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INNOVATIVE TECHNIQUE FOR INSPECTION OF POLYETHYLENE PIPING BASE MATERIAL AND WELDS AND NON-METALLIC PIPE REPAIR

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ABSTRACT

An innovative apparatus and method have been developed that can volumetrically examine any dielectric material, including polyethylene piping and non-metallic pipe repairs. The method employs a first of a kind apparatus that is based on the application of microwave energy. Comprehensive laboratory testing of the method and apparatus has been completed including the inspection of many samples of polyethylene pipe welds and non-metallic pipe repairs. The specimens examined had different types of internal flaws that commonly occur in industrial application. The apparatus has been shown capable of detecting the presence of internal flaws, such as lack of fusion and inclusions in polyethylene pipe welds, thickness changes and voids in polyethylene pipe, delaminations and lack of adhesion at the substrate of a non-metallic pipe repair. Additionally, the method has been tested in field applications.

This paper will describe the method and apparatus and provide examples of polyethylene pipe weld and non-metallic pipe repair examinations.

INTRODUCTION

The method described in this paper was developed in response to a general failing of existing methods to detect common inhomogeneities in dielectric structures, including homogeneous thermoplastic components, reinforced rubber and fiber reinforced plastic (FRP) composites. Existing prior art includes radiography and ultra-sonic methods neither of which are ideally suited for inspection of these structures. Disbonds and inter-laminar adhesion failures (delaminations) are not detectable using radiography, as these are essentially 2 dimensional defects which do not change bulk density to any significant degree. The presence of myriad interfaces in the fiber reinforced structures results in beam scattering and dispersion of ultra-sonic energy, making the use of conventional ultra-sonic methods problematic. Additionally, rubber and plastic materials can be highly attenuative of ultra-sonic beam energy.

A method was sought to allow detailed, high resolution inspections of these dielectric materials which was single-sided (i.e. not pitch-catch), non-contact and fast enough to be used as a screening method for both manufacturing and field inspection environments.

Investigations into the available prior art and research done by Mr. Jack Little ultimately led to the issuance of US Patents Numbers 6,359,446, “Apparatus and Method for Nondestructive Testing of Dielectric Materials”, March 19, 2002 and 6,653,847, “Interferometric Localization of Irregularities”, November 25, 2003. Patents have also been issued in Australia and New Zealand, and remain pending in virtually all countries signatory to the Patent Cooperation Treaty (PCT) administered by the World Intellectual Property Organization (WIPO). The above referenced US Patents contain numerous cited references which place the method and apparatus described in this paper in context for both the existing prior art at the time of filing and regarding the improvements which the method offers over that prior art.

MICROWAVE METHOD, EQUIPMENT AND PROTOCOL

The novel inspection technique is based on monochromatic, phase coherent electromagnetic radiation, preferably in the 5-50 gigahertz frequency range (i.e. - microwaves). The sample to be examined is exposed to microwave radiation at discrete locations along a path whose coordinate locations are known and are returned as part of the data field, thus creating a map of the specimen. A detectable microwave signal is also returned everywhere along the path and a differing signal is generated at each interface where the dielectric constant changes (e.g. - where there are delaminations, cracks, holes, impurities, or other defects). The return signal is generated based on the angle of incidence, the differential in the dielectric constants between the materials (which is related to the index of refraction), the surface geometry, and other factors. Early testing proved that this technique can successfully detect cracks, voids, foreign material inclusions (e.g., water or oil), thickness changes, density changes, delaminations, changes in dielectric constant (which in rubber may, for example, indicate hardening), and other defects in essentially any dielectric or bulk dielectric materials. It was also found that different types of defects have distinguishable and reproducible characteristics. The testing also showed that the transducer may be moved relative to the specimen at any desired speed and the scanning speed need not be uniform.

The equipment consists of a probe, approximately 2 inches in diameter and 10 inches long, that contains the microwave generator, a position (x, y, or x, radial) monitoring device, an analog/digital signal converter, and a computer that collects and displays the data. All of the equipment is portable and the probe can be mounted on multiple types of scanning platforms. The probe is moved in a continuous fashion along the surface of the sample, either in contact or near the surface. No couplant is required. The return signal is voltage from the probe and position along the specimen. A map is generated from these signals that can be manipulated and displayed.

DEFECT DETECTION CAPABILITY

FIBERGLASS PIPING

Following the successful early testing of the inspection method, the microwave technique was improved and streamlined. The data gathering software was also upgraded as required to achieve the required resolution. As a natural progression, its effectiveness as an inspection method was investigated for other dielectric materials. One of the first materials to be tested was fiberglass piping. Fiberglass piping is used extensively in the petro-chemical industry for various services, including highly corrosive fluids. Of particular interest is the non-destructive examination of the joints. Since a typical fiberglass joint is glued, a common defect is lack of or insufficient coverage of the glue bond. This leads to poor adhesion and can result in the joint becoming unstable due to thermal growth or other mechanical loading, which ultimately leads to joint failure.

As part of the proof of principle testing for this method, several samples of fiberglass piping and joints were examined, one of which is shown in Figure 1. Figure 1 is a picture of a sample that consists of two 4 inch fiberglass (FRP) pipes joined by a glued coupling. The coupling was a fiberglass casting, which does not have any glass reinforcing. The joint was intentionally constructed with insufficient glue. Additionally, two internal defects were mechanically introduced in the base piping to simulate typical erosion defects. The microwave scans are depicted in figures 2 and 3.

Figure 2 illustrates the level of detail available in the microwave scan. Note that in this scan, the radial direction of the pipe/coupling is from top to bottom in the scan and the axial direction is left to right. The coupling is the area between the two red lines on the scan, which appear as a result of the thickness change from the coupling to the pipe. The areas of dis-bond and the erosion defects are clearly visible, as called out in the figures. The fiberglass reinforcing is seen as the criss-cross pattern present throughout the image. Of particular interest is the presence of the reinforcing pattern in the region of the coupling. Since the coupling is a cast piece and therefore contains no reinforcing, the presence of the reinforcing pattern in this area indicates that the microwave scan penetrates the coupling and is “seeing” the pipe enclosed in the coupling. Also, the gap between the two pipes beneath the coupling is clearly visible in the scan. All defects were detected.

Figure 3 is a gray scale representation of the same digital data. This image demonstrates the versatility of the data gathering and representation technology. The ability to view the scan in gray scale often provides additional clarity and definition to subtleties of the scan. The rings around the erosion defects are characteristics of the technique that can be used to determine the relative depth of the defect location.

POLYETHYLENE (PE) PIPING

Polyethylene (PE) piping is used extensively in the petro-chemical and utility industries for various services, including harsh environment service. Its use is becoming more prevalent due to its low cost versus steel piping and its ability to withstand corrosive environments. One of the outstanding issues with its use is the current inability to easily examine the weldments. Standard methods, such as radiography and ultrasonics, have proven to not be capable of reliably detecting flaws in the weldments. There are two types of weldments common in PE piping. They are the thermal fusion butt weld and the electro-fusion coupling weld.

Through extensive laboratory investigation, microwave inspection has been shown to be capable of volumetrically inspecting the entire weld and adjoining pipe thickness. As part of the proof of principle testing for this method, many samples of welded PE piping were examined and the results documented. The samples included 2 inch through 36 inch nominal diameter piping that were scanned both in laboratory and field settings. The types of joints examined included both thermal welded and electro-fusion welded types. Only examples of thermal welded joint scans are shown in this paper since they are of primary interest. The weld samples included good welds and welds with flaws of known origin. The flaws were manufactured in the coupons and included drilled holes, inclusions of various natures, and lack of fusion. Figures 4 through 9 are representative scans of PE pipe thermal welds. The piping inspected is manufactured from various sizes and thicknesses with different types of flaws. The scale located to the right of the scans is the return signal and is in terms of voltage. The Y scale represents the axial pipe direction (in inches) and the X scale represents the radial direction along the pipe diameter (either degrees or inches). This is typical of the piping and pipe repair scans shown in these figures. The pipe weld is intentionally centered on the Y axis of the scans. The length of pipe scanned on either side of the weld is typically 3 to 4 times the wall thickness of the pipe.

Figure 4 and 5 are scans of a small bore (4 inch) PE pipe with a thermal weld that contains no known flaws. Note the minimal voltage variation along the length of the weld from X = 0 to 360 degrees. Also note that the weld appears uniform across its length and is symmetric from side to side. These are characteristics of a weld with no flaws.

Figures 6 and 7 are scans (color and gray scale respectively) of a coupon that was manufactured from a piece of 8 IPS, DR17 “Driscoplex” HDPE pipe manufactured with a thermal butt fusion weld with 7 individual intentionally embedded defects. The coupon was created as follows;

1) The piping sections were faced and prepared for fusion per the manufacturer’s recommendations in a McElroy butt welding machine.
2) 3 holes were drilled into the end of one of the sections (the section which is represented in the scan by Y = 0 to Y = 3). Each hole was the same diameter, but was drilled a different depth into the pipe wall axially, and at a different distance

through the pipe wall (different radial spacing). These holes were drilled at approximately X = 15, 18 & 22.

3) The pipe sections were heated, in accordance with the manufacturer's recommendations, and immediately prior to assembly of the weld, the following defects were embedded;
    a) A ½" wide piece of Teflon tape was inserted into the weld zone at X = 2.
    b) A small blade of grass was inserted into the weld zone at X = 8.
    c) The softened HDPE of one piece was cooled to create a "cold lack of fusion" using cold water, centered at X = 9 to X = 14.5.
    d) The water dripped down to the hot plastic 180 degrees away from (immediately below) the intentionally cooled region. This would be centered at X = 25.25.

It should be noted that the intentionally cooled region, centered on X = 11.75, was cooled so severely that a significant deformation of the inner bead resulted. This deformation can be seen as the wide red region from X = 11.5 to X = 13 in figure 6, and also is responsible for the curved interference fringes at these same X locations, but at Y locations corresponding to ½ wavelength offsets. Note that the inner bead interference fringes are elsewhere parallel and continuous. All defects were detectable.

Figure 8 is a scan of a thermal weld in a sample of 355 mm by 21.1 mm wall PE 100 Gris 150 piping. The specimen was tested with the outer bead intact and was inspected as a blind sample. That is, the existence and nature of the defect were unknown at the time of the inspection. Figure 8 indicates heavy disruption in the weld zone from X = 8 to X = 18 and substantial signal shift in region from X = 18 to X = 28. The weld line appears clear and uniform in other portions of the scan. This is indicative of a potential lack of fusion in the weld in these areas, which was later confirmed by the coupon manufacturer. All defects in the specimen were detected.

Figure 9 is an example of a scan of a large bore (8 inch nominal diameter) PE pipe with manufactured defects. This scan was produced using the portable scan equipment shown in figure 16. The coupon was manufactured by thermal welding and had eight defects embedded in each side of the pipe prior to joining. The defects are clearly visible in the scan. Also, there are indications in the base pipe material that are either surface blemishes or internal defects, such as voids. Again, all defects were detected.

PIPE REPAIR

A large quantity of steel piping is currently in use to convey oil and gas products over long distances. This piping is typically of welded joint construction and may be miles in length. A method was needed to repair this piping in areas where corrosion or other wall thinning may have taken place. This resulted in the development of several repair methods, including non-metallic pipe repair.

A typical pipe repair consists of a non-metallic material, like fiberglass, being overlaid onto the outer surface of the steel pipe in the area to be repaired. The non-metallic material is bonded to the surface of the piping using an epoxy or resin like substance. These repairs are typically several layers thick and may extend out to as much as 1 inch above the surface of the pipe.

Since the quantity of steel piping in service has grown over the years, the number of pipe repairs has also grown. There have been instances of failure of some of these repairs in service. Failures and a desire to ensure that a repair has been properly installed led to the need to develop some means of inspection. To be effective, the inspection method should be capable of detecting issues at the substrate, or the steel pipe to repair interface. A typical repair problem is areas of dis-bond between the pipe and the repair, as well as inter-layer disbands in the repair itself. Also, a means of detecting or monitoring corrosion of the steel pipe under the repair would be desirable.

Figure 10 is a photograph of a Clockspring® pipe repair coupon. This repair consists of fiberglass layers with epoxy filler between the layers. The coupon was prepared by drilling a 5 mm hole in the pipe and applying a Teflon cover over the hole. The repair was applied over the Teflon cover. Once the repair was completed and cured, the piping was pressurized to fail the repair. This pressurization typically resulted in the repair becoming dis-bonded from the piping at the repair/piping interface and a leak path being created to the edge of the repair. Figure 11 is a scan of this repair. The dis-bond can be seen in the repair in the region of X = 5 to 10 and Y = 0 to 2. A patch can be seen in the scan from X = 8 to 12 and Y = 2 to 6. Also, several round indications that are potentially the drilled hole appear in the region between X = 7 and Y = 2 to 5. All defects were detected.

Figure 12 is photograph of another brand of pipe repair, manufactured by IMG. This repair is made by applying fiberglass cloth impregnated with resin. The coupon was prepared in the same fashion as the Clockspring® repair coupon described previously. Figure 13 is the scan of this repair. Note the rounded indication located at X = 5 and Y = 4, which is clearly the 5 mm hole and Teflon cover. Also, the region defined by X = 0 to 8 and Y = 2 to 6 is the area disrupted by the pressurization. The area of the repair at X = 5 and Y = 8 is where the repair ultimately failed and leaked. All defects were detected.

Figure 14 is a photograph of a third type of pipe repair. Included in this photograph is the manual microwave inspection device used for these inspections. This repair is made by the application of resin impregnated fiberglass cloth wrapping around the pipe. This repair was intentionally applied over a section of piping that had been removed from service due to surface corrosion in the form of localized pitting. The scan, seen in figure 15, clearly shows the location of the pipe surface corrosion under the repair, which appear as the dark areas in the scan. As can be clearly seen, the major pitting occurs at X = 18 to 25 and Y = 16 to 22. Minor pitting is also evident as dark areas in the other regions of the scan.

FIELD APPLICATION

In order to make to method useful, a means was required to allow piping inspection in field applications. Several manual field inspection devices were developed, which allow scanning of pipe in a fashion similar to portable ultrasonic inspection equipment. Figures 14 and 16 are photographs of two types of manual field inspection devices, or scanners. Currently, automated scanners have been developed and also are in use. Scan time varies from application to application but are typically on the order of 5 to 10 minutes per square foot. The method requires access to only one side of the specimen and does not require direct contact. As such, no liquid or other couplant material is required.

CONCLUSION

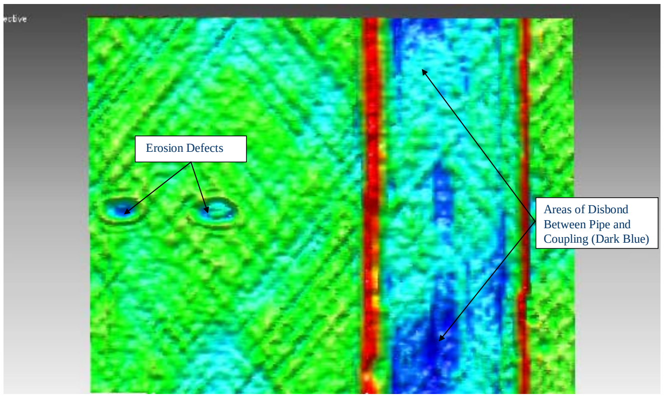
This paper presents the results for inspections performed with a novel microwave based NDE method. The microwave NDE method represents a significant enhancement over current NDE methods for detecting various types of defects in bulk dielectric material. Specifically presented are representative results for fiberglass and PE piping and various non-metallic pipe repairs. The scans shown in this paper represent only a small fraction of the total body of work performed to develop and perfect the technique.

The equipment is compact, portable, and requires minimal set-up time. The inspection technique is non-contact, requires access to only one side of the specimen under test, and the results, as can be seen from the scans, are easily interpreted. Additionally, the images are produced from digital information that can be stored indefinitely. Once stored, the information can be retrieved and compared to information obtained from new scans to show the appearance of, or growth of, defects in the specimen or metal substrate, in the case of non-metallic pipe repairs.

Figure 1

Fiberglass Pipe Coupon Photograph

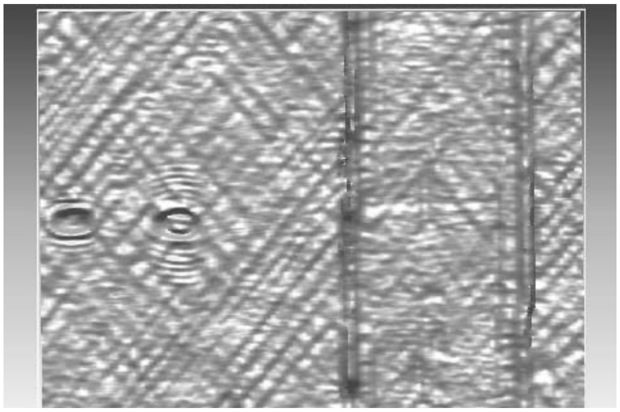
Fiberglass Pipe Coupon



Scan Results
(Shown rolled out into flat plane for ease of viewing)

Figure 2

Fiberglass Pipe Coupon



Grayscale Image of Scan Results
(Note Clear Ability to Detect Pattern of Fiberglass Roving)

Figure 3

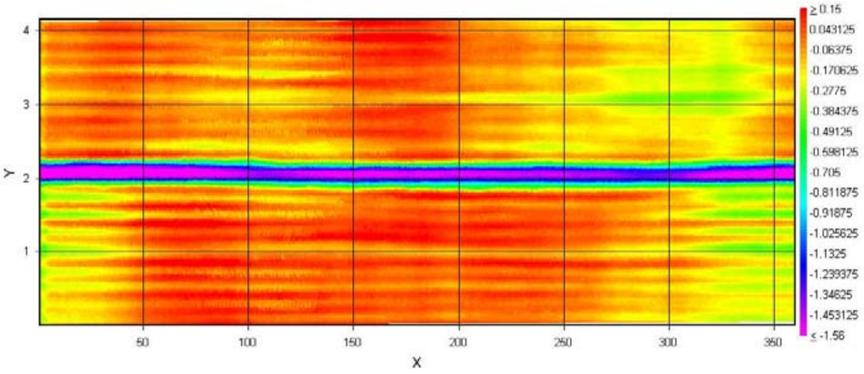


Figure 4

Color Scan of a PE Pipe Weld with No Known Defects

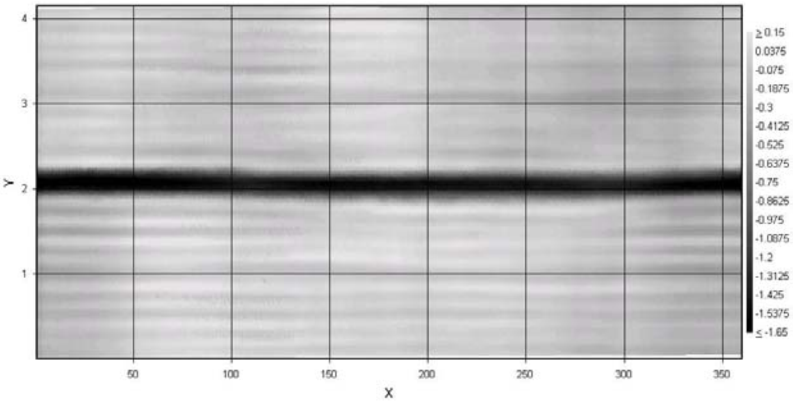


Figure 5

Gray Scale Scan of a PE Pipe Weld with No Known Defects

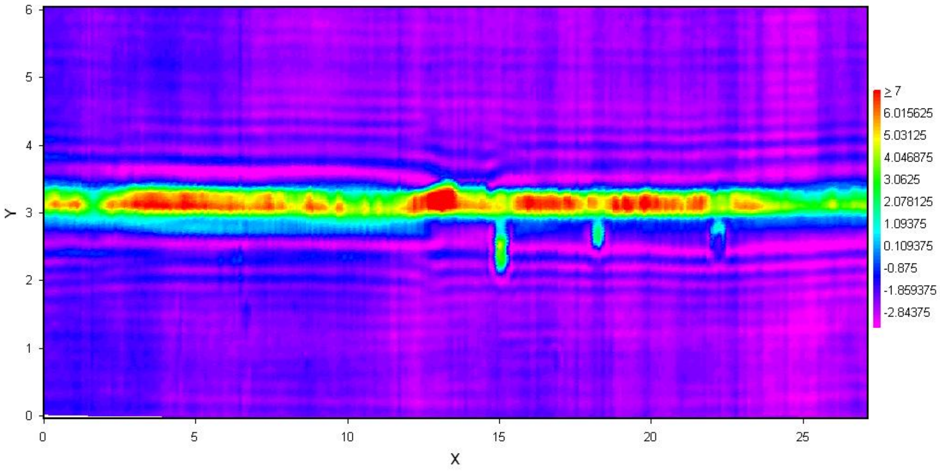


Figure 6

Color Scan of a PE Pipe Weld with Multiple Known Defects

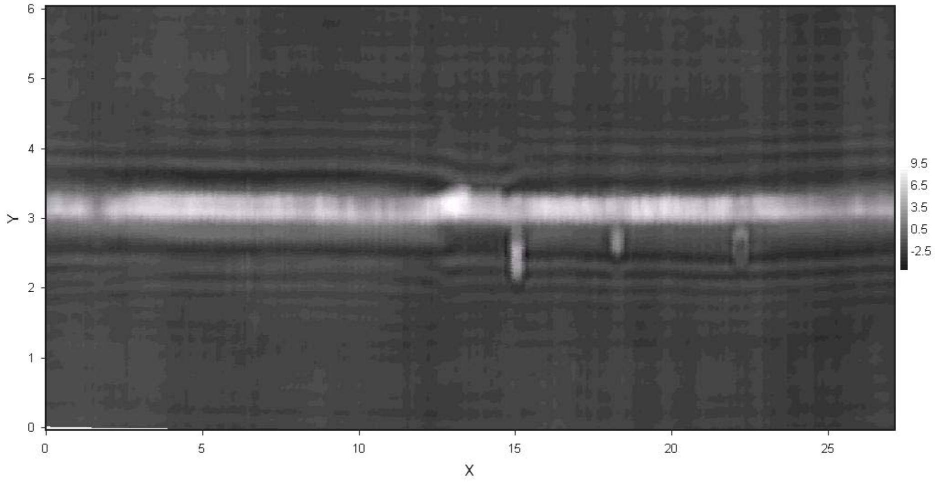


Figure 7

Gray Scale Scan of a PE Pipe Weld with Multiple Known Defects

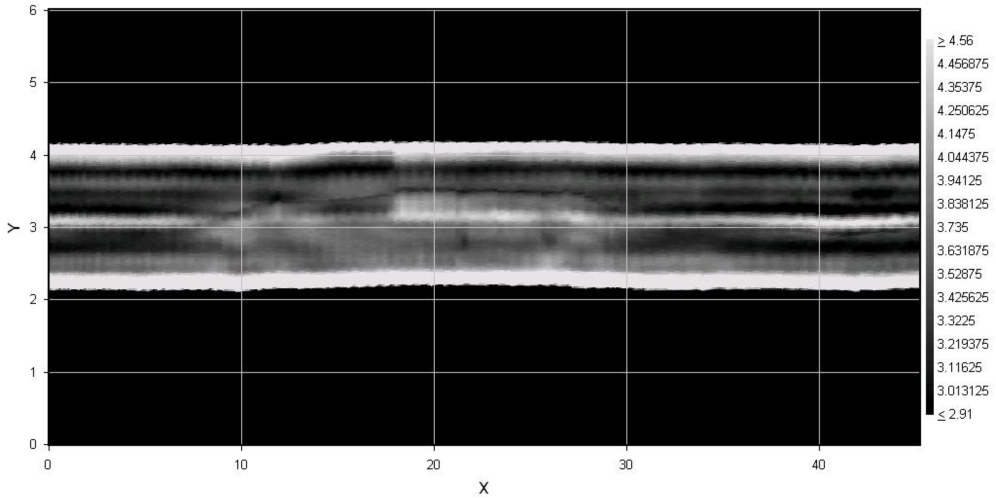


Figure 8

Gray Scale Scan of a PE Pipe Weld with Known Defects

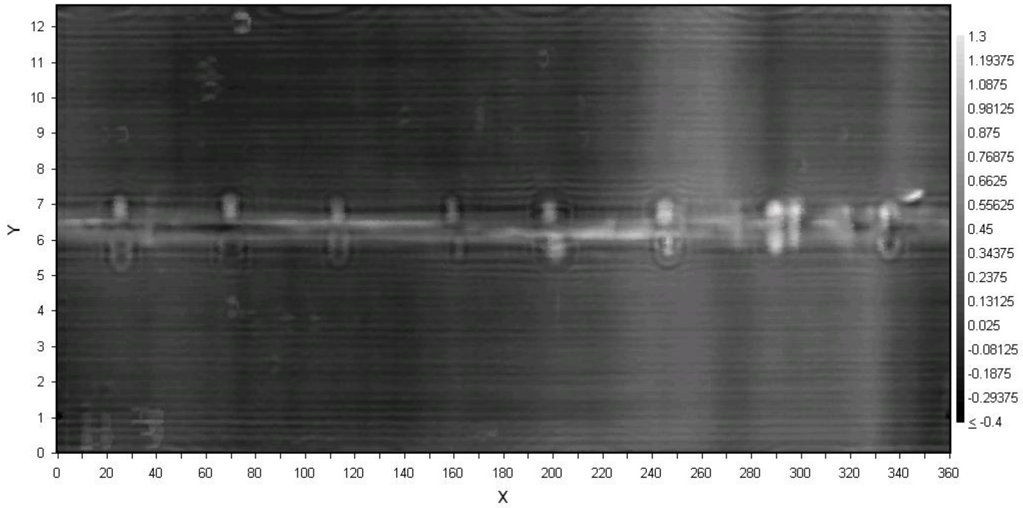


Figure 9

Gray Scale Scan of a PE Pipe Weld with Multiple Known Defects

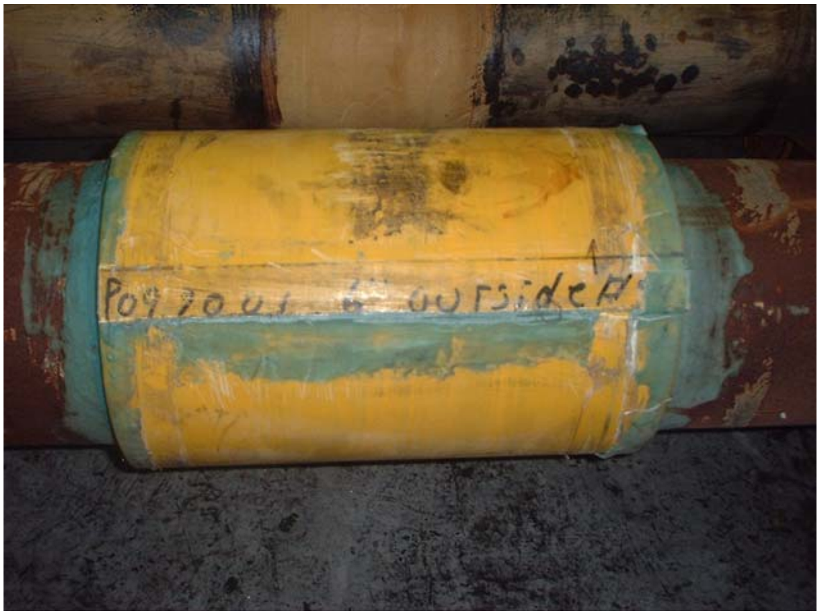


Figure 10

Photograph of Pipe Repair (Clockspring®)

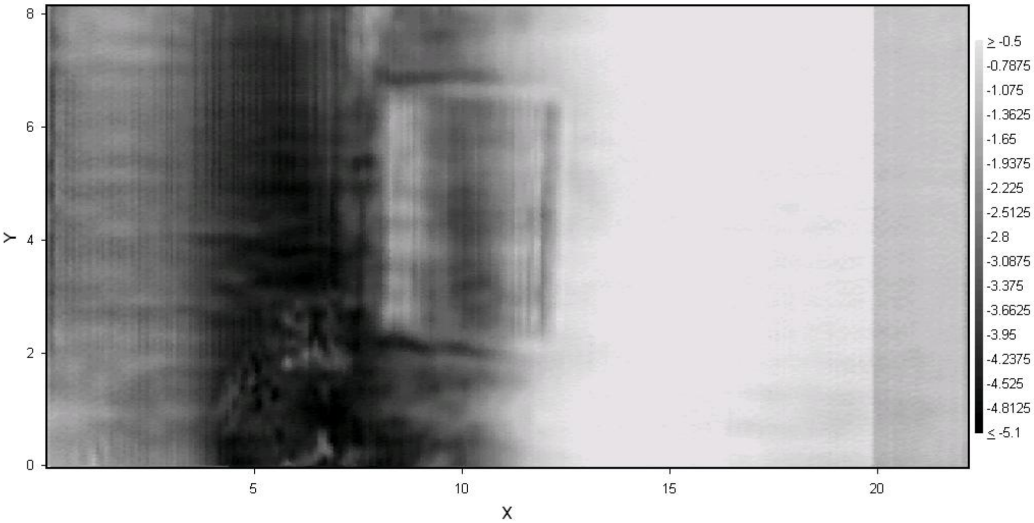


Figure 11

Gray Scale Scan of Clockspring® Repair with Known Defects

Figure 12

Photograph of Pipe Repair (IMG)

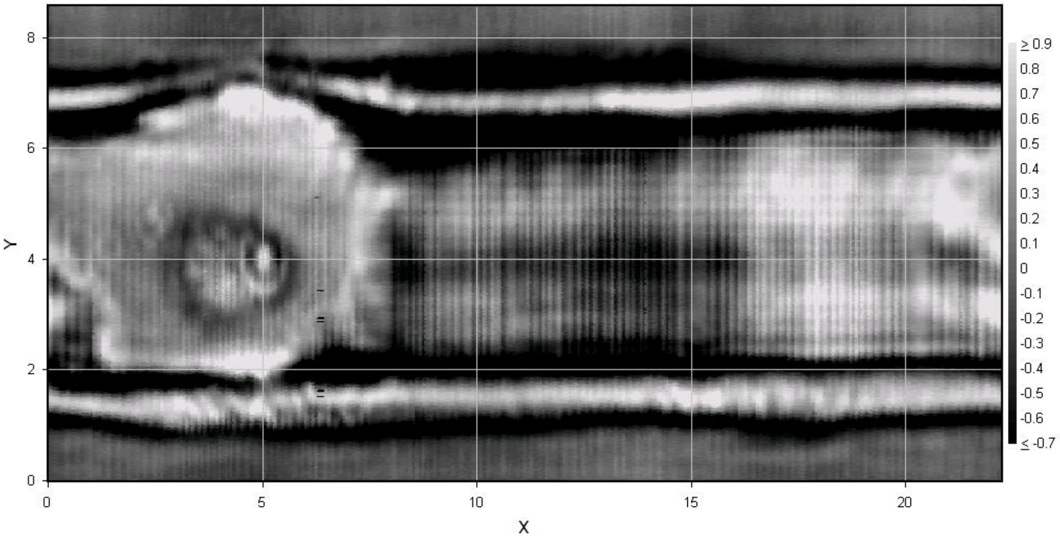


Figure 13

Gray Scale Scan of IMG Pipe Repair with Known Defects

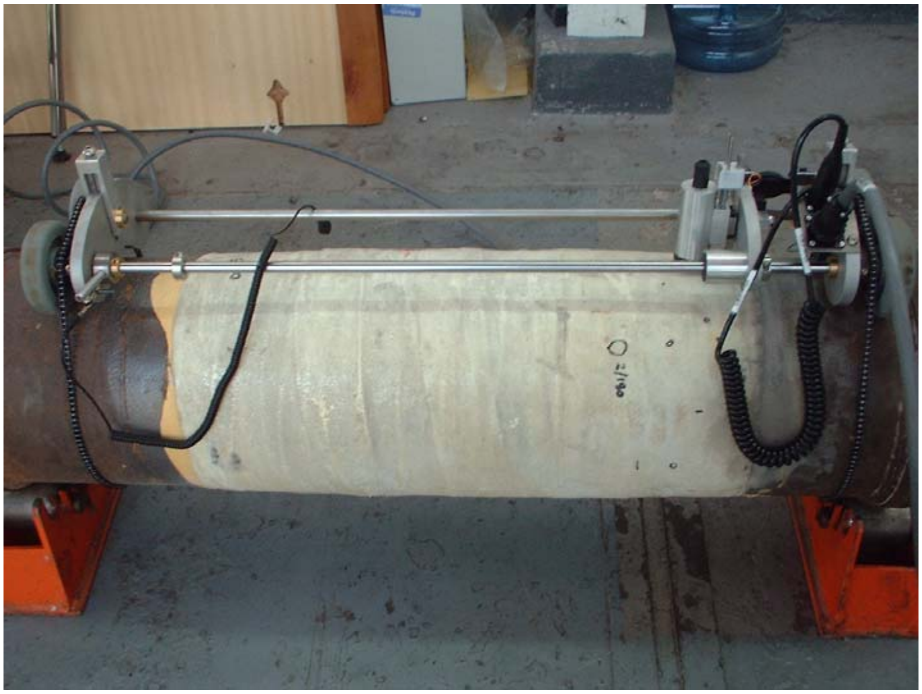


Figure 14

Photograph of Fiberglass Pipe Repair Showing Field Microwave Inspection Device

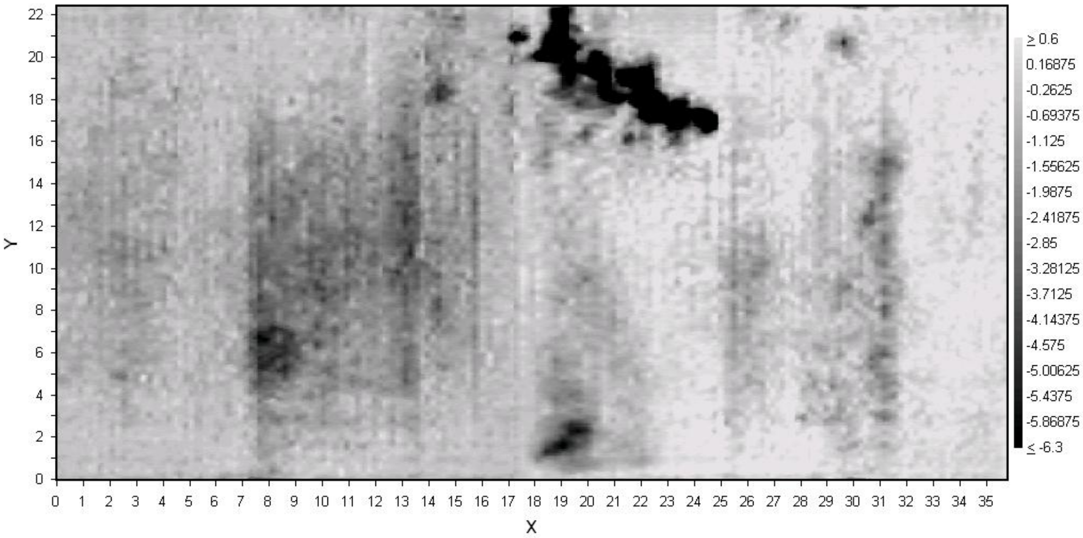


Figure 15

Gray Scale Scan of Fiberglass Pipe Repair Showing Areas of Pipe Corrosion Below Pipe Repair

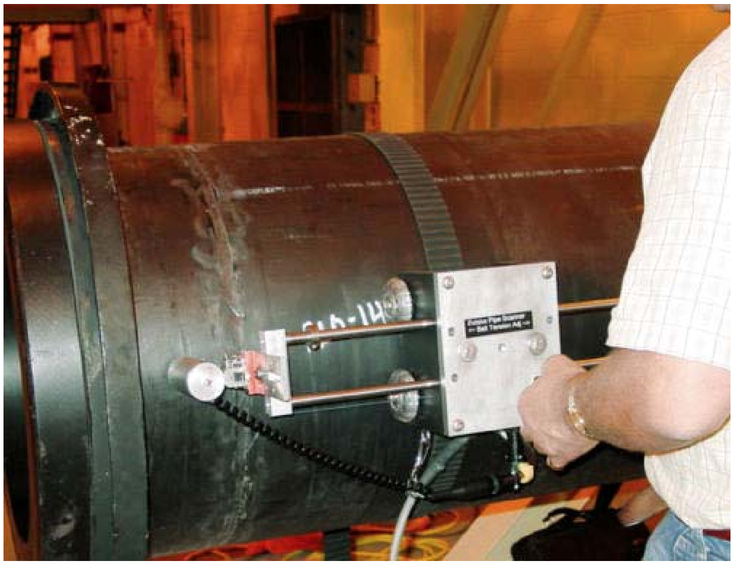


Figure 16

Photograph of Field Microwave Inspection Device Used to Produce the Scan Shown in Figure 9