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ULTRASONICS IN INDUSTRY SESSION.

CRACK DEPTH MEASUREMENT WITH SURFACE WAVES

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A non-destructive estimate of surface crack depth is frequently desirable both in the laboratory to control fatigue and fracture mechanics experiments, and in the workshops or plant to indicate suitability for service. Three electrical methods, a.c. potential drop, d.c. potential drop and eddy currents are widely used as is pulsed echo ultrasonic flaw detection. An alternative method using ultrasonic surface waves, which has features in common with a.c. potential drop and eddy currents is described and the relevant features of the other methods are highlighted.

EDDY CURRENTS

Eddy currents are successfully used to find and measure the depth of surface cracks. When a coil carrying an alternating current is brought close to a metal an alternating electric current (eddy current) is induced locally in the surface of the metal. The primary magnetic field due to the coil and the secondary magnetic field which results from the eddy currents in the metal interacts and changes the electrical characteristics of the coil. If there is a surface crack in the metal the distribution of the eddy currents is modified because they have to flow around the crack. These changes can be detected by suitable electronic circuits in the test equipment.

The change in equipment output produced by a crack of a given length is best obtained empirically by using test blocks. The maximum depth of crack which can be measured with any accuracy is 6 mm. Since eddy current probes can be made as small as 2 mm. diameter without great difficulty local estimates of maximum crack depth can be made.

D.C. POTENTIAL DROP

With this method the specimen is placed in series with a constant direct current source and the potential drop between fixed points on either side of the crack is measured as an indication of crack depth. The output signal is dependent upon the percentage reduction in the total cross sectional area of the specimen. This method is most useful for measuring surface crack depth on specimens of uniform cross section and with uniform crack depth. A theoretical calibration is possible but in general it is preferable to calibrate the equipment using test blocks.

A typical application of this method is with a 25 mm. square steel specimen and 50 amps flowing the signal from a crack would be 45 micro volts/mm crack depth. This signal level allows d.c. amplifiers to be used and thermal drift can be ignored but it is rather sensitive to changes in temperature in the specimen.

A.C. POTENTIAL DROP

If an alternating current is applied to a metal conductor the current tends to flow through the outside wall of the conductor this is due to the "skin effect". This effect can be used to measure the depth of surface cracks. When a constant current is applied to an uncracked specimen the p.d. can be measured across a pair of electrodes applied to the surface, if a crack is present the current flows down the crack and an increased potential drop is measured. Calibration is best achieved using test blocks as with the eddy current method.

If a system is used with a 2K Hz, 0.5 Amp constant current generator about 30 m volts is produced with the supply leads spaced 100 mm apart on a steel specimen. This gives a signal change of approx. 0.6 mV/mm crack depth if the measuring electrodes are placed each side of the crack. As this method uses a localised effect the size and shape of the specimen has less effect on the measuring accuracy than the d.c. system.

ULTRASONIC METHODS

PULSE ECHO

Pulse echo flaw detection methods and their limitations are well known, and it is not proposed to consider them at the present as a practical method of measuring surface crack depth.

SURFACE WAVES USING THROUGH TRANSMISSION

THE NATURE OF SURFACE WAVES

Acoustic surface waves or Rayleigh waves are unusual in that they propagate more on the surface of the body than in it and have displacement vectors both in and perpendicular to the direction of propagation, i.e. they have features in common with both longitudinal and transverse waves.

The velocity of propagation C_S is related to the velocity of the transverse waves C_T by the close approximation

$$C_S - C_T \quad \frac{0.87 + 1.12\sigma}{1 + \sigma} \qquad \sigma = \text{Poisson's ratio}$$

For steel $\sigma = 0.29$ $\quad C_S = 3000$ m/sec

When an ultrasonic surface wave is incident at a crack two things occur :

1) The major proportion of the incident energy is reflected.
2) A much smaller proportion of the energy is transmitted by propagating around the crack.

If the transmit time of this transmitted wave can be measured a value for the crack length can be derived.

GENERATION OF ULTRASONIC SURFACE WAVES

Ultrasonic surface waves can be generated by a variety of methods. The most popular method because of its efficiency and convenience is the use of a wedge and piezoelectric plate to generate a system of normal and tangential stresses at the free surface of the solid which then acts as a source of surface waves. Figure 1. The piezoelectric crystal generates either transverse or longitudinal waves and when the relationship $\sin \phi = \frac{C_B}{C_S}$ is obeyed the maximum conversion of bulk waves to surface waves occurs. In pulse echo ultrasonic flaw detection thickness expander piezoelectric plates (which generate a longitudinal wave) on polymeric wedges are almost exclusively used for the generation of surface waves. More recently the use of shear piezoelectric plates mounted on metal, glass or ceramic wedges has been proposed and this has resulted in an extension in the use of wedges to higher frequencies because the acoustic absorption in the wedge is reduced. The reverberations of the bulk wave within the wedge however has limited their use to separate transmitter and receiver operations; whereas the high absorption of ultrasound in polymers severely reduces the reverberations and permits transceiver operation. The major advantage in using non polymers lies in their high acoustic impedance ($\rho c_{perspex} = 3.6 \times 10^6$ $\rho c_{cu} = 42 \times 10^6$ Kg/m^{2}s). This reduces the reflection losses at the piezoelectric plate/wedge and wedge/workpiece interfaces and additionally because of the greater acoustic load they present to the plate reduces the mechanical Q of the resulting probe with a consequent reduction in pulse length.

The surface wave probes used in this investigation used a shear piezoelectric plate cemented onto a copper wedge. The plates have a nominal 4 MHz frequency as half wavelength resonaters but because of the different media in contact with their faces (copper and air) they oscillate as a quarter wavelength resonater at 2 MHz.

CRACK LENGTH MEASUREMENT

Two surface wave probes are placed on a workpiece surface as shown in Figure 2.

In pulsed operation the receiving probe will be energised by the transmitted pulse after time interval which is proportional to the separation of the probes

$X = \frac{1}{C_S}$ $\qquad$ $Y = \frac{1}{C_{cu}}$

$t = Xd + YA$ $\qquad$ A = total path in C_u both probes

If a surface crack of length l initiates in the surface of specimen between the probes, the surface wave will traverse the crack, and the apparent separation of the probes will increase by a distance which is proportional to twice the crack length. Fig. 3.

$$t_1 = X(d + 2l) + YA$$

$$\text{i.e.} \quad 2l = t_1 - t$$

To obtain a value for l therefore it is necessary to calibrate the timebase of an ultrasonic flaw detector so that it has a fixed and known relation to surface wave velocity, e.g. 1 division = 1 mm. Two methods have been used for timebase calibration, they are, calibration of the timebase using a 2MHz signal or movement of one probe with respect to the other over a known distance. Both methods are best used with an unrectified display to aid interpretation of the resulting traces.

EXPERIMENTAL APPLICATION

The technique was used to show the crack growth in the head of the flat bottom rails fatigued in 3 point bending. The probes were held in their positions using pot magnets, a hydrocarbon grease was used as an ultrasonic couplant. The intention was to grow the cracks to a length of 9 mm.

DISCUSSION

During these tests a number of limitations in the technique were observed :

1. The correct crack length is only indicated when the crack opening exceeds a critical value, i.e. measurements must be made under load. This is a feature which is common to all the crack measurement techniques which use energy flow over the surface to measure crack length, i.e. a.c. potential drop, eddy current and surface wave. The effect is observed but is not so pronounced in the d.c. potential drop method where the energy distribution is uniform over the cross section.

2. There is a minimum crack length which can be measured for any probe/flaw detector combination. This is because for successful measurement a considerable reduction in the direct transmission signal is necessary. Since surface waves are strongly concentrated at the surface, at a surface wavelength (λs = 1.5mm at 2MHz in steel) below the surface the intensity of the wave is negligible. If the crack length is less than λs that part of the surface wave which goes underneath the crack will produce a considerable standing signal at the receiver. This means that the crack length must be greater than λs.

In practice it was found that once a crack was greater than 1.5 mm long its growth could be readily followed i.e. cracks in excess of λs can be monitored.

3. The effective crack width should exceed the effective probe beam width; this ensures that the standing signal due to direct transmission around the crack edges is absent. This either places geometric restraints upon the positioning of the probes or means that strips of a surface damping material such as plasticine must be used to confine the beam.

CONCLUSIONS

Ultrasonic surface waves offer a useful alternative to potential drop and eddy current methods for the measurement of open surface cracks. It has the advantage that no test blocks are necessary for calibration as the depth of a crack is measured as a time difference. Any commercial flaw detector or oscilloscope which has an accurately calibrated timebase can be used. It has been used on a number of specimens to measure cracks up to 18 mm deep and no limit has been found except the available gain in the instrumentation.

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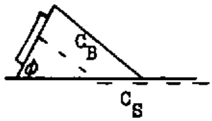

Fig. 1

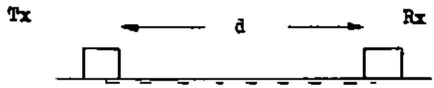

Fig. 2

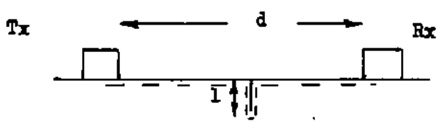

Fig. 3