THE DETECTION OF CRACKS UNDER INSTALLED FASTENERS BY MEANS OF A SCANNING EDDY-CURRENT METHOD

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INTRODUCTION

As a consequence of metal fatigue, cracks can develop and grow in operational aircraft. Periodic inspections must be made in order to detect and repair them before they reach a dangerous length. Cracks which grow from holes are a significant problem for aircraft since the wings and fuselage can contain many thousands of fasteners. Since it is impractical to remove them all, inspection must be made with them installed.

A self-contained automated instrument, the EDDISCAN, has been built to detect and size these cracks. It works on a scanning principle and is based on a microprocessor which controls all aspects of the systems operation, including analysis and display of results. (A photograph of the instrument is shown in Fig 1.) Preliminary tests show that, under laboratory conditions, it can detect the presence of simulated radial cracks as small as 0.2 mm long beneath the heads of fasteners.

PRINCIPLES OF OPERATION

A section of aircraft skin riveted to a stiffener is illustrated in Fig 2. This is a typical example of the situation in which small radial cracks can grow under the heads of installed fasteners. In order to detect these cracks, a small C-shaped ferrite core with a coil on the outer leg is rotated around the axis of the fastener as shown in Fig 2. If it passes over a sub-surface crack, then the reflected impedance of the coil changes. By measuring the impedance repeatedly at different positions as the coil is rotated, a map or image of the impedance variations can be recorded and by suitable analysis, the presence of cracks can be identified.

A block diagram of the instrument is shown in Fig 3. It can be seen that all aspects of its performance are controlled through a microprocessor by means of programmed instructions stored in a 16K EPROM. The coil is rotated at constant speed by a stepper motor. The input signal to the coil is a 1 kHz square wave which is generated as a digital data stream and converted to analogue form by a D/A converter (DAC1). The voltage across the coil is amplified by the pick-up amplifier, converted to digital form by an A/D converter (ADC) and stored in memory (8K RAM). The observed signal consists of four main AC components. These
are due to (a) the impedance of the coil in vacuo, (b) the reflected impedance of the specimen, (c) the reflected impedance of the fastener (and hole) and (d) the reflected impedance of any cracks. Components (a)

Fig. 1. A photograph of the EDDISCAN instrument

Fig. 2. Schematic diagram illustrating the application of the principles of scanning eddy-current methods to the detection of typical small radial cracks growing beneath the head of a rivet.
and (b) are relatively large and contain no useful information since they do not vary throughout each revolution of the coil. They must be removed so that components (c) and (d) can be amplified. They are cancelled by using a hardware/software negative feedback loop to generate a balancing signal through DAC2. Thus at this stage RAM memory contains a digital representation of the variation of components (c) and (d) during one complete revolution of the coil.

Component (c), the reflected impedance of the fastener, is dependent on the position of the coil relative to the fastener. Because the axis of rotation of the coil may not coincide with the axis of the fastener, this impedance may vary considerably during each revolution. By identifying and analysing (c), the relative positions of the axes can be calculated and used to generate a graphical centering display. By observing this, an operator can rapidly adjust the transducer so that it is concentric with the fastener. Under these circumstances, (c) is reduced to zero leaving only (d) in memory, the signal due to any cracks. Digital processing and analysis programs then analyse this data and display results in the form of text and graphics on a VDU which is driven by a graphics display processor.

By taking this approach to the design, it is possible to make considerable reductions in the amount of hardware required. Analogue circuitry is reduced to a minimum since most of the traditional analogue functions can now be done by the microprocessor. Shifting the boundary between hardware and software in this way inevitably involves a significant increase in the level of effort on software development. However, this approach is justified not only by increased flexibility but also by the ability to do things that are not possible using conventional analogue techniques.

PRELIMINARY PERFORMANCE

The VDU screen layout is represented in Fig 4. The screen is divided into four quadrants, each displaying a separate function. Top left is the centering display. As described above, the position of the transducer relative to the axis of the fastener is displayed on the screen in the form of a small cross and a set of axes. The cross is programmed to move in unison with the transducer and when it is at the origin of the display then the transducer is coaxial with the fastener. With this aid, an operator can rapidly center the transducer. Bottom left is a display of the raw impedance measurements which is updated each revolution of the transducer. Bottom right shows the real and imaginary components of the same data after it has been processed and digitally filtered. Finally, top right shows an impedance plane display of the processed data in which the real and imaginary parts are plotted against each other.

Although development of the software for this instrument is not yet complete, in order to obtain a preliminary estimate of its performance, some measurements have been made using test specimens which contained spark-eroded notches to simulate real defects. These results are presented in Fig 5 in the form of photographs taken of the screen during measurements of four different specimens. In each case the specimen consisted of six aluminium alloy plates, each 2.5 mm thick, held together with a 5.0 mm diameter non-ferrous fastener. Figs 5(A) to 5(D) show respectively the instruments response to (a) a 1.0 mm defect in the top layer, (b) a 1.5 mm defect in the second layer, (c) a 0.6 mm defect in the top layer and a diagonally opposed 1.5 mm defect in the second layer and (d) no defects at all. In Figs 5(A), 5(B) and 5(C) the effect of the defects can clearly be seen on the real and imaginary traces in contrast to the traces of Fig 5(D) which are for no defects. Furthermore, since the phase of the signal depends on the depth of the crack, cracks in the
Fig. 3. Block diagram of the electronic hardware

Fig. 4. Schematic diagram of the graphical display of results presented on the screen.
Fig. 5. Photographs of the screen taken during the measurement of various sized notches: (A) 1.0 mm in the skin, (B) 1.5 mm in the second layer, (C) 0.6 mm in the skin and 1.5 mm in the second layer and (D) no defects.

top and second layers cause distinct loci in the impedance plane and thus can be distinguished as is evident from Fig 5(C).

FUTURE DEVELOPMENT

With the instrument in its present form the effect of cracks in the top layer as small as 0.2 mm can be observed by eye. Analysis programs based on pattern recognition are being written which will automatically process the measurements, estimate the size, angular position and depth of any cracks, and generate a comprehensive display of the results. In addition, it is planned to make slight modifications to the transducer that will enable it to work with ferrous fasteners.