.68% IACS. The relative permeability of Aluminium alloy μ_r is 1. Therefore,

$$\delta = 50\sqrt{\frac{172.41}{28.68 \text{x} 1 \text{x} 300000}} \text{mm}$$

$$\delta = \underline{\underline{0.2238\text{mm}}}$$

Therefore, the standard depth of penetration is, 0.2238 mm.

3.3.2 Materials used to fabricate the probe

Materials used to fabricate the ID probes are mentioned below in table 3.3.

Table 3.3: Materials used to fabricate the ID probes

S/No	Description	Size/ Value
1	Graphite rod	5.5mm diameter, 13mm length
2	Copper wire	Gauge 40, 25 turns
3	Capacitor	22 pF
4	Outer sleeve	Length of 2 ft

3.3.2.1 Graphite rod

Graphite is a conductor which conducts electricity due to availability of free electrons. The magnetic field lines formed due to current carrying conductor must travel through the core material. Therefore, the core material must either be a soft iron or a material like graphite.

3.3.2.2 Copper wire

A Gauge 40 copper wire was selected. Copper is a good electrical conductor and is comparatively cheap. Main reason to select a very thin Copper wire is to detect only the necessary defects. If a thick wire is used, the lift off signals, edge effects are also more prominently displayed and the desired crack or corrosion signals will not be highlighted. Length of the Copper wire was limited to 2ft to minimize the resistance of wire and the future studies will be carried out to increase the wire length and the length of entire probe.

3.2.2.3 Capacitor

The capacitance of selected capacitor is 22 pF and was used to make the eddy current signal smoother.

3.2.2.4 Outer sleeve

The copper wires and the capacitor were covered by a suitable rubber sleeve for their protection. This enables the probe to freely travel along the entire length of metal tube.

3.3.3 Probe specifications

Table 3.4: Probe Specifications

S/No	Description	Value
1	Probe Length (from coil to connector)	60 cm
2	Probe Diameter	5.9 mm
3	Output frequency	300 kHz

The fabricated eddy current probe was inserted into the metal tubes and the different resultant signals received were recorded for further analysis. The signals were separately obtained for the corroded areas and non corroded areas of the samples.

As the secondary study, a microscopic examination was carried out on both types of samples in order to check the existance of corrosion and the types of corrosion formed on the inner metal surface. The samples (to check the microstructure) were prepared selecting two corroded areas and two non corroded areas on both types of lines. A total number of 08 samples were prepared for the microscopic examination and the results were tabulated in the following format.

3.4 Detection of internal cracks using the eddy current probe

The eddy current signal for internal cracks was also required to be obtained from the prepared probe as it was essential to distinguish the difference between crack signal and corrosion signal. The internal crack signal was obtained from the samples and the depth of crack was also measured using the calibration block.

3.5 Samples preparation for microscopic examination

The microstructure examination was carried out to create more clear, magnified images of the sample surfaces. The samples were taken from the places which gave the most prominant impedance plane displays during the eddy current inspection. The tubes were carefully cut from the selected areas and samples were prepared by cutting, grinding, polishing and etching using HF acid as the etching chemical. All the samples were observed with the magnifications of 50, 100 and 400. The samples which were prepared are as follows (see figure 3.5).

Sample No 1

Sample No 2

Sample No 3

Figure 3.5: Samples prepared for microscopic examination

3.6 Conductivity test to find the material conductivity

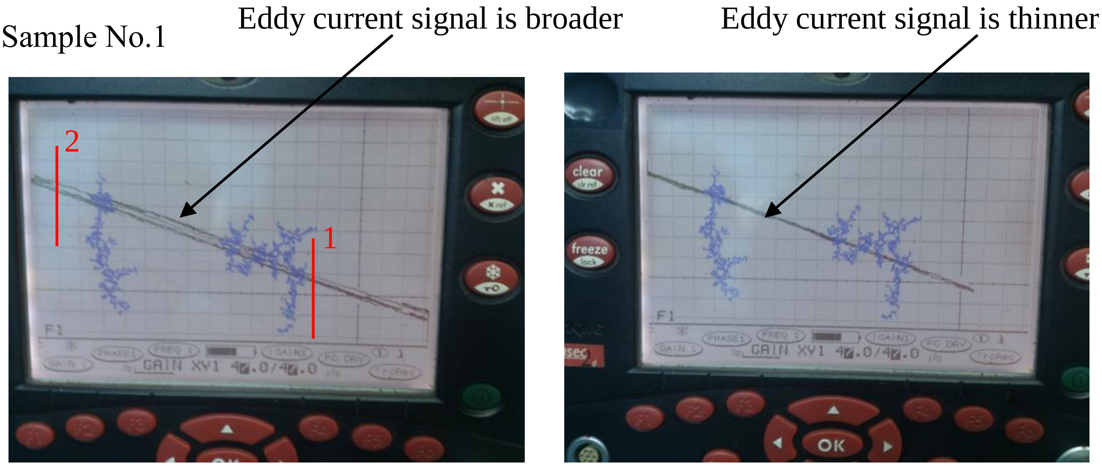
The samples were subjected to a conductivity test using the same eddy current testing machine. The conductivity was then obtained as 28.68% IACS and the material was further identified as an Aluminium alloy using the available data charts.

4. RESULTS

4.1 Eddy current signals of each sample

The resultant impedance plane displays obtained after eddy current inspection of each sample are as follows;

Sample No.1



Corroded area

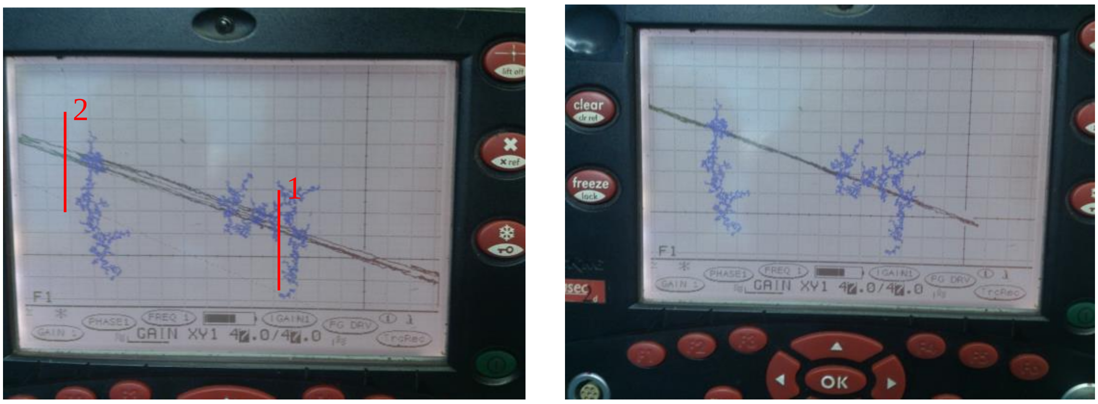
Non corroded area

Figure 4.1: Eddy current signal of sample No.1 for Corroded and non-corroded areas

Sample No.1 is the least corroded sample. The eddy current signal for corroded area is broader than the non corroded area. The broader signal starts from No.1 position and ends at No.2 position. The region of metal line from 1 to 2 can be identified as corroded area. The width of signal will give depth of corrosion. The eddy current signal with respect to non corroded area is almost a straight line in which the depth of corrosion can be identified as zero.

Sample No.2

Sample No.2 is the moderately corroded sample. The eddy current signal for corroded area is broader than the non corroded area as the previous sample. The width of eddy current signal is more than that of sample No.1 which signifies more depth of corrosion pit than sample No.1. The eddy current signal with respect to non corroded area is almost a straight line in which the depth of corrosion can be identified as zero (same as the sample No.1).



Corroded area   Non corroded area

Figure 4.2: Eddy current signal of sample No.2 for Corroded and non-corroded areas

Sample No.3

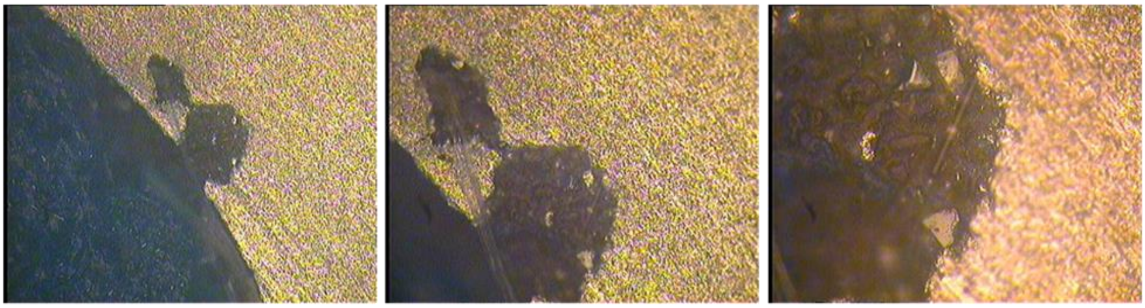
Corroded area   Non corroded area

Figure 4.3: Eddy current signal of sample No.3 for Corroded and non-corroded areas

The respective corrosion signal was received over a specific axial length of the sample. It was recorded as the signal appeared from corrosion starting position and end position, from 1 to 2. The broadest signal was given by this sample and the signal was slightly different from the first two samples. On analysis of microstructure, it was found that the corrosion formed on sample No.3 is more deep, having more area of spread. The lengths from 1 to 2 were different for each sample.

4.2 Microscopic examination results

The areas from which the different eddy current signals were observed were carefully cut and subjected to microscopic examinations. The following are the images obtained after microscopic examinations.



X 50 X 100 X 400

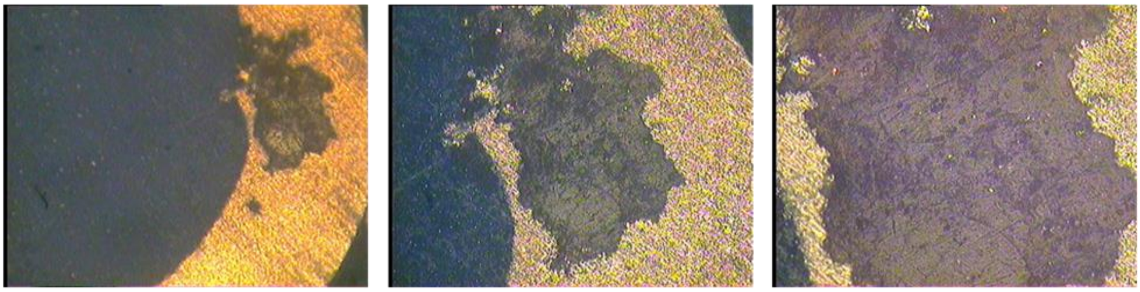
Figure 4.4: Microstructure of corroded area of Sample No.1

These images were received on analysis of sample No.1 and found that the metal tube has a localized corrosion, corrosion pit. The corrosion pit has been started from the inner surface and has been developed into the metal.

X 50 X 100 X 400

Figure 4.5: Microstructure of corroded area of Sample No.2

The depth of corrosion pit formed on sample No.2 is more than that of Sample No.1 as it was appeared in the eddy current signal.



X 50 X 100 X 400

Figure 4.6: Microstructure of corroded area of Sample No.3

The corrosion has more area of spread than the previous two samples (samples No.1 and 2). The corrosion has been developed into the metal and the depth is also more than the other two samples as it was displayed in the respective eddy current signals.

4.3 Signal of the crack appeared in impedance plane display

The crack signal appeared in the impedance plane display is as follows (see figure 4.7).

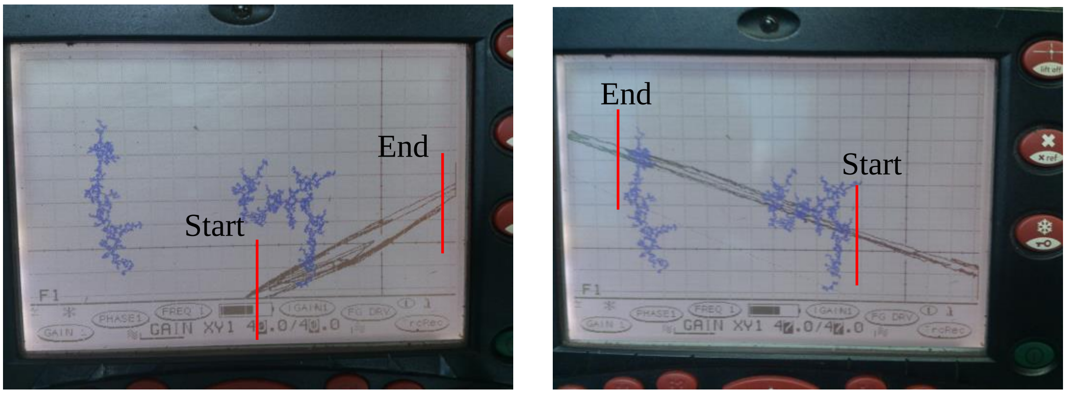


Figure 4.7: Comparison of crack signal and corrosion signal

The signals for crack and corrosion are different from each other. The crack signal was broader than the corrosion signal and is not continuous as a line. Generally, the crack gives a figure of 8 signal with a surface probe. The signal obtained from this experiment was not exactly a figure of 8 but is a discontinuous signal that is different from the respective corrosion signal. The start and End positions marked on the figures are the start and end points of the respective crack and corrosion signals.

4.4 Material conductivity test results

The results obtained from material conductivity test are as follows. It was found that the conductivity of the material is 28.68% IACS. According to the data charts, the respective material is Aluminium alloy. That proved the chemical composition results. The conductivity results obtained from eddy current testing machine is given in the following Figure 4.8.

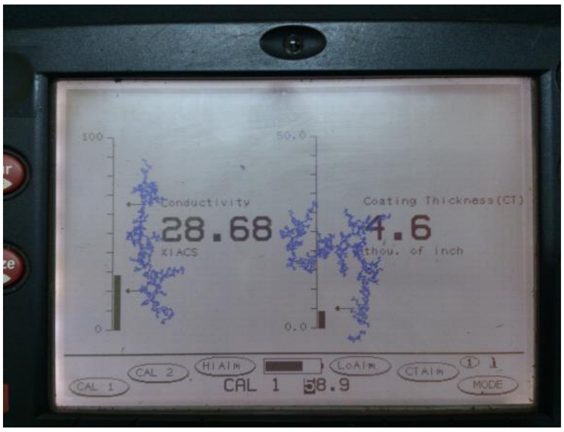


Figure 4.8: Material conductivity test results

5. DISCUSSION

5.1 Detection of corrosion

The eddy current formed on the internal surfaces of metal tubes are disturbed by the presence of cracks and corrosion. Therefore, the total impedance will be changed so that it will be displayed on the impedance plane display. More the cracks and corrosion, more the disturbances and higher the impedance change.

It was necessary to isolate the eddy current signals due to corrosion from the respective signals due to presence of cracks as the aim of this study was to detect internal corrosion. The cracks signals were also obtained for different samples and found that they are different from the corrosion signals. Theoretically, the variations/ widths of resultant eddy current signal are directly proportional to the amount of corrosion formed. The width will be increased when the depth of corrosive areas is increased. In the case of pitting corrosion, the width of eddy current signal is directly proportional to the depth of pits. The principle is almost similar to the measurement of depth of a crack using a calibration block.

The experiment results might not be 100% accurate and might not be sufficient to measure the depth of corrosion as the type of corrosion formed on internal surfaces is unpredictable. If the corrosion is a localized such as corrosion pits, the resultant eddy current signal will give the exact depth. If the corrosion is evenly distributed along the entire periphery, the average metal thinning can be calculated. If the corrosion is unevenly distributed along the periphery, the signal might reflect as an average but the localized attacks are not properly highlighted. But, it was found during the experiments that formation of corrosion mostly is the pitting corrosion and the corrosion is localized. It was noticed that a significantly different signals were observed during the eddy current inspection and the areas with corrosion could be easily detected. To find the type and depth of corrosion, it is required to carry out the experiment with more number of samples with various types and levels of corrosion and further analysis is required.

A qualitative analysis is desired in this study as detection of corrosion is the prime objective for the aircraft fluid pressure lines. Since, neither the aircraft manufacturer nor pressure lines manufacturer has given the limitations for corrosion, irrespective of the depth and the spread of corrosion, the fluid lines are to be replaced with new lines, if the corrosion is detected. Therefore, this study is limited only for a qualitative analysis and will be an eye opener for another study for a quantitative analysis. A quantitative analysis would be helpful to find the depth and area of spread of corrosion. The quantitative analysis will be important to find the root causes for corrosion and to find preventive measures.

5.2 Possible reasons for the internal corrosion

After the priliminary accident/ incident investigations, it was found that the fluid pressure lines had corrosion in most of the areas of internal surfaces which has weaken the metal. The accumulation of moisture and the aging of metal have been identified as the reasons to aggravate corrosion attack. Further, the tangential and radial stresses acting on metal walls will lead for the stress corrosion cracking.

5.2.1 Accumulation of moisture

The moisture will be accumulated on internal surfaces due to extreme environmental conditions in whch the aircraft are operated. The Kfir and MIG-27 aircraft are based at SLAF Base Katunayake and PT-6 aircraft are based at SLAF Academy China Bay. All the aircraft types are operated over sea and lagoon frequently. The pneumatic systems of aircraft are filled with Nitrogen gas when they charge on ground to minimize the corrosion. But, the inbuilt compressor of pneumatic system charges atmospheric air when the aircraft is in air which always mixes corrosion rich moisture with pneumatic air. The accumulation of moisture in pneumatic systems is controlled by a water-oil seperator and silica gel water filters whcih are frequently inspected for their proper operation. Still, the moisture is trapped around water-oil seperators and silica gel water filters and are then mixed with pneumatics. Such accumulation of moisture does not exist in the hydraulic system as it is a closed loop system.

5.2.2 Erosion of metal due to flowing of fluid through lines

The common problem with both pneumatics and hydraulic systems is that the flowing of fluid through metal lines will erode the metal on the walls which results in roughning of surface. The metal tubes, unless replaced during the major overhauls, are weakend due to erosion and over aging. The result will be a formation of a powdery product on the wall and the same will be contaminated with the respective fluid. The evidences for the same problem was found during the inspection of hydraulics and the hydraulic filters [13]. The micro chips of fluid line metals were detected during the analysis of hydraulic fluid using “Spectrometric Oil Analyzer”. The spectrometric oil analysis results proved that the chips material was same as the tube material [18].

5.2.3 Stagnation of fluid in the lines over a period of time

The fluid is flowing only during the operation of aircraft and is stagnated inside the tube whenever the aircraft is on ground. Comparatively, the non operation period of aircraft is higher than the operational period which results the stagnation of fluid inside tube for a long period of time. Hence, the contaminated stagnant hydraulic fluid will be contacted with eroded surfaces and forms small corrosion pits and micro galvanic cells. The formation of erosion corrosion, corrosion pits and intergranular corrosion is most common in the case of fluid pressure lines [17].

5.2.4 Stress corrosion cracking due to residual stresses

The tube material will be frequently subjected to work hardening in order to form bends and flare ends. According to the manufacturer’s recommendations, the Kfir aircraft hydraulic lines are bent and subjected to subsequent annealing for the removal of residual stresses [14]. It has been found during the priliminary accident investigations that, the micro cracks had been formed on bent areas and flared ends. The cracks were appeared as stress corrosion cracking. SCC is a cracking process, caused by the combined action of a sustained tensile stress and a corrosive environment. Once the SCCs formed, failures may occur at stresses well below the yield strength of material.

The work hardened Kfir aircraft metal tubes are annealed as per the directions given by aircraft manufacturer. The manufacturer has further stated that, the tubes should be annealed to the highest temperature of 265^0C and to be retained at the furnace at the same temperature for a period of 24 hrs. It is to be noted that the tubes are manufactured by an artificial age hardening Aluminium alloy in which the strength has been enhanced by solution treatments. The precipitates formed during the solution treatment may be dissolved unless the above annealing process is not properly controlled. It will further weaken the material offering more vulnerability to failures and corrosive attacks.

5.3 Difficulties faced during the test and compensation of errors

5.3.1 The study was limited to a qualitative analysis

The Aluminium corrosion takes a number of different forms. It may vary from general etching of the surface to the localised, intergranular attack. The corrosion products are white to grey and are powdery when dry. The quantitative analysis of corrosion is important to find the area of spread and the type of corrosion formed inside an Aluminium tube. To find the type of corrosion, different eddy current signals are to be obtained for different corrosion types and the experiment is to be carried out with more number of samples [16]. The width and spread of different eddy current signals are to be measured with the help of reference/ calibration blocks. The number of samples which could be prepared for experiments was limited and was not enough to study for a quantitative analysis.

The formation of corrosion inside a small diameter metal tube was out of the control. It is almost impossible to form the type of corrosion as desired. The corrosive environment was created inside the tube and allowed to form corrosion. The only possible variable in formation of different types/ levels of corrosion was the time which was not sufficient to form different corrosion types. The time which the metal was exposed to NaCl was varied as mentioned in the Methodology and was observed that only pitting corrosion had been formed in the metal tubes.

The general or uniform corrosion spreads over the metal surface (probably under the paint layer). This type of corrosion does not form deep pits instead reduces metal thickness of the tube walls. It is possible to find the thinning of metal walls after analyzing the eddy current signals obtained from this study but gives an indication as surface defects only. The randomly formed deep pits may not be distinguished from uniform corrosion as the present signal reflects only an average metal thinning.

The pitting corrosion was prominent in the metal tubes. Corrosion pits were not uniformly distributed over the surface but were observed only on certain areas. The eddy current signals obtained from experiments show only the longitudinal location of the pit but do not show the exact radial location [15]. Although the radial location of localized attacks can be detected by rotating the probe along the internal surface, it was difficult to do the same in this experiment as the fill factor is very close to 1.

The eddy current inspection on small diameter metal tubes might not give a perfect picture on intergranular and exfoliation/ layer corrosion which are not forming on the surface. The intergranular corrosion results from micro-galvanic cells at the grain boundaries in the metal and the corrosion progresses from the metal surface, normally along grain boundaries. The amount of metal corroded in the intergranular corrosion is small, relative to the volume of metal affected. Therefore, the intergranular and minor exfoliation corrosion can be detected with highly sensitive surface probe only. This will be another disadvantage of this method.

Still, the results and analysis are sufficient to address the issues related to SLAF aircraft as the requirement exists to detect corrosions only. Once detected, the lines are replaced with new ones as corroded lines become non-airworthy, irrespective of the type and level of corrosion.

5.3.2 Eddy current signal is affected by other factors

The formation of eddy currents on internal surface is affected by factors such as powdery products deposited on the surface, eroded areas on the surface, pits of different depths etc. The standard depth of penetration is given by the relationship of

$$\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}$$ where;

δ is the standard depth of penetration

f is the frequency of the AC current

μ is the magnetic permeability of material

σ is the material conductivity.

Although the parameters of μ, f and σ are said to be constant, the magnetic permeability and conductivity may vary with the corrosion thereby varying the standard depth of penetration which will directly affect the sensitivity of the eddy current signal. Therefore, detection of corrosion inside a metal tube is not easy as in the case of a thin metal sheet. The sensitivity and accuracy is more important when the internal diameter of the tube is reduced. The eddy current signal is further affected by fill factor. Therefore, the fill factor must be very close to 1 and the coil of the ID probe must perfectly touch the internal surfaces of metal tube. It was possible to overcome this problem by the preparation of an ID probe in which the diameter was exactly matched with the internal diameter of metal tubes. Therefore, it was assumed that the fill factor is very close to 1.

It is clear that, apart from flaws, the eddy current testing is specifically sensitive to a variety of factors that affect the response of the eddy current probe. The aim of a better experiment is to eliminate, reduce, or compensate for these factors in order to achieve consistent and reliable results. One of the drawbacks in these experiments is, the number of external factors that affect eddy current response is more. The external factors are the electrical conductivity and magnetic permeability of the test material, the operational frequency of the eddy current probe, geometric properties of the test material, and proximity of the probe to the surface (fill factor in this case).

The greater the conductivity of a material, the greater the flow of eddy currents on the surface of the material and greater the change in coil impedance. Factors that affect conductivity include material composition (for example, whether an alloy or not), ambient temperature and internal residual stresses, heat treatment, work hardening, and conductive coatings. In the case of a quantitative analysis, all the above factors must be addressed in order to obtain the reliable results.

The standard depth of penetration is greatly affected by the magnetic permeability of the material which needs to be accurately measured for a quantitative analysis. Magnetic permeability is defined as the ability of a material to concentrate magnetic lines. In other words, it is the ease with which a material can be magnetized. Ferrous metals offer greater magnetic permeability which is greater than 1. Nonferrous metals such as Aluminum, Copper, and Austenitic stainless steels have the same relative permeability of 1 which is equal to vacuum or air. In addition, the magnetic permeability may greatly vary as a function of spatial position within a material due to localized stresses, heating effects etc.

The operating frequency selected for the eddy current testing have a greater effect on the response of eddy current probe. Selection of the appropriate frequency is critical for acquiring optimal resolution between flaw signals, corrosion signals and noise contributors from the material under test. The operating frequency can be selected by the inspector and in this study an eddy current probe with a nominal operating frequency of 300 kHz was selected.

5.4 Corrosion and over aging

In general, there are multi pits form on the metal surfaces and the pit spacing is small so that fatigue initiates in the ligaments between the pits. Through thickness cracks may readily form on the surface and the crack may propagate in parallel with pitting. This mechanism operates at low/ medium stress and at low frequency which is more likely to have in the fluid carrying systems. Therefore, it is important to note the storage life for rigid metal lines as well. The metal lines work as parts in a system that in use are exposed to mechanical operation stresses. These products could be stored for a long time, until usage, in extreme environmental conditions. It is proven that the storage time affects the properties of the components and it will naturally age the already age hardened alloys.

Age hardening or precipitation hardening is produced by phase transformations making uniform dispersion of coherent precipitates in a softer matrix. The rate and amount of natural aging varies from one alloy to another. The aging temperature and aging time are factors which significantly affect the alloy properties. Typically the hardness and strength of the alloy increases initially with time and particle size until it reaches the peak where maximum strength is obtained. Further aging will decrease the strength and hardness (so called over aging). Once over aged, the size of precipitates become larger and it might not offer barriers to dislocation movements as normal. The similar thing happen due to heating of an age hardened material. If it is exposed to a higher temperature, the precipitates will be enlarged providing more gaps in between them. It allows bowing or bypassing of dislocations thereby decreasing the material strength. A further overheating may results in dissolving the precipitates.

Once heated the grain boundaries of materials will be further energized and will form micro galvanic cells in between the grains. It will aggravate the rate of corrosion, typically an intergranular corrosion. The age hardening process of fluid line materials is out of control of the aircraft operator. Once it is done by the manufacturer, the operator has no control over that. But the operator can control the same by controlling the storage conditions. Once fitted to the aircraft, the operating conditions cannot be restricted and it will be subjected to various environmental and stress conditions. But upto some extent, the operator may have the control over exposing the metal fluid lines material into a higher temperature. Exposing into higher temperatures may create minor cracks or aggravate the formation of corrosion. Even a minor crack or corrosion will lead to a catastrophic failure of aircraft.

6. RECOMMENDATIONS

6.1 Control of storage conditions of metal fluid lines

It is always recommended that the fluid lines are to be stored in a cool and dry place where the moisture attack and UV radiation is minimum and the lines are allowed to be with a proper packing until used.

It has been practiced in the past to reheat the moisture absorbed silica gel in aircraft pneumatic systems and to reuse them for the same purposes. Once reheated, the silica gel dose not come to its original status and will not absorb the moisture as new silica gel which may permit the compressed air with moisture through them. The previous practice of reheating the used silica gel should be stopped and it is recommended to replace the used silica gel with new ones in all above inspections.

6.2 Proper and careful inspection of metal fluid lines

The pneumatic/ hydraulic system components are inspected in every 25 flying hours or every two months of whichever comes first. Although, the system components and joints are inspected, rest of the lines are not inspected internally which would not give any indication on corrosion. Therefore, it is recommended to inspect all the metal lines, both from externally and internally for the corrosion attacks in all such inspections and the eddy current inspection is recommended for the same purpose. The internal areas of fluid lines are to be inspected using at regular intervals using a fibrescope/ boroscope to detect surface defetcs. During all these inspections, an extreme care is to be taken not to damage the internal surfaces. Even a minor damage on internal surface causes the bare metal to be exposed to contaminants in working fluid thus creating an electrochemical cell to start with corrosion. An incident in similar nature happend to a “Hamilton” standard propeller fitted to Athlantic South East Airlines on 21 August 1995. The corrosion had been formed on central bore of the propeller blade due to accumulation of moisture. The corrosion attack has severely damaged the metal as the internal surface of bore had been roughned by the movement of a boroscope thorugh the bore. The boroscopes are generally used to inspect the internal areas for corrosion and other minor/ macro level damages. But, the movement of a boroscope through a hole or cavity would slighly damage the surface of being inspected, unless the movement is not properly controlled by the operator.

6.3 Usage of appropriate tools for work hardening and carrying out annealing to remove residual stresses

The tube material will be weakened by work hardening when improper bends and flare ends are made on the lines using the improper tools. Although the prominant failures happen due to the corrosion there are some places of the same pneumatic system which have been failed due to the improper bends and flare ends. The stress corrosion cracking are prominant in those areas due to the residual stresses. It is always recommended that the metal fluid lines must be sujected to annealing after work hardening. But the annealing process must be done with appropriate temperatures. Exposing of age hardened material to higher temperatures for a longer periods of time will weaken the metal by enlarging the size of precipitates.

It is also recommended to use proper tooling and standard practices when making the bends and flare ends without weakening the metal. The above recommendations are made through this project to reduce or eliminate such failures in the fluid pressure system lines and it is further recommended to uplift the standard of the maintenance practices and inspections on the whole aircraft and incorporated systems.

6.4 Use of same material during the replacement of fluid lines

It is recommended to replace the corroded fluid lines with new lines once the corrosion is detected. It is to be noted during the replacement of fluid lines that the material composition of both materials should be the same in order to avoid the galvanic corrosion.

6.5 A method to conduct an external surface inspection to detect the internal defects

The disassembly of fluid lines for an inspection in this nature would be rather time consuming. The aircraft has to be grounded for a long period of time for the disassembly of fluid lines, their inspection and assembly. An external inspection will be more suitable for a complex system which is difficult to be disassembled frequently.

7. CONCLUSIONS

In this research, the feasibility of inspecting small diameter, non ferrous fluid pressure lines using eddy current was studied in order to detect and analyze internal corrosion. During the experiments, it was found that the eddy current signal for the corrosive areas is significantly different from the other areas of metal tubes. The signal for an internal crack was also obtained and the different signals were then compared. A qualitative analysis is carried out using the test results in order to prove that special eddy current signals were obtained due to internal corrosion.

A suitable ID probe was fabricated to inspect the metal tubes as SLAF was not equipped with ID probes. The ID probe diameter was arranged in such a way that the fill factor should be very close to 1. While inspecting and after analyzing the microstructure examination results, it was found that the pitting corrosion was mostly prominent in the metal tubes. Therefore, it can be concluded that the signals received in this experiments are due to the pitting corrosion.

The importance of this study is that it can be easily applied to inspect the fluid carrying systems of SLAF aircraft. It saves time, manpower, money while improving the safety standards in aircraft maintenance. This study is a door opener for a quantitative analysis of corrosion using sddy current testing on small diamater metal tubes. A properly controlled process would give positive, successful results. A quantitative analysis must be carried out to find the area of corrosion, depth of corrosion and the reduction of material due to corrosion. More variables such as different corrosion types, different depths, different areas, different materials are required to be used in the quantitative experiments.

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