ADVANCES IN NDE TECHNIQUES FOR DELAYED COKE DRUMS

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Abstract

Delayed coke drums are operated under severe conditions of cyclic heating and forced cooling that apply repetitive thermal stresses to the drum walls. It has long been recognized that the ultimate failure mechanism for coke drums is weld cracking due to low cycle fatigue caused by these thermal stresses. It is also known that coke drums distort and bulge in service and that these bulges can be used as pointers to potential weld failure areas.

CIA Inspection (CIAI) operates a laser profiling service that locates and measures distortions in coke drums. Consistent and accurate measurement of surface deformities has allowed operators to focus on areas of concern, but it has not been able positively identify and size cracks.

TSC Inspection Systems (TSC) is a developer of electromagnetic inspection technology, Alternating Current Field Measurement (ACFM).

CIA Engineering (CIAE) is an engineering/design company with experience in developing automated systems for a variety of industrial applications.

To further assist in the evaluation of the vessels condition, CIAI in conjunction with TSC and CIAE is developing a robotic technique, which allows further evaluations of the indicated areas. This capability will provide operators with a remotely operated Non Destructive Examination technique which can be selectively applied to local, internal surface areas.

This paper outlines the evolution of Remote Coke Drum Inspection discussing a suite of technologies which have been developed to investigate and monitor the condition of delayed coke drums. A key focus of the paper is centered around the introduction of new sensor technology and the specific development of a robotic device which places the sensor remotely, on the inside surface of the vessel. This innovative technology is designed to identify and size flaws without the need to scaffold, remove insulation or blind the vessel.

1 BACKGROUND OF CIA INSPECTION SERVICE

CIA Inspection (herein referred to as CIAI) developed and operates a specialized laser surface profiling system designed to internally inspect coke drums during the short time period between coke cutting and refilling. The engineering company, (now known as CIA Engineering or CIAE), started development of the remote inspection equipment in 1990 and created the commercial arm, CIAI, to perform contract service inspections in 1994. To date, CIAI has performed over 500 site inspections throughout the world. CIAI's inspection system uses a remote sensor package deployed from the coke drum's drill stem as shown in Figure 1:

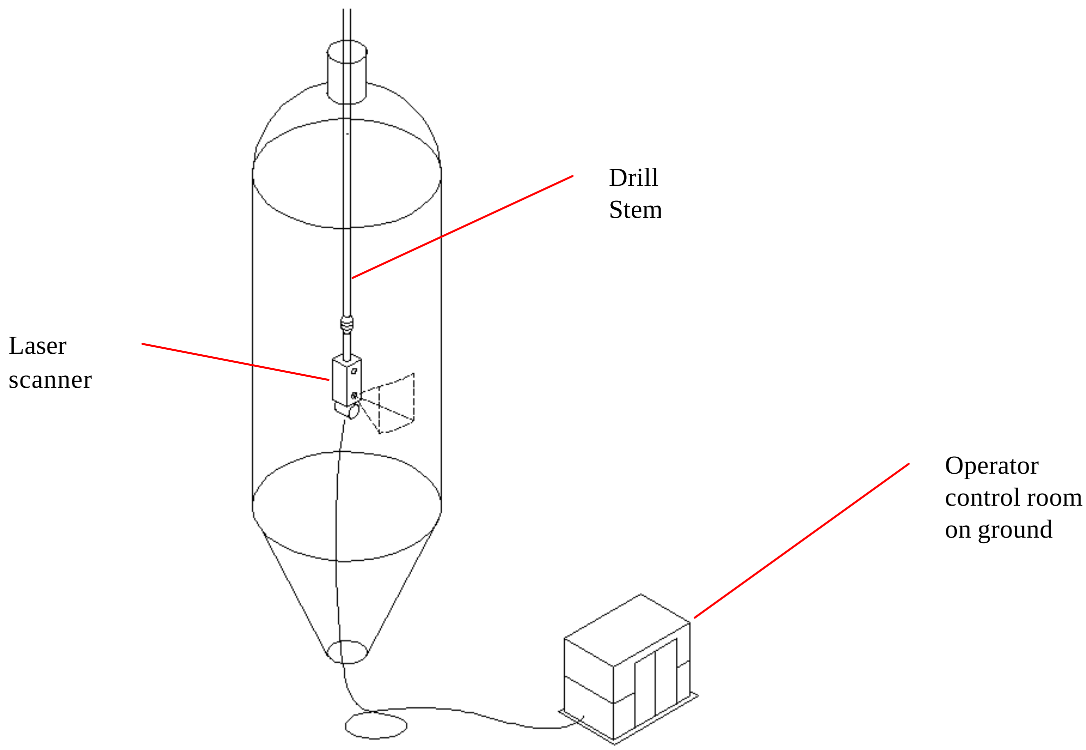

Figure 1: Coke Drum Inspection System with Laser Profiler

A color video camera with zoom lens permits a detailed remote visual inspection of the inside of the drum capable of identifying surface flaws such as cladding defects or potential weld cracks.

A scanning laser range finder produces an accurate and dense surface profile of the entire inside surface of the vertical walls of the drum. The capabilities of the laser scanner have elevated surface profiling from an occasionally-used qualitative method to a much more useful tool which:

- profiles the entire inside surface of the vertical drum walls on a 1" x 1" 25mm x 25mm) grid. This ensures that no deformations are "missed"
- measures depths of deformations to 1/8" (3.2mm) accuracy
- measures drum ovality as well as local bulges or wrinkles
- measures repeatably over time and therefore provides a means of accurately comparing initial scans with subsequent inspections.

The quality of the surface profile data produced by CIAI's inspection system has allowed coke drum operators to:

- compare the degree of deformity among their different drums, thereby identifying which drums are likely to require more inspection effort
- focus further inspection efforts on welds near deformed areas
- compare the change in drum deformities over time through the repeated use of CIAI's inspection system
- use actual drum profiles as input to Finite Element Analysis or to other third-party analyses (such as Stress Engineering's Bulge Intensity Factor – "BIF" analysis)

This use of CIAI's automated inspection service has allowed operators to accurately trend the shape of the vessels as they age. This capability has been useful, as many sites have been increasing throughput by reducing coker cycle times which make the drums age faster. By "benchmarking" a coke drum's surface profile before changing cycle times and then rechecking the profile after several hundred cycles at the new cycling rate, operators can determine whether the cycle change has led to an increase in drum bulging. This information can then be used to formulate pro-active inspection plans to maintain vessel reliability while operating at increased throughput.

1.1 The Traditional Response To Flaw Indications

When areas of concern have been identified by CIAI's inspections, options are considered whether to immediately inspect or wait for the next turnaround with the hope that potential flaws will not progress to a thru-wall condition during the run cycle. Because insufficient information is available to determine the nature of the indication, reliability people are unable to verify whether the visual or distortion indication goes beyond the cladding and into the pressure boundary. Production pressures often force the decision to ignore the indications and continue operating, potentially with disastrous results. The gamble to run to the next turnaround date may not pay off and an unplanned outage could be forced upon operations because of a thru-wall failure.

Once a drum has failed, repair and inspection personnel are placed under tremendous pressure to affect a repair and put the unit back in service. Due to the metallurgy of modern coke drums, repairs require sophisticated weld procedures and care must be taken to follow the procedures or the crack condition can reoccur.

Figure 2 outlines the typical features of flaws found in the clad restoration weld of coke drums

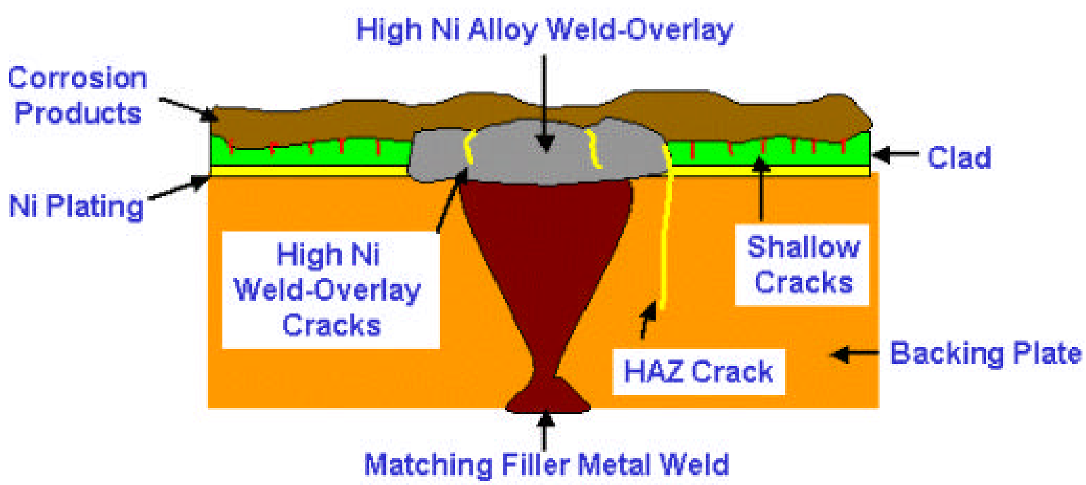

Figure 2. Low cycle fatigue crack caused in the clad restoration weld of coke drum

Traditionally, inspection and reliability technicians employ conventional ultrasonic NDE methods such as SHEAR WAVE or TOFD to these areas of concern to determine both the location and magnitude of the flaw indications. These conventional technologies are applied to the external surface of the vessel. Access to these areas is very difficult and requires the installation of scaffolding and the removal of insulation. Once the surface has been exposed, careful and thorough surface preparation must be performed to remove mill scale, rust and dirt. After all this preparatory work has been completed, inspection contractors can then perform a variety of NDE inspection technologies to verify the presence and size of flaws in the circ welds.

Interpretation problems are often encountered when the “shadow effect”, caused by the boundary between the internal stainless steel cladding and parent material, makes it difficult to interpret the results. Because of this boundary condition, cracks initiating from the inside of the drum in the restoration weld of the cladding and penetrating into the parent metal are often overlooked.

The only way to thoroughly inspect this area from the outside of the vessel is to utilize a new development referred to as PHASED ARRAY in combination with DUAL TOFD. This recently perfected technology is supplied by SUMITOMO Heavy Industries Ltd. and is offered as a contract service through CIAI.

1.2 Phased Array And TOFD Simultaneous Inspection

Phased Array (hereinafter called PA) technology generates an ultrasonic beam by setting beam parameters such as angle, focusing depth, and number of the active elements of PA probes using a computer to control the system. The P.A probe typically consists of a one-dimensional array of small transducer elements. In order to control the beam characteristics, the excitation pulse is applied at different times to the elements of the P.A probe.

P.A Linear Scan is a technique which applies ultrasonic beams to the clad restoration weld and its heat-affected zone. The P.A probe is mounted on the outside weld surface and traverses around the weld via a magnetic crawler. The sliding direction of ultrasonic beams is perpendicular to the scanning direction. The scanning data is normally obtained at every 1 mm in the scanning direction. Since a P.A probe is mounted on the outside weld surfaces, the outside weld protrusion must be removed to make a flush condition. P.A Linear Scan (straight beam technique) is well suited to detect weld defects caused during the manufacturing stage including porosity and lack of fusion between the clad restoration weld and base metal weld.

P.A Sector Scan inspects the weld joint by using a pair of P.A probes which are mounted adjacent to the weld joint and spaced equally around the centerline of weld. This configuration allows the ultrasonic beams to be focused on the clad restoration weld and its heat affected zone. The swing angle range of the focused shear wave is between 30 and 35 degrees. The scanning data is normally obtained at every degree, and at every 1 mm (0.04”) in the scanning direction. Since P.A Sector Scan is the angle beam technique, it is well suited to detect low cycle fatigue cracking in the clad restoration weld and its heat affected zone. Because of the dual probe configuration, P.A Sector Scan does not require removal of the outside weld protrusion.

While these techniques are very thorough and gaining in popularity, they still require access to the exterior of the drum and that requires scaffolding, insulation removal and some preparation of the surface prior to implementing the technique. All of this preparation work means that this sort of inspection can only occur during a planned turnaround.

2 SEARCH FOR NEW TECHNOLOGY

As part of ongoing research to improve inspection capabilities for our clients, CIAI has been searching for a means to quickly verify the presence of cracks in the failure prone areas. From CIA’s point of view, a key requirement for the system would be the ability to perform remote NDE inspection from inside of the vessel without having to scaffold, remove insulation or prepare the surface of the area to be inspected.

A variety of technologies were considered for the task and, after careful consideration of many aspects, ACFM was selected as the most appropriate technology for this particular application.

2.1 What Is ACFM

ACFM is an electromagnetic technique for detecting and sizing flaws breaking the inspection surface of both ferrous and non-ferrous metals and alloys. ACFM is an acronym for alternating current field measurement and was developed during the 1980’s from the a.c. potential drop (ACPD) technique. The initial theoretical work was undertaken at University College London but since then the development and marketing of practical instruments and probes has been carried out by TSC Inspection Systems located in the UK.

Its conventional application is for the detection and characterization of fatigue cracks in and around welded joints but is increasingly used to detect a variety of surface breaking defects.

Since 1991 ACFM has been used routinely for the inspection of underwater structures all over the world. ACFM is also being used in the petrochemical, nuclear, steel and railway industries, as well as research on civil engineering structures such as bridges and amusement rides.

Key features of the technique which lends itself to internal inspection of coke drums include its suitability for remote, robotic deployment and the ability to work on relatively dirty surfaces.

2.2 How Does ACFM Work

ACFM operates using a hand held, or remotely deployed probe which induces a locally uniform AC field into the test surface. This field flows in a thin skin on the surface of the material and is disturbed by the presence of surface breaking defects. These changes are detected by two sensors mounted in the probe which measure the magnetic field strength in two orthogonal directions. One sensor, termed the Bx sensor, measures the reduction in flux density around the center of the crack, which is predominantly caused by the defect's depth. The other sensor, termed the Bz sensor, produces a response due to the curvature of the currents flowing around the ends of the defect. This sensor indicates the position of the defect ends and hence the surface length can be determined.

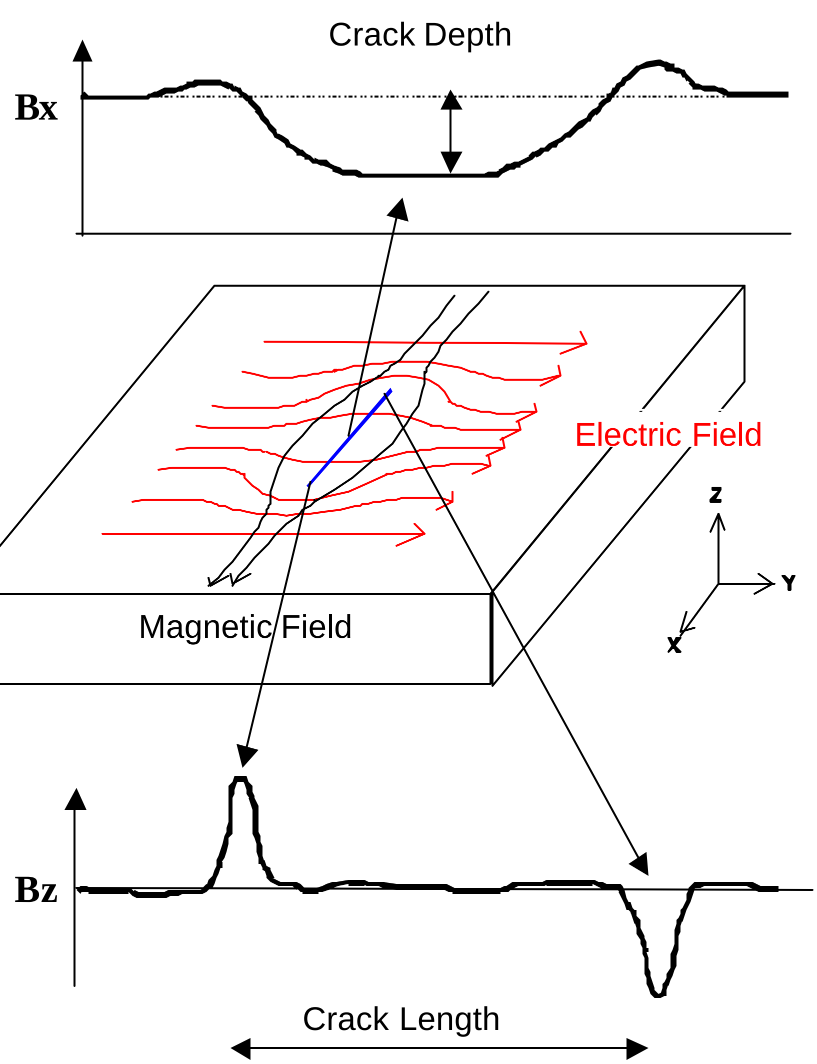

Figure 3. Relationship between electromagnetic fields around crack and ACFM signals

The ACFM probe is connected to a specialized instrument, which is then connected via a communications cable to a standard PC. The ACFM equipment is computer controlled through custom software and all inspection data is recorded for further investigation or for audit purposes.

No electrical connection is required to the structure being inspected, so a minimum of cleaning is required. Rust or protective coatings such as paint or cladding up to 5mm thick need not be removed prior to inspection.

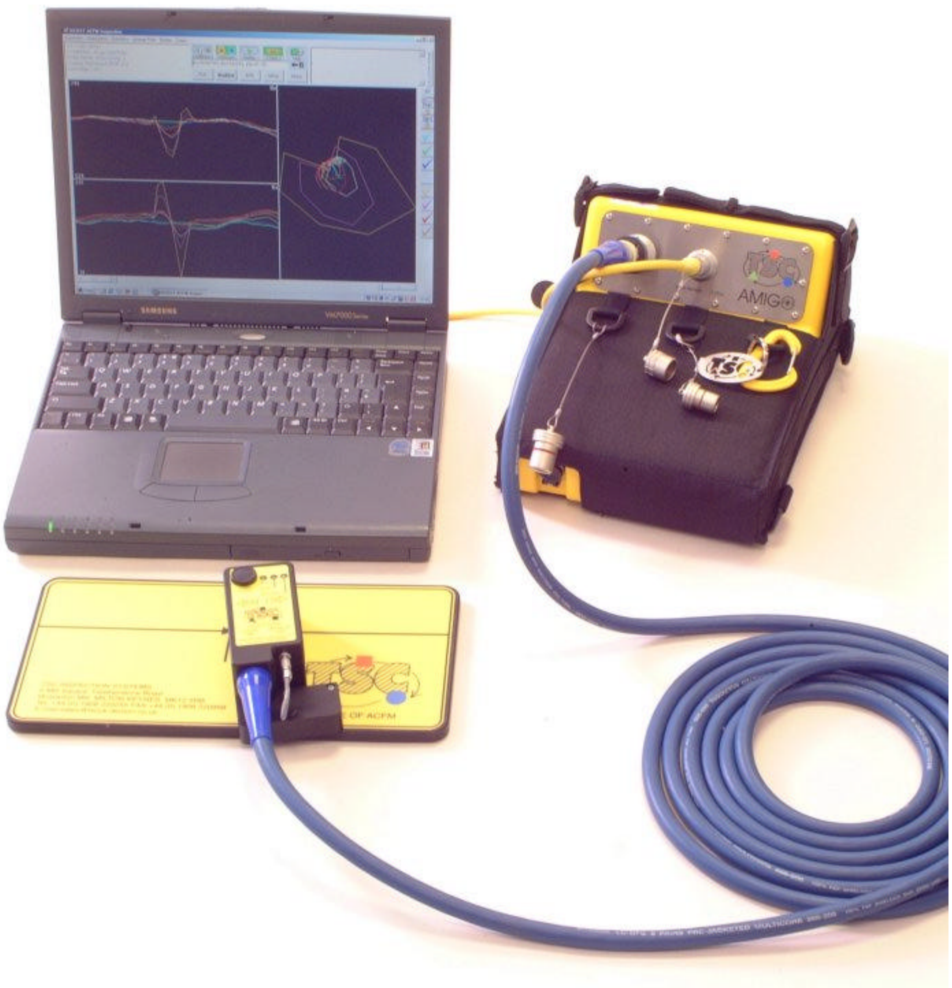

Figure 4: Typical ACFM equipment

Mathematical models of the field interaction with the cracks enable the crack length and depth to be predicted. This mathematical model is based on a defect morphology that is semi-elliptical in shape, the most common shape in fatigue-induced cracks. It should be noted that the crack model is not limited to a fixed aspect ratio but the largest depth that can be determined is usually half of the crack length measurement.

The main aim is to avoid calibration on artificial defects whenever possible because such calibration is known to be prone to error for a number of reasons, including:

- there is increased scope for operator error
- the calibration piece is not representative:
- a slot does not necessarily behave electrically like a crack

- the slot is unlikely to be in material representative of the crack location (i.e. Parent plate, HAZ, Weld)
- the slot is not generally in a geometry representative of the crack location

Calibration can only be valid for the defect length used because crack length influences the depth signal.

2.3 Approvals

ACFM has been approved by Lloyds, ABS, BV, DNV, and OCB Germanischer Lloyd for the inspection of offshore installations. ASTM has recently incorporated it as a Standard Practice for the examination of welds (E2261-03).
ACFM is recognised as a technique by ASNT and a chapter devoted to ACFM is included in the Non-destructive Testing Handbook, third edition, volume 5: Electromagnetic Testing.

2.4 ACFM Development For Use On Coke Drums

In the summer of 2005 a development program was initiated to integrate ACFM inspection technology with CIAI's proven coke drum inspection tools. A detailed feasibility document was produced which outlined the steps required to implement remotely deployed ACFM for this application.

Initial tests were carried out on a sample designed to mimic the form and materials used in the welded sections of a typical coke drum. Artificial surface breaking defects were introduced into this sample by electro-discharge machining (EDM) to help in defining the probe parameters.

Figure 5: Test sample for ACFM experiments

Detailed analysis of the ACFM system performance on the sample enabled the sensor type and operating frequency to be optimized. It was found that it was possible to detect a 7mm (0.28") long x 2.5mm (0.10") deep slot in the toe of the weld. The sensitivity in the Inconel weld cap was less than this due to the electromagnetic properties of this material and due to an increase in signal noise from the irregular weld profile. However in practice the defects are only likely to be problematical when they are deeper than the thickness of the weld cap (typically 5-6mm) and penetrate into the sub-plate.

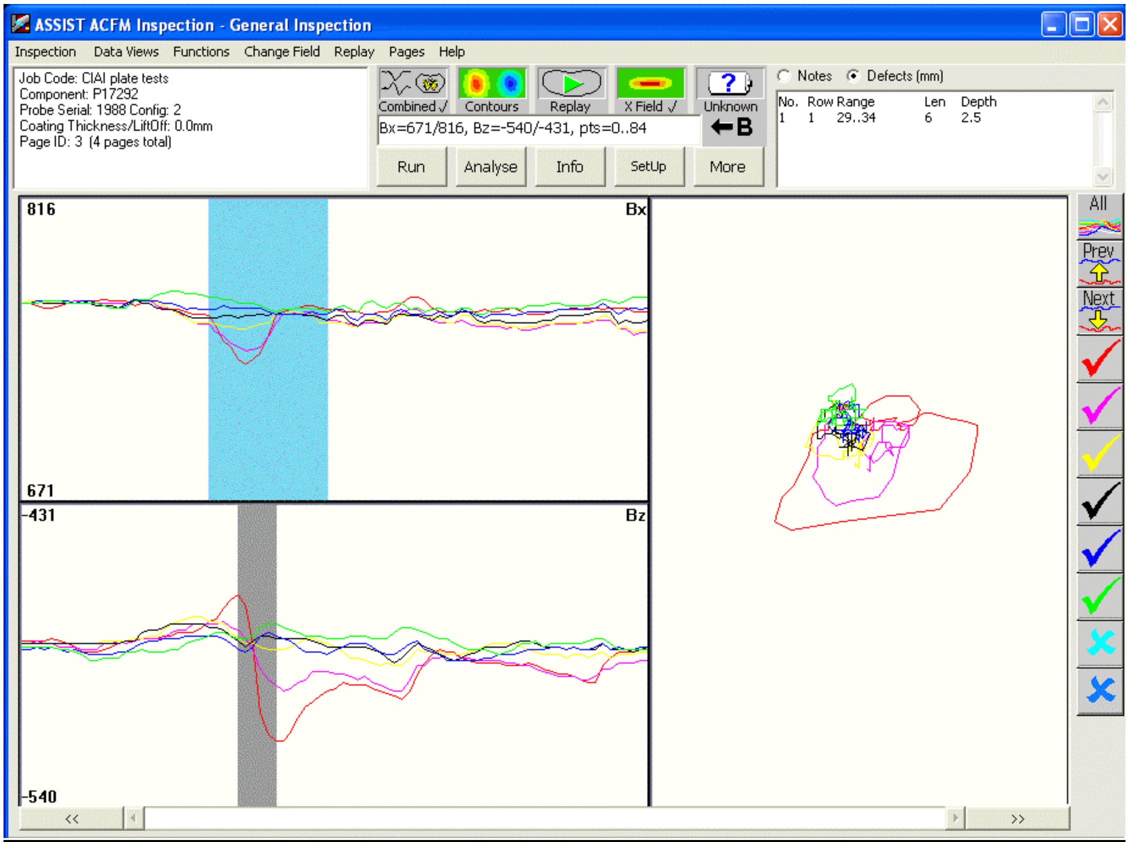

Figure 6: Screenshot showing defect in toe of weld

The system uses a custom designed ACFM sensor head composed of an array of individual sensors incorporated into an integral package. The size and spacing of the sensors are configured depending on the target defect size and other operating factors. The requirement is to be able to scan the weld, both toes and a little into the HAZ with one pass of the probe. This is achieved by using 16 sensor pairs, which cover a width of approximately 114mm (4.5").

3 SENSOR DEPLOYMENT

The ACFM remote deployment system, illustrated in Figure 7, consists of rotary drive, a yoke/tilt drive, an extendable boom and a magnetic-wheeled crawler supporting the ACFM sensor.

The boom is a lightweight structure, which extends to position the crawler on the drum wall. Once the crawler wheels have attached to the wall, the crawler is released and the boom partially retracts. A tether connects the crawler to the boom and a control umbilical connects the crawler and sensor signals to the remote control console.

A video camera mounted in the yoke monitors the sensor and crawler when the crawler is located on the drum wall. This camera provides a “world view” of the drum wall and the relationship between the sensor and the visual indication. The rotary drive moves in azimuth relative to the drill stem to orient the system in the drum.

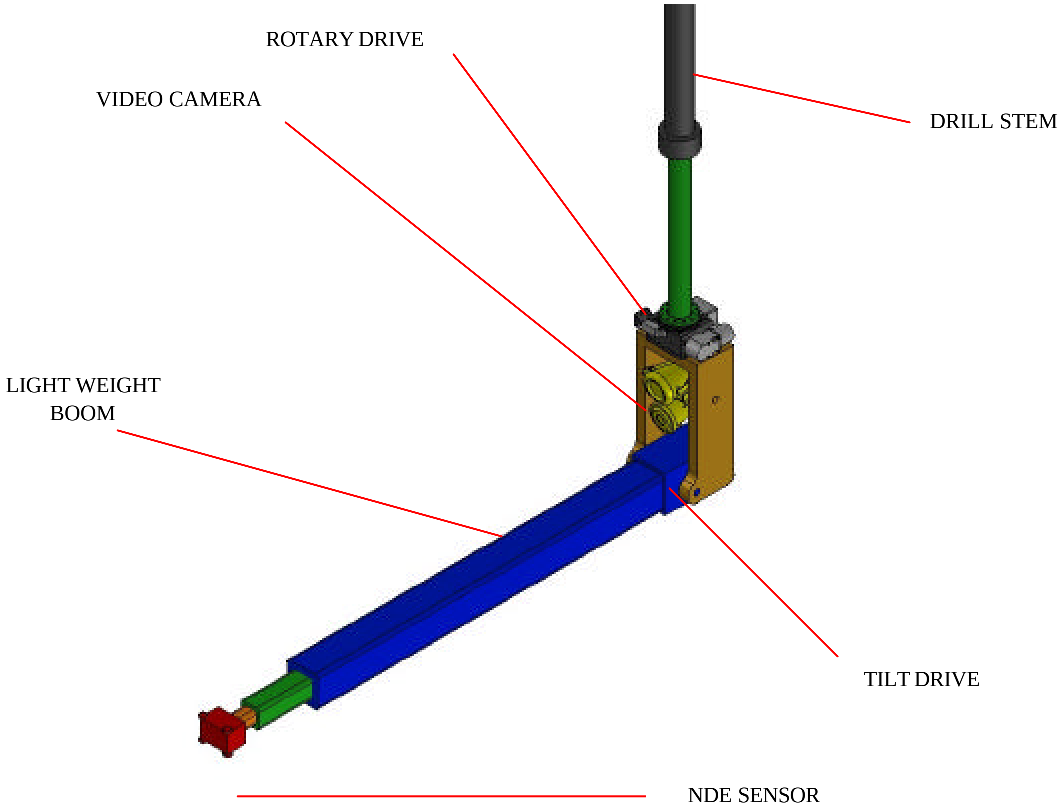

Figure 7 Outline of Remote Deployment System

The tilt drive rotates the boom from its vertical orientation during installation (Figure 8) to a horizontal orientation for the NDE inspection (Figure 9).

System deployment uses the same means of access to the coke drum as the laser inspection system. The system is suspended from the drill stem, which provides the gross vertical placement of the system in the drum.

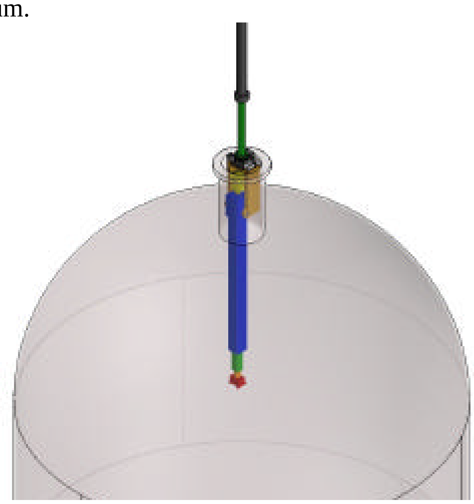

Figure 8 Sensor Arrangement being deployed in to vessel

The drill stem is lowered through the top head of the drum to the weld of interest with the proper elevation confirmed using the video camera.

The boom swings up to locate the crawler at the circ weld. Once attached to the drum wall the crawler is driven along the circ weld returning ACFM signals as it proceeds.

The rotary drive automatically tracks the crawler as it moves around the drum. The equipment is controlled from the same remote control room, located at ground level, used to perform the laser ranging/video inspection.

The advantage of this approach compared to conventional crawler inspections is the rapid deployment of the ACFM sensor to the area of interest. Another advantage is the known location of the sensor since the same system that orientates the laser data is used to position the sensor on the vessel wall

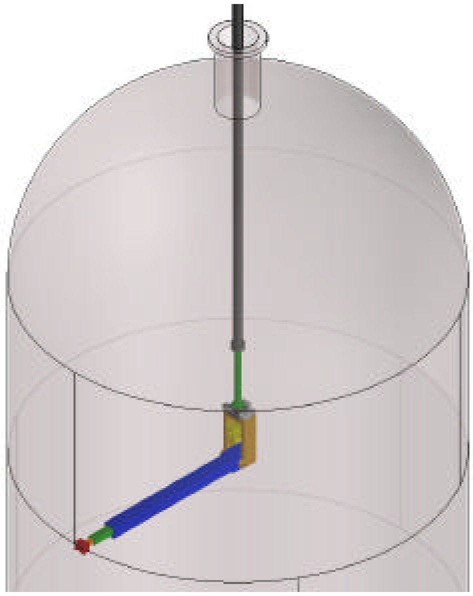

Figure 9 View of Sensor fully deployed against vessel wall

This method maximizes the inspection time for a given window by reducing the time spent traversing to the inspection site. Also, the crawler can be quickly removed from the wall and repositioned to another area of interest.

If, during operation, the crawler inadvertently detaches from the wall, the crawler, which is tethered to the boom, can be "re-grappled", allowing the crawler to be re-attached to the wall to continue the inspection. This minimizes the wasted time traversing a conventional crawler from its manually mounted start point.

By disconnecting the crawler from the extendable boom when mounted on the drum wall, the crawler can move unencumbered by loads that could be induced by the boom or off-centre position of the drill stem.

4 THE COMPREHENSIVE COKE DRUM INSPECTION PROGRAM

Performed in conjunction with CIA's existing Coke Drum Inspection service, this new development will give operators a quick and concise means of confirming the presence of cracks from the inside of the vessel. If cracks are present in the coke drum, the system will be capable of remotely sizing these cracks to determine both depth and length and determine if the crack penetrates into the pressure boundary.

With this innovative system, all of these capabilities can be performed without the need to blind the drum. This service eliminates the need for scaffolding, surface preparation or personnel entry into a confined space.

A typical inspection scenario would have CIAI's service identify a distortion in the vessel wall. This local area would be inspected with both the high-resolution video camera as well as being scanned by the laser profiler.

The resulting images, seen below in Figures 10 and 11, depict a typical example of the correlation between the laser profile section view and the visual indication. As the figures indicate, the distortion is associated with the circumferential weld at elevation 400 inches up from the tangent line of the vessel.

The azimuth of the indication is at 289 degrees west of north. The section view is taken vertically through the circumferential weld and is displayed in graphic form by figure 11. Note that the circumferential weld is at the vertical elevation of 400 inches and this is immediately below a local outward distortion as shown by the red coloration in the laser map. This local distortion is caused by the axial stresses that the drum sees during the quench cycle, and further exaggerated by a step change in wall thickness at the 400-inch circ weld elevation. The combination of these factors combined with the strong visual indication suggests that the crack type indication is indeed a crack.

Figure 10- View of Crack Type Indication

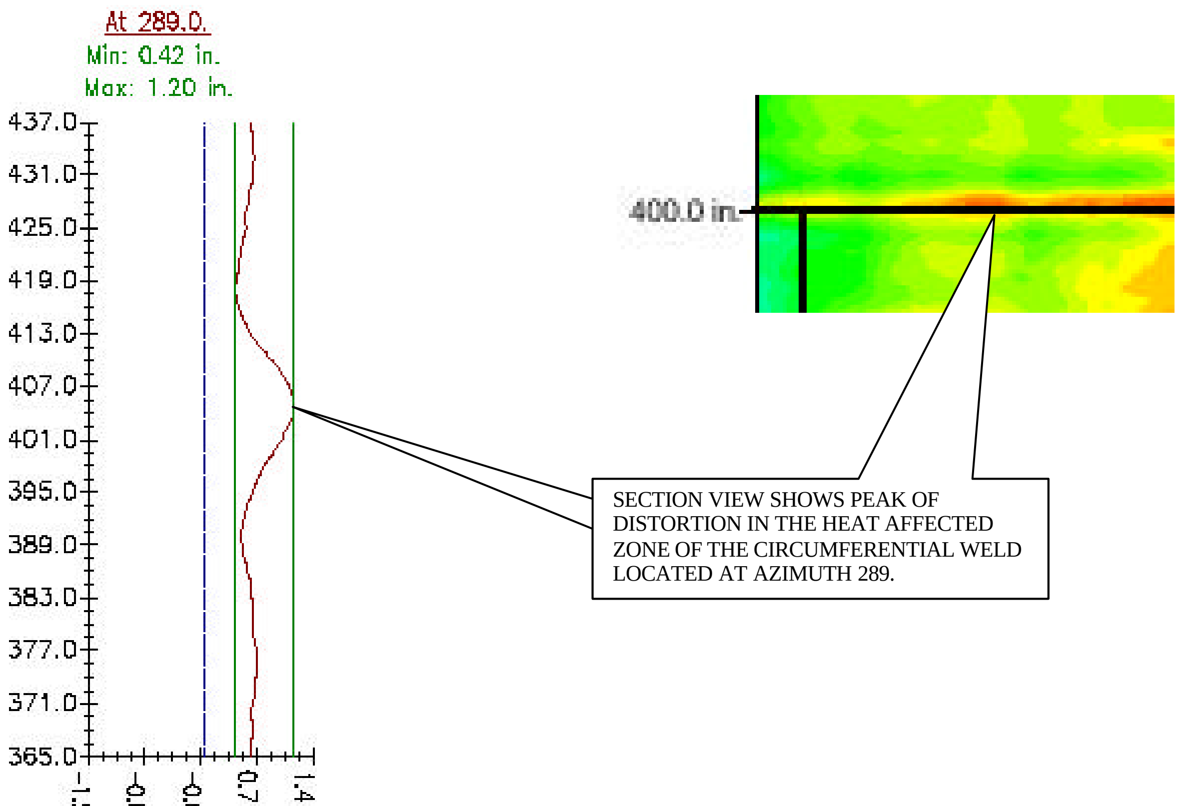

Figure 11 Section View taken from laser scan data

The strong correlation between visual and profile images give cause for concern and raises the question "Are these indications of real cracks, and, if so, how far do they penetrate into the pressure boundary".

Armed with this newly developed remote crack detection system, management now has the capability to assess the significance of these indications without scaffolding, insulation removal or vessel entry.

In such cases management would be briefed on the number and location of relevant indications in the drum and a decision would be made to investigate these indications further.

The inspection equipment would be deployed into the drum at the next available window and used to investigate the specific areas of concern.

The results of this investigation would confirm if the visual indication is really a crack and it would also characterize the crack so that management can make a decision on the urgency to make a repair.

With this new development, all of this inspection work can be accomplished remotely. The system installs from the drill stem, and is inserted between coking cycles in the same window of time that the original inspection service takes (nominally 4 hour window).

The design requirements for the system are aimed at being able to thoroughly inspect at least one circ weld during the available window. Depending on indications and remaining time, several locations on several circ welds could be inspected during the same window of opportunity.

5 SUMMARY

CIA has been involved in remotely inspecting coke drums for the past 15 years and was instrumental in developing the system which is now considered as standard practice worldwide. CIAI has always strived to maintain high standards in both the innovativeness and robustness of the equipment which has proven itself over the years by operating successfully in this very difficult environment.

CIA has applied its years of understanding and experience to the development of this new capability and is anticipating similar performance from this new development as it moves from the prototype to operational stage.

The development of this new capability represents another breakthrough which is aimed at improving the reliability of delayed coke drums. CIAI believes that this capability will be rapidly adopted by industry as an innovative tool which can assist in understanding the condition of operating vessels.

Further, CIA believes that this capability has additional applications in other vessels, and welcomes feedback from industry on other applications which may benefit from this new development.