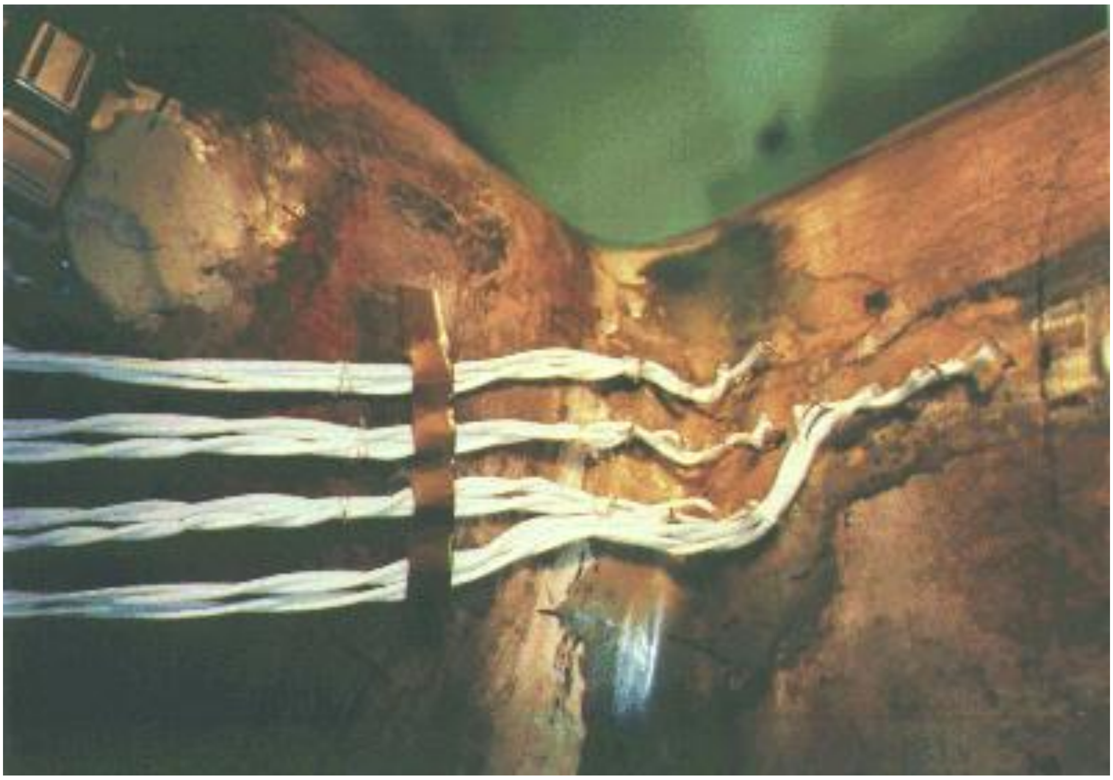
PRACTICAL ASPECTS OF THE ACPD TECHNIQUE

For use with Matelect ACPD products



USER MANUAL

MATELECT

The ACPD technique
A User Manual

CONTENTS

THE ACPD TECHNIQUE

A User Manual

For use with the CGM-5/5R/6/7, SM series units and peripheral equipment

Our potential drop products have been designed to the highest standard in both electronic and mechanical design, with careful attention to stability, reliability and electrical safety.

This manual has been prepared for use with our range of potential drop products. It is recommended that the relevant equipment instruction manuals are read in conjunction with this text.

For further details of our products or for advice and assistance please contact Matelect at the address below.

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INTRODUCTION

This short manual covers practical aspects of specimen connection and test set-up procedures in ACPD studies. In particular, it concentrates upon the use of the ACPD technique for long term continuous monitoring of crack activity in multiple specimens or at multiple sites on one specimen. Reference is therefore made, to both the Matelect CGM-5 and the SM multiplexing system throughout the text. Users should also consult the instruction manuals that pertain to these instruments for further details. A knowledge of the operation of these instruments is assumed in this manual.

Most of the recommendations made in the text are based upon the practical experience of Matelect engineers and our customers. Suggestions based on theory rather than actual practice are kept to a minimum. Users who encounter difficulty with any of the procedures outlined are urged to contact Matelect to discuss their applications problem. We are always happy to assist.

BACKGROUND: PD TECHNIQUES

Potential drop techniques rely upon the basic principle that a conductive specimen that carries an electric current will exhibit a voltage drop across its surface. If the resistance of the specimen is known, the voltage drop can be calculated for any particular value of the current. Specimen resistance can be altered by the presence of a defect such as a crack. Thus, by maintaining a constant current through the specimen, it is possible to detect the initiation and propagation of a defect by monitoring the value of the potential drop.

In potential drop studies, it is not usually important to know the absolute value of the resistance or voltage since it is the relative change in potential that is used to monitor crack growth.

Two variants of the PD technique exist, alternating current potential drop (ACPD) and direct current potential drop (DCPD). The salient qualities of each technique are summarised overleaf.

Users should note that advances in equipment have eliminated many of the deficiencies of the DCPD technique, in particular, the advent of pulsed DCPD has lead to a dramatic improvement in noise performance.

DCPD	ACPD
Direct currents typically to 50 Amperes Signals of nanovolts Sensitive preamplification required Usually a two channel system	**Specimen currents typically 1 Ampere RMS. Frequencies of tens of kHz Signals of nano or microvolts**
Simpler than ACPD Traditional method No inductive pick-up problems Ease of reproducibility	**Developed as an alternative to DCPD Theoretically more sensitive - skin effect Lower noise - phase sensitive detection No thermoelectric EMFs Electrochemically non intrusive No specimen heating Linear response - depth vs. volts Smaller/portable equipment**
Non linear calibrations High specimen currents can cause heating Errors due to thermoelectric EMFs Heavy equipment/cables/contacts.	**Errors due to induced pick-up Lead movement alters results Lead positions can greatly affect results**

Table 1 DCPD vs ACPD

When considering ACPD, it is the change in specimen impedance, rather than resistance, that needs to be considered. ACPD offers a number of advantages over the traditional DCPD method. These are as a direct result of the use of alternating currents and include greatly improved instrumental noise performance and superior crack growth resolution.

With appropriate care and attention, resolutions in the 10 micron region have been obtained by some users. Whilst this may be unnecessary and often difficult to achieve in practice, it does testify to the extra sensitivity that ACPD can confer, even for routine testing.

All PD techniques require at least four connections to be made to the specimen. Two are used to carry the current to and from the specimen whilst the remaining pair transmit the signal to the measuring apparatus.

Modern PD instrumentation such as the Matelect CGM-7 ACPD monitor or the Matelect DCM-2 DCPD monitor, contain both the constant current source and the signal measurement circuitry in one integrated unit. Before the advent of such instrumentation users had no alternative but to build up the monitoring system from separate modules. These were invariably sourced from different manufacturers. The sum of the parts was often more costly, performed less well and was difficult to set-up.

Incompatibility between the configurations of different users often made data comparison dubious because of the unknown effect of instrumental differences. Despite this, some users still assemble "home made" systems.

The methods used to connect the current and signal wires will be discussed later but for now it is sufficient to state that the position of the contacts is of vital importance to the PD technique. Ignorance of the principles of contact positioning is often the reason for the collection of poor or totally useless experimental results. If there is one deficiency of the PD technique it is this dependency upon the user to choose, make, and maintain a good contact arrangement. Once mastered however, good results are easy to obtain.

The following sections apply to the ACPD technique only. For information on DCPD please contact Matelect.

ACPD: THE BASICS

ACPD differs from its DC counterpart in that AC currents are largely confined to a layer immediately adjacent to the surface of the specimen by a phenomenon known as the skin effect. The thickness of this layer (the skin depth) is determined by the electrical and magnetic properties of the specimen and the frequency of the AC current.

The skin effect can be theoretically modelled but for most testing purposes it is sufficient to know that it exists and that it confers dramatic advantages to the user. The effect on the current flow in a typical CT specimen is shown schematically below.

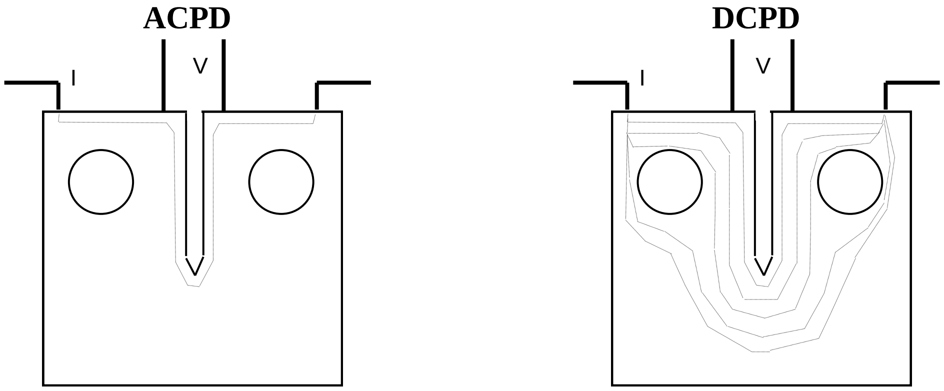

Fig 1 Current flow lines in a typical CT specimen

The skin effect is responsible for many of the advantages of the ACPD technique These include the linear relationship between defect depth (measured from the specimen surface), a lower excitation current (with respect to DCPD) and improved sensitivity. The utilisation of an AC current also enables electronic techniques such as phase sensitive detection to be used. This results in a significant reduction in electronic noise which, once again, enhances the sensitivity and resolution of the technique.

In order to take full advantage of the ACPD technique it is important to utilise equipment that both incorporates phase sensitive detection and in addition offers the user a choice of frequencies for the AC excitation current. The latter requirement allows the user to adjust the skin depth to match the material under test. For example, acceptable skin depths are easily achieved in ferrous materials at a few kilohertz whereas materials such as aluminium require 30kHz or more for similar depths.

The skin depth can be calculated from the following equation. Notice that it depends upon the magnetic permeability and resistivity of the material under test and the frequency of the alternating current that is applied.

Skin depth Δ defined as:

$$\Delta = \sqrt{\frac{\rho}{\pi \mu f}}$$

where μ = magnetic permeability
ρ = resistivity
f = frequency

at 1kHz in steel $\Delta \approx 0.4$ mm
at 100kHz in aluminium $\Delta \approx 0.35$ mm

BASIC PRACTICE : SPECIMEN CONNECTIONS

As mentioned earlier, a minimum of four electrical connections are required to be made to a specimen, two current and two voltage. The ACPD technique is essentially a version of four point resistance measurement, hence the need for four contacts. This method prevents the resistance of the leads and contacts from influencing the potential drop measurement. It is not recommended practice to combine the current contacts with the voltage contacts (i.e. reducing the number of contacts to two). It is important to obtain a good electrical contact between lead and specimen and it is usual to use spot welded, soldered or screwed connections in this respect (see later).

For a typical compact tension specimen (CT) the connections should be made as shown in Fig. 2. below.

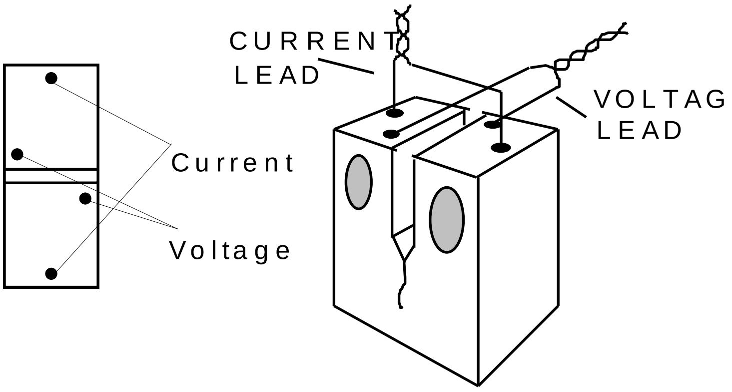

Fig 2. General ACPD connection locations

This is a general arrangement that can be adapted to other configurations such as three point bend and wide plate specimens. Long term monitoring of large components will involve a more complex arrangement of contacts, especially if multiple sensing points are required and if temperature variations are likely to occur during a test. This will be discussed later.

The current leads should be positioned such that the current path encloses the crack. In this manner, the propagation of a defect will cause a perturbation in the current flow that will lead to a change in the measured ACPD.

The voltage sensing leads should be positioned symmetrically about the crack site and between the current connections. By locating the voltage connections as shown in Fig 2, the average depth across the advancing crack front is registered.

It is highly advantageous to make the connections to the specimens as rigid as possible. This minimises possible lead movement during a test and reduces any errors due to changes in a phenomenon known as induced pick-up (PU). This unwanted signal is derived from the interaction of the voltage leads with the magnetic field generated by the passage of the alternating current through the supply leads and specimen. The pick-up signal is explained more fully in the next section.

Rigid connections can be made using thick gauge copper wires. The relevant cables can then be attached to these conductors as close to the specimen as the testing configuration allows. Use adhesive tape to secure the cables themselves to prevent any possible lead movement during a test.

To reduce the actual magnitude of the pick-up voltage it is important to tightly twist the leads (as shown). It is important to note that the magnitude of the PU can be reduced by minimising the area enclosed by both the current and voltage leads. This is illustrated in the following diagram. If large loops are unavoidable, it is best to position them perpendicular to each other.

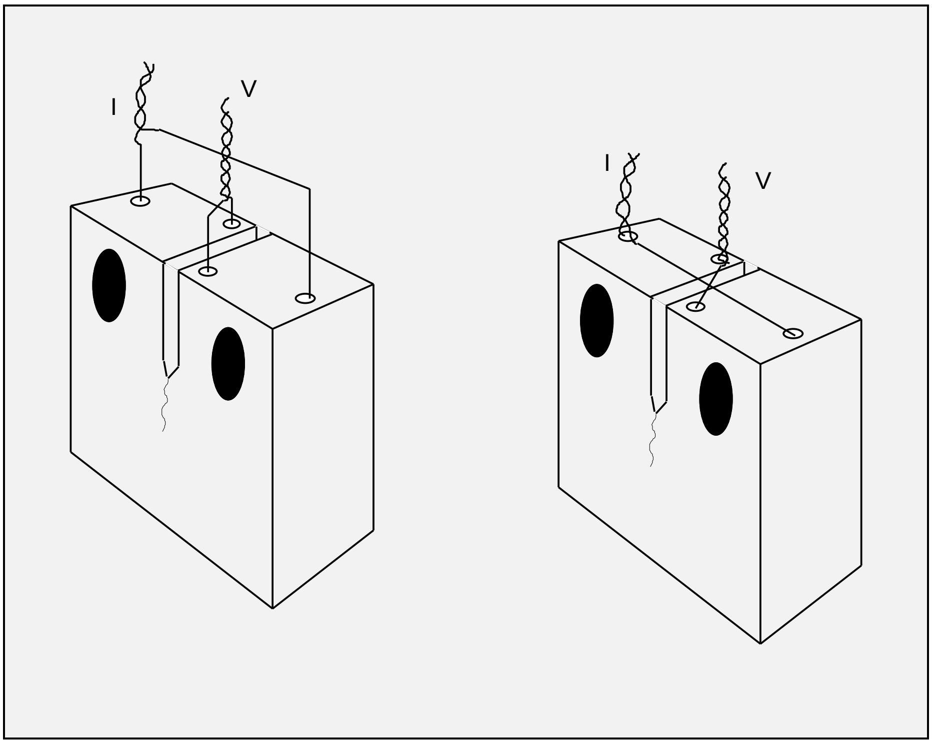

Fig 3. Loop area considerations

When using the ACPD technique on specimens it is important to consider the effect of alternative current paths. These can often divert the current away from the monitored area and rob the user of valuable signal sensitivity. This is an important consideration in specimens of a non-standard configuration such as industrial components.

For standard test specimen, such as the CT specimen, the user should follow accepted practice to ensure good results.

When employing a testing machine, it is not usually necessary to isolate the specimen from the testing machine since the specimen presents a far lower impedance to the flow of current than does the alternative path via the grips and body of the machine. Care must be taken, however, if a clip gauge is used in conjunction with ACPD measurements. The gauge can easily short out the signal from the specimen, so it is important to provide some form of electrical isolation in such cases.

Excessive cable length can seriously degrade the performance of an ACPD system. Users must always try to minimise cable impedance. If the impedance is excessive, the voltage compliance limit of the constant current source will be reached and the maximum specimen current available will drop. In the case of the CGM-5, for example, the compliance is of the order of 4V. For a maximum current of 2 Amperes, this equates to a total tolerable impedance of 2 Ohms. This impedance is the sum of the specimen, contact and lead impedances.

Users should note the word "impedance" rather than resistance (since we are dealing with AC signals). The impedance will be a function of resistance, capacitance and inductance. It will be necessary to minimise all these variables if it is desired to utilise the instrument over the full range of current.

These considerations are therefore especially important for high frequency operation (30/100 kHz) as the contribution to the overall impedance by the capacitive and inductive properties of the specimen and cable configuration becomes significant at high frequencies.

Long signal cables can also lead to problems with regard to induced pick-up and external sources of noise. In such cases use of a signal pre-amplifier should be considered.

One final point relates to a phenomenon known as current focusing which occurs in ACPD experimentation. This effect causes the specimen current to closely follow a path defined by the current leads. It is especially prevalent when the current leads are close to the specimen's surface. Current focusing is used to great effect to increase ACPD sensitivity but it can lead to errors in interpretation of results. Current focusing will be covered in a later section.

OTHER CONSIDERATIONS :
INDUCED PICK-UP

One of the most critical areas of ACPD practice is the method with which the user routes the specimen connections. This aspect of ACPD is important since interactions can occur between the signal and current leads and between the current and specimen. The former interaction leads to a phenomenon known as pick up.

Pick up manifests itself as an extra component of the measured ACPD signal. It is important to note that since we are dealing with AC currents, unwanted voltages such as the pick-up cannot simply be subtracted out, since the various signal components are represented by vectors which differ in both magnitude and phase with respect to one another.

The effect of pick-up can largely be ignored in potential drop work (assuming that it is small in comparison with the true ACPD) if the user maintains a positional constancy between the signal and current leads. In practice this is easily achieved as even dynamic testing causes little lead movement.

Theory predicts that pure ACPD, as generated by passage of an AC current through a metal, will exhibit a phase difference of 45 degrees with respect to the actual current delivered to the specimen.

Theory also predicts that the "pick up" vector lies at 90 degrees to the specimen current vector.

The resultant of the two vectors is the actual measured ACPD. The magnitude of this vector is usually the quantity measured by ACPD instrumentation.

The vectors are shown in the diagram overleaf. As an illustration of the importance of the induced pick-up, two different pick-up vectors are indicated (for one particular true ACPD vector). It can be seen that these will give widely different ACPD readings.

Since the magnitude of the pick-up vector will vary depending on the relative position of the supply and measurement leads, significant errors can occur in ACPD measurements.

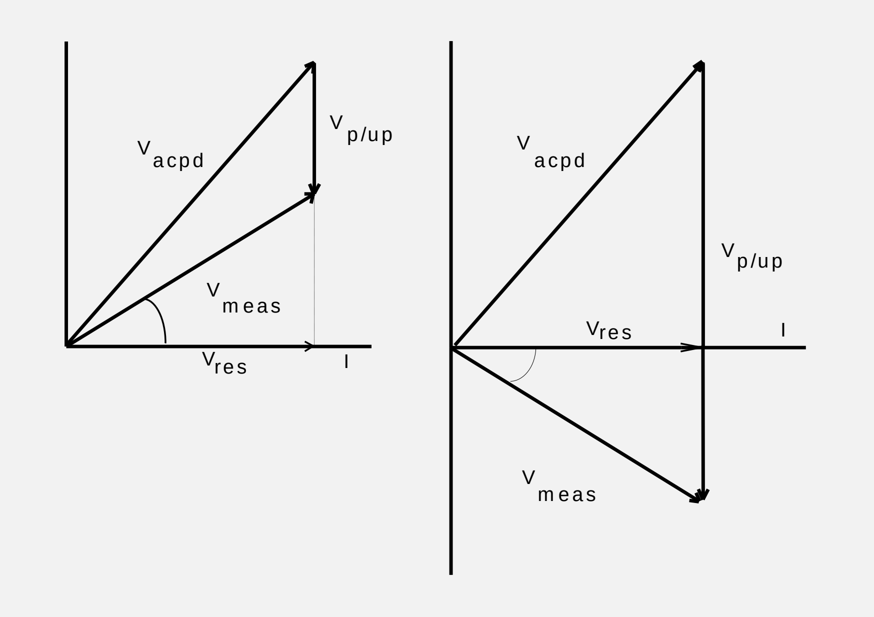

Fig. 4. The relative vectorial positions of signals in ACPD studies.

The resistive or real portion of the ACPD signal lies along the specimen current vector, (i.e. they share the same phase). The magnitude of the resistive vector does not change with a change in the magnitude of the pick-up. Monitoring the resistive ACPD will therefore (theoretically) confer an immunity to errors caused by variation in lead position. Some ACPD instruments such as the Matelect CGM-5R can measure the resistive vector directly.

OTHER CONSIDERATIONS : CURRENT FOCUSING

The interaction of the current leads with the specimen can have a significant influence on the measured ACPD. The current leads can perturb the current flow through the specimen and this can be highly detrimental. Traditional ACPD has reduced this problem by routing the current leads as far away from the specimen surface and measurement area as possible. This method then assumes that a uniform current field distribution results.

The uniform field concept has also been used as a critical assumption in the literature for the calculation of crack depth using ACPD.

This assumption is made because it is necessary to correct for the alternative current paths that exist around the edges of a crack as well as the paths of interest which exist up to and under the crack. A uniform field simplifies the corrections calculations.

Matelect has developed an improved version of the ACPD technique by abandoning the uniform field concept and deliberately created non-linear current distributions. This technique, known as Current Focused ACPD is the subject of a Patent.

Uniform field ACPD has a number of major disadvantages. One of these has already been mentioned - that of the need to model the current distributions around a defect to take into account the alternative current paths around the periphery of a crack. The other significant disadvantage is the fact that the signal levels associated with uniform fields dramatically reduce as the specimen surface area increases. This can result in unacceptably low sensitivities to defects in large specimens such as pipeline components, industrial plant or other structures.

Current focusing was developed to overcome the limitations discussed above. The basic principle of this patented technique relies upon the interaction of the current in the supply leads with the current through the specimen. This is an undesirable interaction in the case of the uniform field theory but has been utilised by Matelect to great effect to enhance signal levels.

By routing one of the current supply leads close to the surface of the specimen, but still electrically isolated from it, the user can perturb the current flow in the specimen so that it largely flows directly below the supply lead and along its length. The supply lead therefore acts as a specimen current focuser. Since the focusing lead effectively causes all of the specimen current to flow in a well-defined, narrow band, the ACPD signals collected from that band are dramatically higher than those that would result from a uniform field approach.

The difference in sensitivities between focused and non-focused techniques obviously depends on the specimen surface area. It may be small in the case of, for example, a compact tension specimen, but for structural specimens, it may be several orders of magnitude higher. Independent tests by Instron USA have confirmed that for a typical aluminium sheet test specimen, an increase in sensitivity of about 80 times is observed.

A schematic of a current focused specimen is shown overleaf. The closer the conductor is to the specimen surface, the greater the current focusing effect. The conductor, however, must be electrically isolated from the specimen surface.

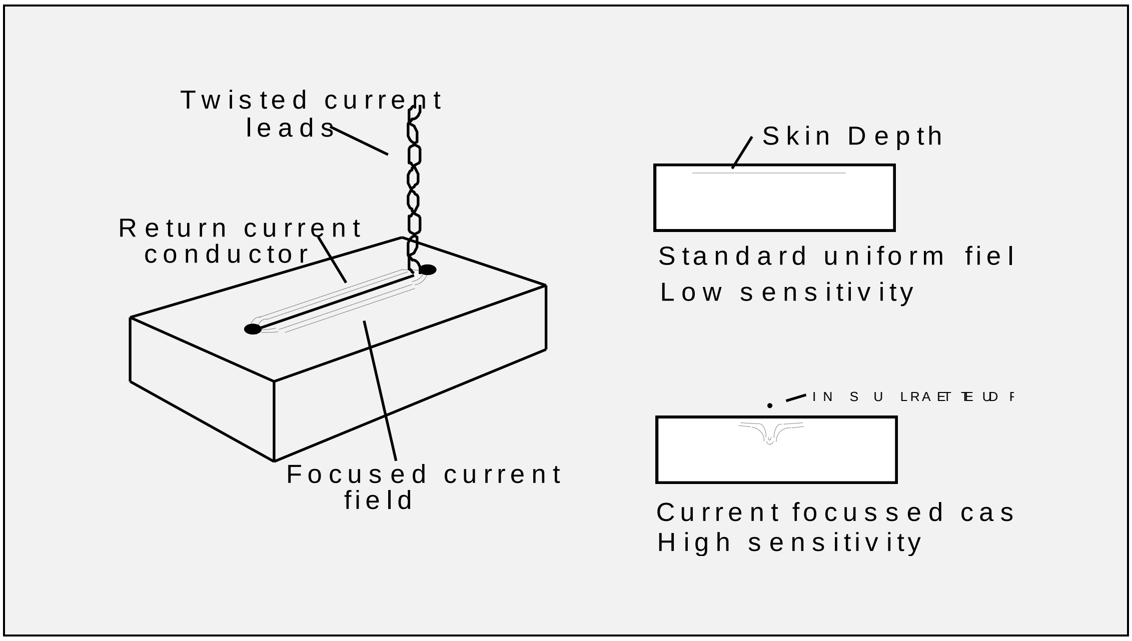

Fig. 5. Current focusing

In addition to increasing signal sensitivity, current focusing permits the user to define where the specimen current flows. This allows extended crack fronts to be profiled by scanning through a series of voltage measurement points and current focusing leads, or, by successively taking readings using a hand-held current focusing probe.

The ability to define a current path also greatly simplifies interpretation of the ACPD signal to such an extent that it is no longer necessary to model current flows in order to allow for alternative current paths, since these are no longer significant operators.

Current focusing therefore confers important improvements in ACPD sensitivity, simplifies interpretation and provides the ability to profile defects. It permits large specimens to be monitored with the same sensitivity as small ones and allows the user to define where the AC currents will flow.

A diagrammatic comparison of a welded joint specimen in both normal ACPD and current focused ACPD is shown overleaf in Fig 6.

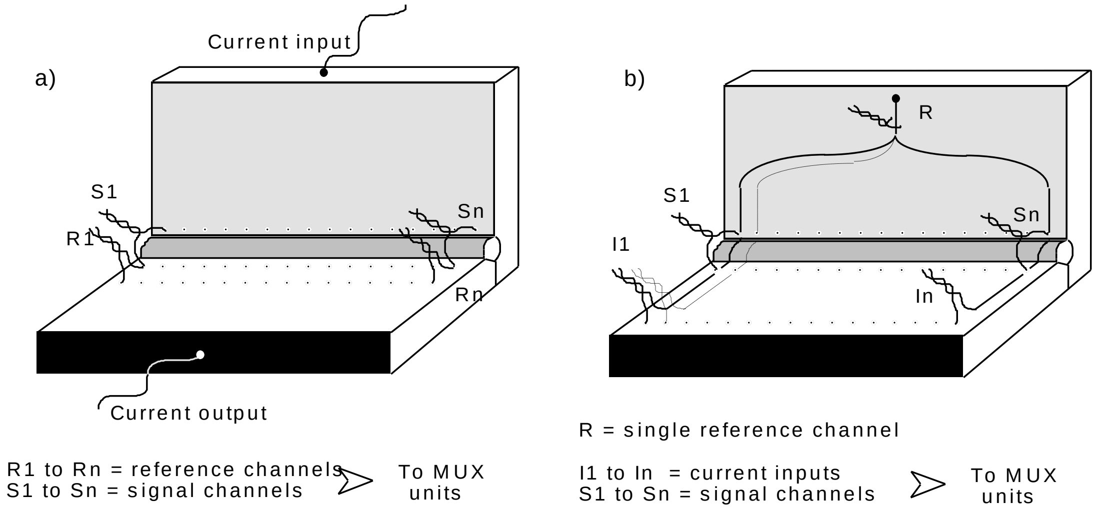

Fig. 6. a) conventional ACPD. b) current focused ACPD

EXPERIMENTAL PROCEDURES:
Connections.

In its simplest form the ACPD technique requires four electrical connections to be made to the specimen under test. These comprise two current connections and two signal connections. Contact can be achieved by a variety of means which include, screw fixation, spot weldment, spring loaded pins or conductive adhesives. The choice of contact method depends on the particular specimen and test configuration. Spot welded contacts are most suitable for on-site ACPD monitoring of defects in industrial plant, whereas screwed connections are more appropriate for mechanical test specimens employed in the laboratory.

Tests performed in corrosive environments or at elevated temperatures can seriously restrict the choice of lead material and the method of connection utilised.

As an example consider a CT specimen used within a testing machine in a standard laboratory environment. In the case of a Matelect CGM-5, the standard lead set should be employed wherever possible. Both leads are screened to reduce the levels of radiation from the current lead, and induced pick-up in the signal lead. Each lead carries a pair of copper conductors, each sheathed in PVC and both twisted together. Twisting also has the effect of reducing radiation/pick-up.

The constraints on the location of the crack growth monitor will obviously determine the minimum cable length. In general it is advisable to use short cables to both reduce the chance of noise pick-up and minimise the lead resistance and hence maximise the current available for a test (remember, the current source has a fixed voltage compliance).

The bare ends of each wire should be connected to the specimen. The best method is to machine threaded holes in the CT specimen at the desired contact points and to clamp the wires to the surface using a washer and machine screw. It is advisable to tin (solder) the bare copper ends of the leads to ensure that no stray wire strands are present and to improve contact. The specimen surface should be abraded around the contact area to ensure good electrical contact.

The use of CT specimens implies that a constant test geometry is being employed. If this is the case, then it is highly advantageous to use a "jig" that holds the leads in a rigid configuration during a test. Obviously the location and size of the jig will depend on the space available around the testing machine grips.

A standard contact configuration and a rigid lead attachment assist in the reproducibility of results and can, if properly implemented, permit direct comparison of results between different specimens. Although useful, this is not absolutely necessary in PD studies since it is the change in PD rather than the absolute magnitude of the PD that is of interest.

Spot welding the contacts to a CT specimen is a less ideal alternative since this will usually have to be performed away from the testing machine. Positional constancy between specimens is also difficult to achieve unless a jig is employed.

The routing of the leads should be carried out as shown in Fig. 3 (RHS). This is the best configuration from the point of view of minimal pick-up and current flow. Note that current focusing will occur in this configuration and the current will be forced to flow directly under the focusing wire. This has special significance in the case of the CT specimen as it results in a better sensitivity to the crack front along the centre of the specimen. The crack front is usually bowed and at its greatest depth in the centre of the specimen.

By raising the level of the focusing wire, (Fig 3. LHS) users can diffuse the current and return to a more conventional ACPD configuration. Experimenting with different set-ups is strongly recommended.

Other standard specimens require different connection regimes. For example a wide plate test with a centre starting notch/crack will not usually tolerate tapped holes close to the crack location. The holes will act as stress concentrators and could seriously alter the result of the experiment. In such cases a number of alternatives exist: Either the connection points can be located further from the crack site or the specimen connection method could be altered.

The configuration is schematically shown below.

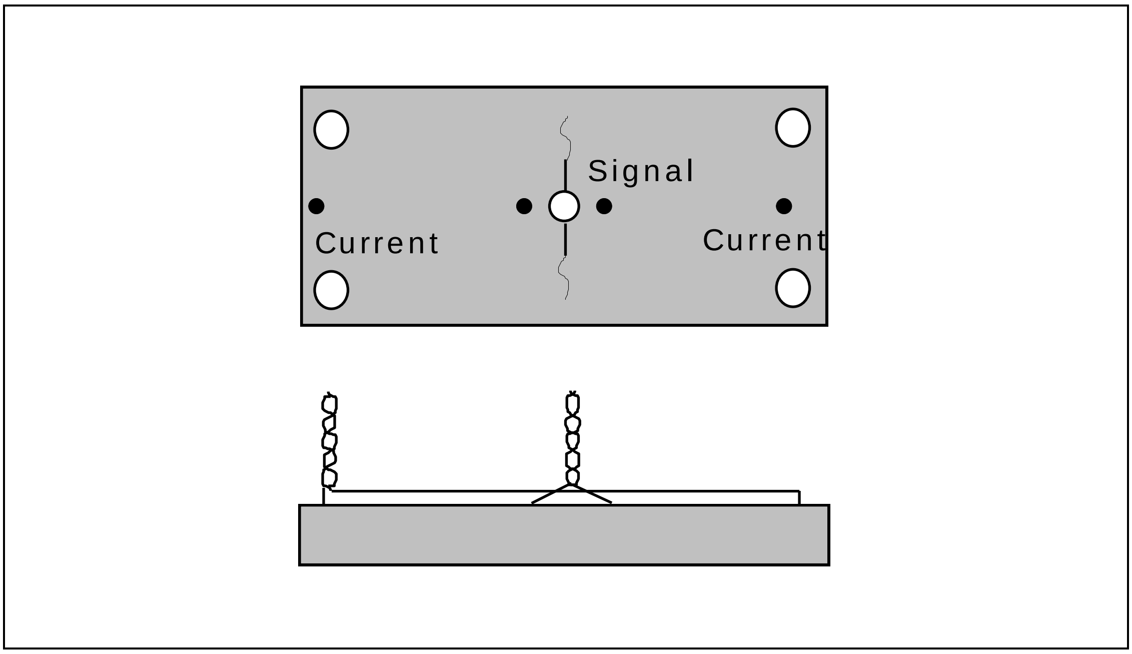

Fig. 7. A wide plate connection regime

Spot welding the wires to the specimens is the obvious answer. Because of its good conductivity, a copper wire will be difficult to spot weld to another metal. It is therefore necessary to use a lower conductivity material such as steel, or nickel as the initial contact. As soon as the constraints of the test configuration permit, the wires should be joined to copper leads to maintain a low lead resistance. It is also important to continue the shielding and the twisted pair configuration as close to the specimen as possible.

For critical work, users should be aware that spot welding can alter the local microstructure of the material under investigation. This could lead to defect initiation and premature failure of the component. Once again alternatives exist, one of which is to use conductive adhesives. These are usually based on metal loaded epoxy resin. The highest conductivity adhesive available should be utilised in order to prevent measurement errors.

A further method is to use a purpose-built jig that contains, within it, sprung loaded pins. The jig is clamped to the specimen so as to compress the internal springs and force the tips of the pins into the surface layers of the specimen.

The pin method is the one employed in hand held crack depth determination probes (e.g. the Matprobe series). Care should be taken to ensure that all surface contamination is removed when using probes.

Specimens that are subject to large strains between the pin positions can exhibit measurement inaccuracies due to slipping pins.

Once again, for very critical testing applications, the minute surface blemishes that an impinging pin might create, could lead to defect initiation and premature specimen failure.

Positioning the signal pick-up contacts away from the crack site will naturally reduce the sensitivity of the measurement. This can somewhat be mitigated by utilising a signal offset control (as provided on a CGM-5) and increasing the signal gain to compensate. This is naturally limited in use because larger signal gains lead to greater noise levels which act to reduce sensitivity (see the section on Gain and Noise in the CGM-5R manual).

Positioning the current contacts away from the crack site is less problematic, although this practice can also lead to a considerable reduction in defect sensitivity due to a reduction in the surface current density in the vicinity of the crack. This is another excellent reason for employing current focusing as it can be used to direct the current from distant contact points all the way to the crack site without fear of a reduction in current density.

An actual wide plate specimen and connection regime is shown below.

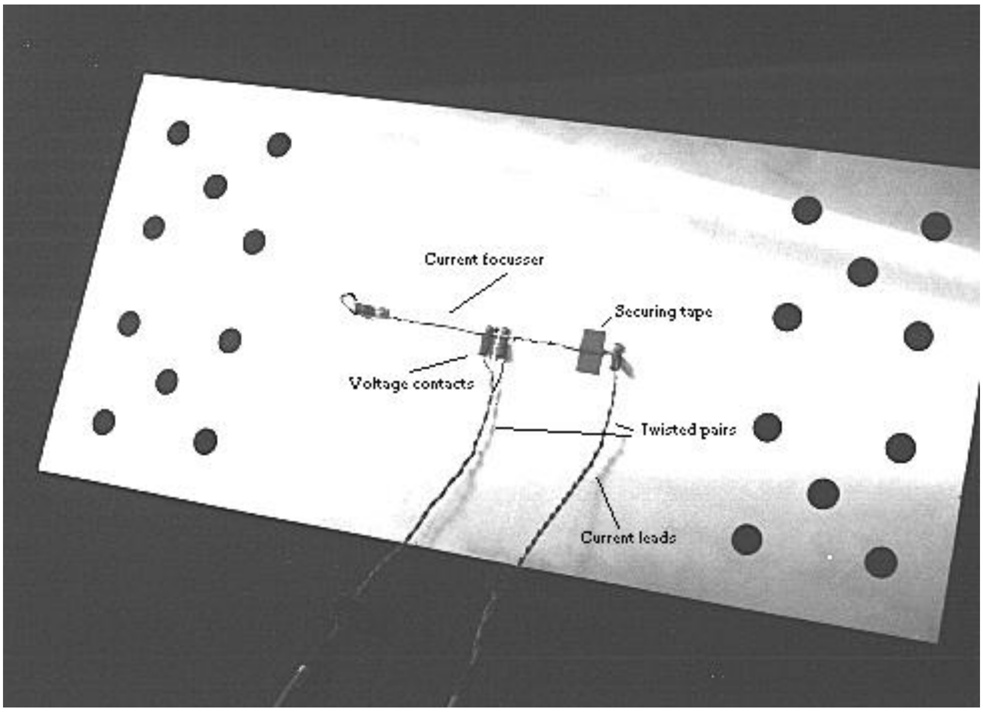

Fig. 8. A wide plate specimen with ACPD connections

CONNECTIONS FOR USE
IN AGGRESSIVE ENVIRONMENTS :

The potential drop technique is frequently employed in the testing of materials within corrosive and/or high temperature environments. Although this is a testimony to the advantages that the PD method has over other depth measurement techniques (e.g. optical methods) it does place severe constraints on the electrical connections.

The ideal solution to this problem is to locate the connections outside the aggressive environment. For example, corrosive media can be contained within a sealed enclosure which only encompasses the crack site. Unfortunately, siting the contacts outside the enclosure fails for the same reasons given in the preceding section, namely that the sensitivity to defect propagation is markedly reduced.

The use of resistant contacts and wires is the only real alternative. As an example, consider copper contacts in an oxidising environment (e.g. air at 600 degrees Celsius) The copper would rapidly corrode, causing degradation of the contacts and eventual failure of the connections. During the failure period, inconsistent PD readings may be observed and possibly misinterpreted as crack activity.

In other applications, it may be the cable sheathing that proves to be the limiting factor. For room temperature studies of specimens undergoing stress corrosion cracking in hydrogen sulphide atmospheres, copper cable can be used but the insulation needs to be polytetrafluroethane (PTFE) based to avoid severe degradation.

The fabrication of cables using separately purchased wire and insulation is often the only way to achieve the required chemical and thermal resistance of the lead. The use of commercial cables should also be considered if these offer the appropriate properties.

When selecting a cable the following criteria need to be considered:

1. ***Thermal range of core and sheath***
2. ***Chemical resistance to ambient and testing media***
3. ***Electrochemical incompatibility of core with specimen***
4. ***The presence of an outer shield/screen to reduce noise***
5. ***The use of a twisted pair to reduce noise***
6. ***Cable flexibility and bend radius***
7. ***The electrical resistance of the cable***
8. ***The electrical capacitance of the cable***

Returning to the monitoring of cracks in high temperature environments, the use of stainless steel or nickel wires is often recommended to reduce degradation. It is important to note that lead materials of poor conductivity (e.g. stainless steel) will place restrictions upon the lead length and maximum allowable current (see earlier). For this reason, such wires should have as large a diameter as possible.

The transition to copper wires should be made as soon as the testing configuration permits it.

One recommended alternative is to use silver wire. Silver has an excellent conductivity and is highly resistant to oxidising atmospheres. Silver is also fairly inexpensive if purchased from silver refiners. A purity no better than 99.5% need be utilised. A suitable wire diameter would be 0.25mm. The wire should ideally be insulated (see below).

With regard to the actual contact, screwed connections are still possible in corrosive media although they may prove to be more unreliable than spot welded contacts. Because of its good electrical conductivity silver is not easy to spot weld.

A far simpler and more reliable method is to use a silver brazing alloy to braze the silver wire to a connection post. This post can be made from a short length of stainless steel wire spot welded to the specimen. The wire should be about 0.5-1mm in diameter and 10mm long. A stud welding unit can be use to rapidly spot weld the posts onto the specimen.

After fixation, the post should be tinned using a small amount of silver brazing alloy and appropriate flux. The end of the silver wire can be wrapped around the post and the brazing alloy remelted to form a bond with wire. All traces of flux should be removed (usually with warm water).

Brazing the silver directly to the specimen is not possible because of the inevitable size difference between specimen and wire. The specimen will thus conduct the applied heat away from the braze area and prevent the braze from melting. Heating the whole specimen should never be attempted as this can dramatically alter the microstructure and hence mechanical properties of the material under investigation.

Ideally, before installation, the silver wire should be wound into a double strand. This has the effect of increasing the conductivity of the wiring, increasing its strength and most importantly removing the annoying tendency of the wire to re-coil itself once it is removed from the reel on which it usually supplied.

To create a double strand, users should measure out twice the length of silver required and bend it in half. The two free ends should be carefully anchored in a vice (use rubber grips) whilst the looped end should be inserted through a wire hook which is then gripped in the chuck of a hand drill.

The drill should be held horizontally and a slight tension applied to the doubled wire. By slowly and carefully rotating the hand drill, the wires can be wound together.

This technique is somewhat of an acquired skill but if performed correctly will greatly ease cable installation. Tensioning the wire too greatly will cause the strands to fail, as will over-winding the cable. Two or three turns per centimetre for a 0.25mm diameter silver wire will prove adequate. Care must be taken not to deform, mark, or kink the wire before it is wound, as this can cause strand failure.

Figure 9 illustrates the winding technique.

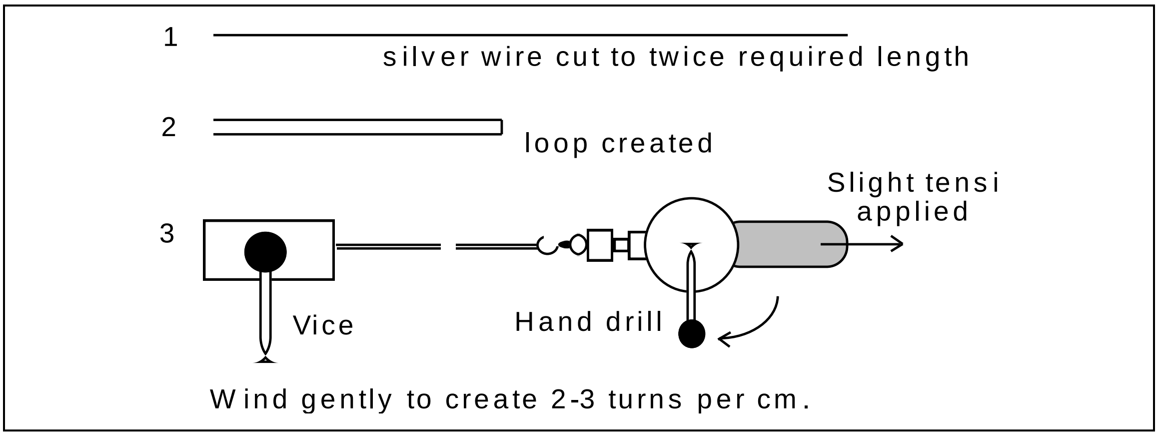

Fig. 9. Creating a silver wire cable.

Whatever material is used, some way will have to be found to electrically insulate it from the specimen and testing apparatus. The choice of insulation is dependent upon the testing ambient. Although some polymer insulation can be used in temperatures exceeding 200 deg C, mineral insulation is the obvious choice.

Glass fibre insulation is recommended to about 400 deg C after which quartz (silica) should be used. Amorphous silica braiding can be used continuously at 1000 deg C and withstands temperatures to 1600 deg C for short periods. Although more expensive than even silver wire (per metre) it provides a simple solution to the problem of high temperature insulation. Its mechanical stress is adequate and it is available in a number of diameters to suit different wire sizes.

One major drawback of silica is that it can easily be degraded by the action of contaminants especially if these are present at high temperature. Finger grease is a common contaminant (the surface of quartz halogen lamps should never be touched by hand) and one that can be easily avoided by the use of gloves when preparing cable assemblies.

Probably the most difficult aspect of cable fabrication is the application of the insulation to the wire. For the case of silica braiding and silver wire, it is necessary to thread the twisted wire into the braid. The use of a wide diameter braid (e.g. 2mm bore) will ease the task. Longer leads become progressively more difficult to thread with 2 metres being a sensible maximum for the wire and braid dimensions given.

Whilst the application of shielding is not easily achievable in the case of user-fabricated assemblies, it should always be considered. If possible, cable assemblies should be made into pairs, and twisted together to mimic a commercial twisted pair cable. This is often difficult to achieve and the resultant twists are relatively widely spaced.

No shielding or a poorly twisted pair will increase the assembly's susceptibility to noise and induced pick-up. The resultant reduction in crack growth sensitivity will depend on many factors and cannot readily be predicted. It may prove insignificant, especially if little or no cable movement is likely to occur during a test. Similarly, binding the cables assemblies together, although guaranteed to generate significant pick-up signals, is often the only way to route cables out of the testing machine/enclosure. In this case, keeping the current and voltage assemblies as far apart as possible, perhaps even with a metallic shield located between them is highly recommended.

Matelect has successfully used the silver/silica braid method for a number of high temperature continuous tests. The technique is readily applicable to laboratory based projects but it cannot easily be transferred to industrial use. This is because the assemblies are fragile and do not lend themselves to installation in aggressive mechanical environments.

A highly robust, but considerably more expensive option of high temperature specimen connection, ideally suited to the industrial environment relies upon commercial mineral insulated cable. The cables are based on a solid copper conductor, surrounded by magnesium oxide, with an overall stainless steel sheath. Common sheath diameters are in the range 2 to 5mm. Matelect has recommended this method to a number of end-users who have successfully implemented the design.

The cables are fairly rigid but can be bent to radii of about 10cm (dependent upon sheath diameter). One cable is required per ACPD contact.

The cables must be professionally terminated using ceramic seals and a screwed connection. This is electrically attached to the copper core. The ceramic seal prevents oxidation and premature failure of the copper core. The cables are pre-made and installed on site. They mate with threaded bolts that are stud welded to the specimen under test.

A schematic of this connection method is shown below. Current focusing can be easily incorporated into this method and the outer stainless sheath provides an ideal radiation shield. Further details can be obtained from Matelect.

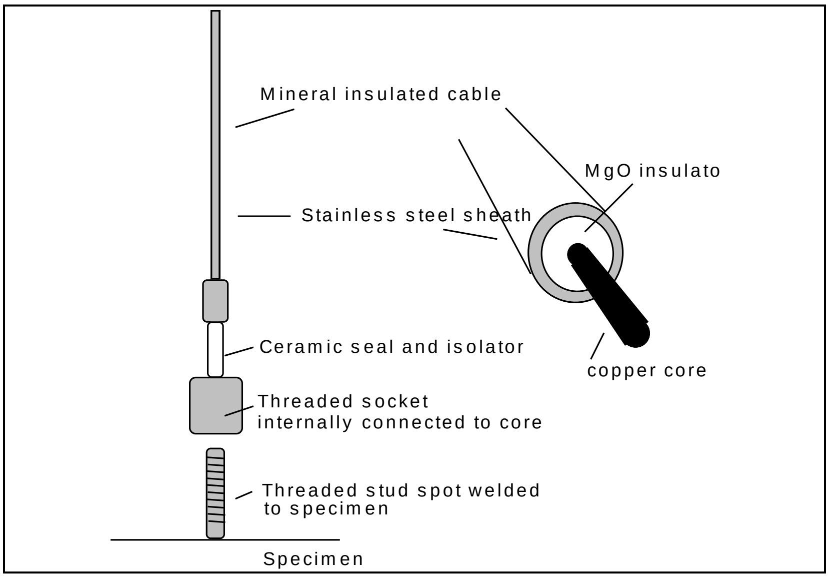

Fig. 10. Robust industrial cable system

Probably the most difficult of testing ambients to work with is high temperature water. The study of crack initiation and propagation in such environments is of importance to those involved in the nuclear power industry. High temperature water (ca 300 deg C) is encountered in pressurised water nuclear reactors. This medium is extremely corrosive and readily destroys most contacts and wires placed within it. Only inert materials such as gold or platinum are likely to withstand the corrosive effects of high temperature water. Stainless steel can be used but its life is limited and its resistivity is high. Silver is also worth trying.

Whatever method or form of cabling is chosen, users should prepare cabling beforehand and then install it on the specimen. This is especially important where access to a specimen is limited such as would be the case in a long term continuous test of an industrial component.

MONITORING MULTIPLE SITES OR SPECIMENS:

The ACPD technique readily lends itself to the monitoring of multiple specimens or sites on one specimen. In addition to the basic current source and signal amplification/measurement circuitry, some means of signal multiplexing needs to be utilised is multiple monitoring is desired. In certain cases, where either multiple specimens or current focusing is employed, the current also needs to be multiplexed.

Matelect manufacture a signal and current multiplexing system for use with their ACPD crack growth monitors. This is modular in design and can be expanded from a basic 8 channels up to a 96 channel system and beyond if required. Further details can be obtained from Matelect.

ACPD multiplexing is usually performed under the control of a host personal computer. This allows unattended data logging and channel switching. Often, tests can last for days, weeks or even months and large amounts of data are collected by the PC. These should be read into a spreadsheet for analysis and plotting.

During any long term test, particular attention should be paid to the variations in the ACPD signals from sources other than the defect site. For example equipment drift can often be wrongly interpreted as the growth or propagation of a defect. The use of commercial ACPD equipment with stability specifications of the Matelect CGM-5 removes the doubt associated with equipment drift. However, both temperature and pressure variations at the specimen can dramatically alter the magnitude of the ACPD signal.

Temperature and pressure affect the both the magnetic permeability and electrical resistivity of metals. This leads to a change in the skin depth and hence a change in the ACPD (for a particular value of frequency and current).

Where temperature and pressures are likely to alter by more than 5% during a test, it is recommended that a signal normalisation method be utilised. Normalisation is most easily performed by assigning one of the signal channels in a multiplexed system as a reference. To be effective, the reference channel should consist of a pair of contacts located near to the "active" contact pairs, but in an area that is not likely to contain or initiate a defect. Any change in the measured ACPD on this channel will thus be due to the changes in the ambient testing conditions.

Once the test is completed, the data from the active channels is normalised (divided by) the data from the reference channel, thus correcting for any variations that are not directly related to defect propagation.

Normalisation is easily performed in a spreadsheet package. Further details of normalisation techniques and apparatus are available from Matelect.

The following traces contain data that had been continuously collected over a period of approximately 2 weeks from an industrial pressure vessel. The top trace represents the active channel, the centre trace the reference channel, and the bottom trace the normalised data. The large peak in the top traces occurred as a result of a pressure variation in the vessel under test. The normalised trace indicates that no crack initiation or growth activity was detected.

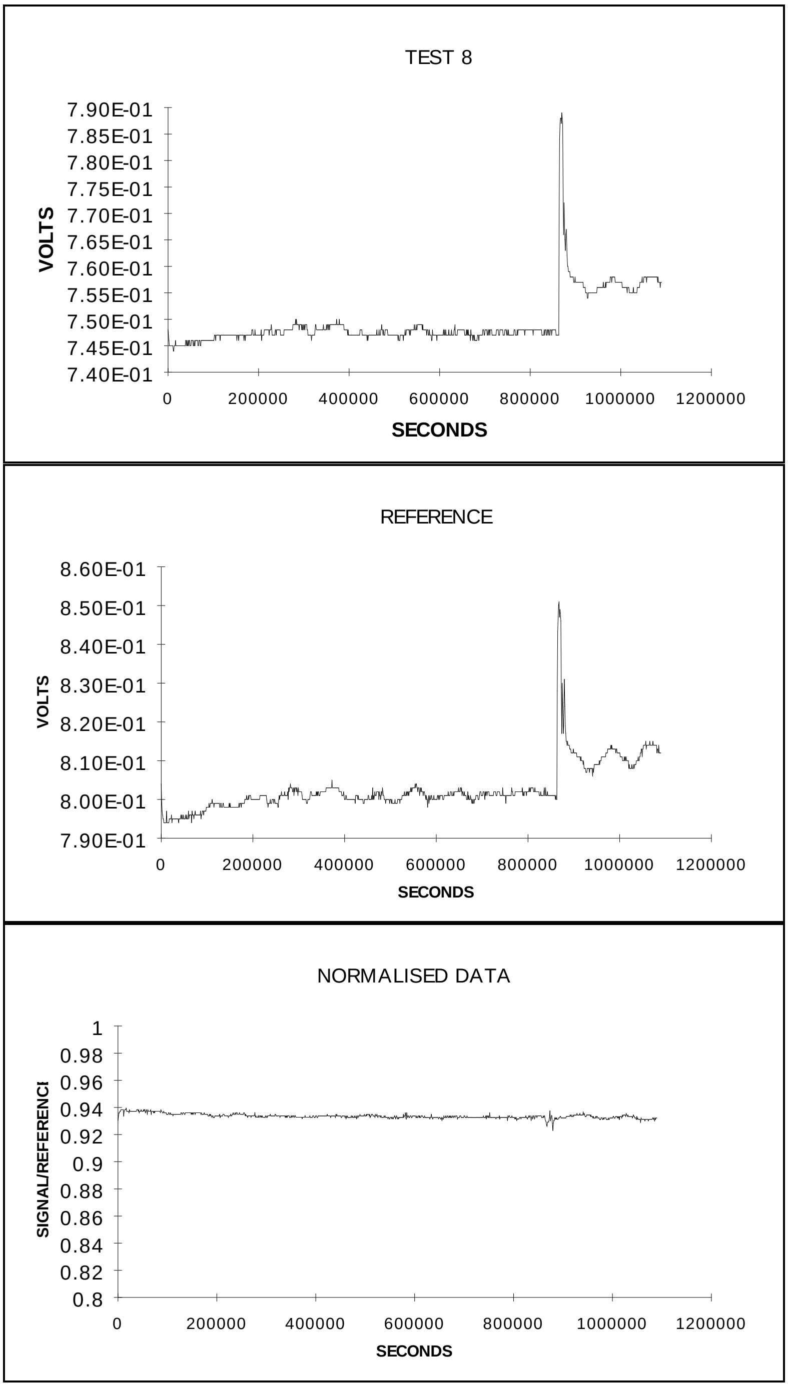

Fig 11. Active, reference and normalised real life data from a steel pressure vessel.

CONCLUSIONS:

In correct hands the potential drop technique, and in particular the ACPD variant, is capable of impressive results in the study of crack initiation and propagation in conductive materials. As with most research based methods, patience, skill and persistence are required to extract the optimum from the potential drop method. Once mastered, however, the user can join the ranks of those who use the method on a routine basis.

This manual has been produced as a guide for the users of Matelect ACPD products. As a company committed to the development of the best in potential drop instrumentation, we are always pleased to obtain customer feedback. We welcome criticism of our products and information on user's test experiences. If you have any queries or any information that you feel would benefit future editions of this manual, please contact our head office at the address given in the Welcome section.

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