
AC or DC

A PRIMER FOR
DECISION MAKERS

MATELECT LTD

AC or DC Potential Drop? A primer for decision makers

This primer has been written primarily to assist end-users, who having determined that the potential drop method offers them the performance and flexibility of an electrical method for crack growth studies, remain unsure as to which of the two available variants (ACPD or DCPD) they should invest in and utilize.

Introduction

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. When considering ACPD, it is the change in specimen impedance, rather than resistance, that is effectively being measured. 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.

The two main variants of the PD technique that exist, alternating current potential drop (ACPD) and direct current potential drop (DCPD), have been in use for many decades. DCPD was historically the first embodiment of the PD method, given its relative simplicity in both equipment design and use. ACPD followed in the early 1980's and offered some important advantages, including better sensitivity to crack measurement.

DCPD technology did not stand still however, and with the advent of pulsed and reversing DCPD (which began to bridge the gap between the DC and AC regimes) the differences in sensitivity performance dramatically reduced. In the mid 1990's microprocessor control and advances in digital electronics arguably removed the performance gap (in terms of sensitivity) but there are still important differences between the two variants which can influence the end-user choice.

The salient qualities of each technique are summarised in table 1, and most of these will be discussed below in some detail to give the end-user a better understanding of the relevant issues.

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*

* Many of these issues have been resolved by new equipment or application regimes.

With appropriate care and attention, resolutions in the sub 10 micron region have been obtained by some (using either technique). The methods for achieving such sensitivities differ depending on which variant is employed, and the precise experimental set-up. ACPD was historically the first to achieve resolutions in this region, but recent DCPD instruments are also capable of reaching down to these levels.

The electronic circuitry used to deliver such performance differs between the variants. As a consequence, this can influence the performance of a particular variant in other ways. This is explained further below.

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. Normally the current source is designed to be constant across the range of likely load (i.e. specimen) impedances. This complicates the instrumentation, but does permit the measurement of absolute voltages using a single set of connections. If the current was not constant, then a separate reference channel would have to be employed, to "normalise" out any variations - and a two channel instrument would therefore be required. Many PD instruments do offer two channel operation as standard, however, but this is usually for the purpose of normalising out other variables such as temperature.

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. Some users still choose this

route, particularly where DCPD is concerned, as they may already have some relevant instrumentation to hand (e.g. a constant current power supply). Doing the same for ACPD is rather more of a complex task. Incompatibility between the configurations of different users can often make data comparison dubious because of the unknown effect of instrumental differences.

Specific issues: Current magnitude, nature and some consequences.

When a direct current flows through a specimen, it is normally regarded as spreading out throughout the bulk of the material as soon as it enters through the input connection. In order to generate a "good" potential drop signal from this current (good in respect of being measurable by the instrumentation and detectable over any noise) large currents are usually required (remember the specimen is essentially a short circuit with very little resistance).

DCPD instruments typically source currents in the range of 10-50 amps but 100 amp supplies have been used in the past and would be required for large specimens, where the current density (and hence the measured PD) would otherwise be low.

In ACPD, advantage is made of the fact that the current chooses to flow in a tight "layer" adjacent to the surface of the specimen between the input wires. This is a consequence of the well known "skin effect" phenomenon. Given that the current is concentrated near the specimen surface, lower currents are required to obtain PD signals of similar magnitude to those obtainable by DCPD methods.

This in turn allows ACPD equipment to consume less power and be smaller than a corresponding DCPD apparatus. Thus ACPD lends itself to battery power and portability, and most PD units that are employed outside of a lab environment for field-based NDE purposes, utilize ACPD. Additionally using a continuous direct current in a resistive specimen will often generate a measurable temperature rise - this in turn can alter the resistivity of the specimen and hence affect the measured DCPD. It is true that such specimen "self-heating" effects can be compensated for by using a dummy specimen as a reference (placed in a series circuit with the active specimen), but some commentators would still prefer that the temperature of the specimen remains relative constant.

With the advent of pulsed DCPD technology, both the size of the DC kit and the self heating effect can be dramatically reduced, and most modern DCPD systems utilize pulsed direct currents. In pulsed DCPD, the current is pulsed on and held for a short period of time before being turned off. During the "on" period, the signal is also recorded. Pulsed DCPD also offers a ready route to the removal of thermoelectric emfs (see below). This is done by also taking voltage readings when the excitation current is in the "off" state - and subtracting the two sets of readings from each other.

Reversing DCPD, where the current is periodically reversed, also provides a route for the removal of thermoelectric emfs, and is often the preferred method for crack monitoring during stress corrosion studies. This is because

there is (divided) opinion that the single polarity driving potentials present during conventional DCPD could affect the electrochemical (especially at the crack tip) and hence alter the rate at which stress corrosion cracking occurs. This would be a case of the measurement system affecting the parameter being measured. The ultimate DC variant is of course, pulsed reversing DCPD, where both the electrochemical and specimen heating issues are tackled together.

It should be noted that in ACPD, the skin effect is frequency dependent and hence if a user has control over the frequency of the AC excitation, then this gives an extra degree of freedom and sometimes extra information/data obtainable from the PD signal.

Signal level, sensitivity and linearity

In DCPD, the bulk nature of the current flow means that the voltage drop that it creates is that due to the resistance of the whole specimen. If a crack propagates through the specimen, the voltage changes in line with the reduction in cross sectional area of the material available for conduction. In ACPD, the current largely flows within the defined "skin depth" and if the electrical connections are positioned appropriately, the current flows up to and along the faces of a crack, so that the potential drop measured is actually dependent upon the depth of the defect, not the remaining uncracked portion.

The result of these differences on the current path and hence measured voltage dependency, is that the change in PD with crack depth is different for the two variants. In DCPD, the response is non linear. As the remaining ligament tends to zero length, the resistance tends to infinity and the measured voltage thus also tends to infinity (although the instrument will "top-out" at its compliance limit). For ACPD, the path length dependency of the PD, means that the response is largely linear with crack length (although there may be some initial non linearity due when the crack length is well below the skin depth).

This difference in response essentially makes DCPD less sensitive the shorter the crack is, whereas ACPD becomes less sensitive as the crack length increases. Using high frequencies essentially accentuates this difference, and this is often the reasons that ACPD is the preferred method for studies involving short cracks or the investigation of crack initiation.

Additionally, it should be noted that a linear response, at least in theory, makes calibration of the potential drop signal against crack length easier. In practice, this is an oversimplification, given the additional problems associated with "pick-up" inherent in ACPD work - this is discussed further below. Furthermore, although DCPD is non-linear, the simplicity of the current flow under DC conditions means that its is far easier to numerically model the current flow, and thus the resultant PD signal, should end-users wish to develop a theoretical basis for their calibration. Indeed there exists several analytical models in the literature for DCPD calibration, that give adequate approximations of the PD vs. crack length response. Achieving the same for ACPD has been attempted, both numerically and analytically, but modelling

AC response is more complex and highly dependent upon specimen geometry and contact positions.

Practical Issues: Connection, and ease of use.

There are many differences between the two PD variants that have a direct implication upon practical and experimental issues and the test set-up. A good example of this relates to the type of wire used to connect the PD equipment to the specimen and the method of connection used at the specimen. In DCPD, the large currents involved mean that thick cables are required to deliver the current to the specimen. This applies even in the case of pulsed DCPD.

The use of thin cables will cause cables to warm and dissipate power (very noticeable when the current is continuous) but also will severely limit the ability of the instrument to pass the maximum rated current through to the specimen. This is because all real/practical current sources have a voltage compliance limit, (the potential drop across the output terminals of the current supply, which is used to drive the current through the wires, connections and specimen) and thin cables simply mean that this limit is reached well before the maximum rated current has been achieved.

Using thick cables has obvious implications upon the size and robustness of the connection points on the specimen and on the flexibility of the cables. Often large bolted connections are employed and flexibility is achieved through the use of cables containing several hundred strands of copper wire. The voltage connections are not subject to such problems and are normally of the type and gauge used for ACPD. Given the currents are often an order of magnitude less in ACPD work, current connections similar in gauge to the voltage connections can be easily employed.

Another relevant practical issue is that of specimen isolation. It is normally necessary during DCPD studies to electrically isolate a specimen from whatever grips or testing machine it happens to be fitted into. This is because the grips and the machine can create a path for the excitation current to Earth, rather than through the specimen, or if the DCPD equipment is of the "fully-floating" type, an alternative current path (in parallel with the specimen) can be created through the testing machine - in other words, the testing machine acts to "short-out" the specimen.

It is highly likely that the route through the testing machine poses far more of a resistance to the current than that through the specimen, so the main effect of a lack of isolation will be a reduction in the measured PD of perhaps 10% maximum. The real issue however is the fact that the parallel path may be intermittent (for example, during fatigue loading, the path may alter its resistance as more load is placed on the specimen/grips) and may change in magnitude during testing. This has obvious implications for the signal to noise ratio achievable for the over DCPD measurement.

Isolation is fairly straightforward to achieve experimentally, although the complication of insulating the specimen from the grips, does add to the cost

and set-up time of a test. Additionally when undertaking stress corrosion studies in an aqueous environment, or high temperature creep/fatigue studies, reliable electrical isolation becomes difficult to engineer. For ACPD studies, however, it is often unnecessary to isolate the specimen or grips. This is largely because of the enhanced resistance to current flow that a pressure based contact makes. In other words ACPD is much more sensitive to surface resistance and therefore the current flow is likely to be more readily interrupted by a contact that is formed when two metals mechanically touch, rather than one where they intimately touch (as would be the case if a welded contact is employed). Additionally the influence of current focussing (see above) will also help to force the current through the specimen rather than around the testing machine.

With regard to ease of use, it is probably fair to say that DCPD is the preferred variant for end-users who are "new" to the technique and who wish to be up and running, obtaining reliable data, with the minimum of fuss, training and attention to detail. One of the principal reasons for this is the issue of "pick-up" which is inherent in any AC based method.

Pick-up, in essence, is an additional signal that vectorally adds to the true ACPD signal from the area under test. It occurs because the PD signal wires act as a very effective aerial arrangement which in turn receives a signal via induction from the current input wires - which are acting as relatively efficient transmitters.

The effect of pick-up is to alter the signal magnitude being measured. This is because the ACPD instrumentation is sensitive to the vectorial summation of the two signal sources, not just to the "true" signal from a crack site. In itself, pick-up poses no real threat to the ACPD measurement, assuming it is remains constant during the duration of a test. It will change, however, any time the configuration of the leads (i.e. the spatial relationship between the transmitter and receiver) changes - and hence the measured ACPD signal will alter commensurately. Thus it is important that during an ACPD test, little or no lead movement occurs. This is simple to ensure in practice, but the sight of a signal that changes simply because the wires to the specimen are moved, often dissuades end-users from trying ACPD.

A more significant issue associated with pick-up is the fact that it can make comparison of the ACPD readings with calibration data impossible. This renders a calibration useless of course. This problem arises from the fact that a variation in wire/connection configuration between the calibration run and the actual experimental test, will vary the pick-up and hence the ACPD, rendering absolute comparisons of voltage readings flawed. Once again, careful attention to the experimental technique (e.g. maintaining lead positions between tests by using a jig arrangement) can eliminate such problems. Additionally, there are well known methods for reducing the magnitude of the induced pick-up (e.g. shielding of leads and twisting of wires to reduce the efficiency of the antennas created by the leads), which can largely eliminate it as a consideration.

Speed of response

One area where ACPD remains king over DCPD is in speed of response. ACPD instrumentation has a far higher bandwidth than DCPD and can thus follow rapid crack growth. It is possible, for example, to generate a meaningful signal from an impact test. Additionally, the way that ACPD instrumentation rejects noise in an experimental set-up (by "locking into" a particular frequency and hence rejecting all others) means that the fast response is achieved with low noise (and hence good resolution).

In contrast, DCPD instrumentation achieves the resolutions required by experimenters by using signal averaging techniques, where sometimes hundreds of readings are taken over a time period that could be as long as seconds, to reject the noise via brute-force numerical averaging. This is achieved nowadays by using microprocessors to handle the maths, but was once achieved through capacitor-resistor filtering.

Additionally, when pulsed DCPD is considered, the need to take readings during both the current-on and current-off periods further lengthens the time required to obtain a single data point. There is simply no solution to this issue. Of course, for some tests and with some types of apparatus it may be possible to operate in a continuous current mode, and, with the advent of fast analogue to digital electronics, to acquire readings quickly, but this still does not deal with the issue of noise. Speed will therefore always come at the expense of noise rejection, and hence ultimate resolution.

Current focussing

ACPD provides end-users with a unique ability to control the path of the excitation current using a technique known as current focussing. Matelect can provide more information about the methodology associated with this technique but put simply it can be thought of in a similar way to the skin effect. The skin effect forces the excitation current to flow in a tight region near the surface – in other words it focuses it in the Z direction. The current focussing method further controls the current in the XY plane. The basic result is dramatically increased current densities in the areas of interest – and hence larger PD signals. This simply cannot be achieved using DCPD. In defence of DCPD however, it is true that whilst current focussing increases sensitivity to cracking, it also increases the sensitivity of the technique to where the measurements are being made. Try to measure the ACPD where no current is flowing and no signal is, of course, registered.

Extra information

It is sometimes seen as ironic that the very factors that make ACPD problematic can also provide end-users with positive benefits over the DCPD variant. For example, the induction effect which is responsible for the generation of the troublesome pick-up signal is also linked to the beneficial phenomenon of current focussing in a specimen. Similarly, it is found that ACPD is much more sensitive to stress levels in ferritic materials (due to changes in magnetic permeability under conditions of elastic and plastic strain) than DCPD. Indeed it has been used to measure internal stress in

structures and load bearing members, and even residual stress levels in shot peened components. This added sensitivity however can sometimes complicate basic fatigue tests where the stress state is periodically varying – and hence give the impression of generating “noise”.

It is important to note therefore, that one person’s disadvantage is often another’s advantage and what may appear to favour the adoption of DCPD instrumentation may exclude end-users from obtaining extra information about the material under test. Another good example of this is the depth information that ACPD can generate via the alteration of the frequency of the excitation current (hence varying the skin depth). Such methods have been used in the past to extract parameters such as case hardening depth from components such as shafts and gears.

Scanning and multichannel operation

This used to be a clear advantage that ACPD had over DCPD – the former (because of the low currents and non-pulsed nature) was always easier to multiplex up. Thus it was fairly simple to expand an ACPD system to cover multiple channels (sites) on one specimen or even multiple systems. DCPD was never multiplexed and if multiple channel capability was required, this necessitated multiple (and simultaneous) signal acquisition circuitry. Matelect changed this a decade ago with the introduction of high current switching units which were intelligently linked to the pulse cycle in our DCPD crack growth monitors. It, of course, may remain an issue should DCPD instrumentation from other manufacturers be employed.

Conclusion

In summary, the choice of AC over DC (or vice versa) often comes down to personal preference. It is fair to say however that ACPD offers a speed of response to crack growth, which DCPD can never match, and hence the possibility of following rapid propagation events - even impact testing, if care and attention is taken. DCPD is notionally, at least, easier to understand and set-up, and is ideally suited to first-time users of the PD technique or those who are involved in routine specimen testing. The added degree of freedom that ACPD offers (the frequency domain) does lend strength to this variant when unusual tests, or applications where new properties are being measured, are being considered.

In the end analysis, the resolutions of both techniques are broadly similar thanks to developments in the instrumentation, but ACPD adds that extra degree of freedom which may be viewed as either an advantage or a disadvantage, depending on one's application, experience or viewpoint. Matelect are conscious of this dilemma and are happy to advise end-users and potential customers alike of the pros and cons of each variant, assuming sufficient information can be provided about the end-use application.