www.ndt.net - 3rd MENDT - Middle East Nondestructive Testing Conference & Exhibition - 27-30 Nov 2005 Bahrain, Manama

# ADVANCES IN THREAD INSPECTION USING ACFM

**David Topp**, Managing Director, PhD, Msc, BSc, IEng, MBINDT
**Martin Lugg**, Technical Director, PhD, MSc, BA, MBINDT, MInstP

TSC Inspection Systems, United Kingdom

## ABSTRACT

The A.C. Field Measurement technique (ACFM) has been used to detect and size surface-breaking defects for 15 years, both topside and underwater. The technique is well suited to inspecting painted, welded structures, but one of the first applications of the technique was on drillstring threaded connections.

Originally based on a mains powered instrument, TSC have recently developed a much lighter thread inspection system based on the rugged, portable Amigo instrument. The new Automated Thread Inspection (ATI) system uses a probe with an array of sensors to inspect the 12 most highly loaded thread roots in one pass. Advanced software automatically detects crack signals in the data and reports length, depth and location information without any need for operator intervention.

This paper reports on the capabilities and results obtained with the new system, including the use of a higher operating frequency to give much greater sensitivity on non-magnetic components.

## INTRODUCTION

Maintaining the integrity of a drillstring is obviously a major consideration in drilling operations. Over recent years, advances in drilling technology, such as enhanced reach and under-balanced drilling, are increasing the demands on the drillstring components, yet at the same time, these advanced drilling methods make drillstring integrity more important since the cost and significance of a failure will be greater.

The very nature of drilling operations mean that downhole drilling components are subjected to significant cyclic loading which can result in fatigue damage and subsequent downhole failure. For drillstring and bottom hole assemblies, the threaded connections between individual elements are susceptible to fatigue damage under certain conditions and these are generally the “weakest link” in the system. Routine inspections of the downhole components are carried out in order to identify the presence of cracking and, if cracking is found, the component is either reworked or removed from service.

The conventional methods for inspection are magnetic particle testing (MT) for ferritic components, and dye penetrant testing (PT) for non-magnetic components. Both can be considered as enhanced optical methods and require skilled operators to deploy the method and interpret the results. In both cases, interpretation relies totally on the operator and any records are generally hand written and limited to the reporting of whether any defect indications were found.

Because of the reliance on individual operators, and the difficulty of applying the techniques to threads, particularly box threads (the female threaded component), the conventional techniques have been found to be unreliable [1]. These conventional methods also have a number of practical limitations. Firstly, they require extensive cleaning and degreasing of the components. Secondly, it is a requirement that the inspections are conducted in low light conditions in order that fluorescent inks and dyes can be used, and finally it is necessary to rotate the drillstring component during the inspection process.

The Alternating Current Field Measurement technique (ACFM) was developed 15 years ago for fatigue crack detection and sizing in welded structures, and is now being used in a wide range of applications in the offshore industry as a replacement to conventional methods [2]. The technique is an electromagnetic method that avoids the need for extensive cleaning and has a number of other advantages over conventional inspection methods. In particular, it does not require visual access to the area being inspected and produces a full record of the inspection results, which can then be used for audit and checking purposes. The technique was soon developed for drillstring thread inspection [3] to provide improved reliability by reducing the reliance on the human operator. Because the technique provides quantitative information about defects in terms of their length, depth and location, the results from these inspections can be used as historic data to plan future inspections using drillstring tracking and management systems.

Recent advances in instrumentation and software have made the technique easier to use, and improved the sensitivity to small defects on non-ferrous threads.

**THE ACFM TECHNIQUE**

The ACFM technique involves inducing a locally uniform current into a sample and measuring absolute values of magnetic field above the sample surface. The current is perturbed by the presence of a surface-breaking defect and these produce perturbations in the magnetic field. The amplitudes of these perturbations are compared with values in look-up tables produced from a mathematical model to estimate defect sizes without the need for calibration using artificial defects such as slots. This feature of ACFM is useful because calibration on slots is known to be prone to error for a number of reasons:

- There is added scope for operator error (and one mistake on a calibration setting will affect all subsequent sizing).
- Slots behave differently, electrically, to real cracks and are often in different material (e.g. parent plate rather than HAZ or weld material).
- Slots often have different geometry to a real crack (e.g. rectangular rather than the more typical semi-ellipse shape of a fatigue crack).
- The range of slots available in a calibration block is limited. In particular, they tend to be of the same length, whereas the signal strength can be affected by crack length as well as depth, particularly for short cracks.

The required locally uniform field is induced using one or more horizontal axis solenoids. By convention, the direction of this electric field is designated as the y-axis, and the direction of the associated uniform magnetic field (at right angles to the electric field and parallel to the metal surface) is designated as the x-axis. The z-axis is then the direction normal to the surface.

With no defect present and a uniform current flowing in the Y-direction, the magnetic field is uniform in the X-direction perpendicular to the current flow. Thus, designating the three orthogonal components of magnetic field Bx, By and Bz, Bx will have a constant positive value, while By and Bz will both be zero.

The presence of a defect diverts current away from the deepest parts and concentrates it near the ends of a crack (Figure 1). The effect of this is to produce a broad dip in Bx along the defect with the minimum value coinciding with the deepest point of the defect. The amplitude of this dip is larger for a deeper defect of a given length. At the same time, concentration of current lines where it flows around the defect ends produces small peaks in Bx. The same circulation around the defect ends also produces a non-zero Bz component. The flow is clockwise around one end, producing a negative value of Bz (i.e. pointing into the surface), and anti-clockwise around the other end producing a positive value of Bz (out of the surface). The location of the maximum (positive and negative) values of Bz are close to, but not coincident with, the physical ends of the defect.

Measurements of the amplitude of the dip in Bx and the distance between the peak and trough in Bz are used together with software algorithms to determine the accurate length and depth of the defect. In order to aid interpretation, the Bx and Bz components are often plotted against each other. In this display, a defect produces a complete closed loop indication. Due to the distinctive shape of this loop, the display is called the Butterfly plot (Figure 2). The size of this loop is not sensitive to probe speed and so is used as a valuable aid in the interpretation of the data collected and the confirmation of defect indications.

The ACFM technique uses a uniform input field to allow comparison of signal strengths with theoretical predictions. However, the use of a uniform field bestows other advantages as well as disadvantages compared to conventional eddy currents.

The main advantages are an ability to inspect through coatings several millimetres thick, an ability to obtain depth information on deep cracks (typically up to 25mm), and easier inspection at material boundaries such as welds. The main disadvantage is that probes have to be larger to accommodate the larger field inducer.

Because ACFM uses a remote uniform field, it is possible to make a number of field measurements at different positions in the same field. This concept is used for thread inspection by producing a probe, profiled to the thread form and containing field sensors located at each thread root. This 1D array of sensors is then swept around the thread to provide simultaneous inspection of all the critical threads with a single probe sweep.

**APPLICATION OF ACFM TO DRILLING COMPONENT THREADS**

## Simple Probe

Manual inspection of drillstring threads is possible using a simple hand held probe, which contains a single sensor pair (Figure 3). This probe is used with a replaceable “shoe” profiled to suit the thread form being inspected and swept around the thread. For all thread roots to be inspected this clearly requires one revolution for each thread. In practical terms, it is easier to rotate the component whilst holding the probe on the thread to avoid twisting the probe cable. In this way, the probe tracks around the complete thread helix to achieve a full inspection. The data is displayed on the PC and the operator interprets the data to establish if defects exist. If they do, the defect depth information can be used to determine whether the connection can reworked or whether it needs to be scrapped. This is very important information because reworking a connection with a deep crack, which is not fully removed, obviously results in cracked components being re-introduced into service.

This type of inspection is now used extensively around the world for the inspection of threaded down-hole motor components. The wide range of thread sizes and types are readily accommodated by the use of the replaceable plastic shoes, profiled to each thread type, where the active part of the probe is unaffected and is designed to fit into the thread root. For mud motor components, this approach is quite practical. The wide range of thread forms and sizes are easily accommodated and the inspections are conducted at a facility where it is practical to rotate the component.

However, for more routine drillstring or BHA component inspection, the requirement is somewhat different, components tend to be similar with standardised sizes, but much larger, and so rotation of the component is less practical. For this reason, a different approach has been adopted for drillstring or BHA component threads. Away from the maintenance facility, control of inspection operations can also be more difficult. For these reasons, a semi-automated drillstring thread inspection system was developed, known as the ATI (Automated Thread Inspection) system.

## ATI System

The ATI system addresses the limitations of the manual system. The need to rotate the component was overcome by providing an inspection head with multiple sensors. The current ATI system inspection head has 12 pairs of sensors allowing the 12 most critical threads to be inspected with a single circumfernetial sweep of the probe around the component. The difficulty of achieving a steady speed during a full circumferential sweep around a stationary component was overcome by incorporating a position encoder in the head. This means that the data can be collected satisfactorily even if the scan is momentarily stopped to allow the operator to change hands during the scan.

In fact, the inclusion of the position encoder introduced a number of additional benefits. The encoder meant it was possible to ensure that a full 360° scan had been achieved, thus checking that the operator had done his job properly. It also allowed the speed of the scan to be checked to ensure the data quality. Finally, it provided the information to allow fully automated detection and sizing to be carried out. Thus it was no longer necessary for the operator to interpret the ACFM signals. This de-skilling of the inspection operation is considered a major benefit in that audit of the system is much simpler with very little reliance on the skill or diligence of the operator.

## ATI System Components

The original ATI system used a mains powered instrument, and had separate array probes for each combination of thread pitch and gender.

In the new ATI system, a more portable battery-powered instrument is used, and one array probe is able to inspect both pin and box threads of a given pitch, thus halving the number of probes required.

The ATI system comprises system electronics, controlled by a rugged PC, and one or more probe heads with assorted scrapers (Figures 4, 5 and 6).

The system PC provides control of the system plus storage of all data. A user interface allows the operator to log in, identify the component ID's and provide shift summaries of all connections inspected and the results in terms of a list of all defects found (with their location, length and depth). The ACFM electronics provide the output signals and condition the measurement signals from the probe heads. The system electronics also provide support for the position encoder.

Recent advances in electronics have meant that the array probe body can be made smaller than for the original ATI system. Each probe can now inspect "standard" API drillstring pin and box threads of size 3½" and upwards, as well as some smaller sizes in other ranges. So far, probes have been produced for 4 tpi and 5 tpi (i.e. ¼" and 1/5" pitch), but probes for other pitches (e.g. 6 tpi, or metric threads) are also possible. The probe is fitted with interchangeable stainless steel scrapers on each side of the probe body (Figure 7). Each set of scrapers is designed for a particular thread size/type taking account of the thread form, taper and diameter. The scrapers ensure that the sensors fit correctly into the thread root with a small radial clearance. Each thread probe contains a linear array of 12 pairs of sensors designed to inspect the 12 most highly loaded (critical) threads in one pass (although any extra threads can be inspected in a second pass if required).

## Data Interpretation and Results

The software firstly filters the raw data to remove any background geometry effects (e.g. from the shoulder), and then Bx and Bz signals are analysed together to determine if any defect-like signals are present. By using both Bx and Bz data, false calls due to lift-off or other effects which only influence one of the components are eliminated. Any defect signals detected are then interpreted in terms of defect size. If a defect is present which is larger than a prescribed acceptable defect size, the system reports the connection is cracked. Typical data is shown in Figure 8, while a typical report screen for a cracked component is shown in Figure 9. Here it is seen that the location and size of the defect is automatically reported. A suitably trained operator can further interrogate the system to manually review the data and carry out manual interpretation if required.

## Operation

For a typical operation, the operator would remove excessive dope or encrusted drilling mud from the connection, install the probe and check the system accepts the probe. The identification of the joint would then be entered and the system started by pressing a button on the probe. The probe is swept one full circumference. The probe can be stopped to allow a change of hand without affecting the data collection process. Status indicators on the probe and PC report if the probe is moved too fast. A typical scan speed is 20mm per second (equivalent to about $25^0$ of circumference per second on a 4.5" IF thread, for example). Typical time for a complete inspection of a pin or box end is 1 minute including probe installation and scan. At the end of each shift, the system produces a printed record of all inspections conducted and the results.

**BENEFIT OF ATI OVER CONVENTIONAL METHODS**

The fact that ATI provides reliable, auditable data means that it can be used to improve the reliability of defect detection in downhole threaded components. Reducing the risk that cracks will be missed during routine inspection provides a very significant potential reduction in downhole failures.

A reliable system performance means that the inspection intervals can be controlled and targeted to allow cost effective use of inspection resources.

Other cost saving benefits are:

- reduced cleaning, no need to clean to bright metal and hence;

- improved environmental considerations by reducing need for kerosene washing
- ability to inspect components in the pipe rack
- reduced handling, no need to rotate pipe during inspection
- can be used onshore or offshore, horizontal or vertical.

## RESULTS OF ACFM INSPECTION OF THREADS

Halliburton [6] have used the manual probe system to inspect downhole motor components which are normally retired at the end of a prescribed operating life. During trials 140 threaded ends were inspected with MT with no positive crack indications, around 10% had surface indications. When inspections were conducted using ACFM, 23 defects were identified. Because the crack depth could be determined with ACFM, 9 were able to be reworked with the remainder scrapped. Two of the scrapped components had significant defects and had been passed by MT as defect free.

The original ATI system detection performance was similar to the manual probe system but with significantly improved throughput and ease of operation. A target defect size of 8 x 0.75mm in ferrous steel was specified and to initially assess the detection capability, artificial defects were introduced into the pin and box ends of tool joints. The systems automated detection correctly identified the defects and gave no false calls on the uncracked sections.

The original ATI system was then evaluated in blind trials in a pipeyard. The results from these trials provided a direct comparison between ATI and conventional magnetic particle inspection. Twenty 6¼ " spiral drill collars were inspected initially with ATI in an uncleaned state. These were then cleaned in preparation for MT. Fluorescent wet MT was then conducted followed by an ATI re-inspection of the box ends in the cleaned condition.

The trials demonstrated that:

1. The results from boxes inspected by ATI pre and post cleaning for MT were similar.
2. Variability was observed between MT operators.
3. There were two discrepancies between the results from ATI and MT, which were further evaluated. After re-inspection and sectioning, it was shown that MT had produced one false call which was not observed on careful re-inspection, and had missed one defect found by ACFM to be 0.4mm deep.

Following the independently witnessed trials, the ATI system was included as an acceptable method in the North Sea Drillstring Inspection Standard NS-2 [7].

## RESULTS FROM NEW ATI SYSTEM

The latest Amigo-based ATI system is an improvement to the previous system in a number of ways. Firstly, the Amigo is a much smaller and lighter instrument than its predecessor. Secondly, the Amigo uses a rechargeable battery pack, so thread inspection can be carried out in areas where no mains power is available. Thirdly, the Amigo supports the use of 50kHz as well as the standard 5kHz carrier frequency. At 50kHz, the skin depth in the metal being inspected is about 30% of the value at 5kHz. This means that more of the current interacts with a defect, making the system more sensitive to shallow cracks, particularly in non-magnetic materials such as stainless steel and Inconel.

Trials carried out with the new ATI system have demonstrated detection of slots as small as 6mm long by 0.25mm deep, or 4mm long by 0.5mm deep, in Inconel.

## CONCLUSIONS

Conventional inspection methods for threaded connections can be unreliable due to the difficult access and operating conditions. By introducing more reliable inspection methods, the likelihood of missing a crack during an inspection is reduced. This leads to a direct reduction in the likelihood of downhole failures due to fatigue. In addition, more quantifiable inspection results lead to the possibility of introducing a more focused inspection planning method based on the inspection system performance and duty cycle of the downhole components. The ability to store and retrieve data electronically enables easy integration into drillstring management systems by allowing inspection data to be linked to individual drillstring components.

**REFERENCES**


[1] Dale B A and Moyer M C. "Sensitivity and Reliability of Commercial Drillstring Inspection Services". 7th Offshore South East Asia Conference, Singapore, February 1988.

[2] Marques, F.C., Martins, M.V.M. and Carneval, R.O. "ACFM in Brazil – New Applications for Equipment Inspection", Proceedings of 8th ECNDT, Barcelona, Spain, 17-21 June 2002.

[3] Topp D A, McGugan J D and Dover W D. "Automated Inspection System for Drillstring Threaded Connections using A.C. Field Measurement (ACFM) Techniques". Offshore Drilling Technology Conference, Aberdeen, November 1990.

[4] Lewis, A.M., Michael, D.H., Lugg, M.C. and Collins, R. "Thin-skin electromagnetic fields around surface-breaking cracks in metals", J.Appl.Phys. 64 (8), pp 3777-3784, 1988.

[5] Gaynor T M, Roberts D L, Homan E and Dover W D. "Reduction in Fatigue Failures through Crack Detection by Alternating Current Field Measurement", Paper SPE 35033. IADC/SPE Drilling Conference, New Orleans, March 1996.

[6] Mason J S and Sprawls M. "Addressing BHA Whirl - The Culprit in Mobile Bay", Paper SPE 35034. IADC/SPE Drilling Conference, New Orleans, March 1996.

[7] "North Sea Drillstring Inspection Standard, NS-2", O.C.T.G. Procter Consultancy Limited, Aberdeen, UK, November 1999.

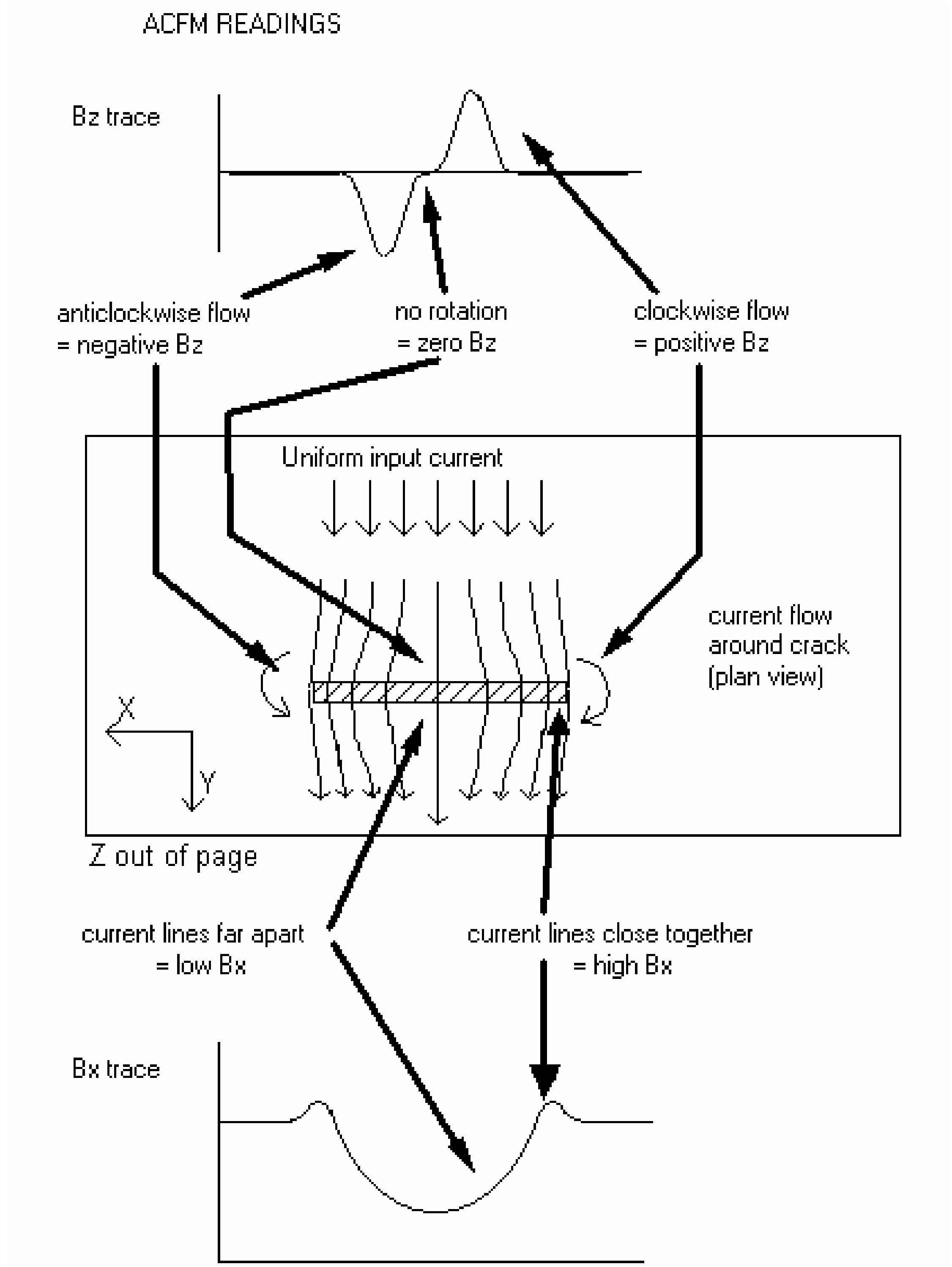


Figure 1. Current Flow and a surface breaking defect

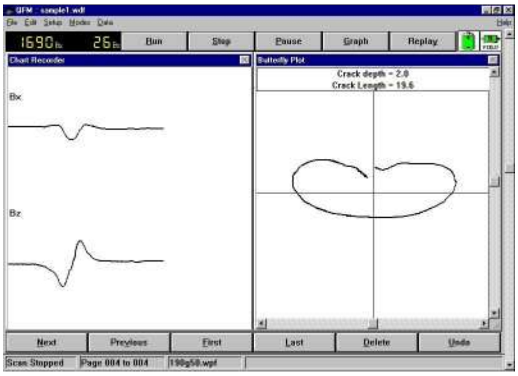


Figure 2. Typical ACFM data from a crack, with butterfly plot on right

Figure 3. Simple thread probe deployed on pin, and shoe for box

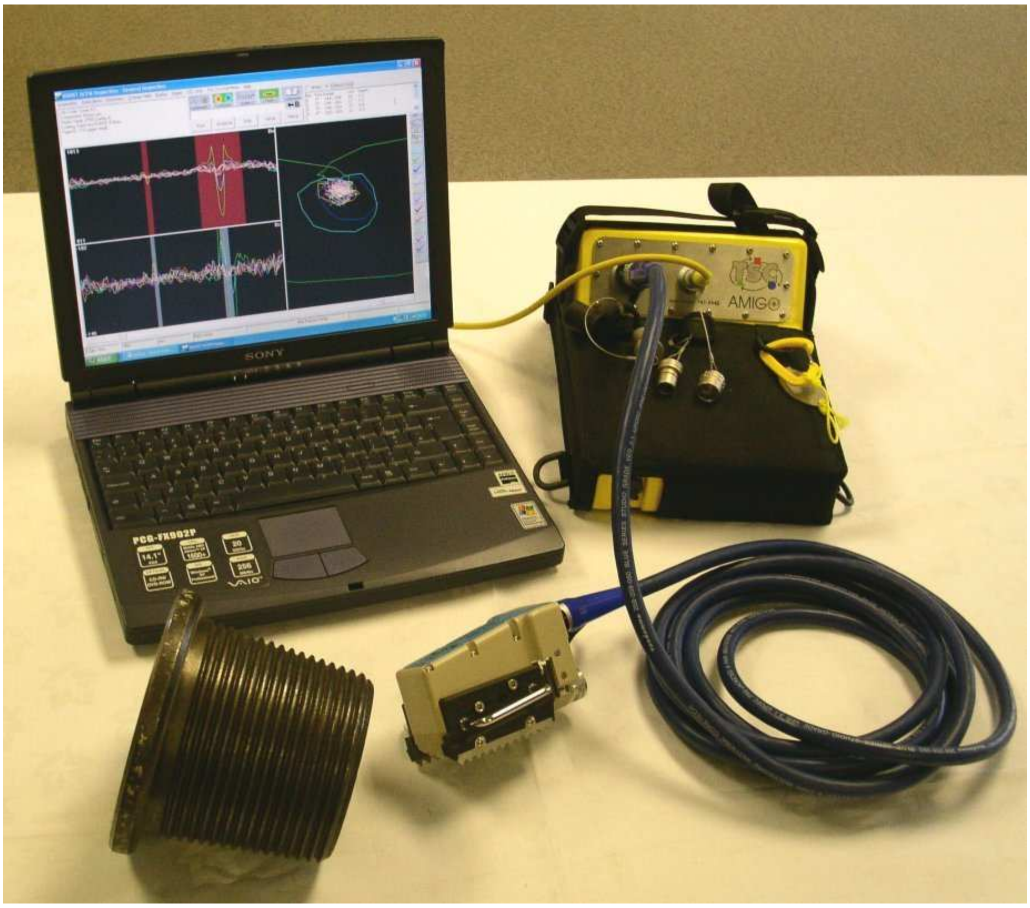


Figure 4. ATI system showing PC, Amigo instrument and 4 tpi array probe

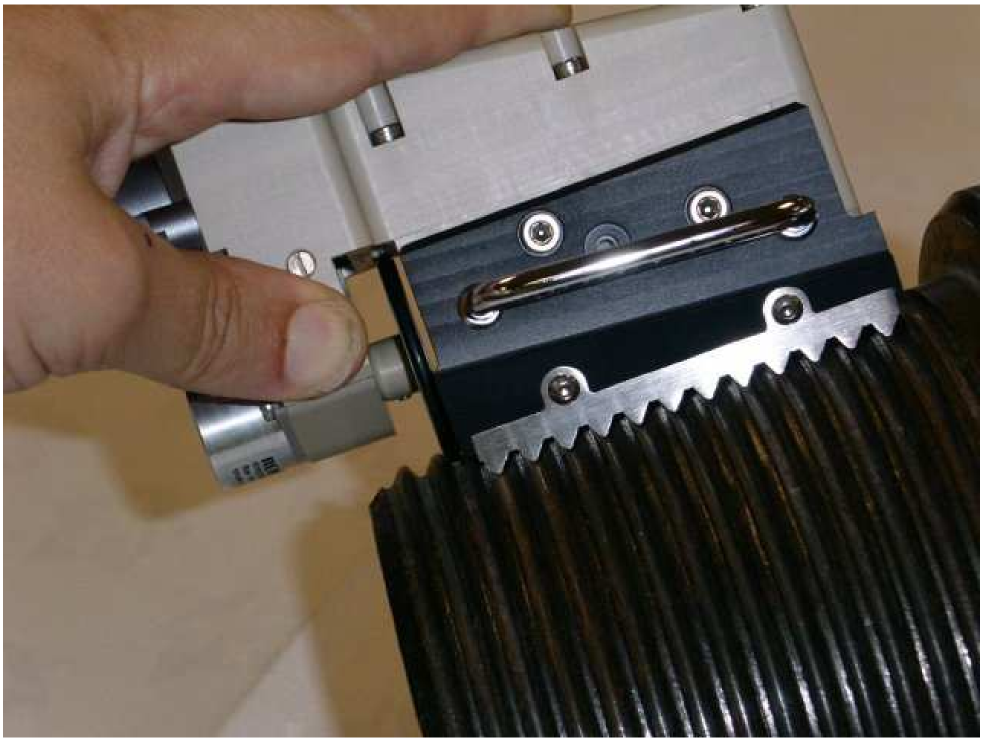

Figure 5. ATI probe set up for pin inspection

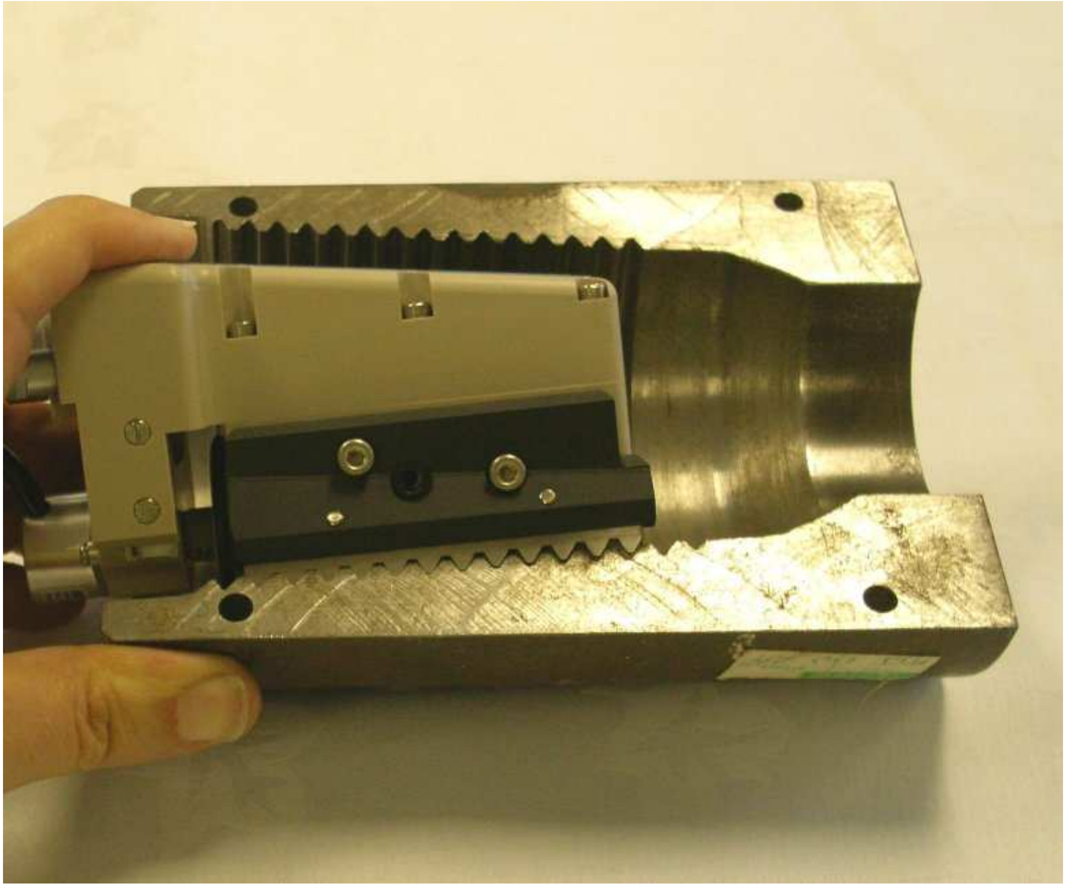

Figure 6. ATI probe set up for box inspection

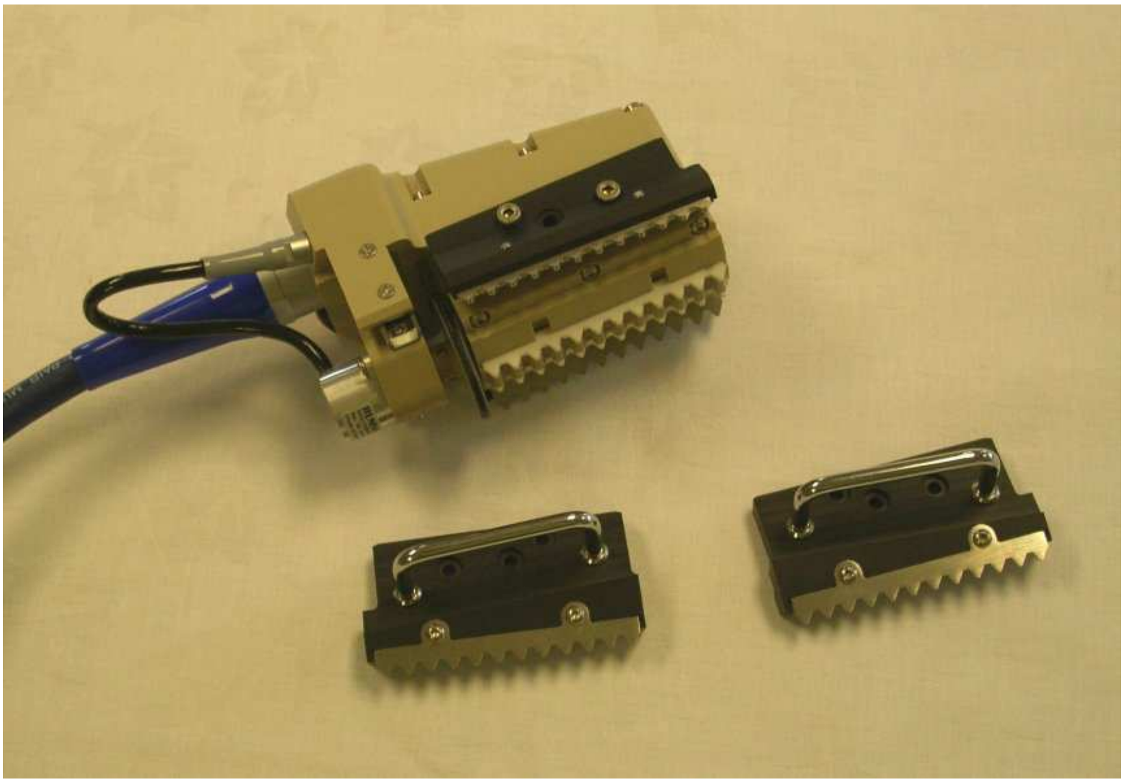

Figure 7. ATI probe with 4.5” 4tpi scrapers for box (fitted) and pin

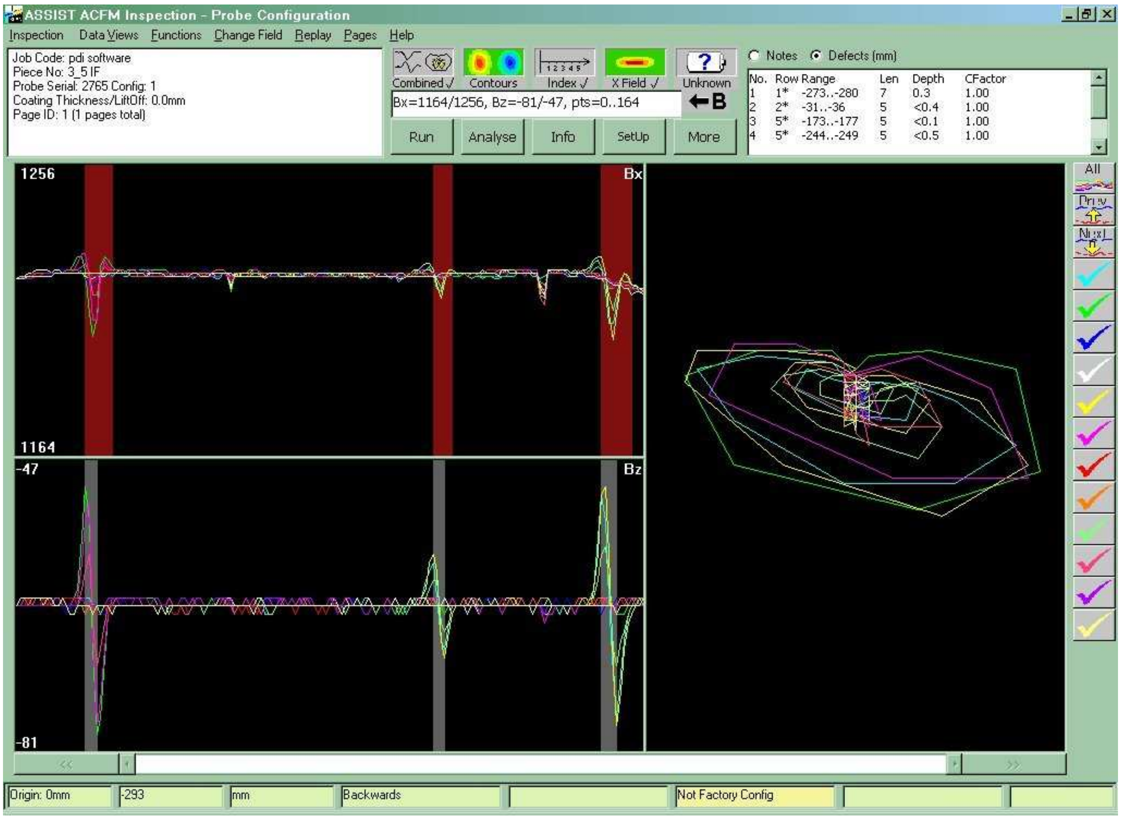

Figure 8. Typical data from ATI system

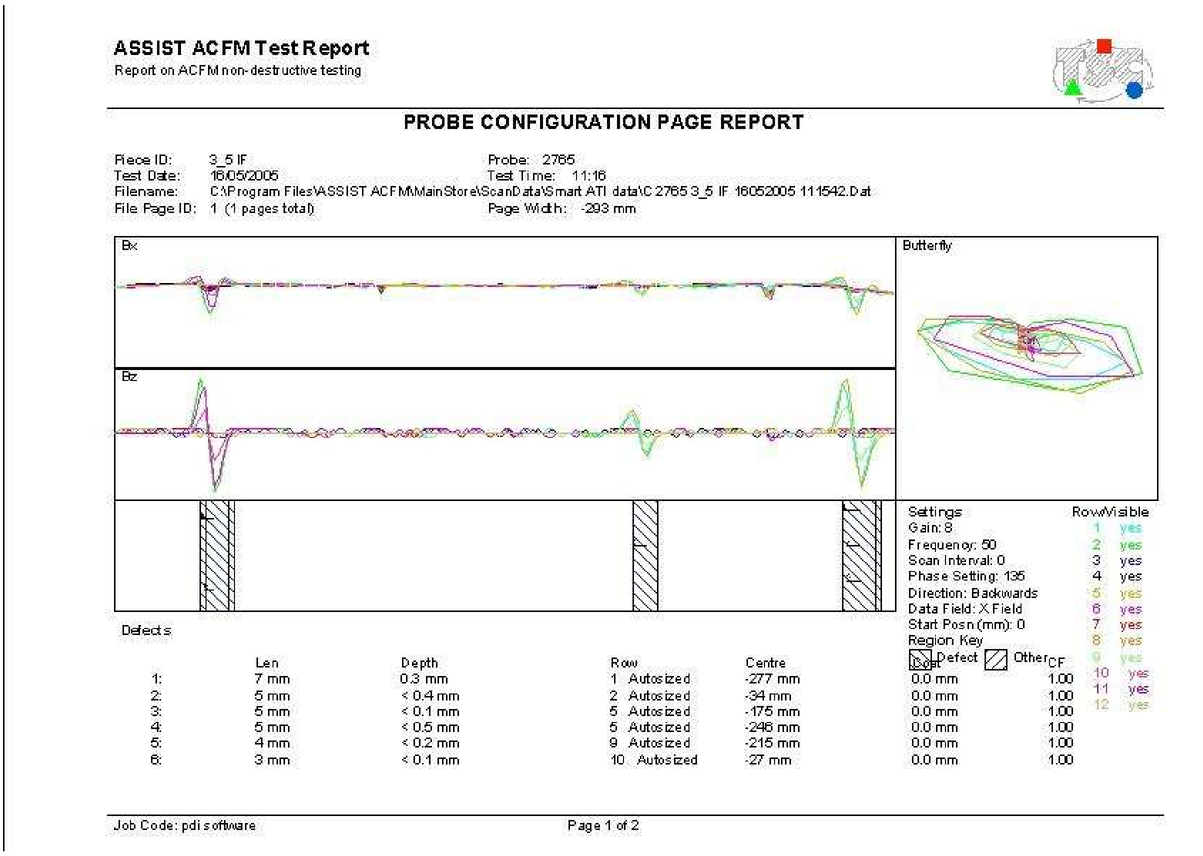

Figure 9. Typical report from ATI system