Improved Eddy current techniques for the Aerospace Industry

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Abstract

It is estimated that over 25% of the world's commercial airline fleets are composed of aircraft over the age of 20 years. As a result of these aircraft exceeding their initial projected lifetime the issue of in-service inspection has become critical for the safe and economical management of fleets. The requirement for reducing inspection time by minimising 'false calls' and avoiding inspection preparation, has to be balanced against the needs for a high confidence level in the accuracy of the inspection.

Research programs currently being conducted include the ARINC research on behalf of the USAF and the Sandia National Labs research for the FAA, which are addressing the issue of procedure definitions for the inspection of ageing aircraft and evaluating a range of different methodologies including Eddy Current, Ultrasonic, Magnetic Particle, Radiographic and Visual.

Eddy Current is presently used in aerospace for over 50% of all applications for the detection of the most common material conditions that might lead to serious flaws. This covers applications for fastener hole inspection, surface and sub-surface cracking, conductivity measurement, and corrosion (which accounts for a high proportion of maintenance actions on ageing aircraft). New techniques such as FastScan allow the detection of smaller hidden cracks associated with fasteners, than was previously possible and cracks which have not yet emerged from beneath the fastener head are readily detectable. Similarly equipment is now un routine use that allows automated inspection of aircraft wheels.

For speed and confidence in the accuracy of the inspection, it is essential that the operator can take the instrumentation into places of limited access and conduct the inspection, whilst being confident that the unit will give indications that are unambiguous and easy to interpret.

It is this combination of instrument capabilities and operator knowledge which makes the most cost effective and reliable form of inspection. The industry emphasis is now on lightweight, high performance instruments which can address a wide spectrum of eddy-current inspection techniques from high to low frequency, dynamic rotating, skin inspection with fasteners in-situ and conductivity measurements with the benefit of dual frequencies.

Introduction

In this paper we shall discuss the historical perspective of eddy current testing in aviation work, its main applications, and how at Hocking we have developed instruments to keep up with our customers' changing needs. In particular we shall describe how our Phasec 2200 unit, with our FastScan probes, have been developed to provide rapid cost-effective detection of small cracks originating from fastener holes in multi-layer structures with the fasteners still in place.

Eddy current testing has been applied in aircraft inspection for around 50 years. Much of the early impetus in eddy current testing, and key aspects such as lift-off suppression, originated from Dr Friedrich Foerster's work, on German aircraft manufacturing problems in the early 1940's. Corrosion problems were not an issue at that time as the anticipated service life of military aircraft was very short. The primary concern was strength and dependability under combat conditions, eddy current was mainly applied to aspects such as verification of heat treatment by conductivity measurememnts.

From the earliest days of pressurised aircraft,high-cycle metal fatigue has been recognised as a problem, particularly with the rapid cycling introduced with the jet age. Eddy current testing has long been employed to find small cracks that may lead to later structural failure.

These techniques were first applied in manufacturing inspection, and later spread into maintenance activities, creating the need for portable equipment.

More recently, with the increasing age of commercial fleets, many aircraft are remaining in service well beyond their originally anticipated retirement dates and a number of high-profile failures have drawn attention to problems of sub-surface corrosion and cracking brought on by age and service cycles.

With the current financial state of the airline industry two things are certain;

That many of the existing "old" aircraft will still be flying at the end of the millennium, and that pressure on maintenance budgets will continue to be as tight as it is at present.

Secondly, while it was once possible to throw money at some of the technical problems, the current reality is that any new developments in inspection techniques have to justify themselves on both technical and financial grounds. In practice few in engineering management today are impressed with purely technical advantages, so these also have to be translated into cost and quality benefits.

These will typically include:

- More reliable flaw detection.
- Cracks and corrosion can be found when small and removeable.
- Less preparation/strip down is needed.
- Less set up time.
- Less "false calls".
- It's quicker so uses less labour.
- It's quicker so returns the aircraft to service sooner.
- Compatibility with earlier capital investments and training.
- One piece of equipment can do several jobs.

Improved eddy current techniques for the aerospace industry

Aviation applications of Eddy current testing.

Conductivity testing

Conductivity testing is the oldest application of eddy current testing - originally demonstrated by Hughes in 1879 to sort metals. In aviation work it is used in two different applications, both utilizing the change in conductivity of heat-treated aluminium alloys

- To monitor the progress of heat-treatment of aerospace alloys during manufacture. Incorrect heat treatment time can result in considerable degradation of alloy hardness, strength and durability
- Inspection of areas exposed to heating in service (e.g. skins of supersonic aircraft) or by accidental events (engine or galley fires, heavy braking on wheels) to check that metallurgical properties have not been dangerously degraded.

Conductivity meters are also used to make measurements before carrying out an eddy current test in order to ensure that the optimum frequency is selected

While approximate conductivity comparisons can be made using standard eddy current flaw detectors, it is customary to use purpose-built instruments giving a direct readout in IACS or MegaSiemens/meter. Over the past 50 years these have evolved from units the size of a modern TV set to handheld gauges such as the Hocking AutoSigma 3000DL; the size of a TV remote control

The Hocking AutoSigma 3000DL

Phasec 2200 includes a direct reading conductivity function, which simultaneously measures lift-off, e.g. due to paint thickness.

Surface Crack Detection

Small high frequency 'pencil' probes, and probes having similar sensor elements in special fixtures, are often used for detection of small surface breaking cracks. Cracks with depths down to 0.2mm (0.008") are typically detectable.

For many years this type of inspection was carried out with ‘amplitude' sensitive, meter based instruments. In recent years, however, it has been recognised that instruments with ‘phase’ sensitivity and an impedance plane display give far more information to the inspector and hence a greater probability of detection (POD) of all but the largest flaws.

Desirable instrument features include clear display, wide frequency range with good low noise performance across the range and the ability to operate with a wide variety of probes produced specifically for particular applications. The weight and bulk of the earlier models of impedance plane instruments was a disadvantage compared to meter crack detectors, newer types have resolved this issue.

Subsurface Crack and Corrosion Detection

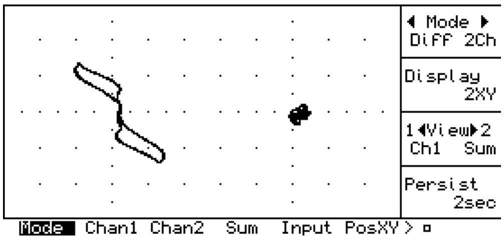
Using suitable low frequency probes it is possible to detect cracks and thinning on the far side of aluminium skins, or at different depths in multi-layer structures.

The use of an impedance plane display is essential for all but the simplest applications. Good low frequency performance and the ability to drive reflection type (driver/pickup) probes are needed in such applications.

Dual frequency techniques are increasingly used to allow the operator to distinguish between thinning and inter-layer spacing variations, and remove other unwanted indications.

Dual frequency inspection

By using equipment operating at two simultaneous inspection frequencies it is possible to subtract one signal from another in order to eliminate an interfering ‘artefact’ which might otherwise obscure flaw signals,



Dual frequency tubing support plate elimination

This principle has been used for many years in the inspection of heat exchanger tubing to eliminate signals from support plates which might otherwise prevent detection and sizing of nearby defects.

More recently the technique has been used in aircraft inspection for applications such as inspecting for second layer thinning in the presence of inter-layer spacing variations [1,2].

Development of dual frequency techniques has been slowed by the size and complexity of older types of instrument, objections which have been removed in the latest ultra-compact and easy-to-use types.

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Rotating probe hole inspection

When fasteners have been removed, the skin and other structure surrounding the holes may be conveniently inspected using a motor driven rotating probe of appropriate diameter inserted into the hole. There are two basic types of drive unit:

High speed, hand-held drives which ensure adequate coverage when the probe is manipulated by hand by the speed of rotation. To give a fast inspection, high scanning speed is important and this demands a high instrument amplifier bandwidth or flaws may be overlooked. Excessive speed may result in unwanted vibration, so it is essential that this can be adjusted to match the size and condition of the hole being inspected.

In incrementing drive units, the movement in and out of the hole is driven at a constant speed by a second motor. These are particularly suited for computer assisted data logging and analysis, and show the depth and angle of the flaw within the hole.

Optimum signal to noise ratio requires both a good design of probe and drive, plus comprehensive filtering options to suppress unwanted signals from hole ovality and roughness. Phasec 2200 and its drive units have gained much customer approval in this respect.

Special purpose rotating probes are also used for inspection of the countersink or hole-edge region in the top skin of aircraft structures.

Aircraft Wheel inspection

The Hocking WheelScan 700 Mk IV

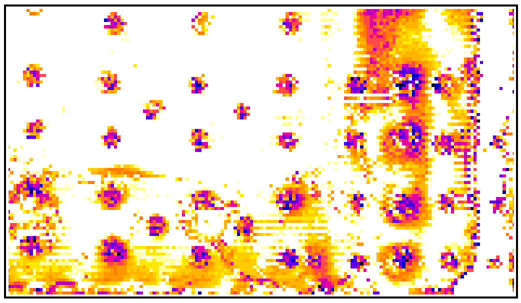
Aircraft wheels are subjected to regular cyclic stresses during take off and landing, and occasional severe stress from aborted take offs or heavy landings. The opportunity to inspect the wheel occurs only when the tyre is changed, so it is vital that all defects which may grow to critical size are found at that time. As tyre life has been increased, it has become essential to detect smaller defects with greater reliability, For many years this was carried out using standard manual crack detection techniques as above, but more recently it has been recognised that the small flaws it is now important to find are likely to be overlooked by manual techniques, giving both an unacceptably long inspection time and low probability of detection.

Most high-volume wheel inspection operations now use automated inspection equipment such as the Hocking WheelScan[3,4] allowing a relatively unskilled operator to reliably inspect a wheel half-hub in two or three minutes.

Eddy current 'C-Scan' inspection

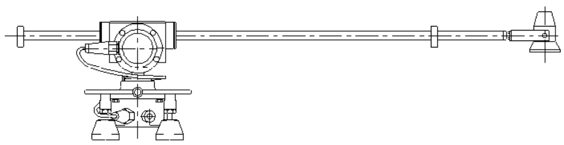
Eddy current signals from many aircraft structures can be very difficult to interpret. Few critical areas comprise simple skins with uniform thickness, there are always fasteners, stringers, doublers and other sub-surface complications, making it very difficult to decide which indications are due to flaws and which to changes of geometry.

In an attempt to make sense of the data systems have been developed which allow a PC to plot the strength of the eddy current indication in a 2-D "C-Scan" presentation. The regular geometry of the structure can then be easily recognised and any unexpected variations noted.



'AndScan' Plot of corroded aircraft structure

Probably the most practical of these systems is the AndScan, developed by Farnborough and marketed by Krautkramer which employs a single-point fixing arm to measure (R,Θ) co-ordinates of the probe position against which the eddy current data can be plotted.



AndScan Test Head

ANDSCAN is a Trade Mark of the Defence Research Agency. The development programme has been funded jointly by the DRA, Ministry of Defence, The Royal Air Force, and Krautkramer

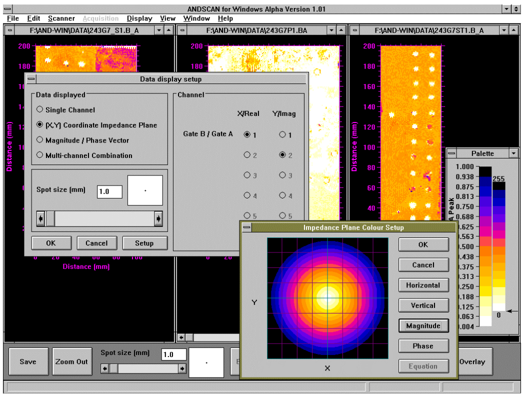
AndScan

ANDSCAN ™ is a Windows-based program.

The program and mechanical manual scanner have been widely accepted as being one of the most effective combinations on the market today.

Andscan may also be used with ultrasonic instrumentation in which case a time of flight and amplitude C-Scan may be viewed and generated simultaneously

- Eight channels each channel store 8 bit (256 levels) data
- Four channels of eddy currents with software mixing and software phase rotation are implemented



- Support of X-Y manual scanners as well as the current R θ mechanics
- Data storage in an industry standard format
- Numerical export of information in a format suitable for databases such as EXCEL
- PCMCIA. A/D card option allows the use of low-cost notebook computers

Windows 95 and 3.1 versions of this program are available, both exclusively distributed and marketed by Krautkramer.

AndScan has proved particularly successful with Phasec 2200.

The Phasec 2200

The Hocking Phasec 2200

Phasec 2200 provides a full function instrument in a very small package, at a competitive price, without compromising either performance or usability.

Key performance aspects of the new equipment are:

Operating frequency range from 60 Hz to 6MHz in single channel mode and 100Hz to 2 MHz in dual channel mode, allowing the instrument to be used for both low and high frequency applications.

Amplifier bandwidth is 2 kHz, allowing a rotating probe drive to be used at up to 3000 rpm. This gives reliable high speed testing of fastener-holes without any risk of missing flaws. Extensive digital filtering allows the amplifier response to be optimized for any particular application by eliminating high or low frequency interfering signals. As the digital filter response is very sharp (24dB per octave) it is possible to operate at frequencies only 2-3 times the filter bandwidth, maximizing test speed with dual channel or low frequencies

The balance circuit accommodates large probe mismatches (around 25% as compared to 5-10% for earlier equipment). Probes made to many different standards may be used without problems. Inbuilt balance loads match common absolute probe inductances, reducing the need for special adapters or leads, while retaining the capability to connect probes intended for other, often earlier instruments, e.g. Locator, ED 520 and Defectometer.

Earlier instruments with many features were sometimes intimidating or awkward to use, so we have included features to ensure that Phasec 2200 is quick and easy to use, even though it is a high performance, high specification package. There are many screens of HELP text ensuring that a brief explanation of any function is never more than a keypress away. On a more active note there are a number of operational features which eliminate some of the common problems experienced in setting up eddy current tests:

With absolute probes a long press on the balance button will automatically select the optimum bridge balance load coil from 5 standard values. In conjunction with the wide balance range mentioned earlier this allows easy balancing with all single coil probes between zero and 200 µH inductance. A further push on the 'Auto' button sets the lift-off angle. Two key presses and it's set up ready for use.

Perhaps the most innovative feature is the RECORD function. This allows up to 15 seconds of signals to be recorded and then played back through the instrument, allowing optimisation of gain, phase, filter settings, alarms, etc. on a chosen, clean signal, with both hands free to do it! With conventional equipment it can be difficult to adjust parameters while simultaneously manipulating the probe (or holding a rotating probe drive) in a completely consistent manner. With Phasec 2200 you can adjust the gain, phase, filters etc and observe the effect on the recorded signal as you do so.

The RECORD function is also used for two frequency mixing. After recording the signals from the unwanted artefact a single button press produces, in around three seconds, an optimized automatic mix with minimal resultant signal. If the operator does not like the result the mix can be further optimized manually, or a different portion of the stored data selected and re-mixed.

When test parameters have been determined they can be stored in the instruments internal memory, each one with a 14 character descriptive name, allowing the parameters to be easily recalled later. Screen traces can also be saved in the same way and recalled on screen as a reference while testing.

In addition to full eddy current inspection functions using either manual or rotary probes the Phasec 2200 can also be used in conjunction with conductivity probes. The electrical conductivity of non-ferrous metals in the range of 1 to 110 % IACS can be measured. Accuracy over the range of aerospace alloys is 0.5% IACS, with approximztely 1% IACS at the extremes of the range.

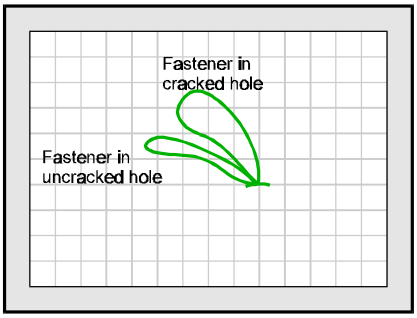
FastScan Probe

On aircraft structures Eddy Currents have become the major inspection technique for detecting flaws around aircraft fasteners. While a thorough inspection can be carried out by removing the fastener and using a rotating probe down the hole, this is extremely time consuming and not practical as a means of inspecting entire structures.

The methods used for inspection with the fasteners installed include a simple pencil probe that is guided round the outside of a fastener head to detect any cracks propagating from the hole beyond the area covered by the fastener head, and low frequency spot face and ring probes used to detect flaws, both cracks and corrosion in the sub-surface area adjacent to and between fasteners. Dedicated equipment such as pulsed eddy current system has been developed at Farnborough and applied to similar inspections. A detailed study by Don Hagemier of McDonnell Douglas [5] compares a range of techniques for the application and demonstrates that FastScan has a high probability of detection for the flaw sizes used in the test.

With the fastener removed rotating bolt hole probes can be used to detect very small cracks, as previously mentioned. With the fastener installed, flat face rotating probes can be used to rotate around the area immediately beyond a fastener head to detect a crack in the first layer immediately it penetrates past the area of the fastener head. This gives good detection of top layer cracks, but no penetration to lower layers.

In the last decade we have seen the development of the sliding probe. In this case the probe is guided along a row of fasteners and as the probe passes a fastener a signature is seen on the display of the phase plane equipment. The signature from all similar fasteners installed in a flawless constant structure will have a similar appearance. If however the probe passes a fastener with associated cracks, then the signature will be changed, typically getting fatter and largerWith appropriate training and calibration standards, the operator can determine the location and severity of any cracks present in the structure. By using dual frequency methods with the sliding probe it is possible to reduce the size of the signature from sound fasteners and make the flaw signal easier to interpret.



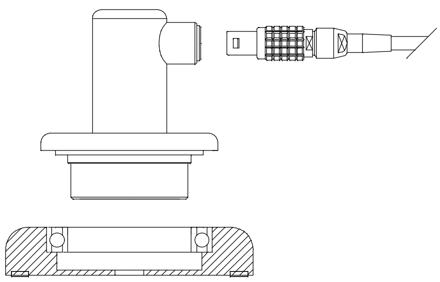
Response from sliding probe

In the last two years The FastScan probe has been developed to exploit the characteristics of dual frequency inspections. This probe has proved very effective in detecting cracks in multi-layered structures both of thin sections (2 mm and less) and thick structures (up to 10 mm). The FastScan probe has the ability to detect cracks underneath fastener heads, and cracks that have propagated half way from the hole to the edge of the fastener can be readily detected using the FastScan technique.

In the FastScan probe a driver coil induces eddy currents to circulate around the fastener. A series of pick up coils are arranged to detect the reflected eddy current field. In a typical arrangement four of these pick up coils are arranged equally spaced at a set diameter, the pick up coils are connected in antiphase to reduce the effect of lift-off.

The probe is centred over the fastener to be inspected and is manually twisted through 90 degrees and back. This allows each of the coils to traverse 90 degrees of the circumference of the fastener; as there are four pick up coils the full 360 degrees around the fastener is inspected. Should any cracks be encountered the field of the eddy currents, the flaw signal will be displayed on the screen.

To allow for the easy operation of the FastScan probe a containing a bearing allows an easy twist of the wrist operation from the operator. A guidance hole slightly larger than the fastener head size allows a perfect concentricity to be obtained round the fastener head.



With practice a skilled operator can achieve a fastener inspection in around three or four seconds, hence the term FastScan. The method is fail-safe in that any misalignment of the guide will produce an apparent flaw signal. On repositioning the guide, if this flaw signal cannot be eliminated then a flaw is being detected.

The FastScan probe is most effective in a dual frequency technique, and gives a very clear indication of small flaws in the second and third layers.

The choice of frequencies for dual frequency operation is important. The main inspection frequency should be chosen to suit the depth of the structure to be inspected. This frequency is usually the effective depth of penetration for eddy currents, approximately three times the standard depth of penetration. In establishing the base inspection frequency, the Phasec 2200 can measure the conductivity of the aluminium structure to be inspected. From the conductivity value, the formula for the effective depth of penetration should used to establish the base inspection frequency.

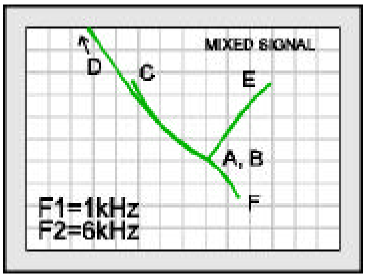
$$d_{eff} = 150\sqrt{\rho/(f.\mu_r)}$$

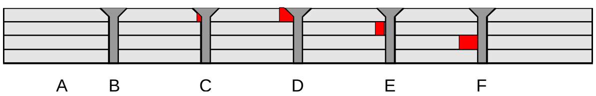
where ρ is resistivity in mW.cm and f is frequency in Hz

For example a typical multi-layer aluminium aircraft structure 8mm thick, would be inspected at around 500 Hz. The choice of the second frequency would be about five or six times the basic inspection frequency i.e. about 3 kHz. The object of dual frequency operation is to eliminate common mode signals from the fastener inspection, these signals are variations in the symmetry of the probe and signals from the fastener and the machining of the structure.

Since the second frequency is very much higher than that of the main inspection frequency, the signals obtained from this relate to the probe and the surface of the structure and fastener. By modifying the phase and gain of the second frequency signal, it can be made to look identical to the first frequency signal when scanning a sound fastener, by subtracting the two signals common mode signals can be eliminated, this difference signal that is used as the inspection signal.

If a sound fastener is inspected then there is very little spot movement on the display. Should a flawed structure be examined then a distinct signal will be produced, this signal gives us two important parameters. The angle of the spot movement on the display indicates the depth or layer at which the flaw exists. The amplitude of movement for that particular angle reveals the size of the crack. By careful selection of the correct operating frequencies, the inspection of a particular structure and area of interest can be optimised.





When devising an inspection method for a new structure, most operators find the main difficulty is adjusting the second layer sound fastener signal to match that of the inspection frequency signal, however with Phasec 2200 this can be done by using the AUTOMIX facility which uses the processing power of the instrument to condition the signals so that a zero signal is automatically obtained for a sound fastener inspection.

In the case of the Phasec 2200 the sound fastener signals are recorded within the unit, the operator can check that these signals are the ones he wishes to eliminate, he then activates the AUTOMIX and the appropriate settings are electronically calculated and set into the instrument. Once appropriate settings for a particular inspection have been obtained and optimised they can be stored in the instrument and called up for use at a later date.

Four standard FastScan probes cover fastener head sizes from 4 mm to 18 mm diameter, and a range of guides with apertures to suit the range of fastener head sizes. Special probes can also be produced. The fasteners can be of aluminium alloy, titanium or steel. Steel fasteners produce better results due to the fact that the fastener itself draws the eddy currents closer to the structure hole, therefore allowing the detection of smaller cracks.

Research has shown that the FastScan probe can detect corrosion as well as cracks. We have been participating in programmes with ARINC in the USA in establishing corrosion detection methods in ageing aircraft and we are also working with the Royal Air Force in assessing the potential of FastScan for corrosion and crack detection in military aircraft structures.

An eddy current wall chart is available which outlines basic eddy current principles and shows how to apply this exciting inspection method.

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