Applications and Limitations for Using ACPD in Crack Depth Measurements

David Utrata a) and Darrel A. Enyart

Center for Nondestructive Evaluation
Iowa State University
Ames, IA 50011

a) heydave@iastate.edu

Abstract. Alternating current potential drop (ACPD) testing has been established as a viable means of measuring crack depth. This paper presents experiences in using a commercially available version of this tool to generate results under flaw constraints encountered in industrial use. Sample geometries with simulated cracks were studied to examine crack depth as a percentage of through-wall thickness and with varying width of contact area adjacent to cracks. A variety of real cracks were also examined, illustrating cracking conditions that may be adequately measured using ACPD, as well as situations where crack depth may be under- or oversize.

INTRODUCTION

The Company Assistance NDE Group at the Center for Nondestructive Evaluation, Iowa State University, works with industrial companies to address various aspects of inspection. As such, activities often straddle research and application. For example, it is well known that the potential drop method (ACPD) may be used to measure crack depth in metallic specimens. Of key interest to our manufacturing clientele is a defined extent of sample preparation and data interpretation needed to apply a commercially available off-the-shelf (COTS) device to their particular inspection needs, such as crack depth measurement. This paper documents some of our experiences using a commercial ACPD device to measure crack depth.

Previous work had been documented in various conference proceedings [1, 2]. In this paper, we extended use of the device to a variety of calibration samples having known cracks and notches, as well as to crack depth measurement on industrially relevant components and samples. The calibration samples had varying contact areas and geometries, and were intended to simulate a range of industrially relevant materials. Results on real components were made to highlight the utility of such inspection methodology, while understanding that there are limitations to its widespread application.

THEORETICAL BACKGROUND

The use of alternating current potential drop (ACPD) crack depth measurement has been known for years and its implementation well documented [3-6]. Figure 1 illustrates the controlled parameters and values measured in this test; this schematic is used with permission from Saguy & Rittel [4].
Briefly, a current is injected into a test piece and the electrical circuit closed at some point along the surface. Between the points where the current flows in and out, a voltage difference (potential drop) is measured. If the injected current traverses a distance within which a crack is located, measurement of the voltage differential will vary, dependent upon the crack depth. Using alternating electrical current confines the current flow to a “skin” on the sample. A break in the component surface creates a longer path for the electrical current to travel, thus increasing its resistivity and voltage. This difference in voltage is known as the potential drop, and COTS devices, when properly calibrated, will use this value to indicate the depth of such surface breaking cracks.

Variables other than crack depth that will affect readings have been identified in the literature. The electrical conductivity of samples will determine the value of an effective skin depth in the material, dictating how deep the current will travel in different material. As the sample thickness decreases, the current density will likewise be affected.

Manufacturers of ACPD devices recommend proper use of these tools with supplied calibration blocks. Additionally, users are encouraged to calibrate the devices further on both crack-free regions on test material, as well as adjust the device response for notches of known depth. Basic recommendations, such as not measuring closer than a centimeter away from any edge, are included in general usage guidelines. For the purposes of this study, tests were performed to illustrate the quantitative error obtained when one would, by necessity or choice, bypass proper calibration practice.

Nothing was found in the current scan of literature that discussed the quantitative effect on crack depth measurement of the width of the contact surface, L. To mimic application to specific industrial inspections, this variable was chosen for inclusion in this study. In addition, crack depth as a function of percentage thickness was monitored.

**TEST METHOD**

A commercially available crack depth gage was used for this study, the Karl Deutsch RMG 4015. Calibration blocks supplied with the device contained a tapered slot that permitted the user to measure known crack depth from zero to a known depth. In this study, we fabricated additional such calibration blocks, labelling them with known crack depths at various points along the length of the slot. In this manner, we could machine or modify the contact surface to replicate various industrial conditions. One such custom made calibration block is shown in Figure 2.

The effect of surface contact width and the percentage of material cracked were measured on a series of blocks that had the complex shape shown in Figure 3. These test blocks presented notches in groups of 9, 6 and 3 mm, in regions that were 20, 16 and 12 mm thick. Additionally, the blocks were slotted to create contact widths of 15, 10 and 5 mm. The blocks were machined from aluminum (measured conductivity ~43% IACS), zinc (~29% IACS) and A-36 steel (conductivity from literature ~3% IACS).
Additional samples with cracks were collected from various sources to represent a range of industrial conditions and applications where crack depth measurement might be needed.

Cracks on the surface of a nodular iron cylinder head from a large engine (found using magnetic particle inspection) were studied. Located between the various intake and exhaust ports on this component, as shown in Figure 4, the
apparent crack depths were measured using ACPD. The cracks were then broken open destructively to permit a visual reading of the crack depth based on surface discoloration.

Samples were obtained from anhydrous ammonia nurse tanks. Shown in Figure 5, a variety of cracks were found in such samples using ultrasonic techniques. They were documented using magnetic particle testing and photographed to visualize them for this work.

FIGURE 4. Cracks detected on a ductile iron cylinder head using MPI, then measured with ACPD and broken open. The intake and outlet ports at the cylinder location shown in the photo provided 5 cracks to be measured using ACPD and then broken open and measured visually.

FIGURE 5. Cracks detected at welds on anhydrous ammonia nurse tanks. Highlighted here MPI, they were measured with ACPD and broken open to permit true crack depth measurement.
Finally, small cracks from three point bend samples used for fatigue crack studies evaluating the sensitivity of magnetic particle testing were used. These were small, penny shaped cracks on smooth surfaces. One is shown in Figure 6.

**FIGURE 6.** A crack on a low cycle fatigue sample used in a magnetic particle study, measured with ACPD, heat tinted to permit clear crack identification and then broken open.

**RESULTS**

We first examined the effect of proper calibration on the accuracy of crack depth measurement one might expect using the COTS device to measure cracks via ACPD. Figure 7 shows test results on our smooth ground steel calibration sample. It is evident that for best results, accounting for both material variation and crack depth responses on calibration samples will provide the most accurate results; to not do so could result in undersizing crack depths.

The effect of surface finish on crack depth measurements is shown in Figure 8. As with the smooth surface, both material and crack depth calibration is needed for best results. But the variation between wire brushed or bead blasted operations to remove surface oxidation and permit ACPD testing did not affect test results.

Figure 9 shows the correlation between measured and actual crack depths on the notched test blocks of three test materials, obtained where the sample was thickest and contact width the widest. Measured results were close to known values until a greater notch/crack depth was achieved. These resultant error was also highest for measurements on more highly conductive material. Both material and known crack depth calibrations had been implemented.

Figure 10 shows test results where the material was thinnest on the notched samples. This means that the crack depths were a greater percentage of sample thickness. Again, error increased on samples with higher electrical conductivity, now to a slightly larger degree than for thicker material.

Figure 11 shows the most dramatic results, obtained where the sample was thick but contact width was narrow. Measurements for materials at all three conductivities appreciably oversized crack depths, misreading them by twofold for steel and four to five times for zinc and aluminum.

Measurement of the intergranular stress corrosion cracks found in anhydrous ammonia nurse tanks did not fare well. As shown in Figure 12, ACPD measurements made along the crack suggested the maximum depth to be about 1.5 mm, when in fact the uneven crack front reached about 8 mm in depth. It is concluded that the discontinuous growth of IGSCC flaws will not permit valid predictions using ACPD. This is likely due to electrical contact being permitted in localized regions within the crack area.

Measurement of fatigue cracks in 3-point bend samples were also undersized, as shown in Figure 13. It is not clear why the nondestructive method did not provide valid readings here. A theory is that the shape of this small crack demanded better probe placement for accurate measurement or that accuracy is lost by the ACPD method for such small cracks of circular shape.
FIGURE 7. Crack depth measurements made using proper calibration for material and known crack depth responses and only using material calibration. Error increased when not calibrating on known crack depths.

FIGURE 8. Crack depth measurements made using proper calibrations and only using material calibration. Error increases were consistent, irrespective of surface finish on sample.
FIGURE 9. Correlation between measured and actual crack depth on samples at thickest region of notched test blocks. Error increased as electrical conductivity increased, but only at deepest cracks.

FIGURE 10. Correlation between measured and actual crack depth on samples at thinnest region of test blocks. Error increased as electrical conductivity increased, only at deepest cracks, but to a greater degree than for thicker samples (when crack depths were greater percentage of sample thickness.)
FIGURE 11. Correlation between measured and actual crack depth on samples at most narrow region of test probe contact. Error increased significantly on all samples, increasing with conductivity.

FIGURE 12. Result of testing on sample of anhydrous ammonia tank. The maximum crack depth predicted is about 1.5 mm, while it was apparent from breaking the crack open that the depth was much deeper. The conclusion is that measurement of such uneven intergranular stress corrosion cracks (IGSCC) is not valid using ACPD.
FIGURE 13. Poor correlation was found between ACPD measurements and visual assessment of a crack from fatigue samples. The source of the error is not clear, but such cracks may be below the low end of reliable depth prediction using this test.

FIGURE 14. Correlation between crack depths measured on a cylinder head using ACPD and visually after breaking open. Agreement is quite good to about 8mm crack depth; outliers are in predominantly thinner areas of the casting.
Finally, the result of using ACPD to measure crack depth on the complex geometries of the bridges between valve ports in cylinder heads is shown in Figure 14. Nondestructive results were obtainable after mechanical cleaning of the cylinder head surface to remove fuel combustion residue; this was necessary to permit electrical contact for the probe to make readings. The destructive measurement of crack depth based on visual measurement of discolored crack surfaces was a somewhat subjective measurement, given that the crack front was often not a clearly defined edge parallel to the component surface. This notwithstanding, a good correlation was noted for cracks depths measured using ACPD and these somewhat subjective visual measurements. The agreement deteriorated when cracks were found to be greater than about 8 mm deep. But it was also found that most of these deeper cracks occurred in regions where an interior surface of the cast component made them an increasing percentage of casting wall thickness.

CONCLUSIONS

A commercially available ACPD device was used to measure crack depths in various test blocks and industrial components. Crack depth measurement accuracy decreased when the samples were thinner, meaning the cracks were a larger percentage of sample thickness. But overriding this were measurements made on relatively narrow regions for probe contact. There, measurement error increased significantly, and more so with increasing conductivity.

Measurements made on a ductile iron cylinder head on bridges between valve ports, regions of complex shape, yielded highly promising results. Predicted crack depth correlated well with post destructive exposure for visual depth measurement up to about 9 mm deep. Cracks deeper than this, however, occurred in regions where the back wall of the casting was close, causing anticipated crack oversizing.

The nature and shape of the cracks in question were also seen to play a role. IGSCC flaws from chemical tanks were too complex to measure accurately, and very small cracks proved elusive for correct depth predictions.

In all tests, adherence to correct calibration procedures that accounted for material variation as well as for response on known crack depths was found to be critical. Using only material calibration, as may be necessary in some industrial applications, can lead to crack undersizing. Irrespective of surface treatment, at least to the extent performed in this study, the test results were identical to those obtained on smoothed sample surfaces.

REFERENCES