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Inspection of Fusion Joints in Plastic Pipe

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Inspection of Fusion Joints in Plastic Pipe

Final Technical Report

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Principal Author: Connie Reichert
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Submitted by:

EWI
1250 Arthur E. Adams Drive
Columbus, OH 43221

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Abstract

The standard method of joining plastic pipe in the field is the butt fusion process. As in any pipeline application, joint quality greatly affects overall operational safety of the system. Currently no simple, reliable, cost-effective method exists for assessing the quality of fusion joints in the field. Visual examination and pressure testing are current nondestructive approaches, which do not provide any assurance about the long-term pipeline performance.

This project developed, demonstrated, and validated an in-situ nondestructive inspection method for butt fusion joints in gas distribution plastic pipelines. The inspection system includes a laser-based image-recognition system that automatically generates and interprets digital images of pipe joints and assigns them a pass/fail rating, which eliminates operator bias in evaluating joint quality.

An EWI-patented process, the Weld Zone Inspection Method (WZIM) was developed in which local heat is applied to the joint region to relax the residual stresses formed by the original joining operation, which reveals the surface condition of the joint. In cases where the joint is not formed under optimal conditions, and the intermolecular forces between contacting surfaces are not strong enough, the relaxation of macromolecules in the surface layer causes the material to pull back, revealing a fusion line. If the joint is sound, the bond line image does not develop.

To establish initial feasibility of the approach, welds were performed under standard and non-standard conditions. These welds were subjected to the WZIM and two destructive forms of testing: short-term tensile testing and long-term creep rupture testing. There appears to be a direct correlation between the WZIM and the destructive testing results. Although WZIM appears to be more sensitive than destructive testing can verify, the approach appears valid.

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1.0 Introduction

Plastic pipe has been used successfully by the natural gas industry for nearly three decades for applications ranging from low-pressure transmission pipelines to residential distribution lines. The standard method of joining plastic pipe in the field is the butt fusion process. As in any pipeline application, joint quality greatly affects overall operational safety of the system. While major failures of polyethylene (PE) pipe butt fusion joints are infrequent, they are dangerous and can be associated with significant monetary losses. The availability of a cost-effective, yet accurate, nondestructive method of assessing butt fusion joint quality in the field is very important and will benefit a number of industries. Currently no simple, reliable, cost-effective method exists for assessing the quality of fusion joints in the field. Visual examination and pressure testing are current approaches, which do not provide any assurance about the long-term pipeline performance.

This project builds off of previous work co-funded by NYSEARCH and Edison Welding Institute (EWI), which demonstrated two innovative methods for assessing the quality of butt fusion joints by using simple and cost-effective means.

The first phase of the development of the Weld Zone Inspection Method (WZIM) was the validation of a destructive method. This WZIM procedure in this phase required cutting a sample from the welded joint, polishing the cross section, and applying local short-term heating to the polished surface. This secondary heating, when applied properly, causes a stress relaxation of the material in the surface layer of the weld zone, thereby eliminating the residual stress developed when the melted polymer cooled under pressure during the welding cycle. As a result of the material relaxation, the outline of the weld zone becomes visible. In cases when the joint was not formed under optimal conditions, and the intermolecular forces between contacting surfaces are not strong enough, the relaxation of macromolecules in the surface layer causes the material to pull back, revealing a fusion line. If the joint is sound, the bond line image does not develop. This phase of WZIM development was demonstrated to be sensitive in differentiating between welds made under standard and non-standard conditions and was verified using a number of short-term destructive tests.(1)

The second phase in the development of the WZIM was a nondestructive extension of the first phase. It involved removing the external weld bead, polishing the pipe surface in the area underneath the bead, and applying local short-term heating to the polished surface. As in the destructive method, this procedure, provided the correct amount of heat is applied, revealed a fusion line at the surface if the joint was not sound.

During the initial testing of this nondestructive evaluation (NDE) technique,[1] it was shown to be sensitive in distinguishing between joints made under standard and non-standard parameters. Several "blind" tests were conducted on the joints prepared independently by gas companies in the U.S. and U.K. In the largest test, eight joints were fused under standard and non-standard conditions, and the technique correctly assessed seven of them. This is significantly better than that achieved by other NDE techniques, and the technique, therefore, has the potential to become a quality-assessment field method to nondestructively identify lesser quality non-standard fusion joints.

This project represents the third phase in the development of the WZIM and is focused on further development and verification of WZIM using short- and long-term destructive tests and the development of a prototype inspection system. This project will develop, demonstrate, and validate an in-situ nondestructive inspection method for butt fusion joints in gas distribution plastic pipelines. The inspection system will include a laser-based image-recognition system that will automatically generate and interpret digital images of pipe joints and assign them a pass/fail rating, which eliminates operator bias in evaluating joint quality.

2.0 Executive Summary

Plastic pipe has been used successfully by the natural gas industry for nearly three decades for applications ranging from low-pressure transmission pipelines to residential distribution lines. The standard method of joining plastic pipe in the field is the butt fusion process. As in any pipeline application, joint quality greatly affects overall operational safety of the system. Currently no simple, reliable, cost-effective method of assessing the quality of fusion joints in the field exists. Visual examination and pressure testing are current approaches, which do not provide any assurance about the long-term pipeline performance.

The Weld Zone Inspection Method (WZIM), developed in previous project work co-funded by NYSEARCH and EWI, proved to be the only known NDE method for determining lack-of-fusion (LOF) defects in the PE joint. During this project, this method has been integrated into an automated, field-robust, prototype tool. The WZIM inspection tool was developed, demonstrated, and validated for butt fusion joints in gas distribution plastic pipelines. The automated system both administers the WZIM and also determines the presence of the bond line by means of a laser-based image-recognition system, which eliminates operator bias in evaluating joint quality.

The WZIM inspection tool was developed during the course of the project to automatically apply the WZIM to in-situ medium-density polyethylene (MDPE) and high-density polyethylene

(HDPE) pipes and then automatically analyze the joint surface by use of a high-resolution laser scanning sensor. The sensor takes the place of the operator's skilled eye and objectively determines the rating and thus quality of the plastic pipe fusion joint.

Feasibility of the WZIM method itself was further validated by short- and long-term destructive tests. Welds were created by NYSEARCH member companies under standard and non-standard conditions. These welds were subjected to the WZIM, tensile, and creep rupture testing. Tensile testing is the short-term destructive test method and creep rupture testing is the long-term destructive test method. The results of the WZIM and all analyses were used to develop the algorithms, which allow the WZIM inspection tool to automatically determine the result of each inspection.

The WZIM inspection tool underwent a field testing program to validate its ability to successfully determine the results of a WZIM inspection. The system was refined and improved based on the results of an early prototype demonstration and the results of field testing program. These improvements helped the tool progress toward commercialization as a viable method of inspecting PE pipe. Specifications and suggestions for developing the commercial unit have been documented and can be used to begin a commercialization phase for the WZIM inspection tool.

The EWI-patented WZIM method incorporated into the WZIM inspection tool is the first tool developed using the only NDE method which can determine LOF defect in butt-fused PE pipe. Successful implementation of this innovative WZIM inspection tool offers benefits to the pipeline industry such as improving the reliability and safety of plastic pipe systems for natural gas distribution, minimizing the cost and need for expensive destructive quality assurance (QA) tests, and increasing the confidence in the use of plastics for pipes in safety critical applications or where the cost of failure would be high.

3.0 Experimental

3.1 Research Management Plan

The first task of the project included creating a Research Management Plan.[3] This document contains a work breakdown structure and supporting narrative that concisely summarizes the overall project. The plan is an integration of the technical and programmatic data into one document that details the technical objectives and technical approach for each task and subtask. The document also contains detailed schedules and planned expenditures for each task and all major milestones/decision points. The major objective of this program is to develop, demonstrate, and validate an in-situ nondestructive inspection method for butt fusion joints in gas distribution plastic pipelines. This includes:

- Proof of concept and optimization of the inspection method for butt fusion joints in selected types and sizes of plastic pipe.

- Verification of the inspection method using short- and long-term destructive tests.

- Development of a prototype field image-recognition laser-based inspection system that will automatically generate and interpret digital images of pipe joints and assign them a pass/fail rating.

- Prototype field-testing and development of guidelines for carrying out inspection of the butt fusion joints in gas distribution plastic pipelines.

3.2 Technology Status Assessment

EWI researched the current state-of-the-art of plastic pipe inspection, including the positive and negative aspects of using each technology. Available options for in-situ nondestructive inspection of butt fusion joints in plastic pipe were identified and a report was submitted.[(4)]

3.2.1 Ultrasonic Techniques

Within the gas industry there have been earlier efforts to provide an NDE tool for the inspection of PE butt fusion joints. McElroy, a manufacturer of fusion equipment, developed a tool for the gas industry that used an ultrasonic technique. The product, marketed as “UltraMac”, was purchased by larger utility companies and NDE service providers. McElroy made a number of attempts to improve the product with respect to resolution and user interface. The product was considered by most companies to be high cost and was limited with respect to its assessment capabilities. One major limitation was that the tool could not detect “cold joints” (a weak interface bond between the pipe-ends being joined). This type of defect accounted for the majority of failures that are experienced in the field. In addition, the images produced were difficult to interpret and joints were assessed incorrectly. Operators that used the equipment with some success needed to be highly trained, which made the device only practical for a limited number of service providers and a few gas utilities. As a result, UltraMac sales suffered and the manufacturer is no longer selling or supporting this product.

Recently, another ultrasonic device is being advertised for the gas industry. Flour Corporation developed an NDE tool and RTD Services is the manufacturer and service provider. The tool at this time is not intended for purchase but is being supplied as a service only. Based on literature and gas industry experience the tool was originally designed for large-diameter PE butt fusion joint evaluation. It employs ultrasonic time-of-flight diffraction (TOFD) technology and claims to have the ability to assess various joint defects, including LOF. The tool requires a trained technician to interpret joint images and is questionable as to it ability to detect cold joint fuses. According to NYSEARCH and ultrasonic experts in this field, this type of joint defect cannot be detected due to ultrasonic technology limitations.

3.2.2 Visual and Destructive Examination

Due to the technical limitations of the technology available for PE butt fusion inspection the majority of gas companies rely on visual inspection and at times destructive examination to determine the integrity of a joint and/or to qualify fusion operators. Visual inspection can be useful at times, but it is not foolproof. There are joint defects that can only be observed by applying some form of technology to it. Visual examination should be considered as a guide or indicator in diagnosing potential problems but does not provide conclusive evidence of future performance. Destructive examination is a foolproof method to determine joint quality but it is quite costly and is of no use when examining joints that are “in service”.

3.2.3 WZIM Application

EWI proposed a method to assess the integrity of PE fusion joints. The one major benefit of this methodology, over ultrasonic techniques, is it ability to detect cold joints. This method can be applied to NDE of all types of PE butt fusion joints and materials. EWI completed a project for NYSEARCH that demonstrated two innovative ways to evaluate PE pipe butt fusion joint quality by using a simple and cost-effective method known as WZIM. Phase 1 of this project established proof of concept by applying WZIM as a destructive test. Phase 2 was a nondestructive extension of this method.

The nondestructive WZIM involves removing the external weld bead, polishing the pipe surface in the area underneath the bead, and heating the polished pipe surface for a short time. Provided that the correct amount of heat is applied, a fusion line or “bond line” is revealed if the joint is not sound. The nondestructive method proposed with WZIM is not anticipated to have any detrimental effect on the performance on an in-service pipeline, but this is one of the items that shall be verified experimentally during this project.

Several “blind” tests were conducted on the joints prepared independently by gas companies in the U.S. and U.K. In the largest test, eight joints were fused under standard and non-standard conditions, and EWI correctly determined the quality of seven of these eight joints. In addition, ConEdison, KeySpan, and NYSEARCH staffs have conducted independent tests to further validate WZIM. To date, these tests have shown a good correlation between joint integrity and the existence of a bond line.

The WZIM inspection tool is planned to produce a visual image of the inspected joint. Along with this weld zone image, the software will automatically assign a pass or fail rating to the joint. This assessment will minimize the training required and will lessen the need for a highly skilled technician to interpret the inspection results. Although the cost of the equipment and software is expected to be competitive with other developing technologies, the overall cost of the WZIM system is expected to be lower due to the required technician skill level.

3.2.4 Commercial Availability

Various technologies are being directed at PE NDE. It should be noted that there is only one technology that is commercially available (Flour Corporation UT-TOFD method) for NDE of PE butt fusion joints. Other applications are either in early stages of development or are not designed for PE butt fusion inspection. At this time, the WZIM proposed by EWI is the only method that specifically addresses “cold fusion” defects, which are a major concern for the gas industry. Table 1 summarizes the pros and cons of each of the NDE methods previously reviewed.

Table 1. NDE Methods for Butt Fusion Joint Inspection

Title	Tech-Type	Sponsor	Pros	Cons
WZIM – Laser Recognition	Laser – bondline recognition in melt zone	NYSEARCH	• Ease of use • Ability to detect cold fusion joint defects	• Unknown at this time
Fluor Corp. UT Inspection	UT – TOFD	Fluor Corp.	• Currently in use in field • Claims can evaluate LOF defects	• No experimental or test results to prove the claim • Available data is related only to thick wall water pipes that are not used for gas distribution • Inability to detect cold fusion joint defects • Product is not available
TWI UT Inspection	UT	British Gas	• Advanced prototype stage	• Inability to detect cold fusion joint defects
Ultramac	UT– pulse echo single point probe	McElroy	• Commercialized	• No longer available on market

3.3 Validation of the Weld Zone Inspection Method

The WZIM for plastic pipe was validated through short- and long-term mechanical destructive testing. In order to gain a proper perspective on the range of joint conditions that the WZIM would be subjected to, a series of 26 joints, marked A-Z, was produced with a wide range of parameters. The parameter changes were to ensure joints of varying integrity would be analyzed by the WZIM. NYSEARCH member companies produced a series of MDPE and HDPE pipes ranging from 2- to 12-in. diameters. EWI examined the welds and analyzed the correlation between the WZIM joint image and mechanical joint strength assessed by the destructive mechanical testing.

3.4 Short-Term Destructive Testing (STDT)

An important fact that should be taken in account while analyzing the STDT results (tensile test results) is that pipe grade PE has excellent weldability – the ability to produce sound welds in a wide range of welding parameters and to tolerate variations from the recommended settings. However, different PE grades showed a different level of tolerance to process parameter variations and that affected specific joint performance. For example, pipe grades of MDPE and 8100 grade of HDPE both demonstrated the ability to produce sound welds at a lower fusion pressure range, although the 8100 grade appears to be more sensitive to the excessive heating (high-temperature condition) than other grades. High-temperature effects were demonstrated to be more detrimental to larger pipes with thicker walls. These pipes are heated for longer times than small pipes, and the material was exposed to an elevated temperature for a longer period. As a result, thermal decomposition of the polymer is much likelier in large pipes, and this was reflected in both the tensile test and WZIM results.

While the short-term destructive test results by themselves are not sufficient for a comprehensive assessment of the joint quality, they help to identify obviously compromised welds. In our test such welds have noticeably reduced energy-at-break values.

EWI validated the WZIM NDE procedure and optimization of inspection system parameters (power output, heating time, and distance) for specific plastic pipe types typically used in natural gas pipeline using the WZIM method developed in the previous projects.[1,2]

3.4.1 Preparation of Fusion Joint Samples

EWI and NYSEARCH identified the most commonly used plastic pipe materials and sizes used by gas distribution companies, NYSEARCH members. Driscopipe 8100, Driscoplex 6500 and 6800 were the most commonly used materials. 101-, 152-, and 203-mm (4-, 6-, and 8-in.) diameters were determined to be the most commonly used sizes for these grades.

Twenty-six fusion joint samples were prepared under the cost-share portion of this project, which was funded separately by NYSEARCH. These 26 samples, labeled A-Z, were used throughout the course of this project for destructive testing for validation, algorithm development, and calibration. This sample set includes a wide range of fusion parameters that generated a wide range of fusion joints that are representative of in-situ pipe. Each of the 26 pipes was cut up into several test coupons to be used in tensile, creep rupture, and WZIM tests.

3.4.2 Inspection of Fusion Joint Samples

Weld zone images of standard joints and joints with typical defects were developed and the inspection results are reported in Figures 1 and 2. The sample data includes:

- Material – the PE number and manufacturer of the pipe
- Pipe size and type
- Outside diameter (OD) in inches
- Inside diameter (ID) in inches
- Weld zone area
- Condition of the welding or fusion parameters
- Temperature during fusion
- Time for the fusion process
- Pressure at which the joint was fused
- Samples ID A through Z
- NDE results.

The column titled NDE Results is a description of what the operator visually observed about the surface of the joint at the fusion area. For example, line, ridge, projection, smooth surface, etc. The NDE results were later narrowed down into pass, fail, and uncertain categories, which will be discussed in the following sections. Figure 1 includes data from HDPE pipe samples made at ConEdison, a NYSERACH member, and Figure 2 includes data from MDPE pipe samples made at KeySpan, a NYSERACH member company.

3.4.3 Correlation of Inspection and Mechanical Joint Test Results

The strength of each fusion joint was assessed with mechanical tensile tests. The test data was analyzed and correlated to the welding conditions under which the joints were produced. EWI conducted analysis of the data and compared the results of the tensile tests to the WZIM inspection results. At this point, the WZIM results are based on human visual examination (not laser scan results).

Material	Pipe Type and Size	OD (in)	ID (in)	Area (in^2)	Condition	Temp (^oF)	Time (sec)	Fusion Pressure (psi)	Sample ID	NDE Results
Driscoplex 6800, PE 3408	6" Yellowstripe SDR11	6.625	5.42	11.39	Standard	475	85	30.7	T	low profile projection
Driscoplex 6800, PE 3408	6" Yellowstripe SDR11	6.625	5.42	11.39	Low P	475	85	10	V	defined ridge
Driscoplex 6800, PE 3408	6" Yellowstripe SDR11	6.625	5.42	11.39	Low T	375	85	30.7	S	sharp indentation w. offset slight line in it
Driscoplex 6800, PE 3408	6" Yellowstripe SDR11	6.625	5.42	11.39	High T	550	85	30.7	U	line
8100 Driscopipe, PE3408	8" SDR11	8.625	7.06	19.27	Standard	475	148	47	O	no line
8100 Driscopipe, PE3408	8" SDR11	8.625	7.06	19.27	High T	550	148	47	R	thin line
8100 Driscopipe, PE3408	8" SDR11	8.625	7.06	19.27	Low T	375	148	47	Q	slight line
8100 Driscopipe, PE3408	8" SDR10	8.625	7.06	19.27	Low P	475	148	14	P	no line
8100 Driscopipe, PE3408	8" SDR11	8.625	7.06	19.27	SuperLow P	475	148	n	N	ridge with defined peak
Driscoplex 6800, PE 3408	4" SDR11	4.5	3.68	5.25	Standard	480	85	manual	X	low profile projection
Driscoplex 6800, PE 3408	4" SDR11	4.5	3.68	5.25	High T	550	85	manual	Y	ridge with defined peak
Driscoplex 6800, PE 3408	4" SDR11	4.5	3.68	5.25	Low T	375	85	manual	W	ridge with thin line on the top
Driscoplex 6800, PE 3408	4" SDR11	4.5	3.68	5.25	Low P	480	85	10	Z	ridge

Figure 1. Welding Parameters and NDE Results for ConEdison Samples

Material	Pipe Type and Size	OD (in)	ID (in)	Area (in^2)	Condition	Temp (^oF)	Time (sec)	Fusion Pressure (psi)	Sample ID	NDE Results
Driscoplex 6500, PE2406	8" SDR13.5	8.625	7.35	16.014	Standard	425	220	30	C	no line
Driscoplex 6500, PE2406	8" SDR13.5	8.625	7.35	16.014	Low P	425	220	10	A	no line, very slight projection
Driscoplex 6500, PE2406	8" SDR13.5	8.625	7.35	16.014	High T	550	220	30	B	line
Driscoplex 6500, PE2406	8" SDR13.5	8.625	7.35	16.014	Low T	350	220	30	D	no line
Driscoplex 6500, PE2406	6" SDR13.5	6.625	5.67	11.76	Standard	425	75	26	I	no line
Driscoplex 6500, PE2406	6" SDR13.5	6.625	5.67	11.76	Low T	375	75	26	G	no line
Driscoplex 6500, PE2406	6" SDR13.5	6.625	5.67	11.76	High T	550	75	26	H	no line
Driscoplex 6500, PE2406	6" SDR13.5	6.625	5.67	11.76	High P	550	75	60	E	no line
Driscoplex 6500, PE2406	6" SDR13.5	6.625	5.67	11.76	Low P	425	75	10	F	no line
Driscoplex 6500, PE2406	4" SDR11.5	4.5	3.72	5.045	Standard	429	60	manual	L	ridge
Driscoplex 6500, PE2406	4" SDR11.5	4.5	3.72	5.045	Low T	350	60	manual	K	no line, slight projection
Driscoplex 6500, PE2406	4" SDR11.5	4.5	3.72	5.045	High T	550	60	manual	J	ridge
Driscoplex 6500, PE2406	4" SDR11.5	4.5	3.72	5.045	High P	429	60	90	M	slight line w. indentation

Figure 2. Welding Parameters and NDE Results for PS and G Samples

Tensile testing data is reported with two measurements:

- Average elongation of the material (%)
- Energy at break area (kg/mm).

Both measurements are used for correlation studies with the WZIM. At this point, a new column was added to the data for WZIM correlation. The new parameter, WZIM prediction, is what the operator predicts the WZIM method will result in, based on the NDE results mentioned in the previous section. WZIM prediction is the predicted quality of the joint, rated as reduced or good in terms of quality. When the NDE result was not clear, the WZIM prediction was rated as uncertain. The NDE result was unclear if the WZIM observation did not imply quality, such as with the observations of “ridge with defined peaks” and “slight line”. In these cases, the WZIM prediction defaulted to an uncertain rating.

Based on STDT results, as shown in Figures 3 through 14, the WZIM accurately detected all welds with reduced strength. A graph of the STDT results for each pipe material type versus the fusing parameters are in Figures 3, 5, 7, 9, 11, and 13. Each graph shows the value of the STDT result of *average elongation of the material (%)* and the *energy at the break area (kg/mm).* Also for each pipe material type, is a table of the actual data values of the STDT, compared with the NDE result and WZIM prediction (Figures 4, 6, 8, 10, 12, and 14). Several joints made under substandard conditions were detected by the WZIM, which did not show a reduced strength during the STDT. It appears that the WZIM inspection is more sensitive in distinguishing joints made under substandard conditions than STDT. This can be explained by the fact that STDT, while providing an initial indication of the weld quality, is not sensitive enough to be used as a final means for evaluating the effect of flaws in plastic welds, including those resulted from substandard welding conditions. Also, STDT may not directly correlate with long-term strength of the joint under static and fatigue loading.

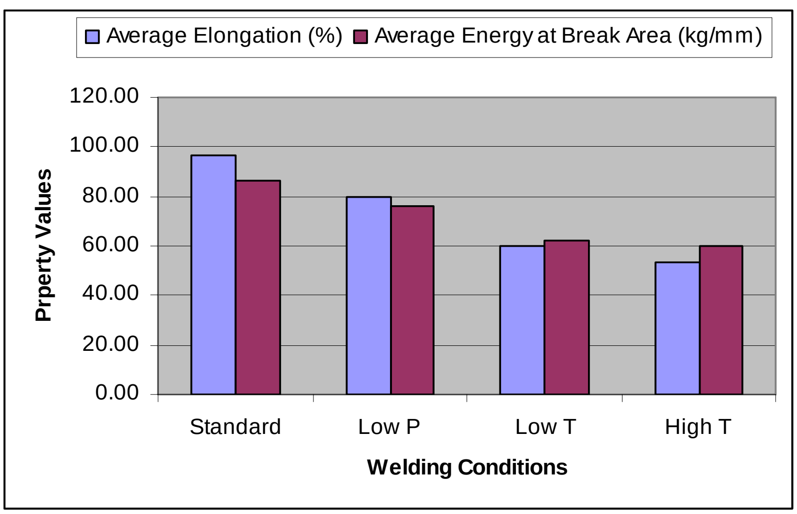


Figure 3. Driscoplex 6800, PE 3408, 152-mm (6-in.) Yellowstripe SDR11 STDT Results Graph

Condition	Average Elongation (%)	Average Energy at Break Area (kg/mm)	WZIM Observation	WZIM Prediction
Standard	96.41	86.4	Low profile projection	Good
Low P	79.44	76.1	Defined ridge	Uncertain
Low T	60.30	62.2	Sharp indentation with slight offset line	Reduced
High T	53.61	60.0	Line	Reduced

Figure 4. Driscoplex 6800, PE 3408, 152-mm (6-in.) Yellowstripe SDR11 STDT Results

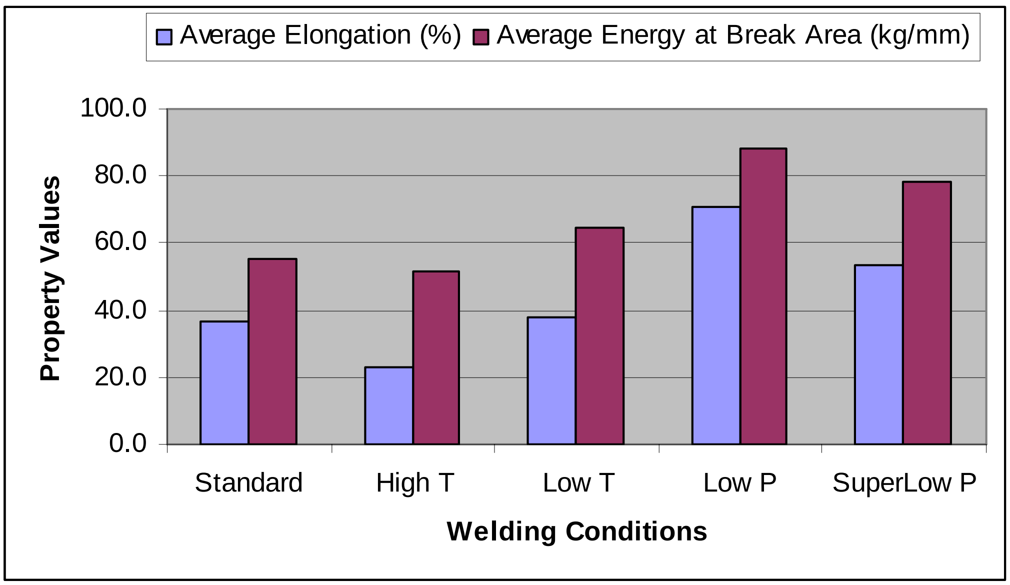


Figure 5. 8100 Driscopipe, PE 3408, 203-mm (8-in.) SDR11 STDT Results Graph

Condition	Average Elongation (%)	Average Energy at Break Area (kg/mm)	WZIM Observation	WZIM Prediction
Standard	36.6	55.4	Very slight line	Uncertain
High T	22.7	51.5	Thin line	Reduced
Low T	37.9	64.6	Slight line	Reduced
Low P	70.6	88.2	No line	Good
SuperLow P	53.1	78.3	Ridge with defined peak	Uncertain

Figure 6. 8100 Driscopipe, PE 3408, 203-mm (8-in.) SDR11 STDT Results

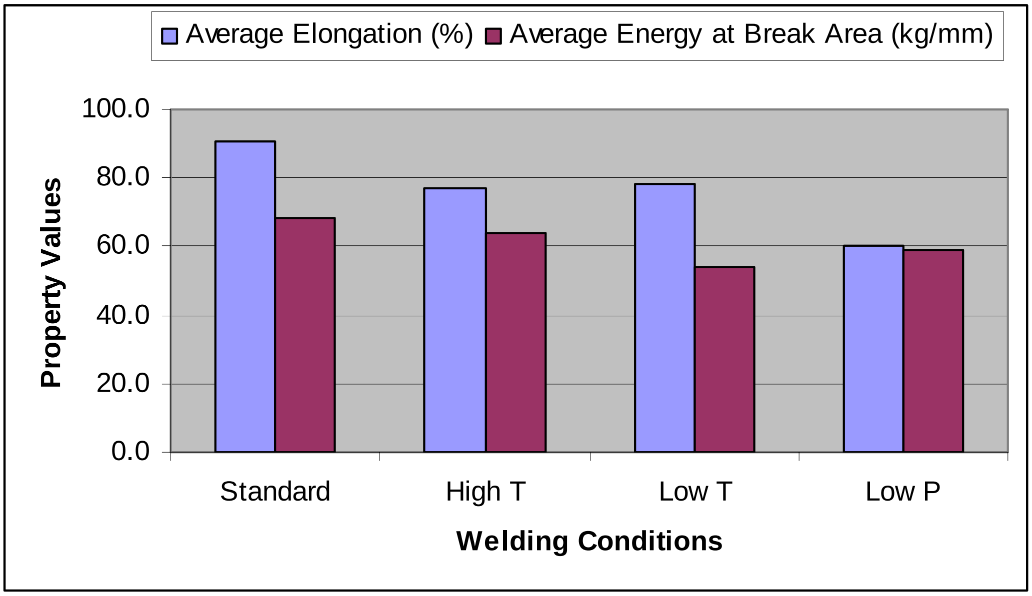


Figure 7. **Driscoplex 6800, PE 3408, 101-mm (4-in.) SDR11 STDT Results Graph**

Condition	Average Elongation (%)	Average Energy at Break Area (kg/mm)	WZIM Observation	WZIM Prediction
Standard	90.8	68.3	Low profile projection	Good
High T	76.8	63.9	Ridge with defined peak	Uncertain
Low T	78.4	53.9	Ridge with thin line on the top	Reduced
Low P	60.1	59.2	Ridge	Uncertain

Figure 8. **Driscoplex 6800, PE 3408, 101-mm (4-in.) SDR11 STDT Results**

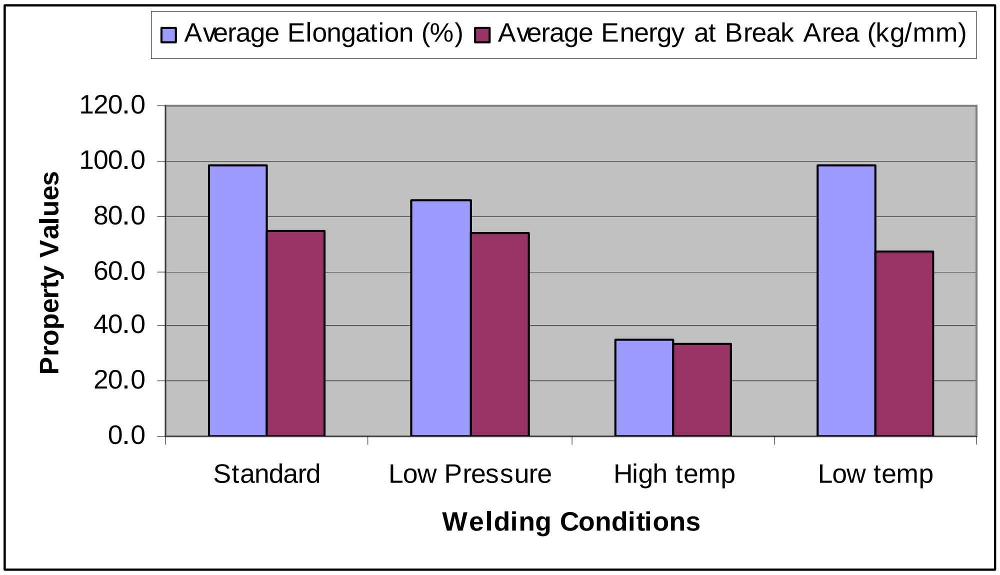


Figure 9. **Driscoplex 6500, PE 2406, 203-mm (8-in.) SDR13.5 STDT Results Graph**

Condition	Average Elongation (%)	Average Energy at Break Area (kg/mm)	WZIM Observation	WZIM Prediction
Standard	98.3	74.6	No line	Good
Low Pressure	85.6	73.5	No line, very slight projection	Good
High temp	34.7	33.3	Line	Reduced
Low temp	98.6	67.2	No line	Good

Figure 10. **Driscoplex 6500, PE 2406, 203-mm (8-in.) SDR13.5 STDT Results**

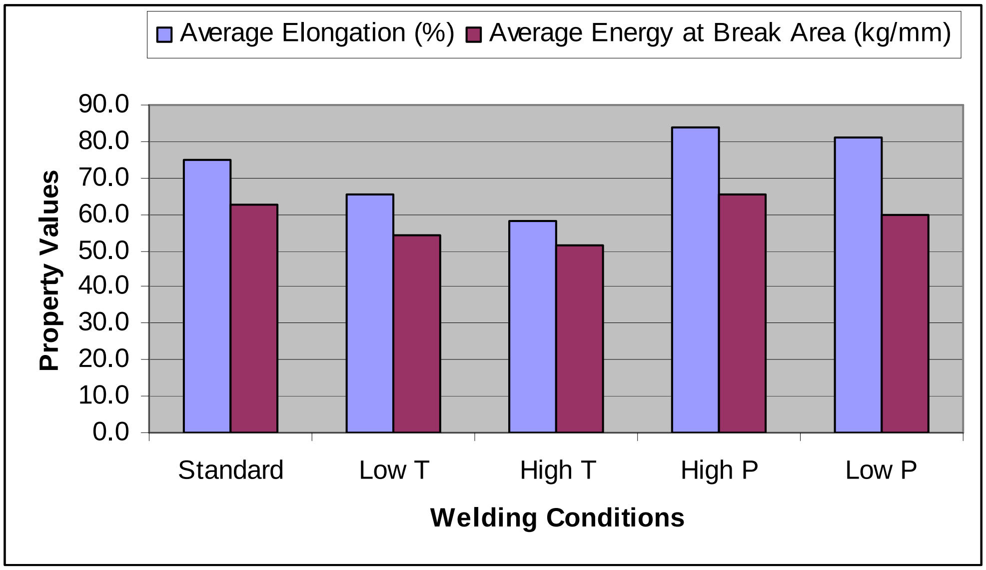


Figure 11. Driscoplex 6500, PE 2406, 152-mm (6-in.) SDR13.5 STDT Results Graph

Condition	Average Elongation (%)	Average Energy at Break Area (kg/mm)	WZIM Observation	WZIM Prediction
Standard	74.8	62.8	No line	Good
Low T	65.4	54.1	No line	Good
High T	58.3	51.5	No line	Good
High P	83.9	65.5	No line	Good
Low P	81.2	60.1	No line	Good

Figure 12. Driscoplex 6500, PE 2406, 152-mm (6-in.) SDR13.5 STDT Results

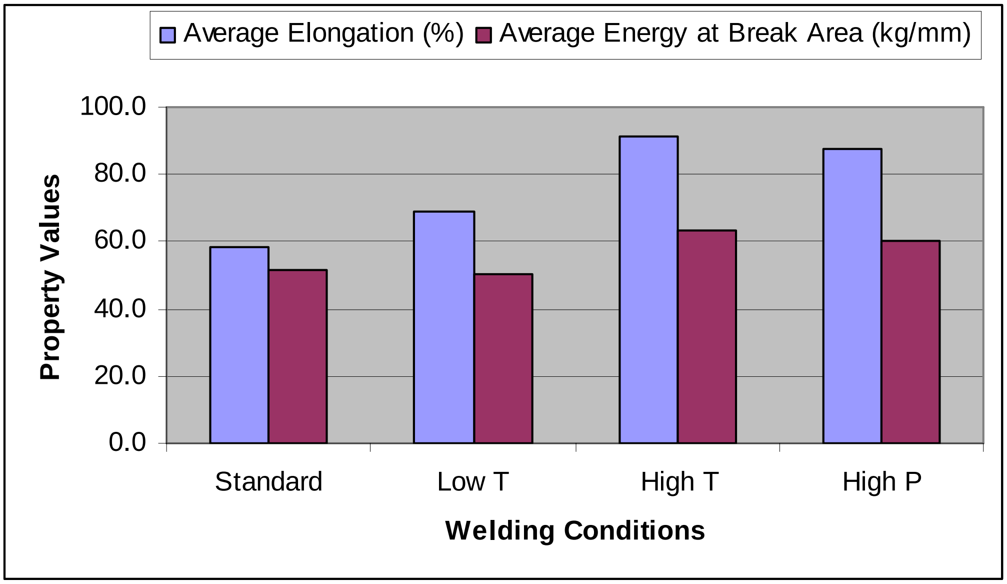


Figure 13. Driscoplex 6500, PE 2406, 101-mm (4-in.) SDR11.5 STDT Results Graph

Condition	Average Elongation (%)	Average Energy at Break Area (kg/mm)	WZIM Observation	WZIM Prediction
Standard	58.6	51.7	Ridge	Uncertain
Low T	69.2	50.0	No line, slight projection	Good
High T	91.2	63.1	Ridge	Uncertain
High P	87.5	60.1	Slight line with indentation	Reduced

Figure 14. Driscoplex 6500, PE 2406, 101-mm (4-in.) SDR11.5 STDT Results

Another factor that should be considered while analyzing the STDT results is that PE has good weldability – its ability to produce sound welds in a wide range of welding parameters and to tolerate variations from the recommended settings. However, different PE grades may show different process parameters variation tolerance and these factors should be considered as the results are being analyzed.

For example, pipe grades of MDPE and 8100 grade of HDPE both demonstrated the ability to produce excellent welds at a lower fusion pressure range, based on their high melt flow index (Figures 5 and 6). However, the 8100 grade appears to be more sensitive to the excessive heating (“high temperature” condition) than other grades. High-temperature effects are more detrimental to larger pipes with thicker walls. These pipes are heated for longer times than small pipes, and as a result the material is exposed to an elevated temperature for a longer period. Based on this, thermal decomposition of the polymer is much likelier in large pipes, and this is reflected in both tensile test and WZIM results.

3.5 Long-Term Destructive Testing (LTDT)

Since the most important property of a butt fusion weld in a PE pipeline is its long-term performance, in order to verify the WZIM procedure it was necessary to carry out accelerated long-term testing of the joints. LTDT was used to verify the sensitivity of the NDE results and the STDT through long-term elevated temperature creep rupture destructive testing on specimens cut from selected welds. Long-term testing was performed at The Welding Institute (TWI). Two sets of specimens were sent to TWI throughout the course of this project. Specimens were cut from welds that failed the WZIM inspection method and welds that passed the WZIM, and from locations where local reheating (from WZIM) took place and locations that were not subjected to local reheating. There were two main objectives in carrying out creep rupture tests:

- Validate the results of WZIM
- Investigate the effect of the WZIM on long-term performance of the welds.

TWI has developed the creep rupture test and associated equipment located at the TWI facility in the U.K. The test was created and has been used to validate the performance of PE100 material, a common piping material used in the U.K. It should be noted that PE100 has different characteristics than the HDPE and MDPE materials used on this project.

3.5.1 Creep Rupture Test Process

The equipment needed to perform the creep rupture tests was located at TWI. This equipment, shown in Figure 15, consists of two hot water baths, each containing 10 test stations. Each bath contains two heaters, and water is constantly circulated throughout the bath to maintain an even temperature. Each test specimen is fit onto a hanger that applies a load force onto the specimen while it is submerged in 80°C water. The amount of load applied to the specimen is determined by the size of the specimen and prior experience of TWI using PE100 material. A timer is set from the moment the load is applied and the specimen submerged, and continues to count until the specimen fractures, indicating time to failure. After failure, the specimen is tested to make certain it failed with at least 30% brittle surface. BS EN 12814-3[5] specifies that at least 30% of the fracture surface must be “brittle” for the test to be considered valid. If the failed specimen does not have the brittle characteristic, the results from the creep rupture test will not be considered for that particular specimen. Please refer to Appendix A for a full description from TWI about the creep rupture test.

Figure 15. Photograph of Tensile Creep Rupture Test Rig

3.5.2 Specimen Set 1

The first set of specimen included a total of nine samples cut from the original 26 pipes. Three specimens were cut from welds that failed the WZIM inspection method and six specimens were cut from welds that passed. Of these specimens, three were taken from locations where local reheating took place and three from locations that were not subjected to local reheating. This was in an effort to determine if the WZIM of reheating degraded the pipe integrity. The results of the first set of specimen are shown in the Table 2.

3.5.2.1 Comparison of Creep Rupture Test from Specimen Set 1 and WZIM Results

TWI reported on the test results which suggest that the welds from which Specimens B and S were cut were of poor quality. WZIM previously determined that these specimens were of reduced quality. Unfortunately, a number of specimens failed in a predominantly ductile manner, which meant that the tests results were not considered valid. Only one pair of specimens provided results that could be used to determine the effect of the WZIM on the long-term performance of butt fusion welds in PE pipes, and this suggested that, possibly the WZIM might have a slight detrimental effect. However, this was only one result and the difference may well be within experimental scatter.

Table 2. LTDT Results on Specimen Set 1 (Yellow highlight indicates the test was invalid.)

Specimen ID	Station No.	Test Duration	Comments
B	14	5 hr 46 min	Failed – completely brittle fracture
O	14	1723 hr 42 min	Failed – fracture surface >30% brittle
O (after NDE)	5	1288 hr 33 min	Failed – fracture surface >30% brittle
E	18	2227 hr 27 min	Failed – fracture surface >30% brittle
E (after NDE)	8	671 hr 22 min	Failed – fracture surface <30% brittle
F	19	1211 hr 05 min	Failed – completely ductile failure
F (after NDE)	7	4529 hr 12 min	On test
S	15	371 hr 20 min	Failed – fracture surface >30% brittle
N	4	4176 hr 16 min	Failed – fracture surface >30% brittle

As it was reported by TWI, Specimens B and S failed in a brittle manner very fast, after 6 and 371 hr, respectively, and based on the test results, both were qualified by TWI as “of a poor quality”. From all nine samples selected for long-term testing, only on these two welds the bond line was detected and they were qualified as “R” (reduced) quality rating by the WZIM test. TWI results confirmed WZIM qualification. The rest of TWI’s data was less definitive, as a number of joints with the “U” (uncertain) WZIM rating failed in a wide range of time (from 1723 to 4176 hr) and a number of joints failed in a ductile manner, which according to the standard under which the test was carried out, BS EN 12814-3, made the results invalid.

3.5.2.2 Effect of the WZIM on Long-Term Performance of the Welds in Specimen Set 1

To evaluate the effect of the WZIM on long-term performance of the weld, six specimens made from three welds (E, F, and O) were included in the test, each pair represented by a specimen not exposed to WZIM and after WZIM. According to the report, two of the specimens, E (after WZIM) and F, did not fail with a fracture surface greater than 30%, which made the results invalid. The data from one pair, Specimens O and O (after WZIM) suggests that WZIM may have a slight detrimental effect on long-term performance of the weld. However, the difference was small and may well be within experimental scatter. In fact, the only one specimen that stayed under the test the longest time and did not fail until the test was stopped, was the specimen after WZIM, Specimen F (after WZIM), which shows that there was no detrimental effect from the WZIM.

3.5.3 Specimen Set 2

The second set of specimens tested using the creep rupture technique at TWI included six samples. Three specimens were cut from welds that failed the WZIM inspection method and two specimens were cut from a weld that passed the WZIM. Of these specimens, one was taken from a location where local reheating took place and five from locations that were not subjected to local reheating. The results from the second set of specimen are shown in the Table 3.

Table 3. LTDT Test Results on Specimen Set 2 (Yellow highlight indicates the test was invalid.)

Specimen ID	Station No.	Test Duration	Comments
M	7	28 hr 13 min	Failed – fracture surface >30% brittle
Q	15	1399 hr 59 min	Failed – fracture surface >30% brittle
R	19	2101 hr 50 min	Failed – fracture surface >30% brittle
T	14	486 hr 4 min	Failed – fracture surface >30% brittle
T (after NDE)	4	932 hr 23 min	Failed – fracture surface >30% brittle
V	18	458 hr 48 min	Failed – fracture surface <30% brittle

3.5.3.1 Comparison of Creep Rupture Test from Specimen Set 2 and WZIM Results

TWI reported on the LTDT test results and analysis. The results suggest that the welds from which Specimens M and T were cut were of poor quality. WZIM previously determined that Specimen M was of reduced quality and Specimen T was of good quality. Only one specimen result could not be considered and was invalid. Only one pair of specimens provided results that could be used to determine the effect of the WZIM on the long-term performance of butt fusion welds in PE pipes, and this suggested that the WZIM has no detrimental effect.

As TWI reported, Specimen M failed first at only 28 hr on test. The WZIM previously identified this specimen as a reduced quality joint and a line was observed on the surface. TWI results confirmed WZIM qualification for Specimen M. The WZIM Specimen V failed with a less than

30% brittle structure so it could not be used or considered valid in this analysis. Specimen T failed next, after 486 hr, but was determined to be a good quality joint by WZIM. STDT confirmed with WZIM on the good quality of the specimen, which was made under standard conditions. Specimen T did not exhibit the characteristic bond line seen in reduced quality welds, which also confirms with WZIM. In this case, LTDT did not correlate with any of the other testing result, yet the other testing results (STDT, WZIM, and visual inspection) all correlated with one another. This could be a result of the creep rupture test parameters being developed for the PE100 material which is different than the HDPE and MDPE used in this project. Samples Q and R were reported to fail at 1399 and 2101 hr, respectively. Both of these joints had been determined to be of reduced quality by the WZIM system.

3.5.3.2 Effect of the WZIM on Long-Term Performance of the Welds in Specimen Set 2

To evaluate the effect of the WZIM on long-term performance of the weld, two specimens made from Weld T were included in the test, one was exposed to WZIM and one was not exposed to the localized heating of WZIM. According to the report, the WZIM does not have a detrimental effect on the long-term performance of the welded joint. In fact, Specimen T (after NDE) lasted twice as long (932 hr and 23 min) as Specimen T which had not undergone the localized heating. This contradicts the results for Specimens O and O (after WZIM) from Specimen Set 1.

3.5.4 LTDT Conclusions

The LTDT performed on HDPE and MDPE pipes were able to validate the results of WZIM on only the most extreme cases of reduced quality (Specimens B, S, and M) and the absolute best cases of good quality (Specimens F and E). TWI recommends further testing be done to validate the results and perhaps further study the uncertain result, which includes joints that are not considered reduced quality, but do have some surface feature (such as ridge) that prevents them from being labeled a good quality joint. Unfortunately, the two valid tests used to verify the long-term performance of the welded joint were not enough to be conclusive. TWI has recommended that further tests be performed on at least four specimens where the weld has been subjected to the WZIM and on the corresponding specimens from as-welded samples. It might be possible that further testing on more samples will determine if the NDE technique has a detrimental effect on the weld.

3.6 Automated WZIM System Development

3.6.1 User Requirements

A document was created by EWI with NYSEARCH cooperation that outlines operational, performance, and user requirements for the prototype WZIM inspection system for butt fusion joint inspection in gas distribution plastic pipelines under field conditions. These conditions helped define requirements for assignment of pass/fail rating of inspected joint.

The document contained two sections:

- Performance requirement
- Operational requirement.

The Performance Requirement section detailed the pipe material and sizes that the system is required to inspect. It also outlined the joint configuration and the specific defect type of weak fusion associated with improper welding parameters. The last item outlined in the Performance Requirement section was the evaluation process, including using the WZIM method by applying heat, looking at the surface with a laser scanning sensor, assigning a rating to the joint integrity, and then saving the results of the inspection.

The Operation Requirement section had more to do with specifying how the system would operate. In particular, physical size and weight of the unit, the hardware items that will be contained in the unit, how it clamped onto the pipe and alignment of the system on the pipe. Various other items were also named including how the software would communicate with the hardware on the finished system. Please see Appendix B for the User Requirements Document.

3.6.2 WZIM Inspection Tool Development

EWI has developed of a nondestructive, laser-based plastic pipe inspection system and associated software, which can assign a pass, fail, or uncertain rating to the inspected joint based on data collected from the laser scan of the weld area. EWI developed the WZIM inspection tool to automatically inspect the butt fusion joint on MDPE and HDPE pipe. The WZIM inspection tool is made of both hardware and software. The hardware unit is placed upon the pipe, over the fusion weld. The software makes the hardware perform the inspection when the operator tells it to begin. The software will perform the inspection and then produce a result that indicates if the pipe passed or failed the inspection. The output is a report that indicates the inspection result and an image of the pipe surface that was inspected. The WZIM inspection tool (Figure 16) is a portable device to be used in-situ, and this prototype system was designed, developed, and demonstrated throughout the course of this project.

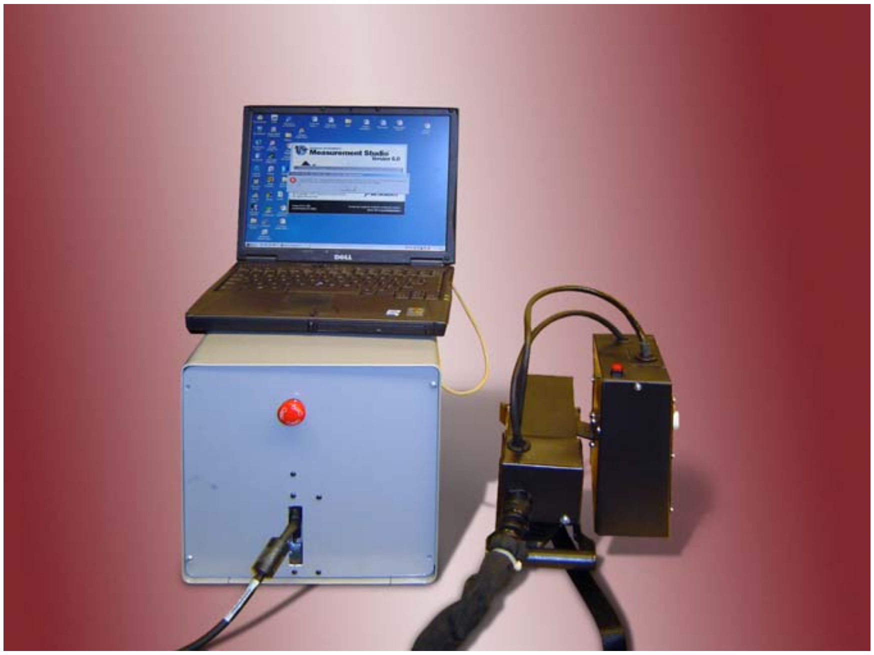


Figure 16. WZIM Inspection Tool

3.6.3 Hardware Overview

A laptop computer is required to run the software program that controls the WZIM inspection tool operations. All hardware components fit together on the inspection unit, except for the power supply.

3.6.3.1 Laser Sensor System

Laser sensing is a fast, non-contact approach to objectively evaluating surface features. A laser displacement sensor measures discrete changes on the pipe surface and forms a topographical surface map as it moves over the weld zone area. The task of the laser in this project is to automatically determine the result of the inspection after the WZIM has been applied. Unlike a human inspector, the laser is able to perceive the formation of a line or ridge on the surface of the joint that is just a few microns wide. The sensitivity of the laser to pick up the surface features is far greater than an operator, and the laser provides the same objective analysis of the weld zone every time.

3.6.3.2 Motion System

The motion system is responsible for moving the heating element into position and moving the laser sensor on the pipe surface. Task 1 Functionality Requirements of the system state that both the laser sensor and the heating element must be designed to work independently. Key factors involved in selection of motion system components include weight, rigidity, and performance. The weight of the system had to be kept under the specified amount, yet still allow for ruggedness during field trials. Since the user must manually place the system on and off the pipe, it had to be designed for easy portability and rigidity to withstand handling. Most importantly, the motion system needed to maintain solid, repeatable performance. This is due to the sensitivity of the laser measurements requiring a smooth scanning motion so as not to induce error in the topographical map. Once completed, the motion system had to be integrated with the software program. The software involved in the system at this level is responsible for controlling the motion and laser system. System hardware was selected, assembled, and tested on calibrated samples in the lab.

3.6.3.3 Control Box

One main control box was developed that includes the power supplies for each component of the WZIM inspection tool and any control devices. An emergency stop button was placed on the outside of the box, and only one connector was used to connect to the laptop computer. Figure 17 is a picture of the control box developed for the WZIM inspection tool.

Figure 17. Control Box for the WZIM Inspection Tool

3.6.4 Software Overview

EWI was tasked with developing software for analysis of scanned weld data and measurement of weld zone characteristics including weld zone shape and size and the presence of weld bond line. There are four sub tasks within the development of inspection system software. The first task involved the software developed for controlling motion and laser hardware. The second task involved gathering the data from the laser sensor and positioning it within a file that is easily readable by the computer or person. A software program was written to acquire data from the laser sensor and package the data into a standard file format. This task involves time management to ensure the data is captured as fast as possible in preparation for analysis by the inspection algorithm. The third task involved development of the inspection algorithm. At least 10 different measurements are required in order to accurately assess the weld zone. The series of measurements were all evaluated on known samples in the lab. Large amounts of data are being manipulated so time conservation was a priority. The last task involved designing the user interface (UIR) for ease of use and display of inspection results. The UIR is the point of interaction between the operator and the WZIM system (Figure 18). It displays the pass, fail, or uncertain rating to each inspected weld zone and generates both a report and a text file including all measurement data (Appendix C). The major task was the third task, involving the development of the algorithm to determine integrity of the pipe joint.

Figure 18. UIR Shown on Laptop Computer Screen during an Inspection

3.6.4.1 UIR

The UIR is the main interface between the operator and the WZIM inspection tool. It is through this software that the operator tells the system to begin an inspection, view a past inspection, or make a report from an inspection. There are two main parts to the software that operates the WZIM inspection tool: main panel and results panel.

The operator only sees two different panels, or viewing screens, on the laptop computer and these two panels allow him to operate the tool and view the inspection results.

3.6.4.1.1 Main Panel

The main panel is the first panel that the software displays to the operator. This is the panel that is shown on the laptop screen anytime the software program is launched and waiting for input from the operator. This panel allows him to begin an inspection or go to a new panel to view a previous inspection result. Figure 19 shows the main panel on the software program which operates the WZIM inspection tool. The four buttons on the UIR include: calibrate, start, open, and quit. The calibrate button is used for calibrating the WZIM inspection tool. The start button is used to begin an inspection after the WZIM inspection tool has been placed and secured on a pipe. The open button is used to go to a previous inspection file in order to view it and make a report. Pressing this button will open the results panel screen. The quit button exits the main panel and stops the software program completely. Please refer to the User Training Manual in Appendix D for descriptions of all capabilities of the user interface program.

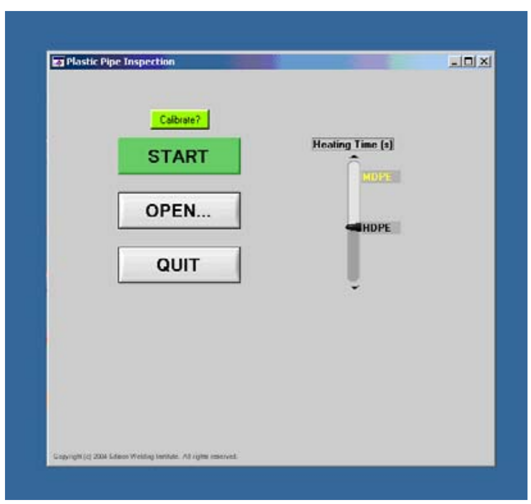


Figure 19. UIR Main Panel Screen

3.6.4.1.2 Results Panel

The results panel is used to view an inspection result immediately after the inspection has been completed by the WZIM inspection tool and at any time after an inspection has been completed (Figure 20). The WZIM inspection tool will automatically open and display this panel on the UIR during each inspection. The results panel can be used with or without the WZIM inspection tool attached and can display results of any inspection completed by the tool.

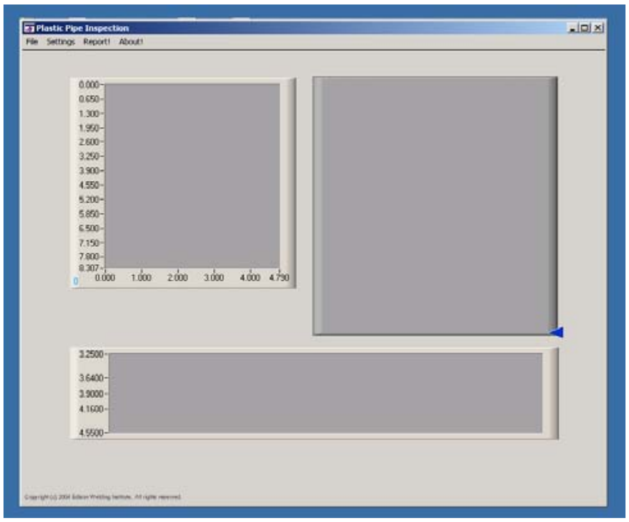


Figure 20. UIR Results Panel Screen

Please refer to the User Training Manual in Appendix D for descriptions of all capabilities of the user interface program. Section 7.2.1 will describe all part of the Results panel as it relates to inspection data and output results from the WZIM inspection tool.

3.6.4.2 Algorithm Development

The series of 26 sample joints, marked A through Z, were used in support of the development of the algorithm for automatically determining the WZIM result. This combination of HDPE and MDPE joint samples had already undergone the WZIM method: the joint was subjected to local reheating at the bond-line by means of a light source. Each of the samples was then analyzed visually by an operator with the help of a microscope. A classification system was used to manually inspect each weld zone area after the WZIM was applied. The results of the visual (operator) inspection of the weld zone area after applying WZIM are in Table 4. WZIM operator observation is what the operator observed on the surface of the joint. For example, line, ridge, etc. WZIM operator prediction is the operator's guess as to whether the pipe sample was a good or reduced integrity joint. Throughout the course of the project, this algorithm was refined and tested against these original 26 pipe specimens. WZIM tool result is the output result of the system based on the version of the algorithm before the uncertain rating was added.

Table 4. Operator-Based Visual Inspection Results on 26 Samples

Specimen ID	WZIM Operator Observation	WZIM Operator Prediction	WZIM Tool Result (P/F Only)
A	No line, very slight projection	Good	Pass
B	Line	Reduced	Fail
C	Ridge	Good	Pass
D	No line	Good	Pass
E	No line	Good	Pass
F	No line	Good	Pass
G	No line	Good	Pass
H	No line	Good	Pass
I	No line	Good	Pass
J	Ridge	Uncertain	Pass
K	No line, slight projection	Good	Pass
L	Ridge	Uncertain	Pass
M	Slight line with indentation	Reduced	Fail
N	Ridge with defined peak	Uncertain	Fail
O	Very slight line	Uncertain	Fail
P	No line	Good	Fail
Q	Slight line	Reduced	Fail
R	Thin line	Reduced	Pass
S	Sharp indentation w. offset slight line in it	Reduced	Pass
T	Low profile projection	Good	Pass
U	Line	Reduced	Fail
V	Defined ridge	Uncertain	Pass
W	Ridge with thin line on the top	Reduced	Fail
X	Low profile projection	Good	Pass
Y	Ridge with defined peak	Uncertain	Pass
Z	Ridge	Uncertain	Fail

Each of the 26 samples was scanned by the chosen laser sensor in the lab. Data was collected from each laser scan of the sample and the data was analyzed to find differences and similarities between known good and bad samples.

3.6.4.3 Pass and Fail Ratings

The 26 pipe samples were characterized by their surface features. Both densities of pipe exhibited similar results when a pipe with an acceptable joint was subjected to WZIM and analyzed by the laser. Based on the laser sensor data, certain characteristics of the weld zone are measured that the algorithm then uses to determine a resultant pass or fail output. Along with the output result, all surface features such as weld zone width, area, etc. are also calculated and saved in a text-based format that can be retrieved and viewed by the operator, if desired. The result is determined completely and automatically based on the algorithm.

The pass and fail rating were the initial two rating that the WZIM system was to assign. Although the operator identified an uncertain condition in his observation about the surface features of the joint, only a pass or fail output was programmed into the algorithm at this stage in the project.

3.6.4.4 Field Demonstration

In October 2004, the WZIM inspection tool was demonstrated to NYSEARCH members at one of their facilities (Figures 21 through 36). The purpose was to demonstrate and obtain user/advisory feedback on the WZIM prototype field tool and the early version of software programming designed to interpret joints. EWI provided an overview of testing done to date, including short-term tensile and long-term tests performed by TWI. A total of six joints were fused including 4-, 6-, and 8-in. MDPE material. The overriding opinion after the demonstration was that the prototype tool performed well for a first prototype of its kind. It appeared to be field rugged enough and relatively easy to use. Several valuable comments from NYSEARCH members were used to improve the system or make necessary changes before the field testing program. Some of the comments include:

1. An additional category of uncertain (U) needs to be added to software, at least in its early evaluation stages. This information will be analyzed further to determine appropriate category and/or predicted service life.

2. Need to continue tests to determine the “true” bond line signature from other profiles. For example, a 6-in.-pipe sample tested produced a defined ridge and it was not clear if this joint was considered to be P (pass) or R (reduced in quality).

3. Our original understanding of WZIM was that for a joint to be good there was no line or ridge in the center of the fusion area. Based on the demo it appears that other ridge anomalies may exist that could produce an acceptable joint.

4. Future tool improvements – beta design

    a. WZIM to be more light and compact.

b. Needs new pipe strap design or eliminate the need for straps by designing a handheld application

c. Expand the tool to NDE the entire joint by rotating around the pipe.

Figure 21. Early Demonstration of the WZIM Inspection Tool at ConEdison Facility in October 2004

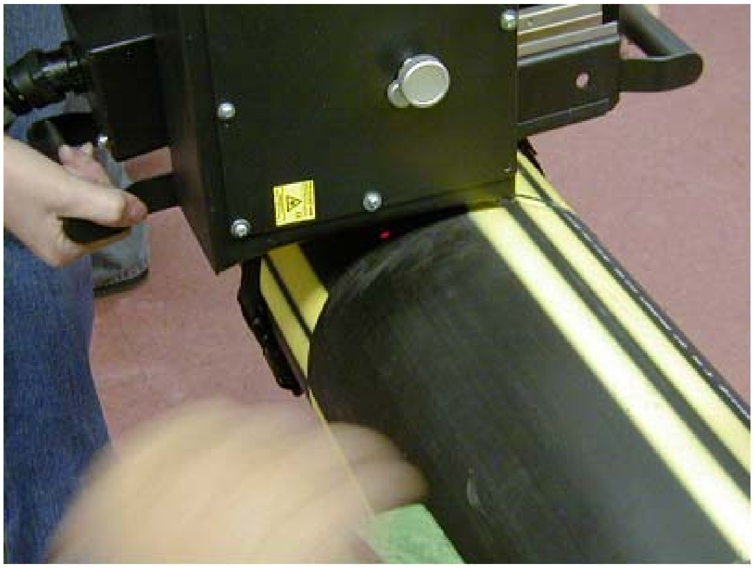


Figure 22. Placing WZIM Inspection Tool on Pipe

Figure 23. WZIM Inspection Tool Performing Local Reheating

Figure 24. WZIM Inspection Tool Performing Laser Scanning Process

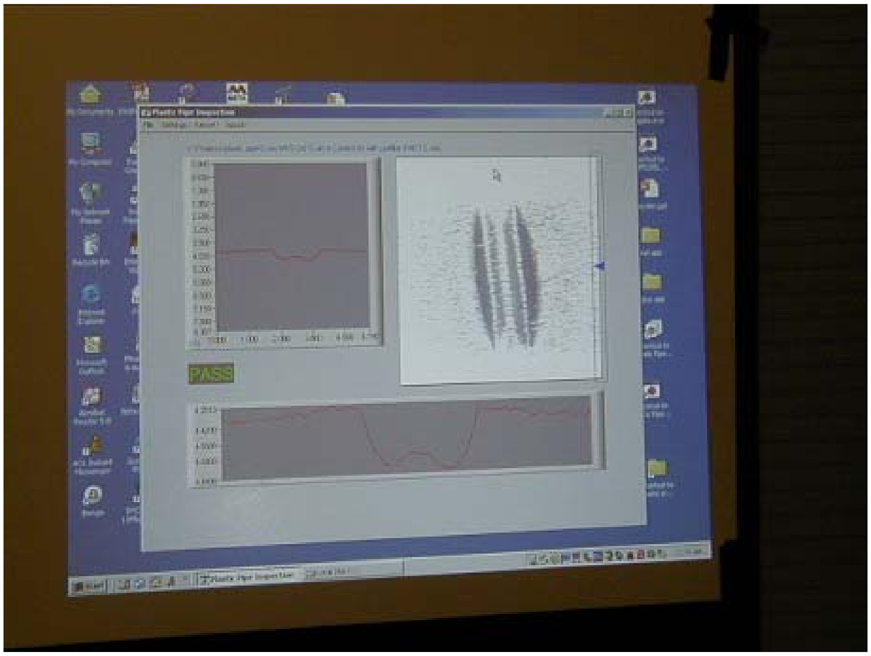


Figure 25. **Result of Pass shown on Laptop Software Screen on the WZIM Inspection Tool**

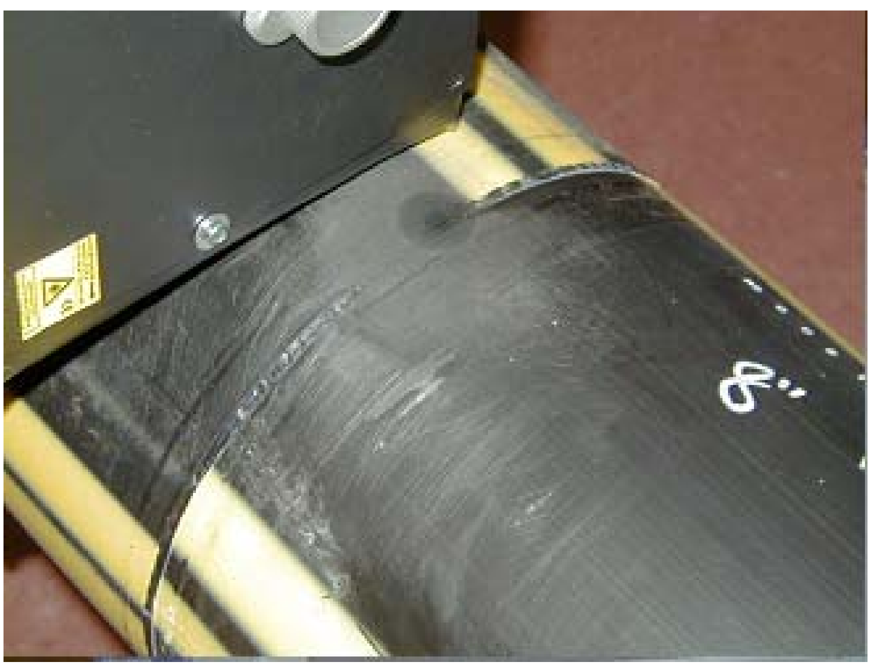


Figure 26. **Removing the WZIM Inspection Tool from the Pipe after the Inspection is Complete**

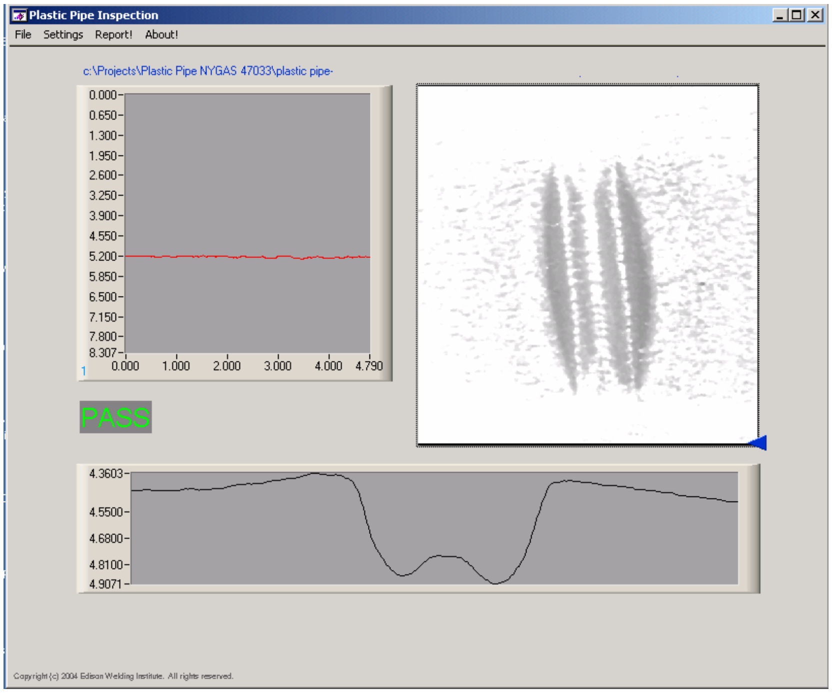


Figure 27. Typical Pass Result on UIR Screen for MDPE Pipe

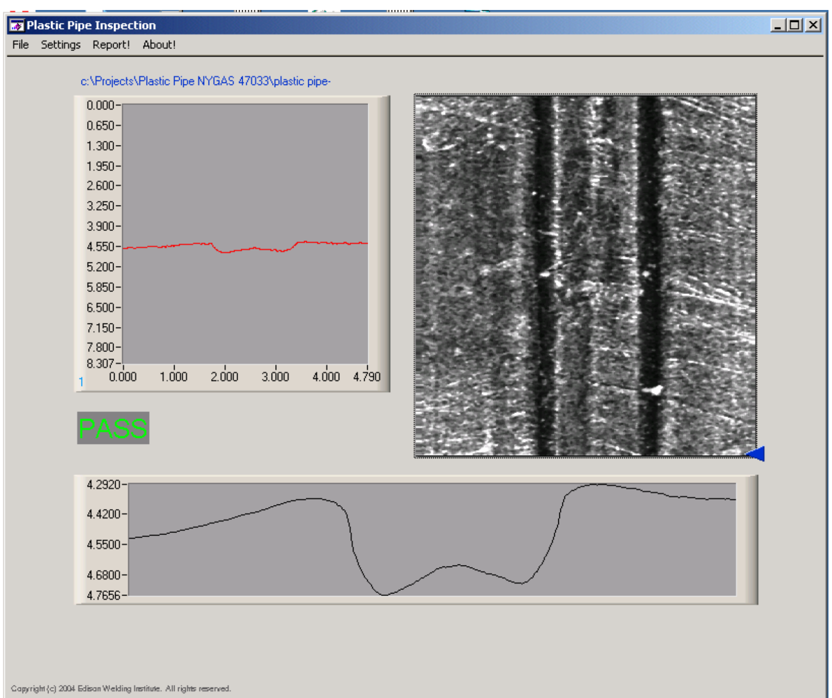


Figure 28. Typical Pass Result on UIR Screen for HDPE Pipe

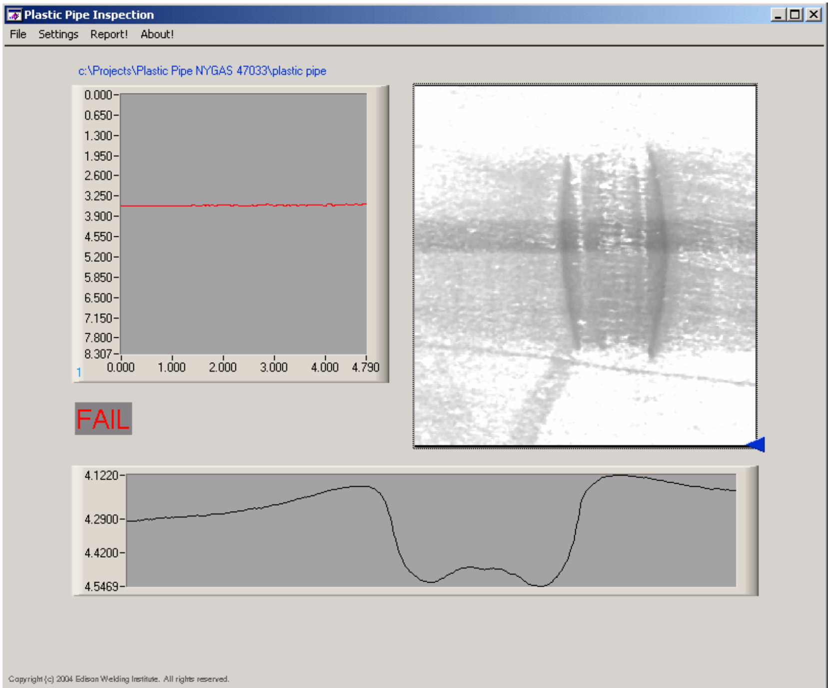


Figure 29. Typical Fail Result on UIR Screen for MDPE Pipe

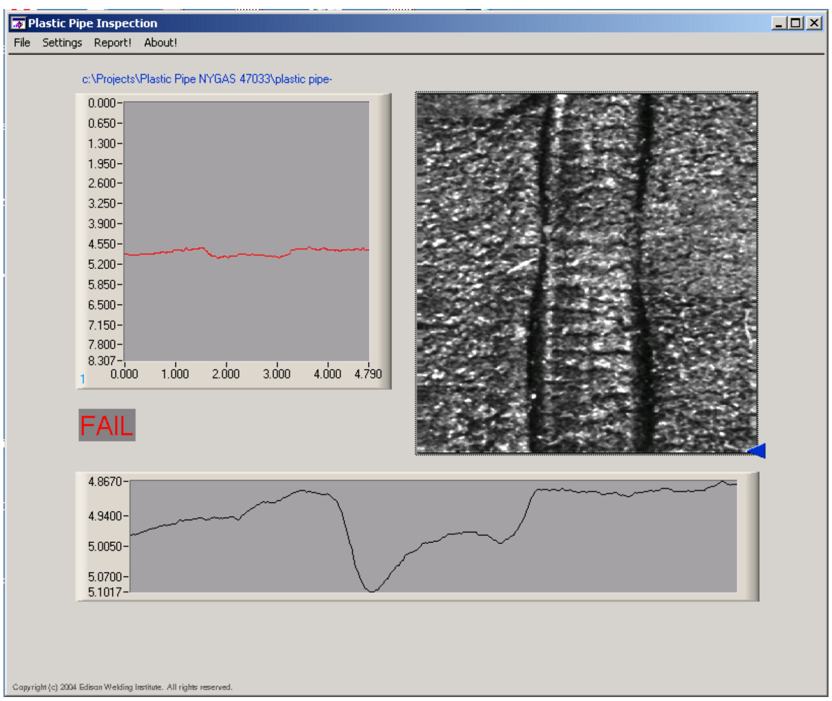


Figure 30. Typical Fail Result on UIR Screen for HDPE Pipe

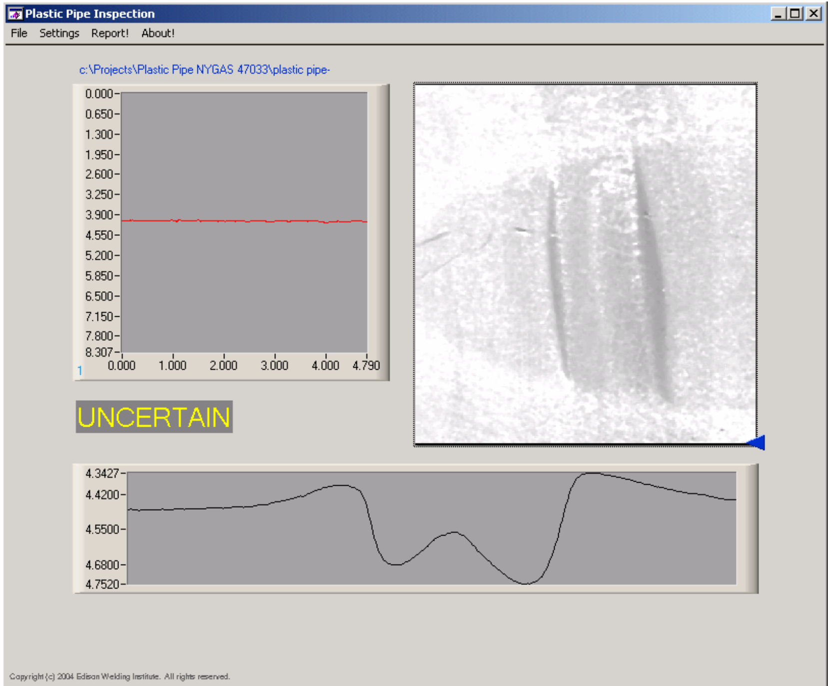


Figure 31. Typical Uncertain Result on UIR Screen for MDPE Pipe

Figure 32. HDPE Pipe in Fusing Machine at ConEdison Facility

Figure 33. Debeading (Removing the Excess Weld Bead) from a Pipe at ConEdison Facility

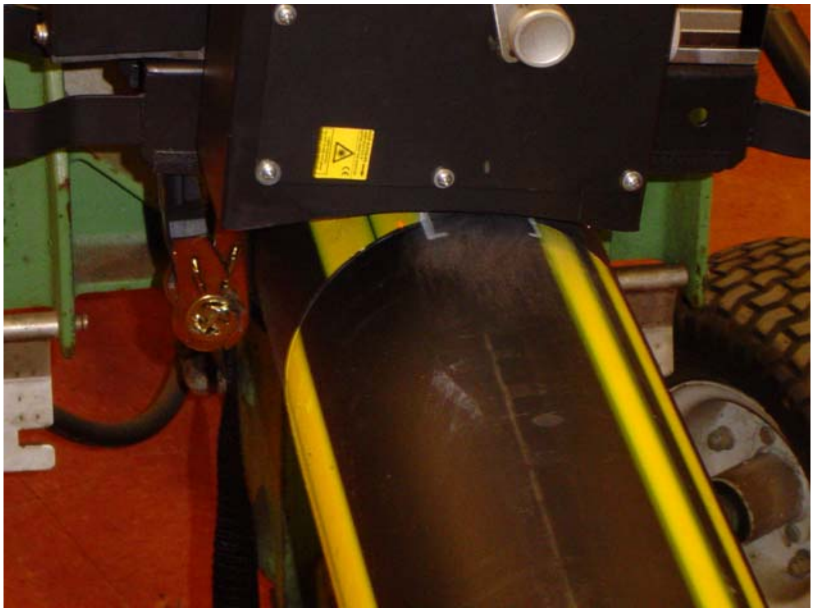


Figure 34. WZIM Inspection Tool Performing Inspection at ConEdison Facility during Field Trials

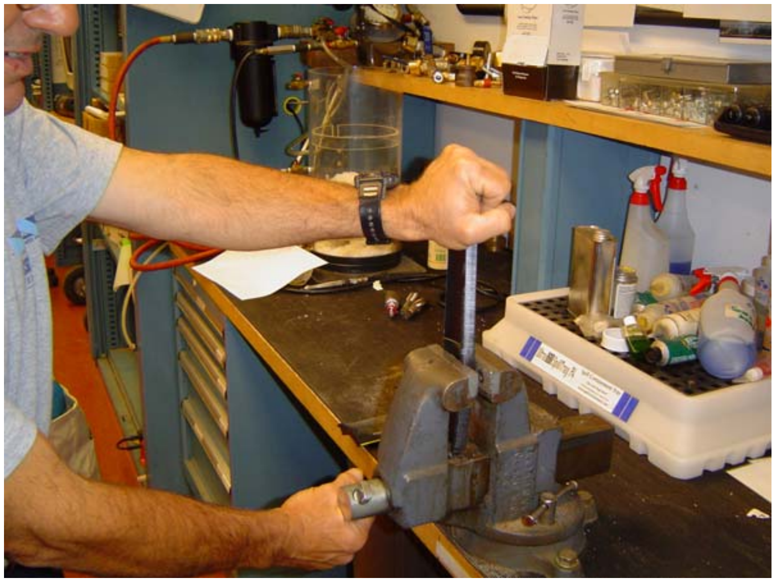


Figure 35. Operator Performing a Destructive Bend Test on a Piece of Weld Joint Cut from a Pipe Inspected using the WZIM Tool

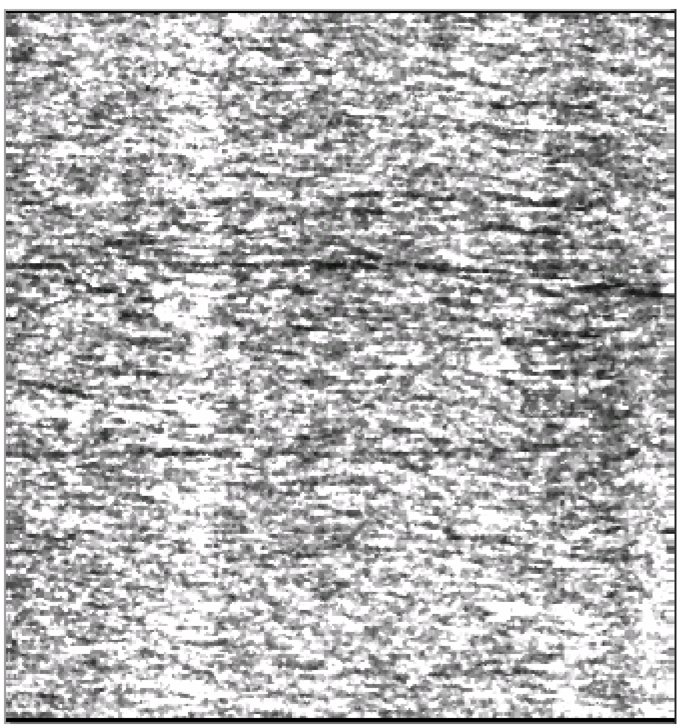


Figure 36. ConEdison Pipe 1 Position 1 Scanned Image

See Appendix E for document from NYSEARCH with complete list of comments.

3.7 WZIM Inspection Tool Field Test Program

The objective of the field testing for the WZIM inspection tool involves coordinating tests of WZIM laser tool inspection system on existing and new gas pipelines conducted by gas distribution companies. This was accomplished at two NYSEARCH member companies with a range of pipe materials and sizes applicable to current field situations. The field testing provides invaluable data and user comments that were used to make the following recommendations for system improvement to the WZIM inspection tool on the way to commercialization.

3.7.1 Field Test Preparation

Several improvements and modification were made to the WZIM inspection tool following the field demonstration at NYSEARCH facility. This section describes the improvements made to the program in detail.

3.7.2 Hardware Improvements

Hardware improvements included changing the strap on the WZIM tool to better secure it during use. The original strap was rubber-coated to help keep it from slipping. Unfortunately, the locking mechanism did not prevent the tool from sliding about the pipe. The improved strap fit the pipe ranges to be encountered, was easier to use, easily replaceable in the field, and very secure. This allowed the WZIM inspection tool to perform inspections at any orientation about the pipe.

3.7.3 Software Improvements

Several software changes improved the use of the system and the capability of the system.

The first software change improved the algorithm by adding an uncertain category to the output result. This category was used when there was no line detected on the surface, but the surface wasn't completely smooth. A ridge or projection in the surface that did not create a line was assigned with an uncertain rating and this knowledge was programmed into the WZIM Inspection algorithm. This change enabled the WZIM inspection tool to provide one of three results after inspecting a joint. The algorithm is now able to determine the following features:

- A line in the weld zone at the bond line = fail
- No surface abnormality in the weld zone = pass

- A ridge or projection in the weld zone at the bond line = uncertain.

A second software change involved improving the algorithm by using a better pipe surface baseline. Using a baseline closer in shape to the actual pipe surface improved the detection capability of the algorithm.

3.7.4 Calibration

In order to calibrate the WZIM inspection tool, several pipe samples from a NYSEARCH member company were created and evaluated at EWI. Of the 14 samples created, 10 were sized between 4- and 12-in. diameters, providing a range of pipe sizes that are representative of what is to be expected in the field. The WZIM inspection tool analyzed the series of pipes in the lab at EWI, in preparation for the field trials. Table 5 shows the parameters for the pipes used for calibrating the WZIM inspection tool. WZIM operator observation is what the operator observed on the surface of the joint. For example, line, ridge, etc. WZIM operator prediction is the operator's guess as to whether the pipe sample was a good or reduced integrity joint. WZIM Tool Result I is the resultant WZIM output from the WZIM inspection tool before the algorithm was updated and improved. WZIM Tool Result II is the resultant WZIM output from the WZIM inspection tool after the algorithm was updated and improved, just prior to beginning the field testing.

Table 5. Calibration Pipe Specimens

Sample	Diameter (in.)	WZIM Operator Observation	WZIM Operator Prediction	WZIM Tool Result I	WZIM Tool Result II
S-5	4	Bad preparation, possible line	Uncertain	Fail	Pass
S-6	4	Uncertain	Uncertain	Pass	Uncertain
S-7	6	No line, raised peak	Uncertain	Pass	Uncertain
S-8	6	No line, raised peak	Uncertain	Pass	Uncertain
S-9	6	No line, raised peak	Uncertain	Pass	Pass
S-10	8	Uncertain	Uncertain	Fail	Fail
S-11	12	No Line	Good	Pass	Pass
S-12	12	Line from overheating	Uncertain	Uncertain	Uncertain
S-13	12	Bad preparation, possible line	Uncertain	Fail	** Weld zone larger WZIM system field of view
S-14	12	Line	Reduced	Fail	** Weld zone larger WZIM system field of view

3.7.5 Field Trial Matrix and Specification

A meeting was held at the NYSEARCH facility in preparation of the field tests. The result of this meeting was solidifying the field trial schedule and locations. A matrix of pipe sizes, materials, and welding conditions was generated by NYSEARCH for the member companies to adhere to during the field trials (Table 6). The goal was to try to create good, bad, and marginal welds so that the WZIM inspection tool has a varied set of pipes during the field trials.

Table 6. Matrix of Pipes and Conditions for Field Testing

No.	Size (in.)	Condition	Temp (°F)	Pressure (psi)	Heat Soak (min)	Visual Results	WZIM Results	Bend Test Results
ConEdison Facility								
1	4 MD	Standard						
2	4 MD	High P (max)						
3	4 MD	Deflection (10%)						
4	4 MD	Low T (50%)						
5	8 MD	Low T (50%)						
6	8 MD	Low P (25%)						
7	6 HD – DR9	Standard						
8	6 HD – DR9	Low P (50%)						
9	6 HD – DR 9	Low P (25%)						
10	6 HD – DR 9	Low T (50%)						
KeySpan Facility								
1	4 HD	Standard						
2	4 HD	High P (max)						
3	4 HD	Low P (25%)						
4	4 HD	Low T (50%)						
5	4 HD	Deflection (10%)						
6	6 HD	Standard						
7	6 HD	Low T (25%)						
8	8 HD	Standard						
9	8 HD	Low P (25%)						
10	8 HD	Low T (50%)						

A training manual was developed in preparation for the field testing. This manual was written to guide the operators through the steps of making an inspection using the WZIM inspection tool. The training manual can be found in Appendix D.

3.8 Results and Analytical Discussion of Field Test Data

Before the data from the field trials is analyzed, it is useful to go through typical inspection results from the lab samples used in this project. This will help set the stage for analysis of the field test data as to what has been defined as a typical “good” surface condition and what should be considered atypical “bad” surface condition.

3.8.1 Typical WZIM Inspection System Output Results

Each inspection performed using the WZIM system produces several items: an image of the scanned weld surface, a single profile of the joint surface topography, and a result indicating joint integrity. MDPE and HDPE pipe surfaces are affected differently by the local heating applied during the WZIM process.

3.8.1.1 Typical Pass Result

A typical pass condition as defined for the WZIM Inspection system is a weld zone area with no evidence of a line or any surface deformation at the bond line interface. This definition was programmed into the WZIM system software algorithm so that it uses the same criteria to inspect PE pipe welds every time. Figure 27 is an example of a pass result on a MDPE pipe.

HDPE pipe is different. Figure 28 shows an example of the pass result portrayed on the software UIR screen for a HDPE pipe.

3.8.1.2 Typical Fail Result

The WZIM inspection system defines a fail condition as one where the weld bond line interface clearly displays a line between the weld fusion bond lines. A typical example of a fail condition for MDPE and HDPE pipe can be seen in Figures 29 and 30, respectively.

3.8.1.3 Typical Uncertain Result

A typical uncertain condition is the result of either a ridge formation or projection on the surface of the weld zone area. Figure 31 shows a typical uncertain result on MDPE pipe.

3.8.2 ConEdison Facility

The first set of field trials took place at the ConEdison facility in Bronx, New York (Figures 32 through 35). This facility was joining HDPE pipe during the field trials in 4-, 6-, and 8-in diameters. The joints were hot-plate welded using a McElroy hot-plate but welding machine for the 4- and 6-in. joints and manual method for the 8-in.-diameter joints. The high density pipe is usually black with yellow stripes.

3.8.2.1 Pipe 1 Results

See Table 7.

Table 7. ConEdison HDPE Pipe 1

No.	Size (in.)	Condition	Temp (°F)	Pressure (psi)	Heat Soak (s)	WZIM Observation	WZIM Results	Bend Test Results
1	4	Standard				Ridge	Pass	
1	4	Standard				Ridge	Uncertain	

3.8.2.2 WZIM Inspection System Data

Pipe 1 was produced under standard welding conditions (Table 5) for a 4-in., HDPE pipe. Tests from Pipe 1 were completed at 180 degrees from one another on the bond line. Figures 36 and 37 show the image of the laser-scanned surface of the pipe, after the local reheating has occurred.

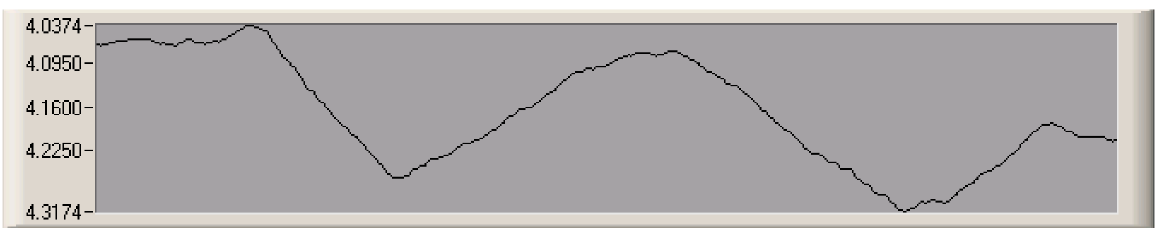


Figure 37. ConEdison Pipe 1 Position 1 Surface Profile

The operator physically looked at the surface of the pipe after the local heating was completed to see if he could see anything on the surface that resembled a line, a ridge, or projection. In this test, the operator visually saw a ridge on the surface of the joint.

Figures 38 and 39 are from the second test completed on Pipe 1. Again, the operator visually perceived a ridge formation within the weld zone area, after the WZIM system had performed the local reheating at the surface. Figure 39 shows the single profile across the surface of the weld bond line. In this test, the WZIM system correctly identified the joint as uncertain because of the ridge formation.

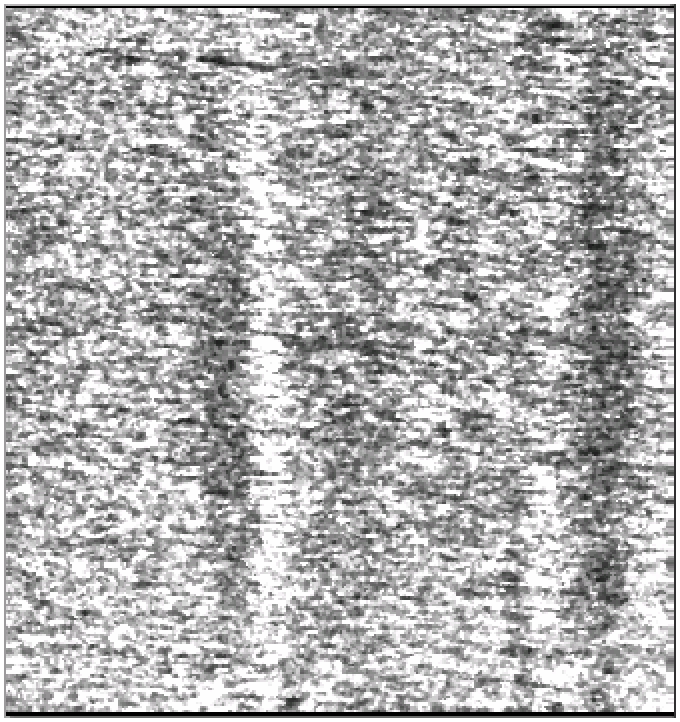


Figure 38. ConEdison Pipe 1 Position 2 Scanned Image

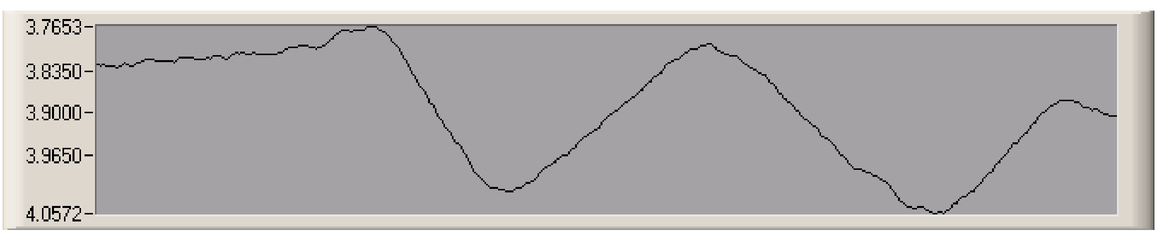


Figure 39. ConEdison Pipe 1 Position 2 Surface Profile

3.8.2.3 Pipe 2 Results

See Table 8.

3.8.2.4 WZIM Inspection System Data

Pipe 2 was created using a high pressure condition on a 4-in., HDPE pipe (Table 7). Three tests were performed on this pipe at equal distances around the circumference. The test results from WZIM performed on this pipe are shown in Figures 40 through 45. Figure 40 shows the image of the scanned joint.

Table 8. ConEdison HDPE Pipe 2

No.	Size (in.)	Condition	Temp (°F)	Pressure (psi)	Heat Soak (s)	WZIM Observation	WZIM Results	Bend Test Results
2	4	High Pressure				No Line	Pass	Pass
2	4	High Pressure				No Line	Pass	Pass
2	4	High Pressure				No Line	Pass	

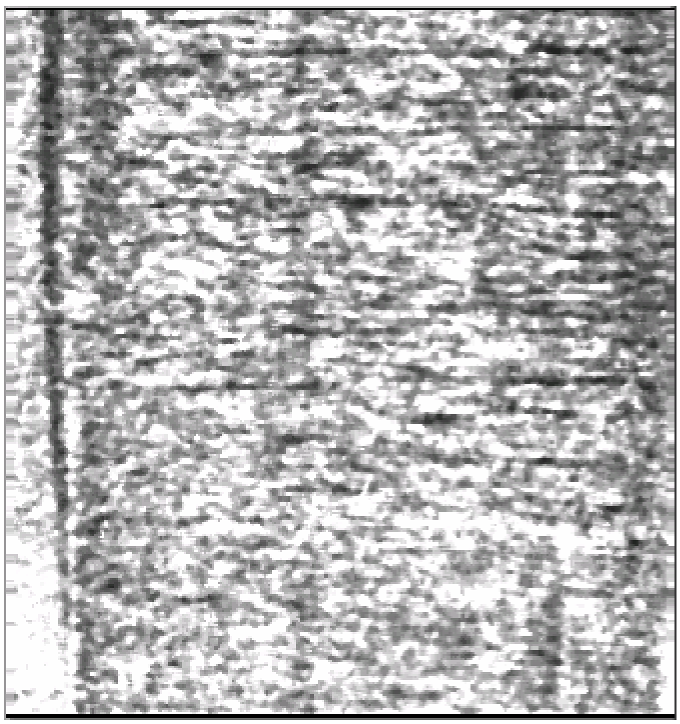


Figure 40. ConEdison Pipe 2 Position 1 Scanned Image

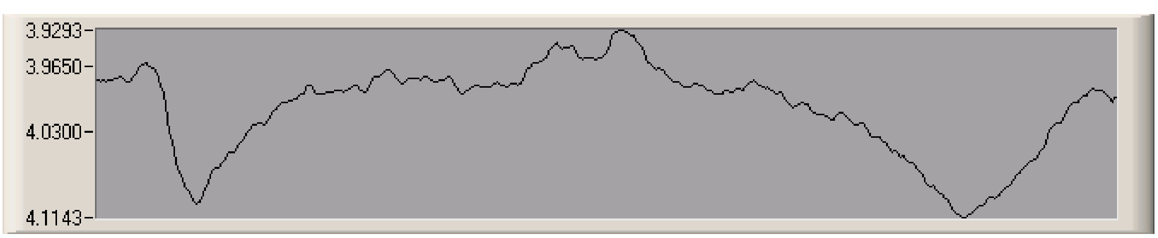


Figure 41. ConEdison Pipe 2 Position 1 Surface Profile

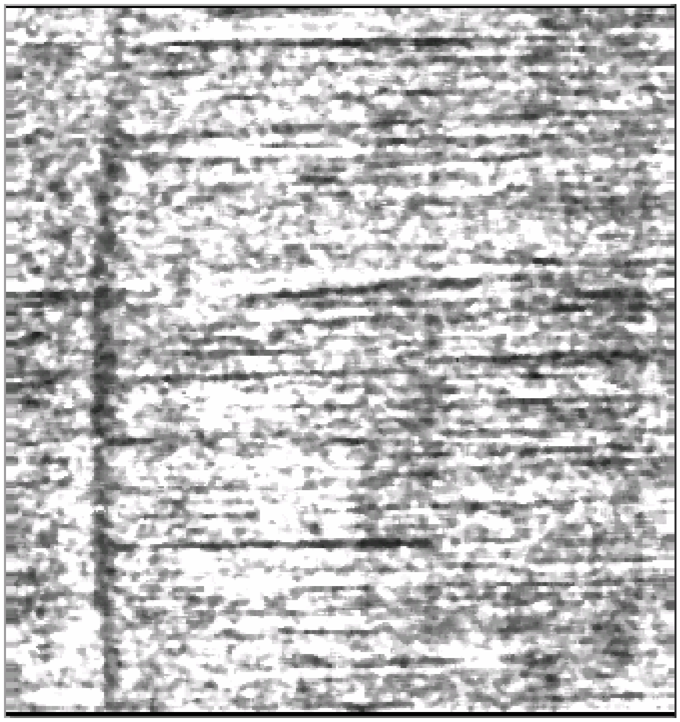


Figure 42. ConEdison Pipe 2 Position 2 Scanned Image

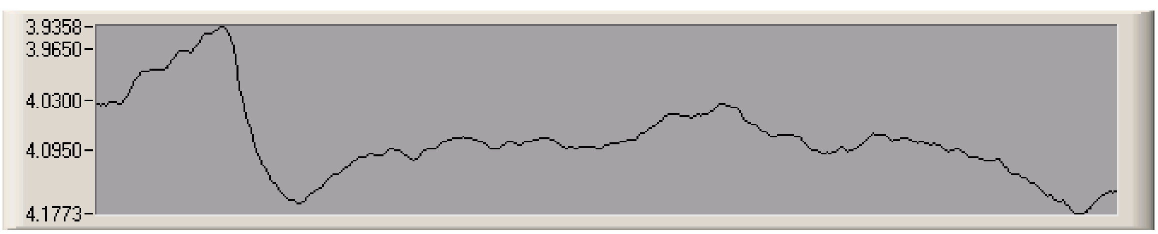


Figure 43. ConEdison Pipe 2 Position 2 Surface Profile

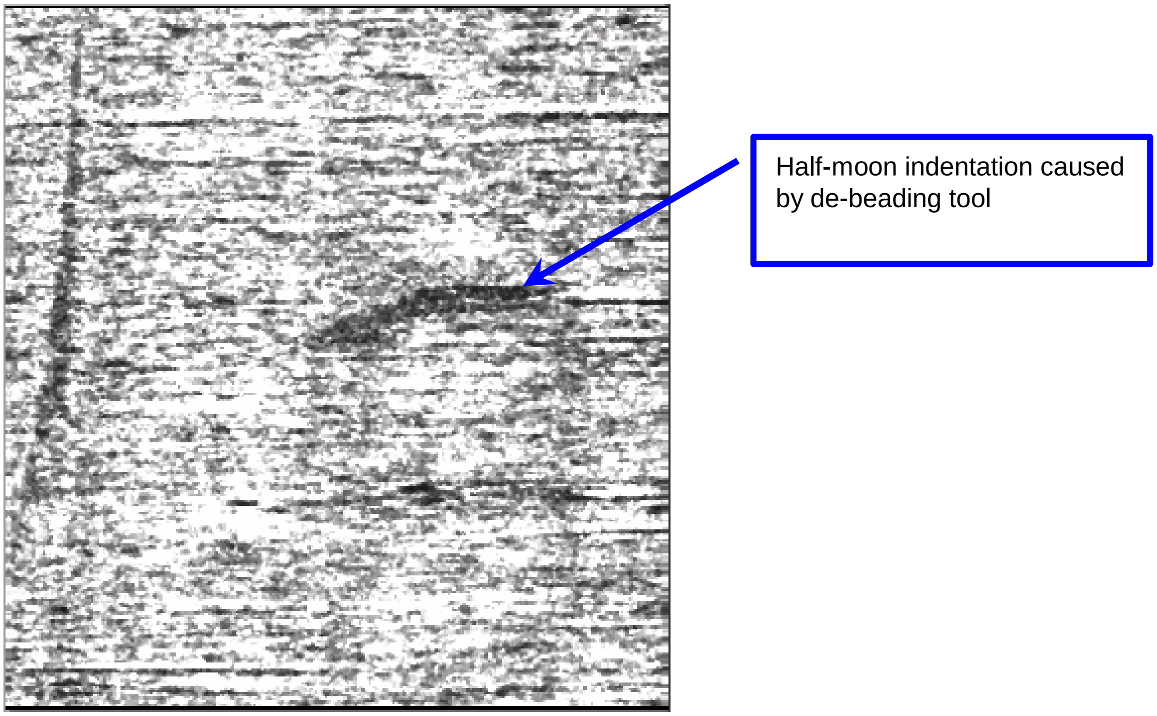


Figure 44. ConEdison Pipe 2 Position 3 Scanned Image

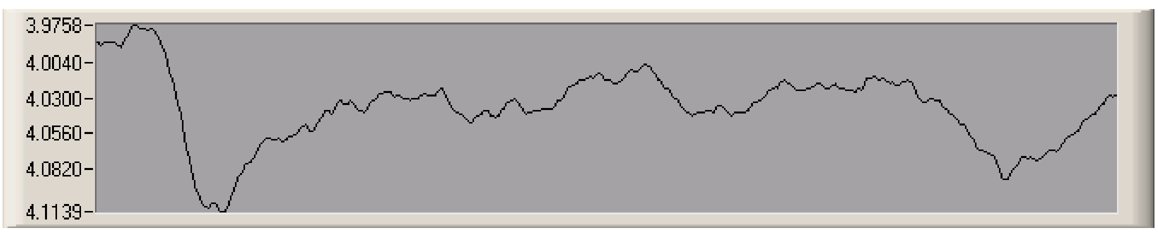


Figure 45. ConEdison Pipe 2 Position 3 Surface Profile

Figure 44 is an example of the indentation that is sometime left from a dull, manual de-beading tool. The half-moon shapes interfere with the WZIM system's interpretation of the surface, so they need to be sanded down.

The WZIM system correctly identified each of the three tests as a pass. The operator then visually inspected the joint area and saw no evidence of a line or ridge formation on the surface.

3.8.2.5 Pipe 3 Results

See Table 9.

Table 9. ConEdison HDPE Pipe 3

No.	Size (in.)	Condition	Temp (°F)	Pressure (psi)	Heat Soak (s)	WZIM Observation	WZIM Results	Bend Test Results
3	4	Low Pressure				No Line	Pass	Fail
3	4	Low Pressure				Line	Pass	Fail

3.8.2.6 WZIM Inspection System Data

Pipe 3 was fused with a low pressure condition (Table 8). This condition generally causes the fusion zone to be larger because of the low pressure used in fusing the joints together. Figure 46 shows that the first test on this pipe was within the limits of the laser window and so there is a high confidence in the result of this first test. It is also clear in Figure 47, that both edges of the weld zone are apparent in the single profile. The WZIM system result produces a pass outcome, indicating that no line on the surface exists. This was also verified visually by the operator, after the WZIM local heating was applied. The WZIM system result produces a pass outcome, indicating that no line on the surface exists. This was also verified visually by the operator, after the WZIM local heating was applied.

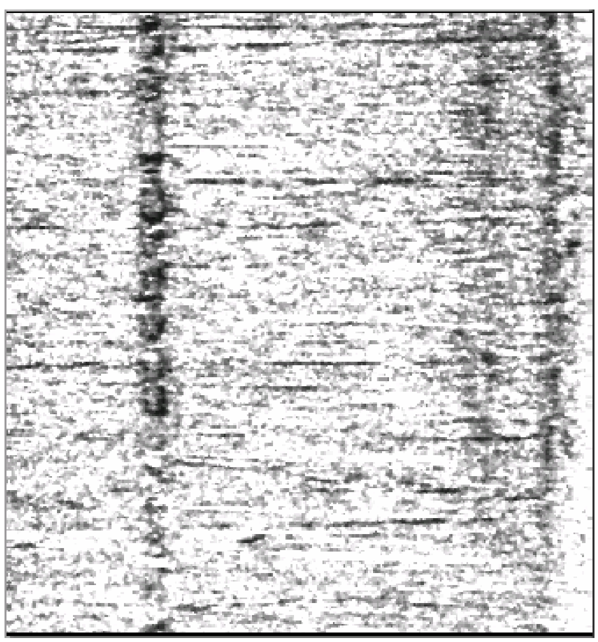


Figure 46. ConEdison Pipe 3 Position 1 Scanned Image

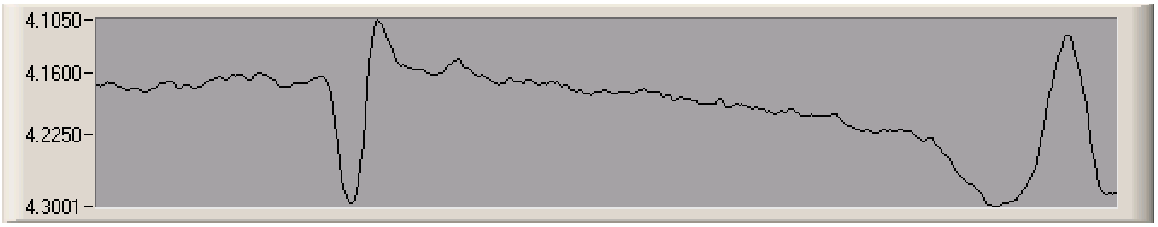


Figure 47. **ConEdison Pipe 3 Position 1 Surface Profile**

The weld zone area in the case of the second test on Pipe 3 was wider than the WZIM laser window. This means that the WZIM could not accurately determine the joint integrity. The result of this test is considered invalid due to the WZIM system laser not being able to see the entire joint area. Figures 48 and 49 show that the joint area is outside the viewable range of the laser. This yields a low confidence level that the laser could interpret the profile of the joint and the test should be considered invalid.

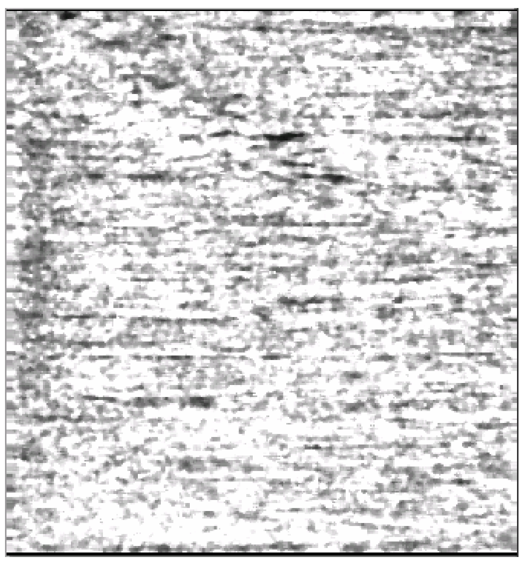


Figure 48. **ConEdison Pipe 3 Position 2 Scanned Image**

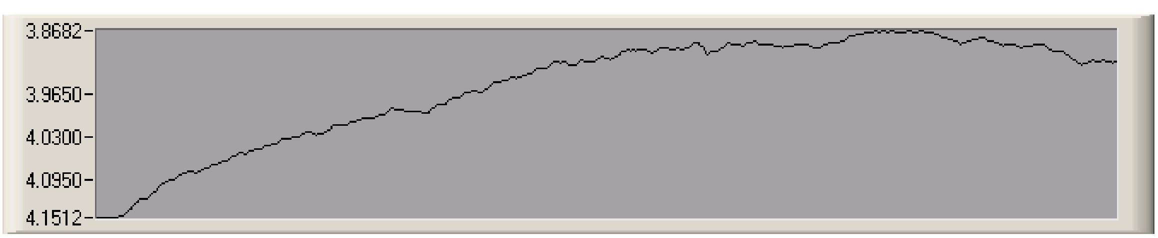


Figure 49. **ConEdison Pipe 3 Position 2 Surface Profile**

3.8.2.7 Pipe 4 Results

See Table 10.

Table 10. ConEdison HDPE Pipe 4

No.	Size (in.)	Condition	Temp (°F)	Pressure (psi)	Heat Soak (s)	WZIM Observation	WZIM Results	Bend Test Results
4	4	Low Temperature				Line	Uncertain	Fail

3.8.2.8 WZIM Inspection System Data

Pipe 4 fusion joint was created with a low temperature condition (Table 9). This usually results in no fuse at all, or a minimal fusion area. It was clear before the WZIM method was even applied to test this joint, there was no fusion zone and the joint was bad. The joint did not even bond at the surface. The WZIM system had not been programmed to interpret this type of condition as this condition had never been seen before in all the lab samples. Regardless, the WZIM system inspected the joint and assigned an uncertain rating (Figures 50 and 51) because it had not seen this condition before. It should be noted that should this condition appear in the field, the operator would be skilled enough to know that the joint was bad and would not need the WZIM system to determine pipe joint integrity. The operator assessed Pipe 4 as bad before the WZIM system was applied.

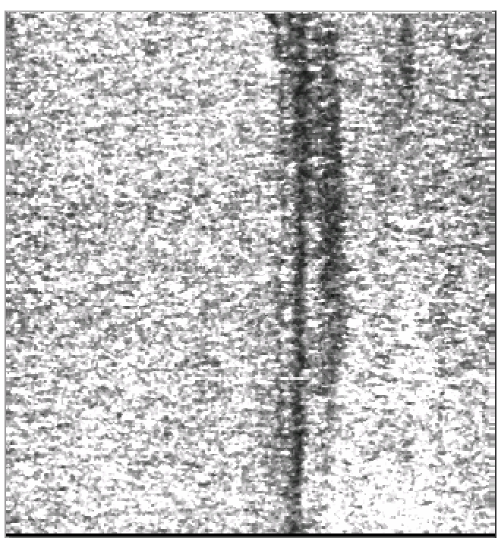


Figure 50. ConEdison Pipe 4 Position 1 Scanned Image

Figure 51. ConEdison Pipe 4 Position 1 Surface Profile

3.8.2.9 Pipe 6 Results

See Table 11.

Table 11. ConEdison HDPE Pipe 6

No.	Size (in.)	Condition	Temp (°F)	Pressure (psi)	Heat Soak (s)	WZIM Observation	WZIM Results	Bend Test Results
6	6	Standard				No Line	Pass	
6	6	Standard				No Line	Pass	

3.8.2.10 WZIM Inspection System Data

Pipe 6 was fused under standard conditions and was a 6-in., HDPE pipe (Table 10). Two tests were performed at opposite orientations about the circumference of the pipe. Figures 52 and 53 are the images of the surface after the WZIM system has performed the local heating and produced the laser scans. Figure 53 shows the single profile across the surface of the weld zone. The confidence in the result of this test is high. The WZIM system correctly assigned a pass result to this test, and the operator visually verified that there was no line on the surface.

The second test performed produced a pass result and the images from the WZIM tool are shown in Figures 54 and 55. The WZIM system correctly assigned a pass result to this test sample.

3.8.2.11 Pipe 11 Results

See Table 12.

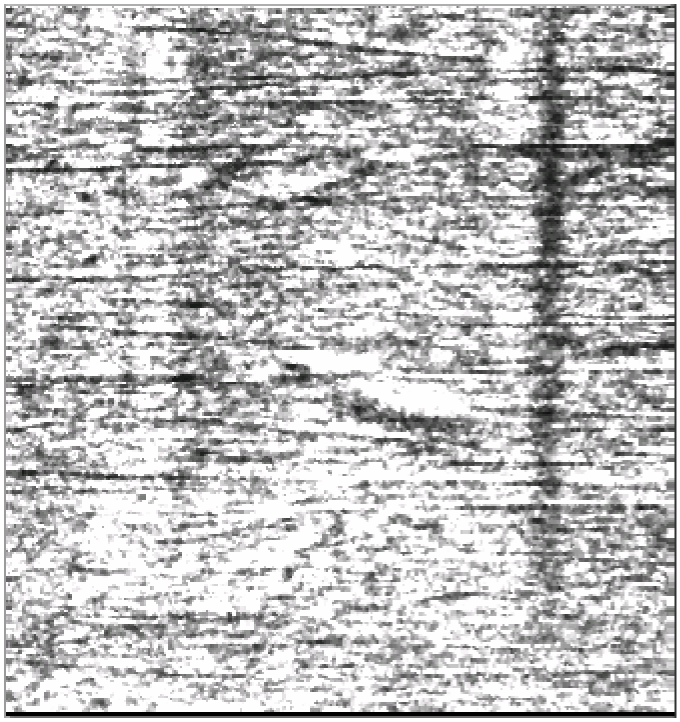


Figure 52. **ConEdison Pipe 6 Position 1 Scanned Image**

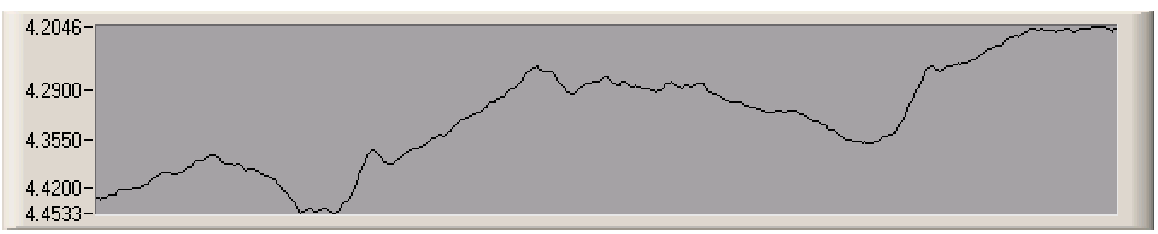


Figure 53. **ConEdison Pipe 6 Position 1 Surface Profile**

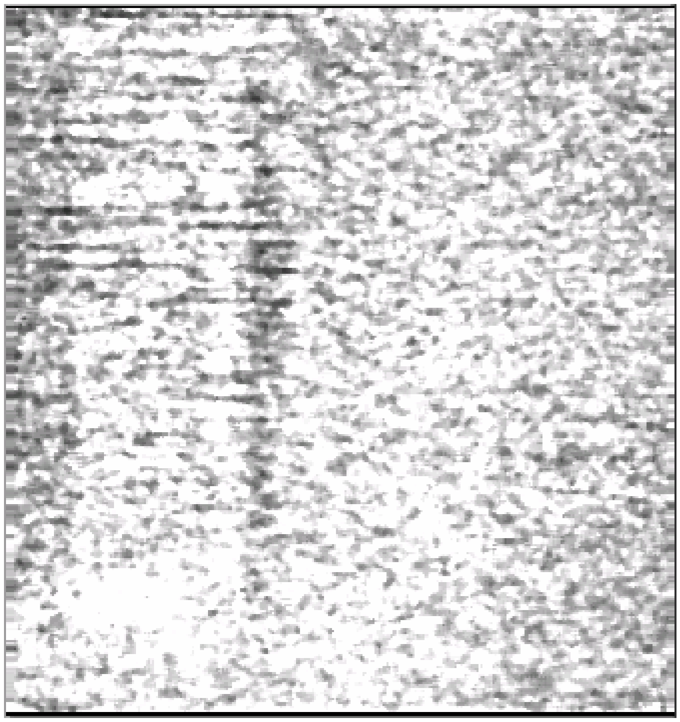


Figure 54. **ConEdison Pipe 6 Position 2 Scanned Image**

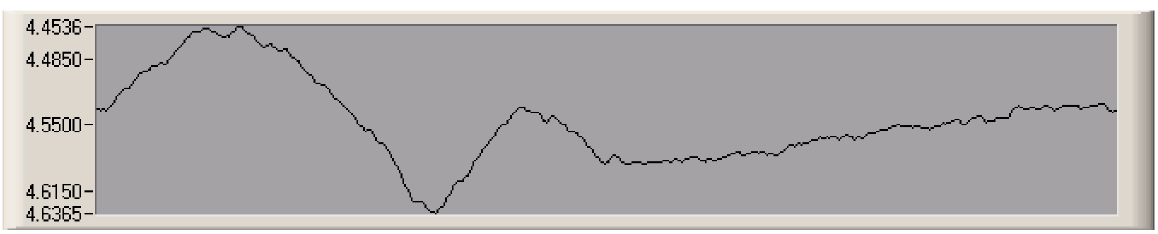


Figure 55. **ConEdison Pipe 6 Position 2 Surface Profile**

Table 12. **ConEdison HDPE Pipe 11**

No.	Size (in.)	Condition	Temp (°F)	Pressure (psi)	Heat Soak (s)	WZIM Observation	WZIM Results	Bend Test Results
11	4	Cool down				Line	Uncertain	Fail

3.8.2.12 WZIM Inspection System Data

Pipe 11 was created by a special set of parameters (Table 11). During the fusion process, the hot plate was removed and the joint was allowed to sit for 45 seconds before the two ends were butted together to form a joint. This condition produced little to no fusion zone. Again, this is a case the WZIM system was not programmed to interpret. The positive aspect is that the WZIM system gave the joint an uncertain result as it was programmed to do this when it perceived a condition it had not yet encountered (Figures 56 and 57). The operator visually inspected the joint and saw an obvious non-fused condition prior to using the WZIM system to inspect the joint.

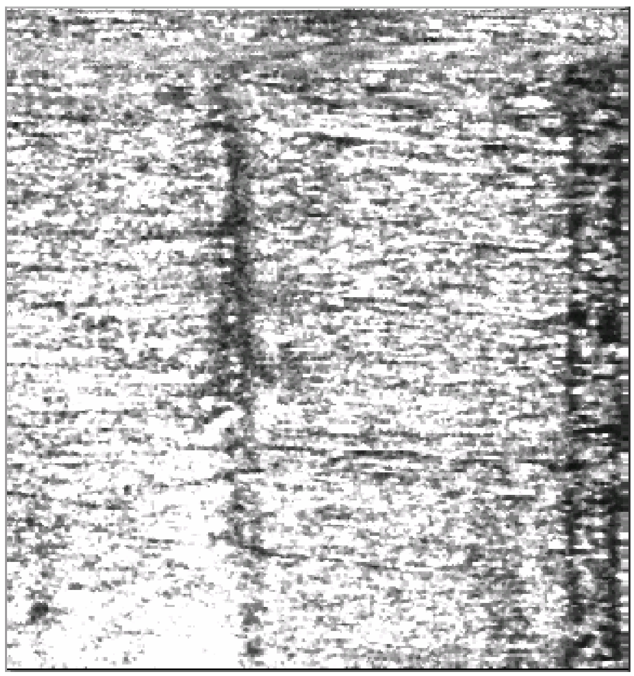


Figure 56. ConEdison Pipe 11 Position 1 Scanned Image

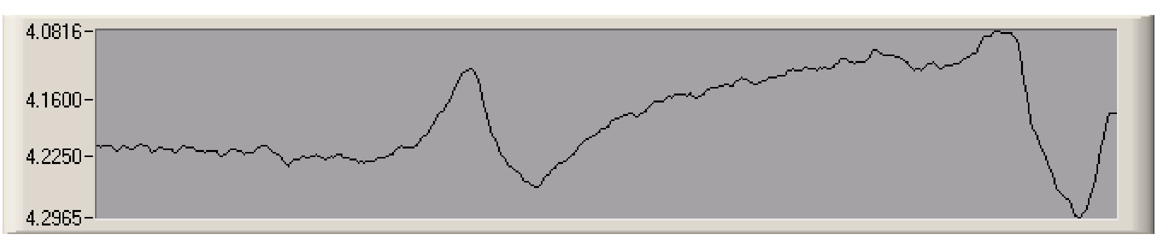


Figure 57. ConEdison Pipe 11 Position 1 Surface Profile

3.8.2.13 Pipe 12 Results

See Table 13.

Table 13. ConEdison HDPE Pipe 12

No.	Size (in.)	Condition	Temp (°F)	Pressure (psi)	Heat Soak (s)	WZIM Observation	WZIM Results	Bend Test Results
12	6	Cool down				Line	Fail	Pass
12	6	Cool down				Line	Fail	Pass

3.8.2.14 WZIM Inspection System Data

Pipe 12 was a 6-in.-diameter, HDPE pipe (Table 12). The condition on this joint was produced with a special set of parameters, just like the previous Pipe 11. During the fusion process, the hot plate was removed and the joint was allowed to sit for 45 seconds before the two ends were butted together to form a joint. In this case, a joint was formed that had a visible weld zone area. Figures 58 and 61 show the scanned images of the surface and profiles. In both inspections, the WZIM system correctly identified the joint as bad and assigned a fail result to the output. The operator visually verified that a line had formed on both test samples.

3.8.3 KeySpan Facility

The second set of field trials took place at the KeySpan facility in Hicksville, New York. This facility was joining MDPE pipe and one HDPE pipe during the field trials in 4-, 6-, and 8-in. diameters. The joints were hot-plate welded using a McElroy hot-plate butt welding machine for the 4- and 6-in. diameters and a manual method for the 8-in.-diameter joints. Figures 62 through 65 are from the field trials with KeySpan.

3.8.3.1 Pipe 1 Results

See Table 14.

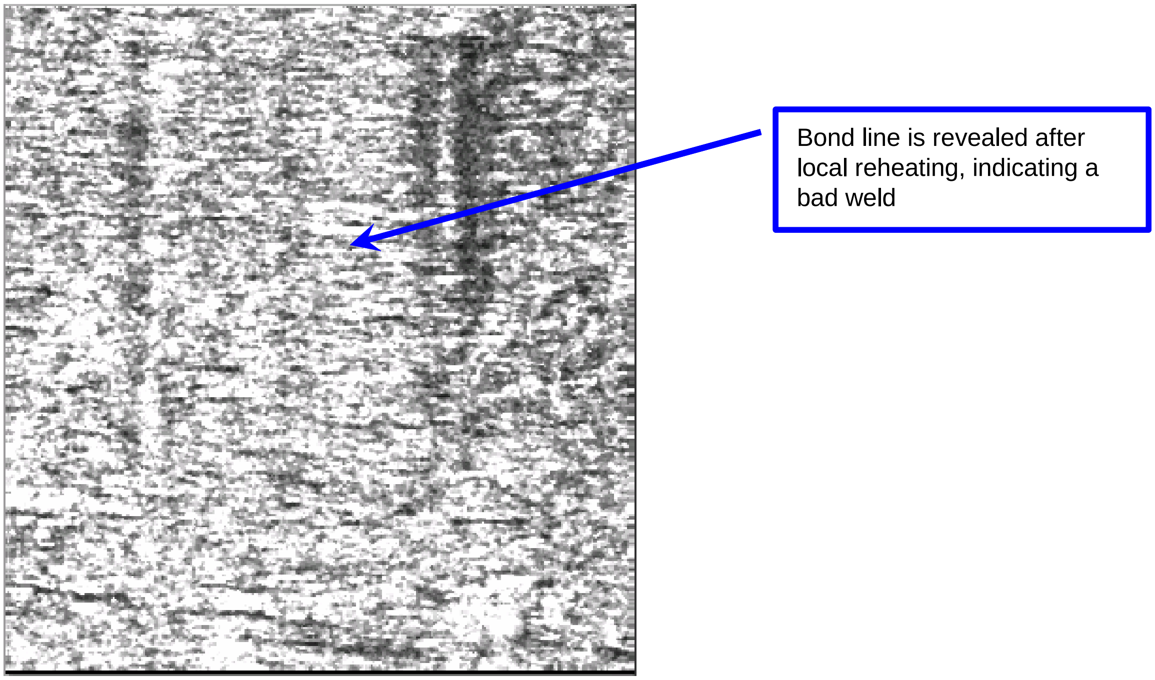


Figure 58. ConEdison Pipe 12 Position 1 Scanned Image

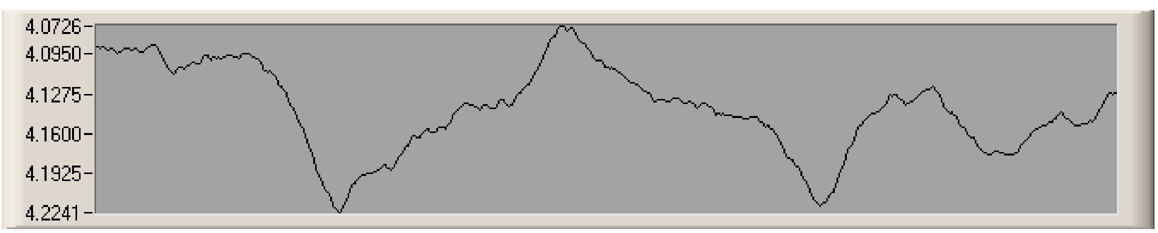


Figure 59. ConEdison Pipe 12 Position 1 Surface Profile

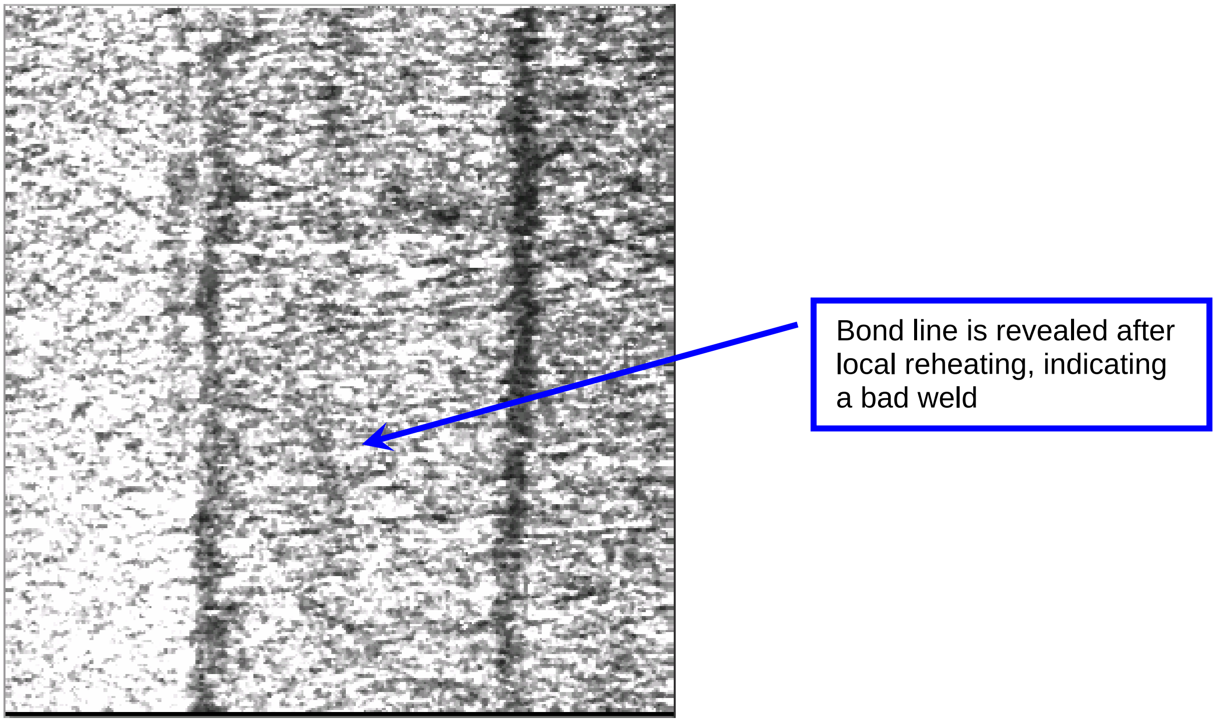


Figure 60. ConEdison Pipe 12 Position 2 Scanned Image

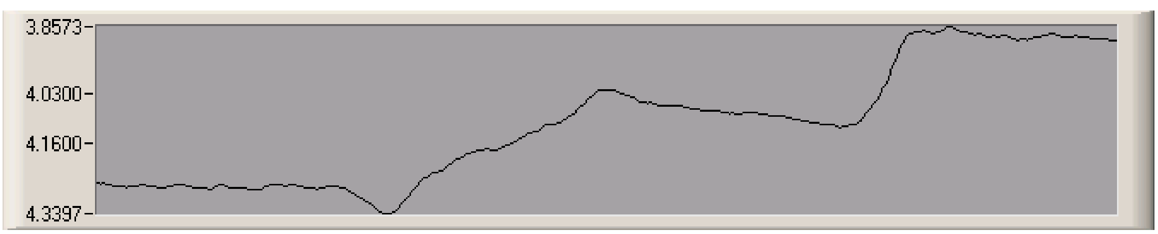


Figure 61. ConEdison Pipe 12 Position 2 Surface Profile

Figure 62. Operator Awaiting Results from WZIM Inspection using Tool on MDPE Pipe at KeySpan Facility during Field Trials

Figure 63. WZIM Inspection Tool Performing Laser Scanning Sequence during Field Trials at KeySpan Facility

Figure 64. Operator Awaits WZIM Inspection Tool Results on Laptop Screen

Figure 65. WZIM Inspection Tool on 8-in. MDPE Pipe during Field Trials with KeySpan

Table 14. KeySpan MDPE Pipe 1

No.	Size (in.)	Condition	Temp (°F)	Pressure (psi)	Heat Soak (s)	WZIM Observation	WZIM Results	Bend Test Results
1	4	Standard				No Line	Pass	Pass
1	4	Standard				Ridge	Uncertain	Pass

3.8.3.2 WZIM Inspection System Data

The first pipe tested at KeySpan was Pipe 1, a 4-in. diameter, MDPE welded under standard conditions (Table 13). The WZIM inspection system correctly identified the no-line condition on the first test. Figure 66 is the image of the scanned surface after local heat was applied. It is clear that the formation of a line cannot be found within the image. Figure 67 shows a profile across the joint. This profile fits within the window of the laser and both edges of the joint area are clearly seen. The WZIM system identified a pass result for this joint.

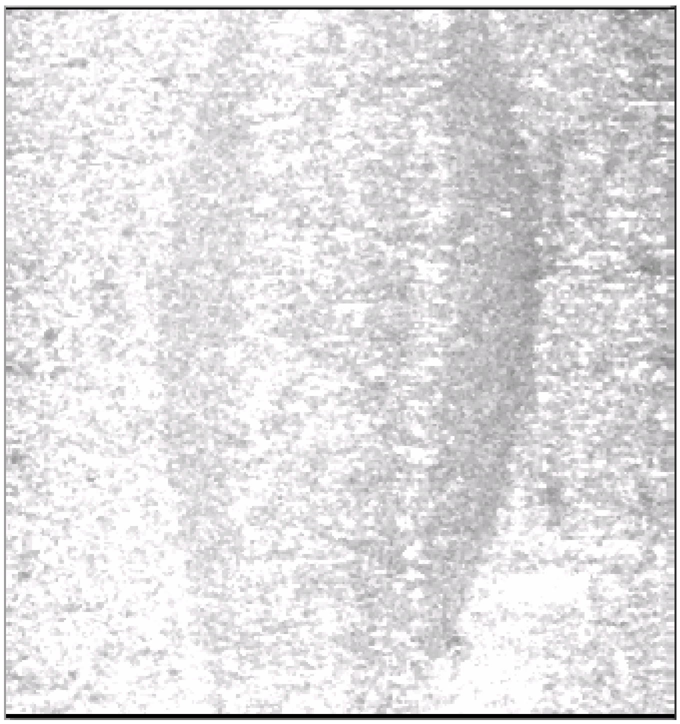


Figure 66. KeySpan Pipe 1 Position 1 Scanned Image

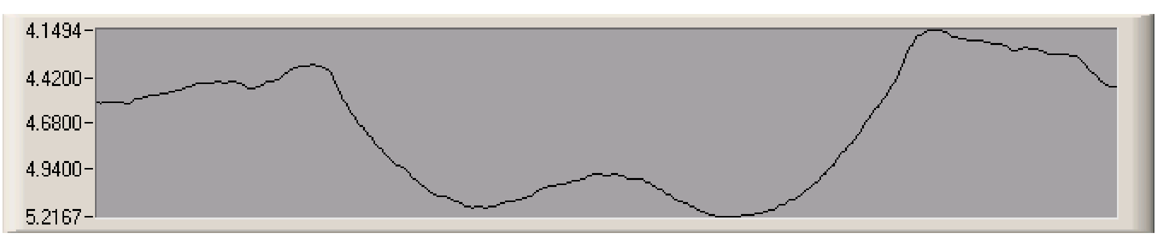


Figure 67. KeySpan Pipe 1 Position 1 Surface Profile

Figure 68 is the image from the second WZIM test performed on Pipe 1. This image shows a definite ridge in the weld zone area. Figure 69 shows a single profile across the joint surface. The weld zone fit well within the window of the laser sensor indicating a high confidence in the systems result. A ridge could be clearly seen on the surface of the joint by an operator. The WZIM inspection system correctly identified this joint as uncertain.

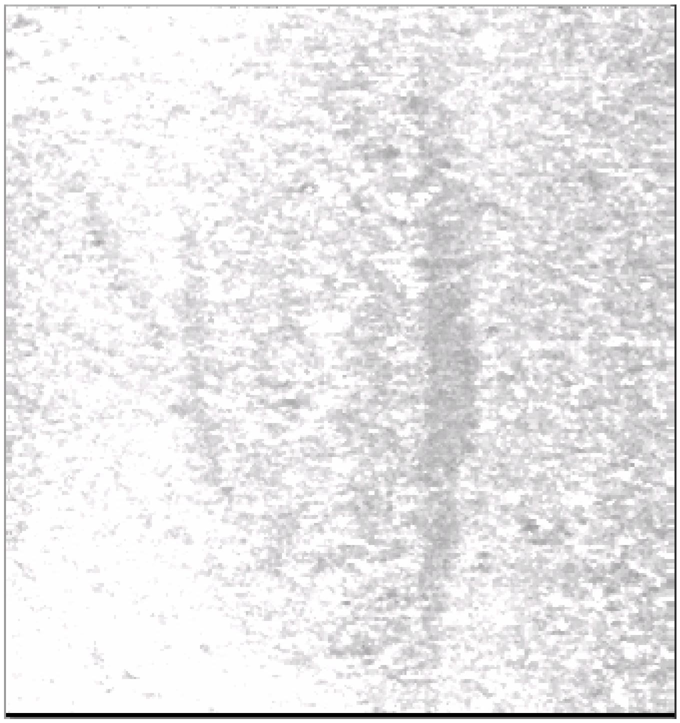


Figure 68. KeySpan Pipe 1 Position 2 Scanned Image

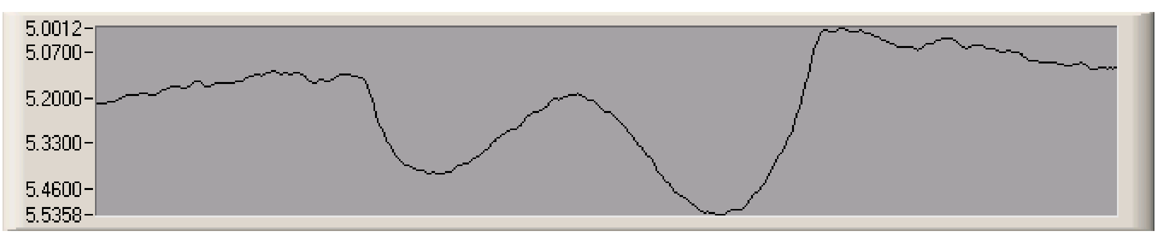


Figure 69. KeySpan Pipe 1 Position 2 Surface Profile

3.8.3.3 Pipe 5 Results

See Table 15.

Table 15. KeySpan MDPE Pipe 5

No.	Size (in.)	Condition	Temp (°F)	Pressure (psi)	Heat Soak (s)	WZIM Observation	WZIM Results	Bend Test Results
5	8	Low Temperature	280	270	80	No Line	Pass	None

3.8.3.4 WZIM Inspection System Data

Joint Pipe 5 was produced with low-temperature condition (Table 14). Figure 70 is the image of the joint and Figure 71 is a profile across the joint. After the local heat was applied using WZIM, no line was visually observed by the operator. The WZIM system correctly identified this pipe sample as pass.

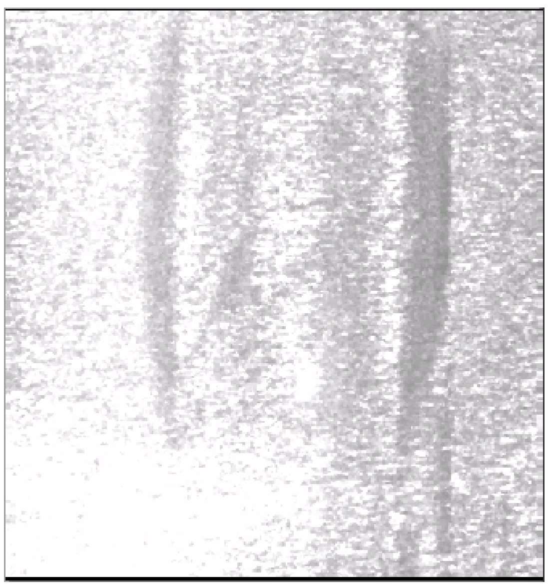


Figure 70. KeySpan Pipe 5 Position 1 Scanned Image

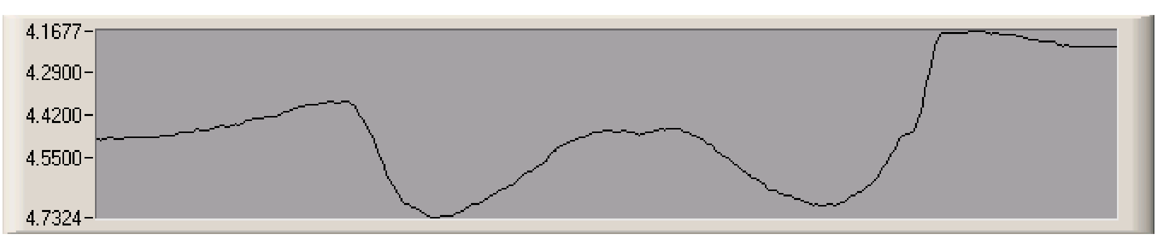


Figure 71. KeySpan Pipe 5 Position 1 Surface Profile

3.8.3.5 Pipe 6 Results

See Table 16.

Table 16. KeySpan MDPE Pipe 6

No.	Size (in.)	Condition	Temp (°F)	Pressure (psi)	Heat Soak (s)	WZIM Observation	WZIM Results	Bend Test Results
6	8	Low Pressure	500	67.8	75	No Line	Pass	None
6	8	Low Pressure	500	67.8	75	No Line	Uncertain	None

3.8.3.6 WZIM Inspection System Data

Samples from Pipe 6 were created with a low-pressure condition (Table 15). This generally causes the weld fusion area to be larger than expected. In these cases, the fusion zone was larger than the window of the laser sensor so an accurate measurement cannot be made. This is clear in the image of the scanned pipe in Figure 72 and in the single profile across the joint in Figure 73. The system produced a result and classified the joints, but the confidence in the classification of both tests performed on this pipe is low due to the weld zone size being larger than the field of view of the WZIM system. Two tests were performed on Pipe 6. Figures 74 and 75 also indicate the joint area was outside of the laser window field of view.

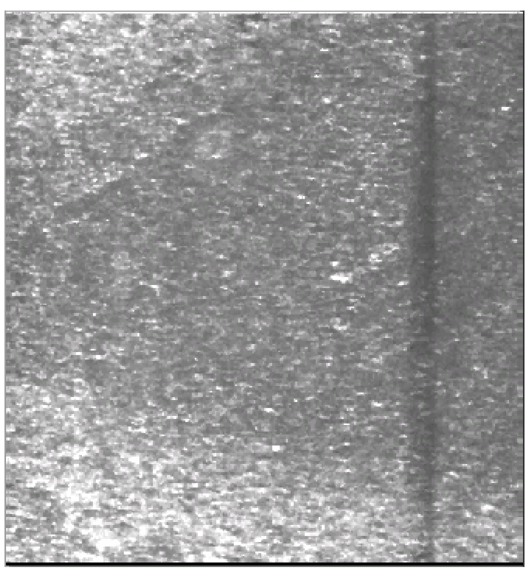


Figure 72. KeySpan Pipe 6 Position 1 Scanned Image

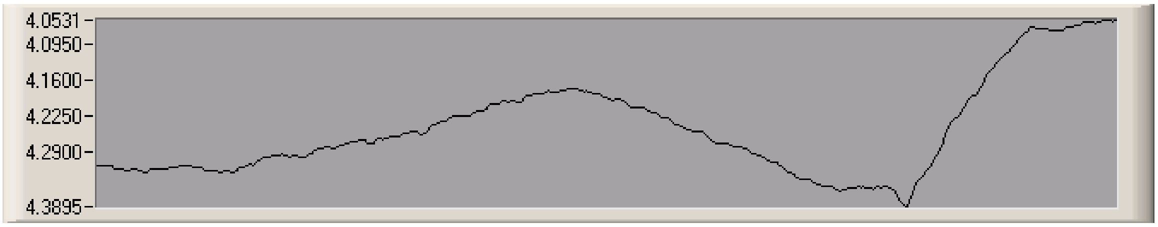


Figure 73. **KeySpan Pipe 6 Position 1 Surface Profile**

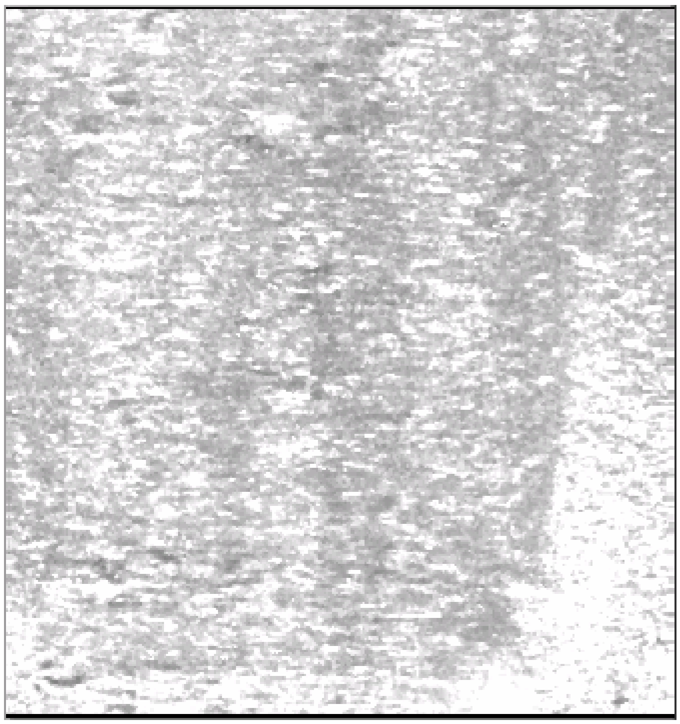


Figure 74. **KeySpan Pipe 6 Position 2 Scanned Image**

Figure 75. **KeySpan Pipe 6 Position 2 Surface Profile**

3.8.3.7 KeySpan Pipe 10 Results

See Table 17.

Table 17. KeySpan HDPE Pipe 10

No.	Size (in.)	Condition	Temp (°F)	Pressure (psi)	Heat Soak (s)	WZIM Observation	WZIM Results	Bend Test Results
10	6	Low Temperature	280	280	65	No Line	Pass	Fail
10	6	Low Temperature	280	280	65	Line	Fail	Fail

3.8.3.8 WZIM Inspection System Data

Pipe 10 was HDPE and was made with a low-temperature condition (Table 16). Two tests were performed on this pipe and both test results were different. The first test did not produce a characteristic line on the surface of the weld, as verified visually by the operator. Figure 76 shows the image of the sample and no line is visible on the image. Figure 77 is the single profile across the joint. The second test on this pipe produced a visible line on the surface of the pipe, as viewed by the operator. The WZIM system correctly identified the line and produced a fail output (Figures 78 and 79). It is interesting to note that one side of the joint produced a line after WZIM was applied and the other side pipe did not. What is also interesting to note is that a destructive bend test was performed on each section, with one section passing and the other section failing the destructive bend test, further validating the WZIM results.

3.8.3.9 Pipe 11 Results

See Table 18.

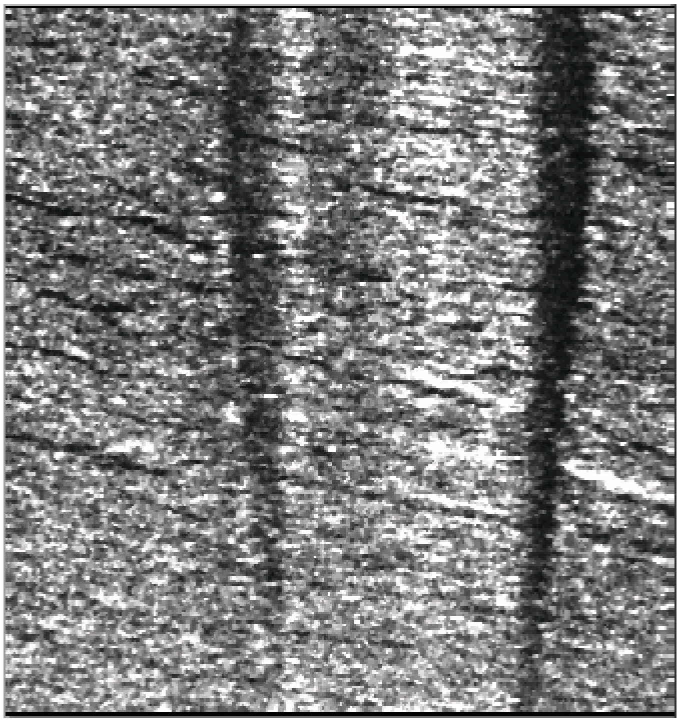


Figure 76. KeySpan Pipe 10 Position 1 Scanned Image

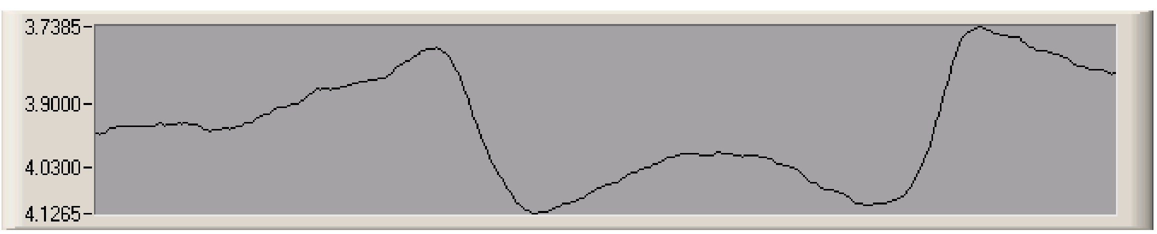


Figure 77. KeySpan Pipe 10 Position 1 Surface Profile

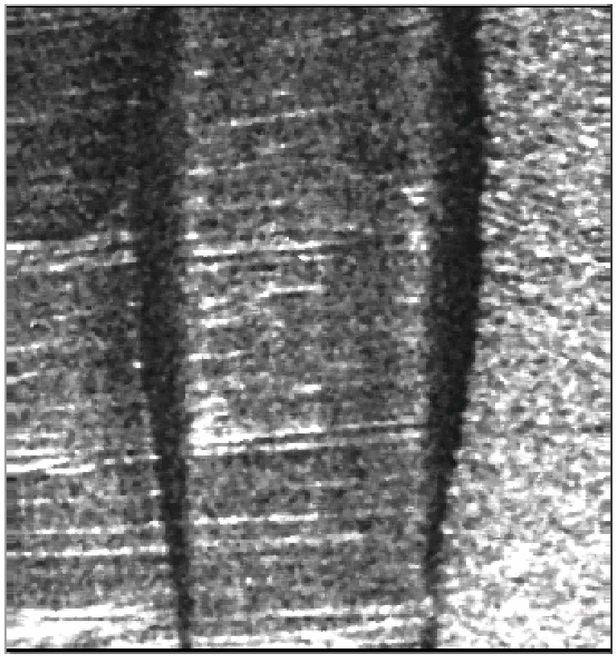


Figure 78. **KeySpan Pipe 10 Position 2 Scanned Image**

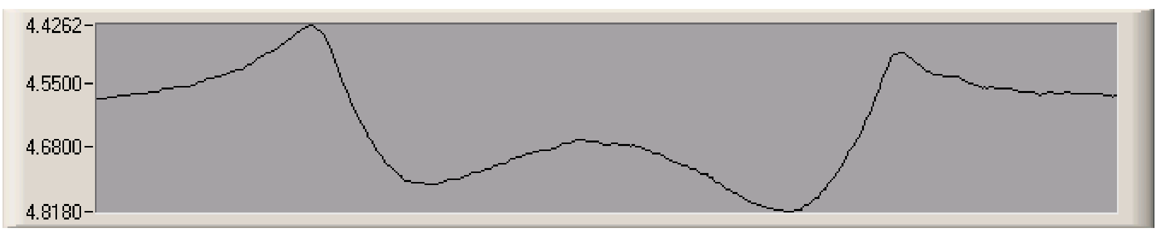


Figure 79. **KeySpan Pipe 10 Position 2 Surface Profile**

Table 18. **KeySpan MDPE Pipe 11**

No.	Size (in.)	Condition	Temp (°F)	Pressure (psi)	Heat Soak (s)	WZIM Observation	WZIM Results	Bend Test Results
11	4	Cool down	500	Manual	29 + cool for 30	No Line	Uncertain	Pass
11	4	Cool down	500	Manual	29 + cool for 30	Sharp Ridge	Pass	Fail

3.8.3.10 WZIM Inspection System Data

Pipe 11 was created with a cool down condition but at standard welding parameters (Table 17). The cool down is described as heating the joint sections with the hot plate, but then allowing them to cool for 30 seconds before fusing them together to create a weld. The operator did not observe a line on the surface of the weld after the WZIM applied local heating. Figures 80 and 82 show the scanned surface image of both positions where WZIM was applied on Pipe 11. The WZIM system produced an output of undecided for this weld sample. However, as seen in Figures 81 and 83, the profiles of the surface of the joint did not fit within the field of view of the WZIM system. The confidence in the WZIM system result for each of these samples on Pipe 11 is low due to the fact that the joint could not fit within the WZIM system field of view so it could not be accurately measured.

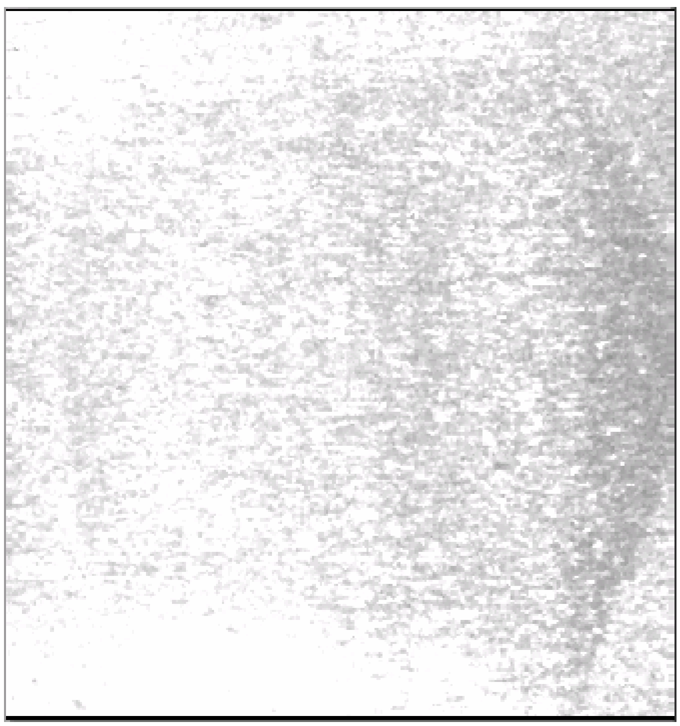


Figure 80. KeySpan Pipe 11 Position 1 Scanned Image

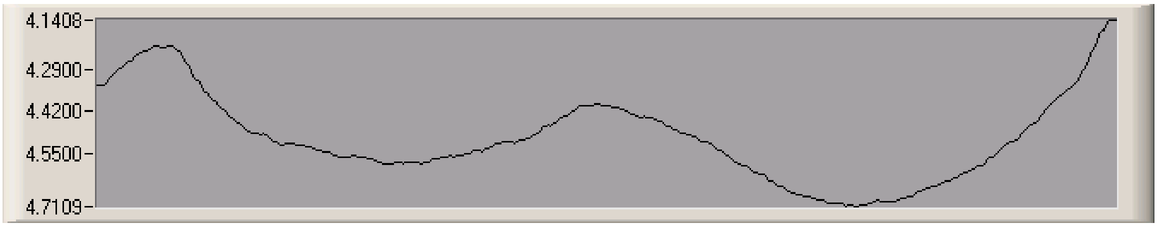


Figure 81. KeySpan Pipe 11 Position 1 Surface Profile

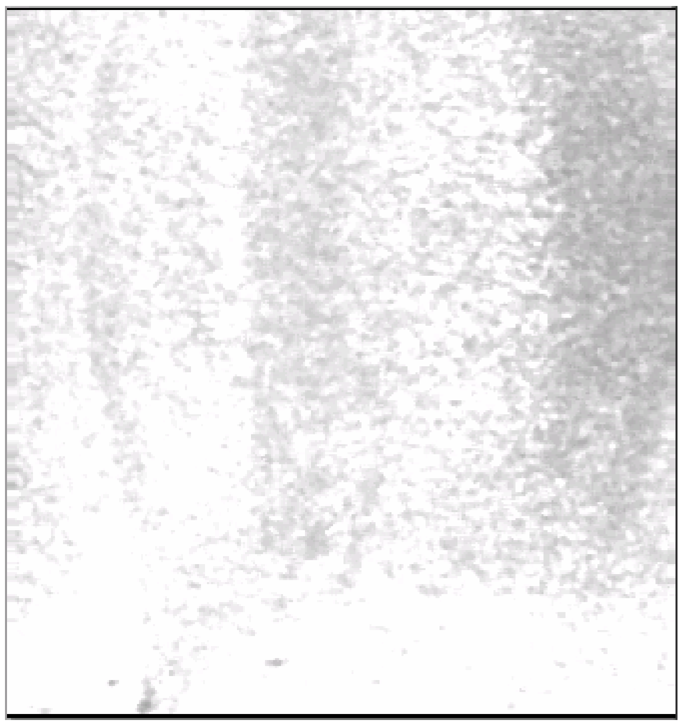


Figure 82. KeySpan Pipe 11 Position 2 Scanned Image

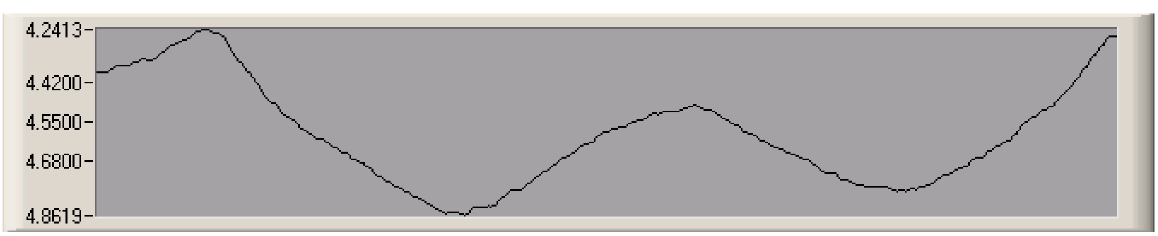


Figure 83. KeySpan Pipe 11 Position 2 Surface Profile

4.0 Results and Discussion

The prototype laser tool incorporating the WZIM method performed well for correctly identifying the surface features of line, no-line, and ridge condition on PE butt fusion joints. Future generations of the tool will require hardware changes to make is easier and less reliant on the operator to correctly position upon the pipe. The Field Testing task of this project helped determine the current status of the WZIM technology, what it can and cannot inspect and the progression toward commercialization.

4.1 Operator Observations and Bend Tests

The WZIM method was proven and validated using two forms of destructive testing including tensile tests and creep rupture tests. The WZIM method was never compared or validated using a bend test which PE pipe operators currently use as their indication of PE butt weld integrity. The operators also believe that the bend test can detect only extreme cases of reduced quality welds. The results of bend tests have been included in the data for reference only. The pipeline operators predicted the outcome of the joints they fused before any WZIM or bend testing was completed. Based on their experience and know-how, they predicted what would happen when the bend test was performed, based on physical characteristics of the fused joint. The operators were not always correct in their prediction, demonstrating the need for an automated system for testing PE pipe quality. Other assumptions about the cold weld defect also arose. It was initially thought that the defect would exist around the entire pipe joint. It was observed during the field trials that this was not always the case (Figure 84). In one instance, two straps were cut from the same pipe during field testing (KeySpan MDPE Pipe 11). One strap passed the bend test and the second strap failed the bend tests, further demonstrating the need for an automated, sensitive system for testing PE pipe quality.

4.1.1 Pipe Samples and Field Test Preparations

PE pipe can produce a good butt fusion joint with a wide set of parameters. Because of this, it was hard to create a bad weld containing a "LOF" defect. In order to create such a defect, some joints were made at conditions so far out of specification that either they would not be expected in the field or the weld joint was so noticeably deformed that a WZIM test would not be necessary to determine the integrity of the joint.

Figure 84. Cold Weld Defect on Small Section of Joint Interface (Notice that the cold weld defect does not exist over the entire joint.)

Some pipes provided and tested during the field test were not representative of the original pipe samples (marked A through Z) which were used during this project for validation and algorithm development. In these instances, the WZIM laser tool was inspecting conditions it had not seen before and had not been programmed to detect. The “no weld zone” condition is a fusion joint characteristic that the WZIM inspection tool had not been subjected to.

On some of the PE joint samples that underwent the destructive bend tests, the weld defect was not consistent throughout the joint (Figure 84). It is important to keep this in mind when determining repeatability of the laser tool, because testing was completed on at least two places around each pipe.

4.1.2 WZIM Tool Results

The prototype WZIM laser tool performed well at detecting the characteristic WZIM “line” on the surface of the joint which results in a fail rating. The prototype WZIM laser tool performed well at detecting the characteristic WZIM “no line” condition which results in a pass rating. The WZIM laser tool performed satisfactory at detecting the “ridge or slight projection” condition that results in an uncertain rating. As expected, the WZIM laser tool could not interpret joint conditions it had not seen before such as the “no fusion zone” condition which it encountered during these field trials.

A total of 22 tests were performed during field trials on MDPE and HDPE pipe. Of the 22 joint tests, five joint tests were from weld zones that were larger than the WZIM system field of view and could not be interpreted. Of the 22 joint tests, two joint tests were from pipes that had no fusion zones, a condition that the WZIM inspection tool was not programmed to be able to detect and identify. This leaves a total of 15 valid pipe tests. Table 18 shows a breakdown of the number of successful WZIM results divided by the total number of WZIM tests performed per defect type. Of the 15 valid pipe tests, nine did not exhibit evidence of a bond line at the surface and were considered passing welds. The WZIM inspection tool correctly identified all nine joints as pass. Of the 15 valid pipe tests, three exhibited a bond line visible at the surface and were considered to be of reduced quality. The WZIM inspection tool correctly identified all three joints as fail. Of the 15 valid pipe tests, three showed a ridge or projection on the surface. The WZIM inspection tool correctly identified two out of three of the joints as “uncertain”.

4.1.3 Tabulated Test Results

The field testing samples were rated and documented based on several items per each test. Please note that “*” indicates the joint area was too wide for the WZIM laser tool to interpret correctly. Please note that “+” indicates the joint area had no fusion zone, a condition that the WZIM laser tool had never encountered. Tabulated results of all pipe samples testing during the field trials is in Table 19.

Table 19. Ratio of Correct WZIM Tests Results per Total Number of Test Completed
(This includes only valid test results from the field trials.)

Results	Number of Joints with ***No Line*** Successfully Detected	Number of Joints with ***Line*** Successfully Detected	Number of Joints with ***Ridge*** Successfully Detected
Laser Results (15 valid tests)	9/9 = 100%	3/3 = 100%	2/3 = 60%

4.1.4 WZIM Laser Tool Alignment

Alignment of the WZIM laser tool is time consuming due to the limited flexibility in the design of this prototype system. However, the flexibility of the system can be greatly increased in future versions by *hardware only* changes to the prototype system.

Initial set-up (out of the box) was the most time consuming. During shipment or transport of the system, the laser and heating element inside the WZIM laser tool shifted out of place. This required an additional 30 min for set-up. After the initial set-up, alignment of the tool on the pipe joint took, on average, 5 min per pipe. Again, all set-up issues can be remedied with either changes in the laser length or changes in the alignment hardware.

4.1.5 Fusion Joint Preparation before WZIM

The joint surface preparation was time consuming when performed manually in the field. Previous samples used in the lab had been prepared using a belt sander which quickly prepared the weld surface in a matter of seconds. In the field, the standard de-beading tools used by the operators actually make it more labor intensive as they are generally dull and leave indentations in the weld zone area that need to be sanded out of the surface so they do not affect the measurement.

In the lab, the entire circumference of the weld bead was removed. It was discovered in the field that only a 2-in. length of the weld bead reinforcement needed to be removed and prepared and the prototype system could still be used.

4.1.6 WZIM Laser Application

Several welding parameters conditions resulted in a joint that had a wide fusion zone, due to a low-pressure condition when forming the butt joint. The field of the view of the WZIM inspection tool was smaller than the bond area in these few conditions. During development, all lab samples were within the field of view of the system so this had not been an issue. Regardless, this limitation can be easily overcome with a hardware modification to the laser sensor inside the WZIM system.

4.1.7 WZIM Laser Algorithm

The WZIM laser tool algorithm was designed to determine a pass or fail rating on a joint. These field tests reconfirmed the ability of the algorithm to consistently make this judgment, regardless as to whether the joint failed a bend test or the operator thought it should fail based on his experience and know-how.

The uncertain category was discovered during the course of this project as a WZIM category to assign to weld joints samples that did not have a characteristic line but that were not completely smooth across the weld zone. It has been known and documented that further work needs to be completed to fully understand the integrity of the joints that exhibit uncertain conditions. Only after the physical effects of these features with respect to the joint quality is known can the WZIM be programmed with this knowledge and thus accurately predict this condition.

The uncertain category that was programmed into the algorithm of the WZIM inspection tool was programmed for a small set of uncertain conditions, including ridge and projection.

4.2 Hardware Recommendations

The change in field of view of the laser sensor will remedy most, if not all, problems of the weld zone area not fitting within the WZIM system field of view. EWI researched this possibility to uncover the cost of this change. A replacement laser is priced around $16,000. See Appendix F.

The prototype system was developed using the most economical means possible and per the user requirements and specifications created in Task 4. A commercial unit could be made of lighter materials and smaller components. Individual power supplies for each component were left intact, and simply mounted inside the box for this pre-commercial unit. The components in the control box could easily be combined to decrease the size by at least half, simply by combining power sources into one main source with multiple power taps.

The combined weight of the laser sensor and heating source is less than a pound. The main source of weight in this prototype was positioning assembly. This component can be downsized and specified for lower weight bearing. Doing this would both decrease the size and the weight of the overall tool, making it much easier to handle and use. A commercial WZIM inspection tool could even be manufactured of different materials, such as plastic, further decreasing the weight.

The prototype WZIM inspection tool requires the user to calibrate the system once it is placed on the pipe. Although this does not take much time, it does introduce the possibility of error by requiring the operator to make the adjustment. This setting is currently accomplished with manually adjusting slides (Figure 85). One way to relieve the operator requirements is to provide for automatic adjustments. This would decrease the operator involvement down to two tasks:

1. Placing the tool onto the pipe
2. Pushing the start button.

Table 20. Tabulated Results of all Field Test Data from both NYSEARCH Facilities
(Yellow highlight indicates the test was invalid due to field of view constraints.)

Facility	Pipe Size (in.)	Welding Condition	Pipe Number	WZIM Observation	WZIM Laser Tool	Bend Test
ConEd	4	Standard	1	Ridge	Pass	
ConEd	4	Standard	1	Ridge	Uncertain	
ConEd	4	High press	2	No Line	Pass	Pass
ConEd	4	High press	2	No Line	Pass	Pass
ConEd	4	High press	2	No Line	Pass	
ConEd	4	Low press	3	No Line	Pass	Fail
ConEd	4	Low press	3*	Line	Pass	Fail
ConEd	4	Low temp	4 +	Line	Uncertain	Fail
ConEd	4	Cool down	11+	Line	Uncertain	Fail
ConEd	6	Standard	6	No Line	Pass	
ConEd	6	Standard	6	No Line	Pass	
ConEd	6	Cool down	12	Line	Fail	Pass
ConEd	6	Cool down	12	Line	Fail	Pass
KeySpan	8	Low press	6*	No Line	Uncertain	
KeySpan	8	Low press	6*	No Line	Uncertain	
KeySpan	4	Standard	1	No Line	Pass	
KeySpan	4	Standard	1	Ridge	Uncertain	
KeySpan	4	Cool down	11*	No Line	Uncertain	Fail
KeySpan	4	Cool down	11*	Ridge	Pass	Pass
KeySpan	8	Low temp	5	No Line	Pass	
KeySpan	6	Low temp	10	No Line	Pass	Fail
KeySpan	6	Low temp	10	Line	Fail	Fail

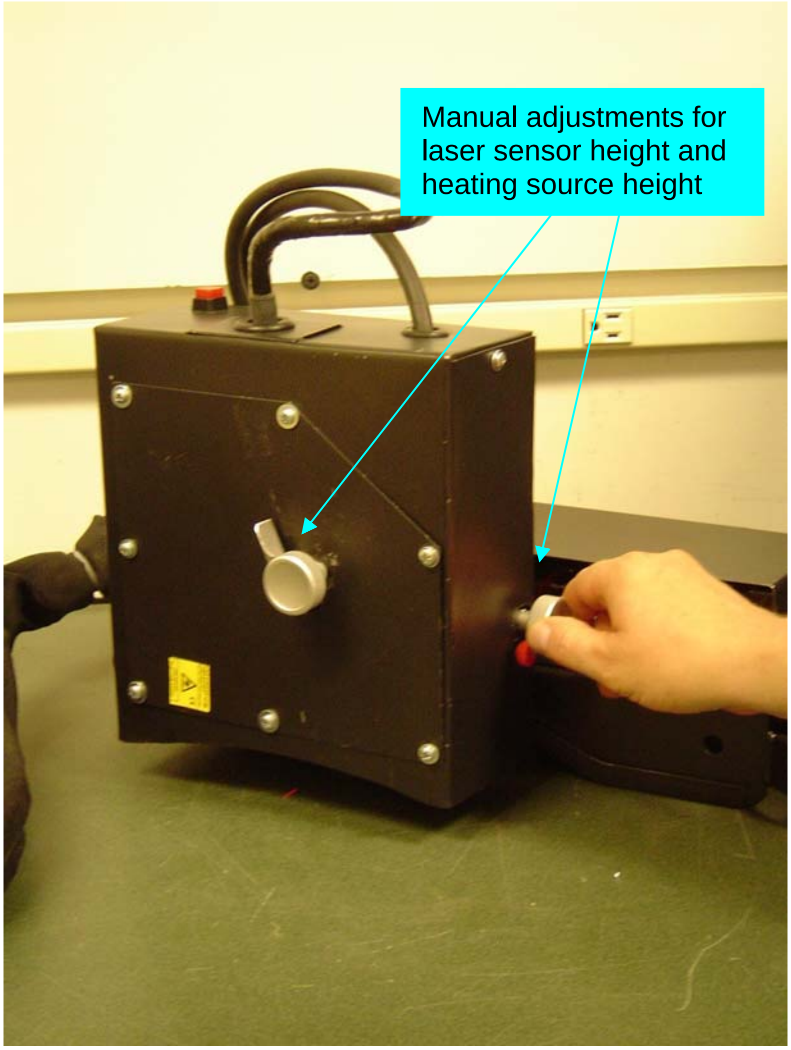


Figure 85. Operator Manually Adjusting Heating Source Height on WZIM Inspection Unit

4.3 Software Recommendations

The uncertain category was discovered during the course of this project as a WZIM category to assign to weld joints samples that did not have a characteristic line but that were not completely smooth across the weld zone. It is recommended that further research with the WZIM method on the integrity of an "uncertain" result needs to be completed to fully understand this condition. Thus far, only two surface features have been assigned to the uncertain category: ridge and projection. It is not known what the weld zone characteristic of ridge or projection indicates about the integrity of the weld joint. Only after the condition is analyzed and related to the meaning of these surface features can the algorithm be developed to allow the WZIM inspection tool to accurately predict this condition.

The densities of the PE pipe are different and thus look different to the laser sensor in the WZIM inspection tool. One way to improve the algorithm is to determine pipe integrity based on the density of the pipe currently being measured. This will allow the algorithm to make a customized analysis of the weld zone area based on the density. Making this determination could be accomplished automatically by allowing the laser to sense what color, and thus, what density, the pipe is.

During the field trials, improper welding parameters caused the fusion to produce no weld zone at the surface. The WZIM tool was not programmed to detect this feature. Although it may not be a typical failure, the *no weld zone* condition should be programmed into the WZIM inspection tool algorithm so that this defect could also be detected.

5.0 Conclusions

5.1 STDT and LTDT Validation Conclusions

1. The STDT validated the WZIM results for determining joint integrity on specimens that exhibited a line (fail) and specimens that exhibited no line (pass).

2. The LTDT validated most WZIM results for determining joint integrity on specimens that exhibited a line (fail) and specimens that exhibited no line (pass).

3. One LTDT result for a specimen that was made of standard conditions, passed the STDT and passed the WZIM results, yet failed the creep rupture test early. The LTDT did not correlate with any of the other results for this perfect case of a passing joint. This result questions the validity of the creep rupture test process and applicability of the creep rupture test method to determine integrity of MDPE and HDPE.

4. The LTDT did not validate the effect of the WZIM method on the joint integrity due to small number of test samples able to be used.

5. Operators use a standard bend test to test the integrity of pipe welds in the field. The WZIM inspection tool should be validated with the standard bend test for the sole purpose of gaining acceptance by the operators who will be using the WZIM inspection tool.

5.2 HDPE and MDPE Defects and Defect Characteristics

1. The welder or operator cannot always identify by external joint characteristic, if the joint will pass or fail a standard bend test.

2. The cold fusion or LOF condition is not completely understood, as evidenced by the surprise find of this defect existing in only one small section on the butt joint, rather than continuous throughout the joint.

3. The category of uncertain rating for PE pipe must be further explored to understand what effects the ridge, projection, etc. have on the quality of the PE pipe. Only then can the WZIM inspection tool's algorithm be programmed to know what to do when it detects such a condition.

4. Several factors can make the weld zone size larger than the 5 mm maximum that was stated in the functionality description by the project team.

5.3 WZIM Inspection Tool Functionality

1. The WZIM inspection tool was able to detect all joints that exhibited a line during the field trials.

2. The WZIM inspection tool was able to detect all joint that exhibited no line during the field trials.

3. The WZIM inspection tool was able to detect some of the joints that exhibited a ridge formation during the field trial.

4. The WZIM inspection tool is rugged enough to be used in the field, but cumbersome due to weight and required manual adjustments during setup.

5.4 WZIM Inspection Tool Improvements for Commercialization

1. The WZIM inspection tool can be manufactured to weigh less by using readily available lighter components. These components have been identified and disclosed within this report.

2. Manual adjustments on the WZIM inspection tool can be made automatic. These changes have been identified and disclosed within this report.

3. The WZIM inspection tool field of view should be made larger to accommodate a larger weld zone size.

4. The WZIM inspection tool software algorithm should assess the weld zone and joint integrity of HDPE and MDPE differently because they exhibit slightly different surface characteristics after the local heating of WZIM has been applied.

5. The "no joint" condition, although rare, should be programmed into the WZIM inspection tool software so that it can be detected and identified.

6. The de-beading process is not easily completed in the field with manual sanding techniques. An easier method for surface preparation should be researched or using WZIM without surface preparation should be researched.

6.0 References

1. "Nondestructive Quality Test Method for PE Pipe Butt Fusion Joints," EWI Project No. 42686CAP (Aug. 2000).

2. "Development of NDT Technique for the Detection of Non-Standard Butt Welds in PE Pipelines," EWI Project No. 46876CAP (Oct. 2004).

3. Savitski, A. and Coffey, J., "Inspection of Fusion Joints in Plastic Pipe – Research Management Plan," Report to National Energy Technology Laboratory, U.S. Department of Energy, DOE Award No.: DE-FC26-02NT41882, Edison Welding Institute (Oct. 2003).

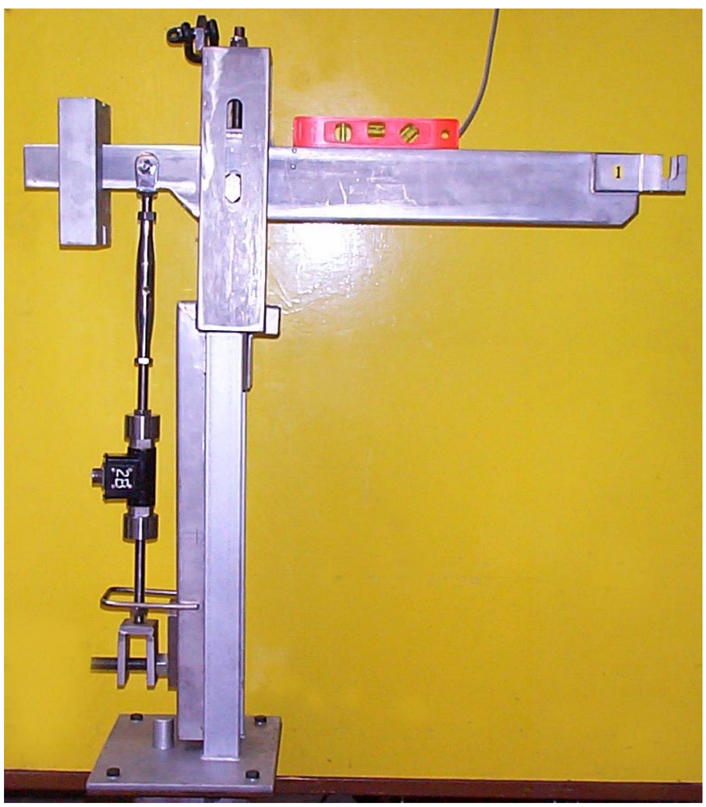
4. Savitski, A. and Fabiano, A., "Inspection of Fusion Joints in Plastic Pipe – Technology Status Assessment," Report to National Energy Technology Laboratory, U.S. Department of Energy, DOE Award No.: DE-FC26-02NT41882, Edison Welding Institute and NYSEARCH (Nov. 2003).

5. BS EN 12814-3:2000: "Testing of Welded Joints of Thermoplastics Semi-Finished Products – Part 3: Tensile Creep Test".

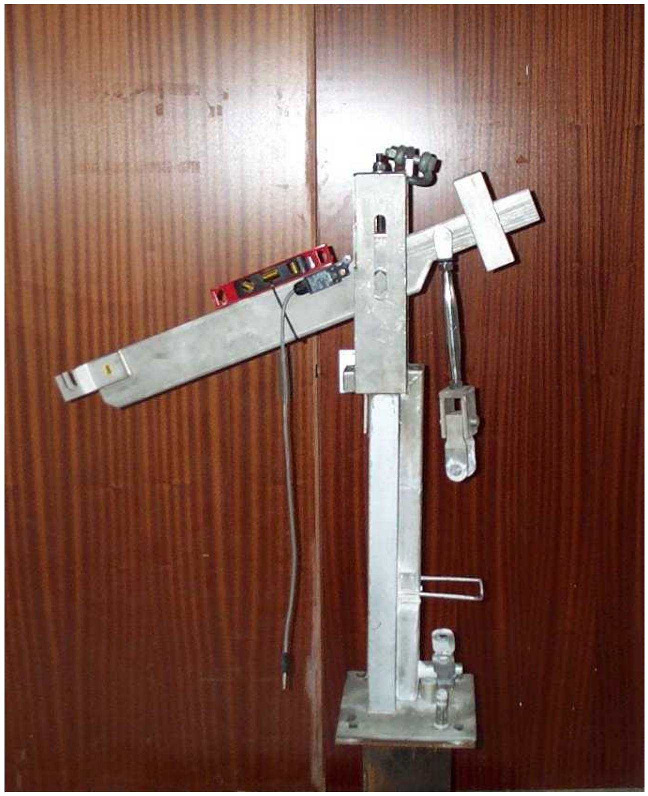
Appendix A

TWI Description of Creep Rupture Test and Rig

1)

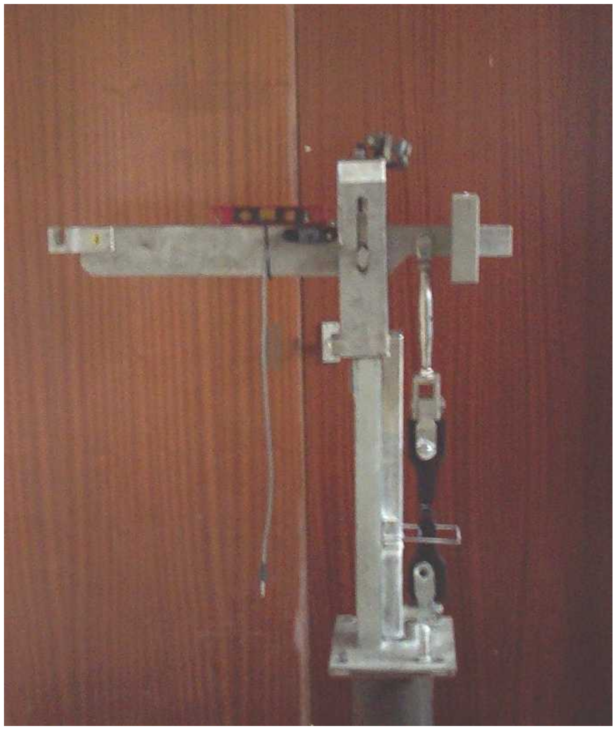


2)



3)

4)

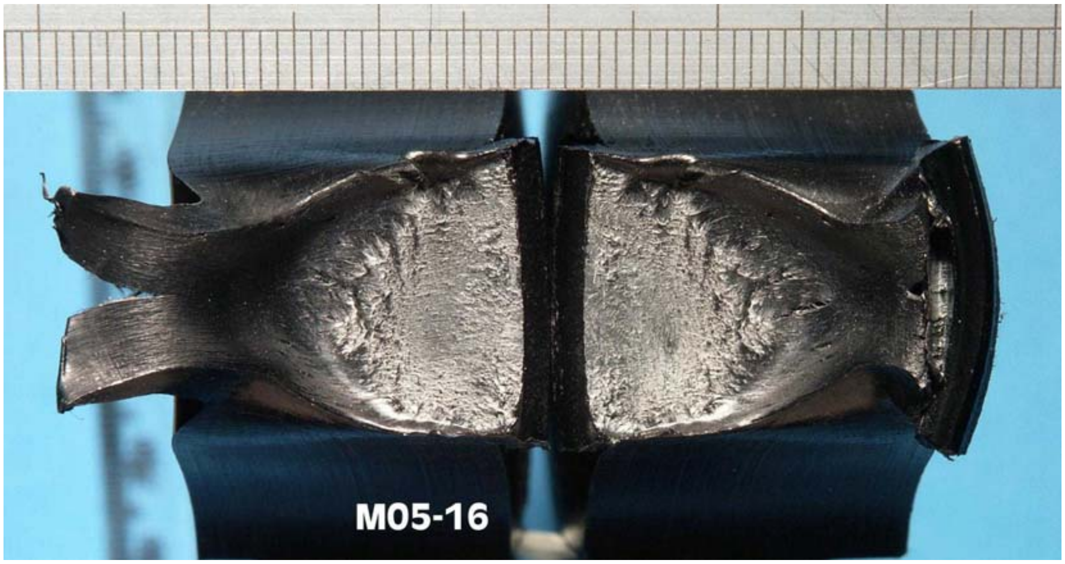


5)

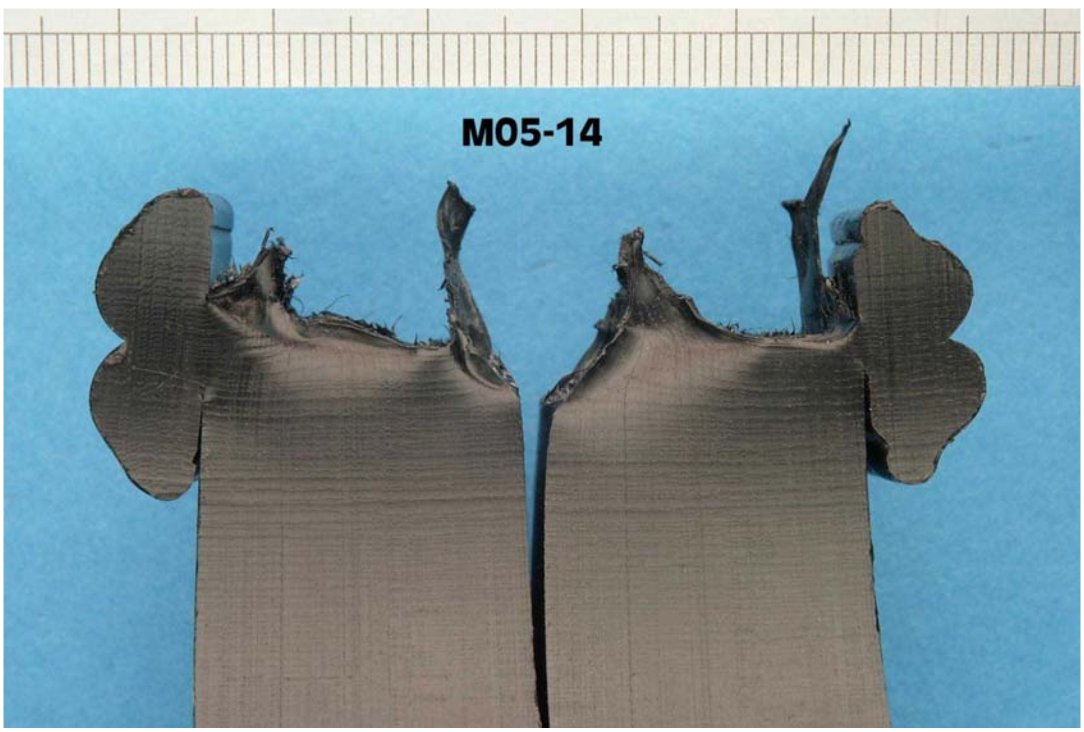
6)

7)

8)

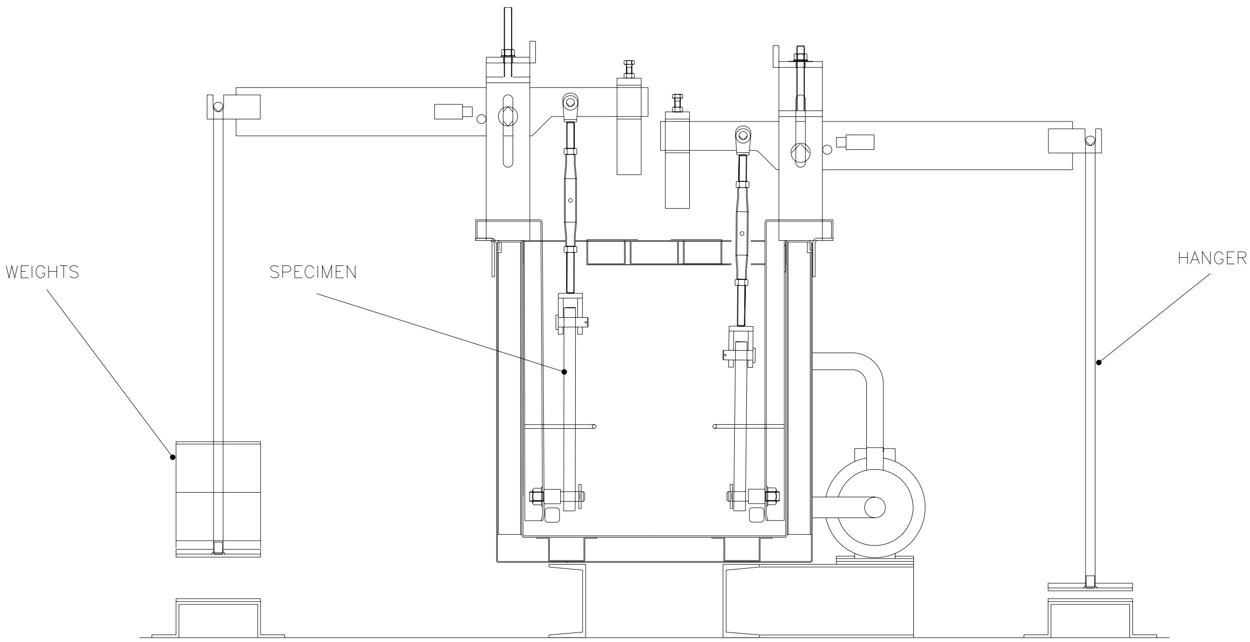


9)

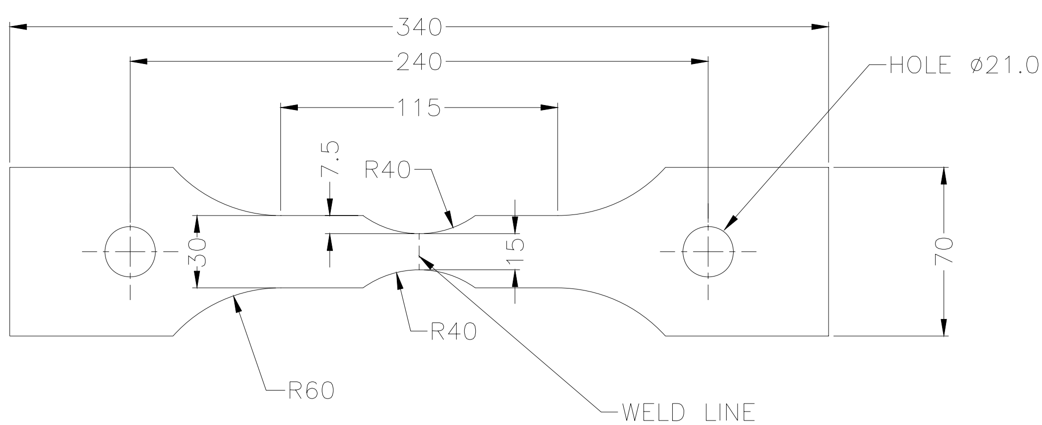


10)

11)


WEIGHTS
SPECIMEN
HANGER

12)


340
240
115
HOLE ø21.0
7.5
R40
30
15
70
R40
R60
WELD LINE

COUPON TENSILE CREEP RUPTURE TEST RIG

General (see Figures 1 and 11)

- The rig consists of two hot water baths, the temperatures of which can be set and controlled separately.
- There are 10 test stations per bath.
- The maximum specimen thickness that can be accommodated is 32 mm.
- All pivots are knife-edges to reduce friction.
- The equipment conforms to EN 12814-3.

Temperature Control

- Operating temperatures up to 95ºC (normally 80ºC).
- Temperature control ±1ºC.
- Each bath contains two 4-kW heaters (see Figure 4).
- Water is constantly circulated throughout the bath to maintain an even temperature.
- The temperature is constantly monitored using a datalogger, which is connected to an alarm system. This will activate if the temperature goes outside –1,+0.5ºC of the set value. It will also activate if the water pump fails. As well as an audible alarm, the system will AutoDial the mobile phone of a 24-hour on-call technician.

Load Calibration

- Each station is calibrated separately.
- A calibrated load cell is attached at the specimen location and the lever arm is balanced without a weight-hanger on the end, using the counterbalance block (see Figure 2).
- The weight hanger is then attached, weights added (200 N at a time, up to 1400 N) and reading on load cell measured. This is repeated on removing the weights. The lever arm ratio is then calculated.

Specimen Set-up

- Holes are drilled into the specimen for the loading pins and the specimen is waisted at the joint to ensure that failure occurs at the weld rather than in the parent pipe (see Figure 12).
- The thickness and width of the specimen are measured and the cross-sectional area is calculated.
- The required test load is calculated from required stress, specimen cross-sectional area and lever arm ratio.
- Previous work has shown that a test stress of 5.5 MPa is optimal for butt fusion joints in PE pipes. Higher stresses and the failure is ductile, which means that the test is invalid (EN 12814-3 specifies that at least 30% of the fracture surface should be “brittle” for the test to be valid); lower stresses and the time to failure is excessive (greater than 1.5 years), depending on the quality of the joint.
- The loading rig is removed from the tank and placed on a stand (see Figure 3).

- The specimen is attached to the top fitting via the loading pin and the lever arm is balanced using the counterbalance block (see Figures 5 and 6).
- The lower loading pin is then fitted (see Figure 7 and 8).
- The loading rig is then lifted into the water bath and the specimen allowed to soak at temperature under no load for 8 hours.

Applying the Load and Monitoring the Test

- The lead from the microswitch attached to the lever arm (see Figures 3 and 5) is plugged into the timer.
- The weight hanger containing the correct weight is lifted onto the end of the lever arm and lowered slowly and smoothly until the full load is applied.
- The timer is started.
- The loading saddle screw is adjusted to return the lever arm to the horizontal, as shown by the spirit level.
- Throughout the test, the duration and temperature are checked and recorded, and the lever arm position is checked and adjusted as necessary at least once a day.

Specimen Failure

- When the specimen fails, the lever arm drops. This activates the microswitch, which switches off the timer.
- The time to failure is recorded.
- The loading rig is removed from the tank and specimen is taken out.
- The specimen is checked to make sure that the fracture surface is greater than 30% brittle (see Figures 9 and 10 for typical fractures).

Appendix B

Weld Zone Inspection Method User Requirements

Weld Zone Inspection Method

User requirements for the prototype system (Version 1)

Operational and performance requirements for prototype NDE system that can test the method in field conditions

1. Performance requirements

1.1 Pipe material and sizes
1.1.1 Material: MDPE and HDPE all pipe grades.
1.1.2 Pipe diameters: 4 to 12 in. (try to get 2 in.); estimated weld zone width 2-5 mm.

1.2 Detect non-standard joints.
1.2.1 Joint Type: Butt joint.
1.2.2 Defect Types: Weak fusion associated with non-standard welding parameters.

1.3 Evaluation process
1.3.1 Apply secondary heating on prepared pipe surface to expose weld zone.
1.3.2 Scan weld zone, acquire and analyze the image.
1.3.3 Assign a Pass/Fail output to user.
1.3.4 Save data record and all inspection results for future reference.

2. Operational requirements

2.1 Portability/physical parameters:
2.1.1 Physical parameters of the system include a weight of no more than 25 lb and a physical size such that would easily fit within a trench.
2.1.2 Rugged for in-field application

2.2 Clamping system
2.2.1 System to be easily clamped on pipe using a device or component that will insure the system will remain stationary during the heating and inspection.

2.3 Main components - System to accommodate two main components: Heating System and the Inspection System. The tool design will try to incorporate both components into a single tool.

2.4 Alignment requirements – System shall provide proper alignment of the Heating System and the Inspection System. The alignment must be such that the user can easily and correctly position either System over the weld zone.
2.4.1 The Heating System's *heating element* shall be able to be positioned directly above the weld zone.
2.4.2 Height of heating element should be adjustable and measurable such that the operator can manually position the heating element while visually observing a measurement of this height.

2.4.2.1 An independent measuring device or sensor could be used for exact positioning and measurement of height of heating element.

2.4.3 Inspection System's *laser* shall be positioned perpendicular to joint and at centerline of weld zone.

2.5 Heating system

2.5.1 Heating source will be an off-the-shelf halogen lamp and socket, 250 watt

2.5.2 A 120 volt supply must be supplied to the lamp.

2.5.3 The lamp On/Off time will be manually controllable by a timing device.

2.6 Sensor requirements

2.6.1 The sensor type will be a laser sensor of CLASS 3B or lower.

2.6.2 Size of laser scan should be adequate to accommodate specified range of weld zone widths.

2.6.3 Sensor resolution will be sufficient to detect relative weld zone characteristics.

2.6.4 Ease of calibration - the Inspection System will include a sensor calibration routine that can be executed by the operator at will.

2.7 Software requirements

2.7.1 Image recognition capabilities – the software must be able to detect pertinent weld zone characteristics.

2.7.2 Joint acceptance capabilities – the software must include an algorithm to determine acceptance or rejection of the inspection result.

2.8 Inspection hardware requirements

2.8.1 A computer (PC) will be used to run the C-based executable program.

2.8.2 A data-acquisition hardware card will be used for laser sensor data collection.

2.9 System power requirements

2.10 All parts of the system will operate at 120 volts AC.

2.11 Any smaller power requirements will make use of transformers.

Appendix C

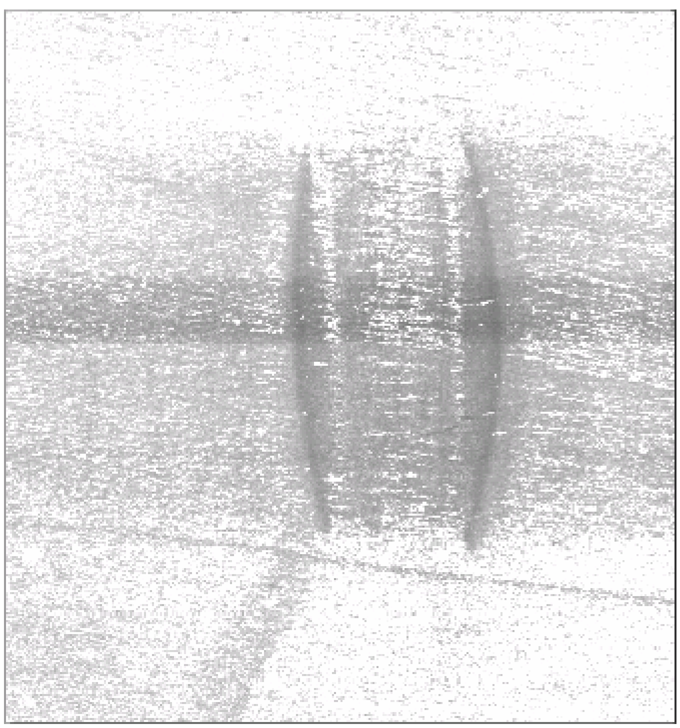
WZIM Inspection Tool Laser-Based Inspection Report Sample

EDISON WELDING INSTITUTUE
1250 Arthur E. Adams Dr.
Columbus, OH 43221

WZIM Inspection Tool
Laser-based Inspection Report

FAIL

PART B.bmp



Appendix D

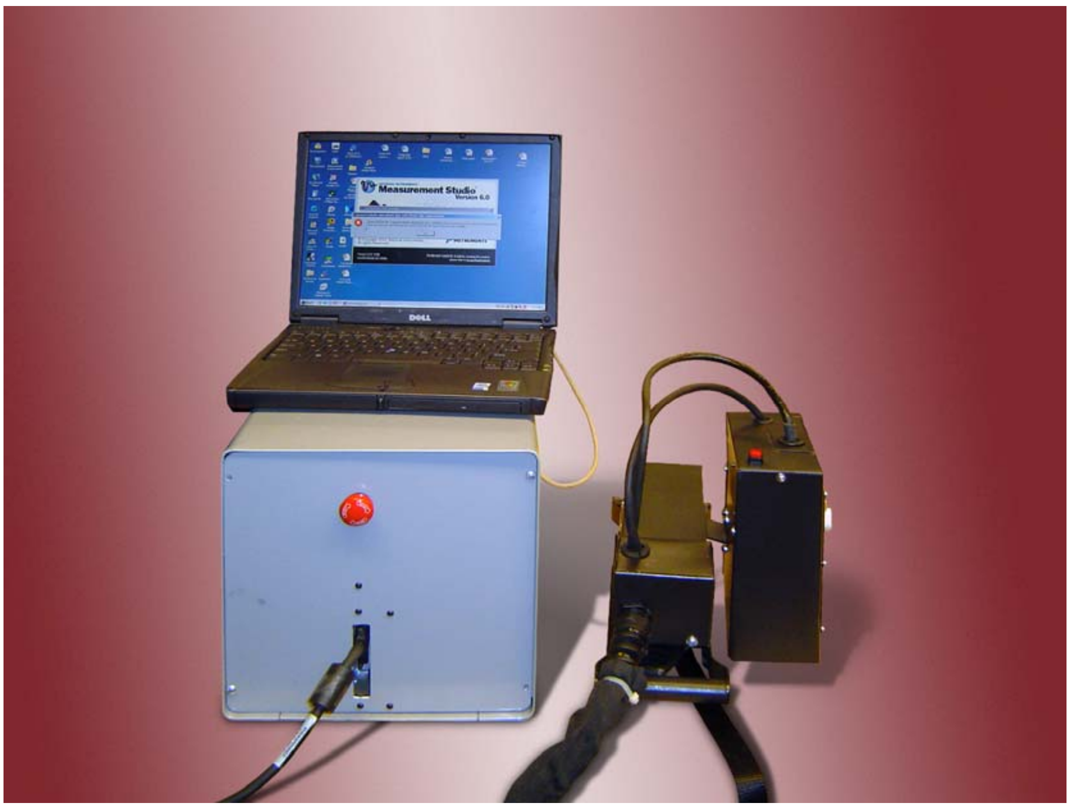
WZIM Imspection Tool Training Manual

REPORT

August 1, 2005
U.S. Dept of Energy NETL
EWI Project No. 47033GTH
Contract No. DE-FC26-03NT41882

WZIM Inspection System™ Training Manual

Prepared by
Constance T. Reichert



Prepared for:

USDOE/NETL

EWI
MATERIALS JOINING TECHNOLOGY

U.S. Dept of Energy NETL
EWI Project No. 47033GTH
Contract No. DE-FC26-03NT41882

WZIM Inspection System
User Manual

by

Constance T. Reichert

Prepared for:

U.S. Department of Energy NETL
Morgantown, PA

August 1, 2005

EWI
1250 Arthur E. Adams Drive
Columbus, OH 43221

Contents

7.Page

Welcome

This manual was prepared for you by Edison Welding Institute (EWI).

EWI developed the WZIM (Weld Zone Inspection Method) and the WZIM Inspection System. This inspection system was made to enable you to automatically inspect the butt fusion joint on MDPE (medium density polyethylene) or HDPE (high-density polyethylene) pipe. This system will accommodate pipe sizes of 4 to 12 inch diameter.

The WZIM Inspection System is made of both hardware and software. The hardware unit is placed upon the pipe, over the fusion weld. The software makes the hardware perform the inspection when you tell it to begin. The software will perform the inspection and then tell you if the pipe passed or failed the inspection. The output is a report that indicates the inspection result and has a picture of the pipe surface that was inspected.

This manual tells you how to use the WZIM Inspection System so that you can inspect MDPE and HDPE pipe welds.

Specifications

This was made specifically for DOE/NETL and NYSEARCH.

For EWI Project No. 47033-GTH, "Inspection of Fusion Joints in Plastic Pipe."

For use by DOE/NETL and NYSERACH.

Special Notes

WARNING MESSAGE

A warning message will appear in this user manual when the next action taken will power on the WZIM Laser Unit. Use **CAUTION** whenever the unit is powered on. The LMS can cause INJURY if not used properly. The safety message appears as follows:

CAUTION – WZIM INSPECTION SYSTEM POWERED ON – THE WZIM SYSTEM IS POWERED ON AND MAY MOVE AT ANY POINT IN TIME. CLEAR HANDS AND FINGERS FROM UNIT!

WZIM Inspection System^{TM} Manual Objective

This manual will guide you through using the WZIM Inspection System ^{Tm} to perform an inspection of PE fusion joint.

Section 1. Identifying the WZIM Inspection System Parts
At the end of this section you will be able to:

1. Identify both cases holding the WZIM Inspection System
2. Unpack both items from the storage cases
3. Locate and identify WZIM Inspection System Parts
4. Get ready to connect the system parts

Section 2. Connecting WZIM Inspection System Parts
At the end of this section, you will be able to:

1. Locate all connectors on each part
2. Connect the Control Box to the Laser Unit
3. Connect a laptop computer to the Control Box
4. Power On the WZIM Inspection System

Section 3. Inspect a Pipe Using the WZIM Inspection System
At the end of this section, you will be able to:

1. Prepare the pipe surface for inspection
2. Place the unit onto a pipe
3. Set height of heating element
4. Start the software program
5. Perform an inspection
6. View the inspection result

Section 4. Operating the WZIM Inspection System Software
At the end of this section, you will be able to:

1. Locate and open inspection records after an inspection
2. View inspection data and results
3. View or Make an Inspection Report
4. Change software default settings

Section 5. Shut Down and Disconnect the WZIM Inspection System
At the end of this section, you will be able to:

1. Power Off the WZIM Inspection System
2. Unplug connection on each part
3. Disconnect the laptop computer from the system
4. Disconnect the Control Box and the Laser Unit

Section 1. Identifying the WZIM Inspection System Parts

Instruction Pages

This section describes how to unpack and identify the WZIM Inspection System parts. Please use caution when unpacking the components as they are heavy and can cause injury if dropped or mishandled. Use help or assistance while unpacking parts that are too heavy to carry. The WZIM Inspection System is stored in 2 cases. These cases will keep the system safe and clean while it is not in use. Take great care in unpacking both system components.

Control Box
The WZIM Inspection System has two parts that will be connected together by connector cables. The first part is the Control Box. The case with the Control Box inside weighs 28 lbs. The Control Box itself weighs 20 lbs.

The Control Box has the main power plug to connect to a standard 120 Volt A/C grounded wall outlet. The main Power Switch is located on the back of the Control Box. The power switch will be illuminated when there is power applied to the unit.

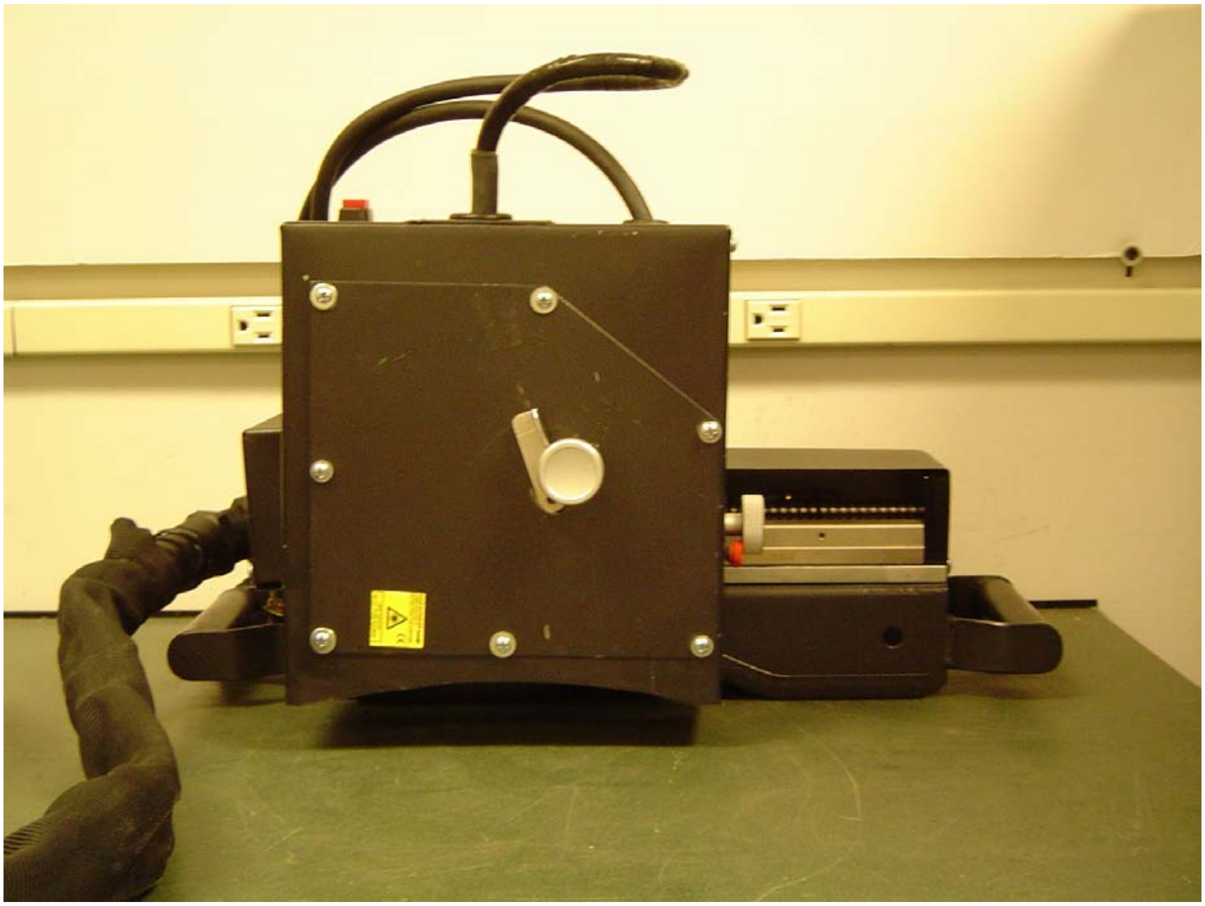
An Emergency Stop button is located on the front of the Control Box. Pressing the Emergency Stop Button will cut power to all components inside the Control Box until the Emergency Stop Button is reset. Reset the Emergency stop button by twisting the button to the right.

Laser Unit
The second part is the Laser Unit which weighs 40 lbs including the case. The Laser Unit itself weighs 24 lbs. Inside the Laser Unit is a Class 3B Laser Sensor. Eye protection is suggested but not mandatory by *ANSI Z136.1 for Safe Use of Lasers*. Inside the Laser Unit is a Halogen light bulb. During use, the Halogen bulb will become very hot. Use caution around the Laser Unit to prevent burn. Do not stare into the Halogen light source while it is on.

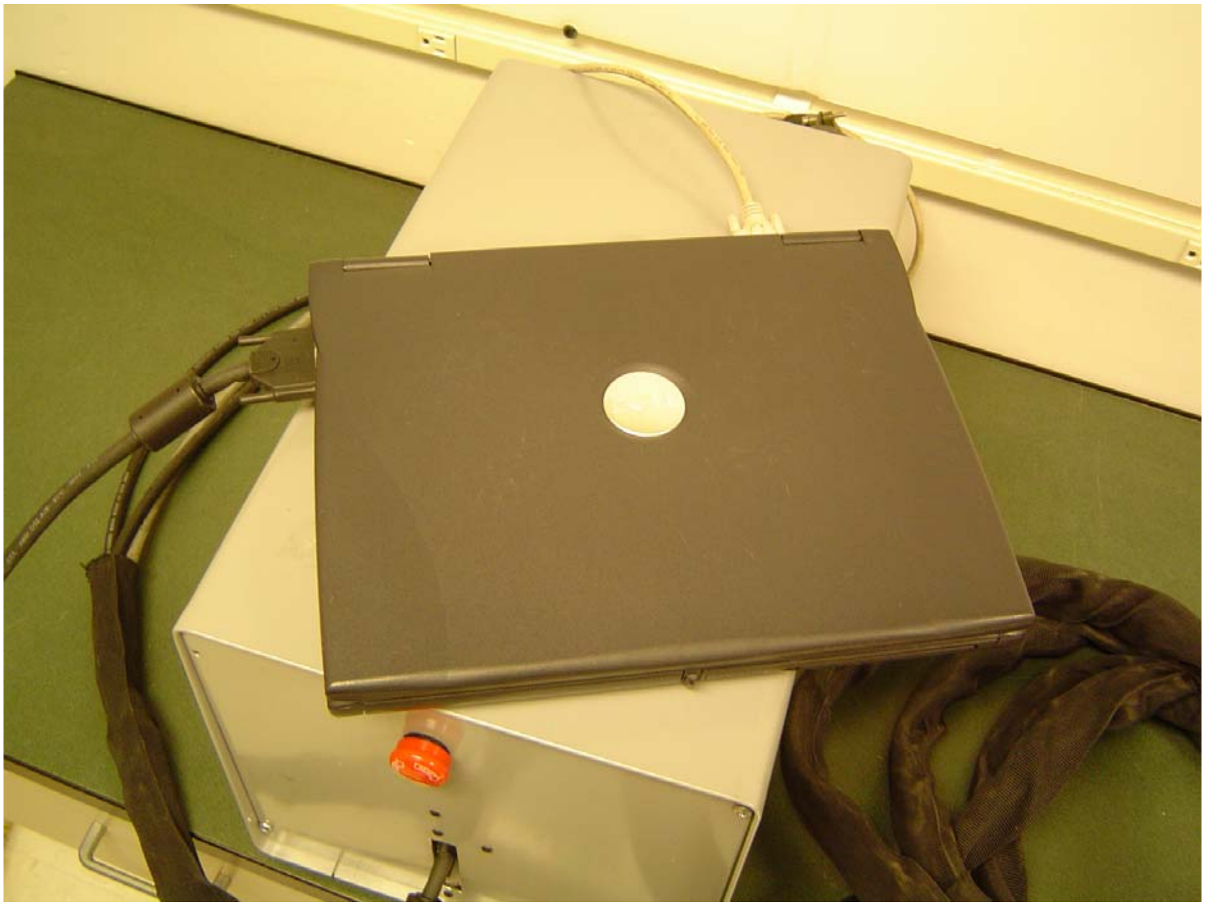
Laptop Computer
A laptop computer will be connected to the Control Box. The computer will run the WZIM Inspection System software and make the Laser Unit move. The laptop is also what you will use to talk to the WZIM Inspection System or to begin an inspection.

Step-by-Step Instructions

- **Unpack and identify the Control Box**



- **Unpack and identify the Laser Unit**



- **Unpack and Identify the laptop computer**

Section 2. Connecting the WZIM Inspection System Parts

Instruction Pages

This section describes how to connect the different parts of the WZIM Inspection System together. The Control Box will be connected to both the Laser Unit and the Laptop. After this section you will be able to identify the connectors on each part of the system and how to power on the system.

Control Box Connections

The Control Box connects to the Laser Unit and the Laptop Computer. There are several connectors on the back of the Control Box.

- Main Signal Connection
- Heating Element Connection
- Laser Signal Connection
- Main Power Plug

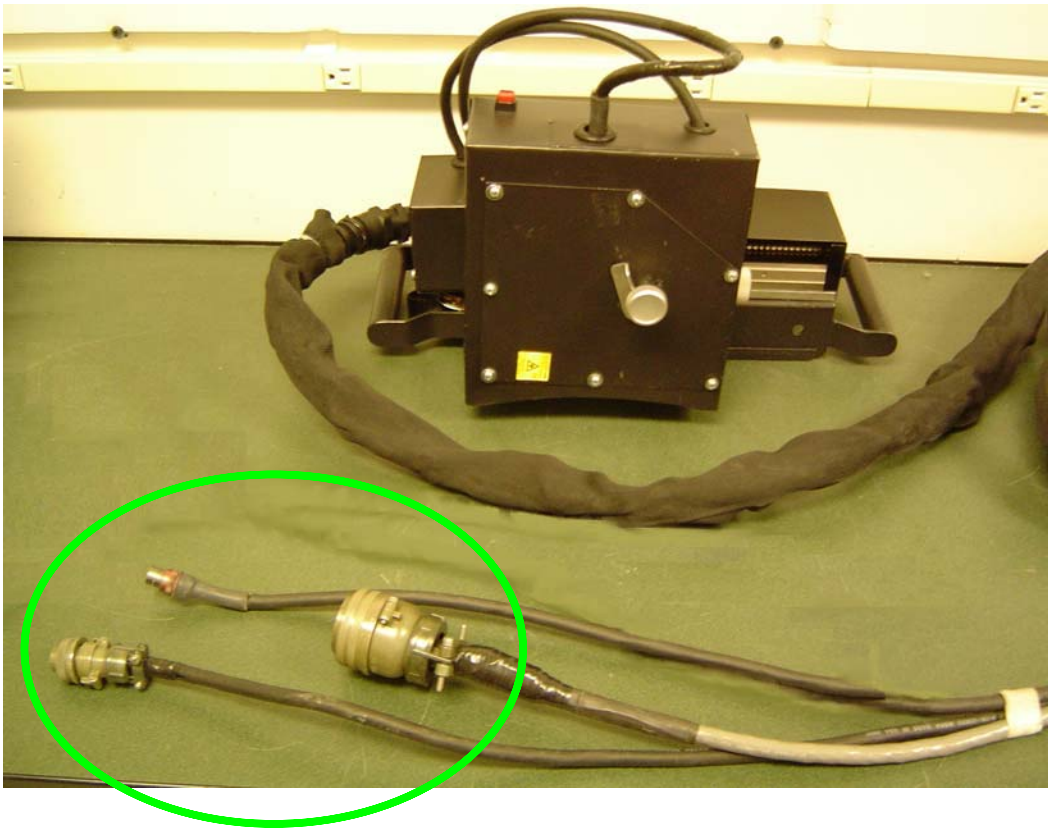
Laser Unit Connections

The Laser Unit has one umbilical cable attached to it. This cable splits into two connections on the Control Box

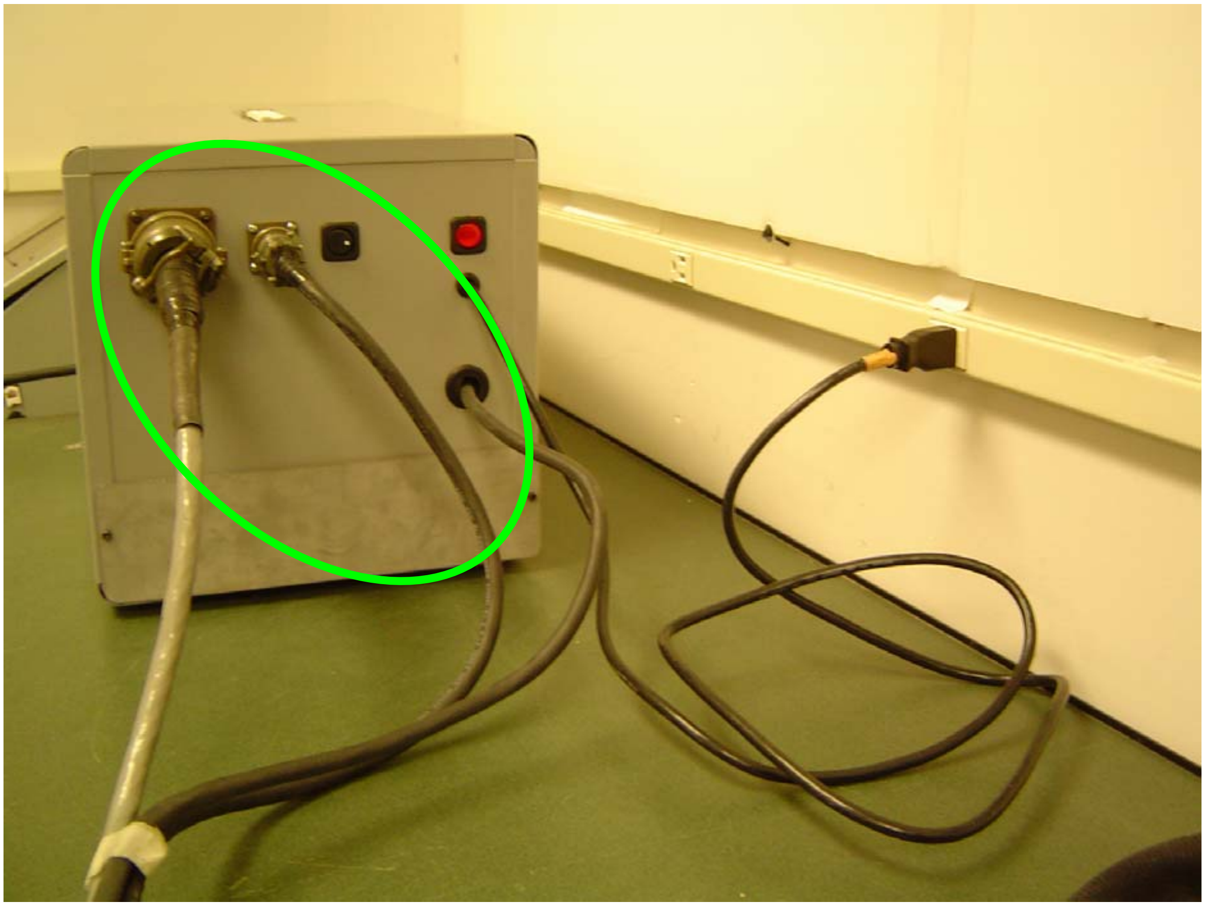
Laptop Connections

The laptop is connected to the front of the Control Box by a cable from the laptop's PCMCIA port. The laptop is also connected to the Control box by the Serial Port on the laptop computer.

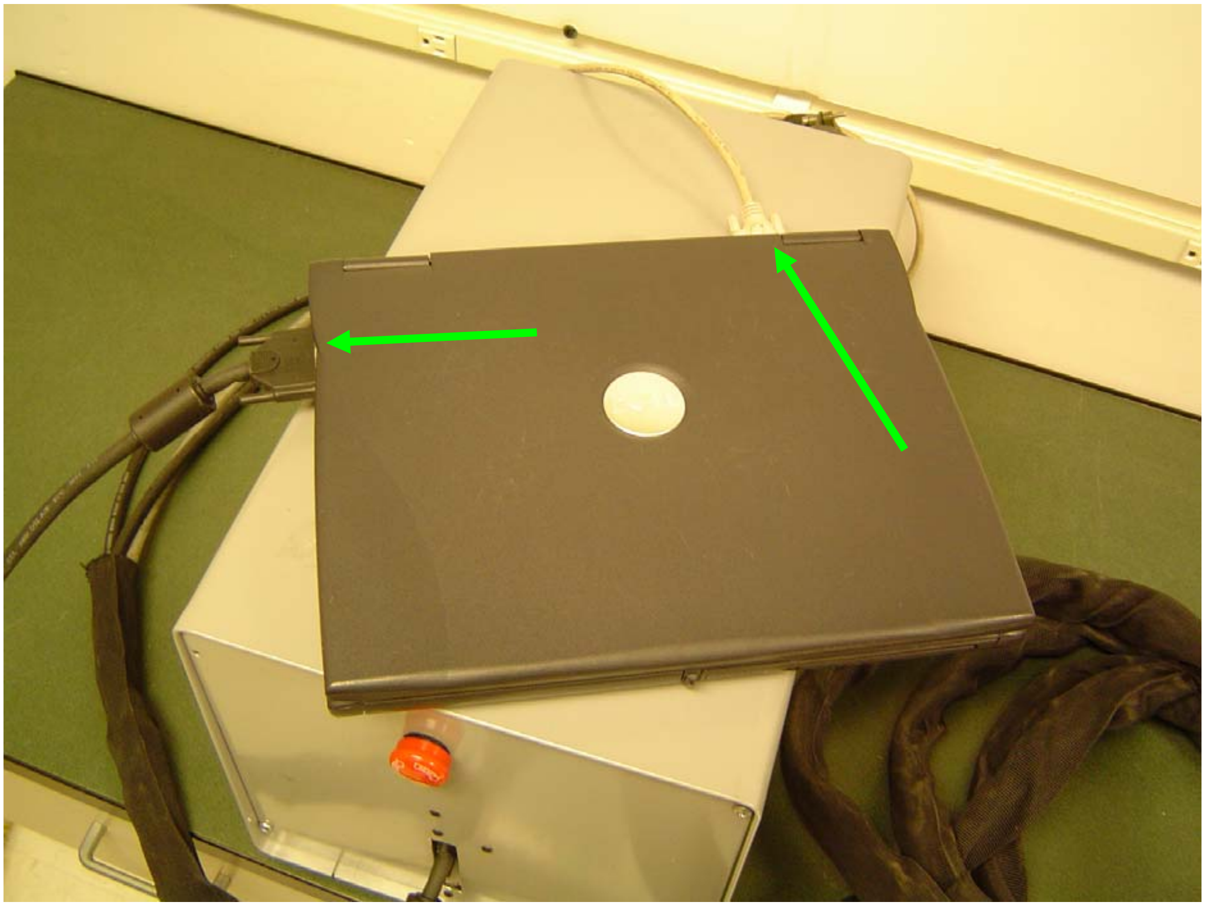
Step-by-Step Instructions



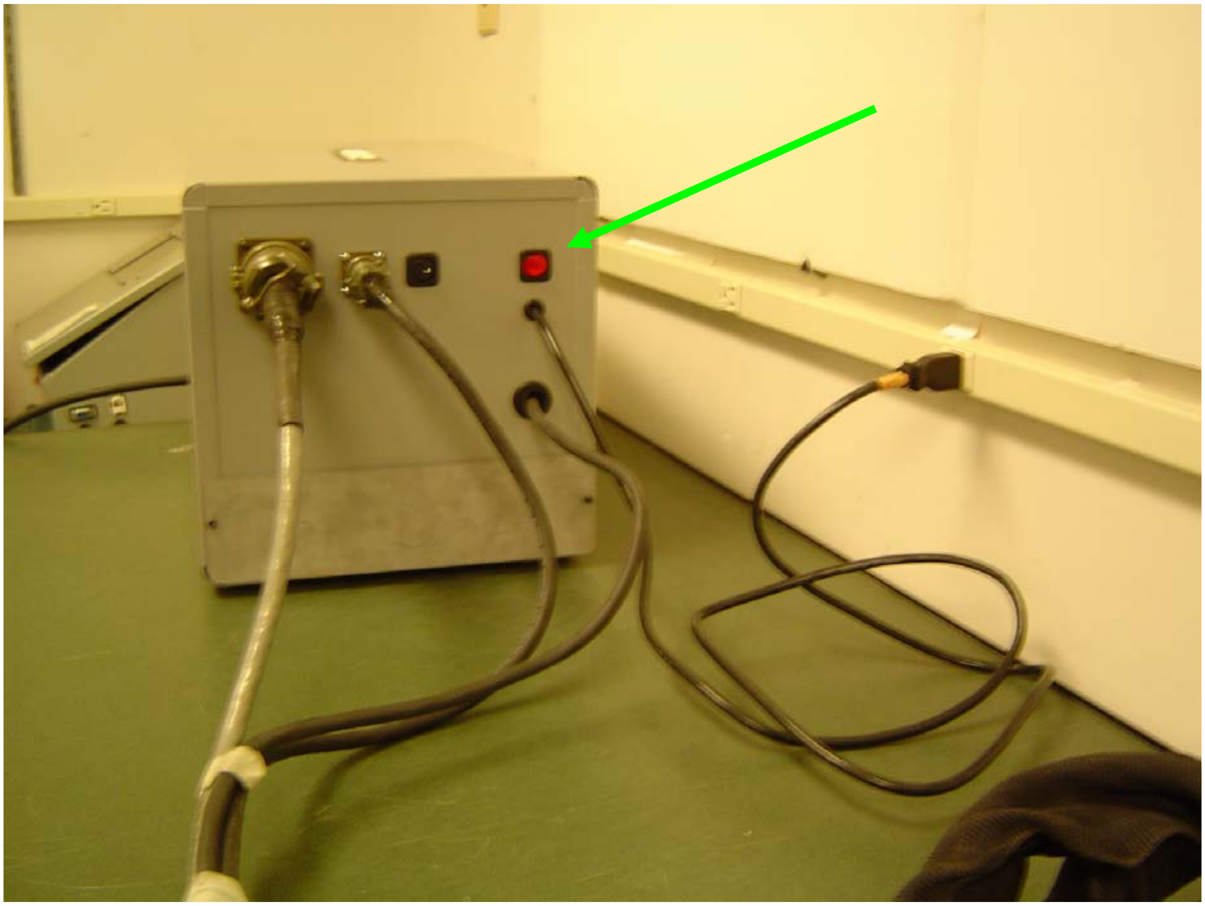
- **Locate all connectors on each part**



- **Connect the Control Box to the Laser Unit**



- **Connect a laptop computer to the Control Box**



- **Power On the WZIM Inspection System**

CAUTION – WZIM INSPECTION SYSTEM POWERED ON – THE WZIM SYSTEM IS POWERED ON AND MAY MOVE AT ANY POINT IN TIME. CLEAR HANDS AND FINGERS FROM UNIT!

Section 3. Inspect a Pipe using the WZIM Inspection System

Instruction Pages
This section explains how to complete an inspection on a pipe using the WZIM Inspection System.

Prepare the pipe surface for inspection
Before the inspection system can be placed on the pipe, the surface of the pipe must be prepared. The external weld reinforcement must be removed from the outside surface of the pipe at the weld. You can use a de-beading tool to remove the entire circumference of the reinforcement. After the bead has been removed, you must make the surface smooth over the joint bond line. This can be done using sand paper of varying grits.

Place the Laser Unit onto a pipe
After the surface has been prepared, you must place the Laser Unit onto the pipe. First turn on the alignment spot. This laser spot should be positioned right at the joint intersection. This will align the scanning laser and the heating element on the same plane. Once the Laser Unit is positioned, wrap the wench around the pipe and tighten until it cannot be ratcheted any further. The Laser Unit can be used in any orientation around the pipe.

Set height of heating element
After the unit is secured onto the pipe using the wench, use the knob on the side of the Laser Unit to position the halogen bulb at the set distance away from the pipe. Use the height adjustment tool to set the correct distance based on the type of pipe you are going to inspect.

Start the software program
Once the heating element is set to the right height, you are ready to start the software program. The software program will allow you to calibrate the Laser Unit, Start an inspection or Open previous inspection files. The buttons on the UIR (user interface) screen include:

- Calibrate
- Start
- Open
- Heating Time

Perform an inspection
The following sequence of actions will complete an inspection. Press the buttons on the UIR in the following order.

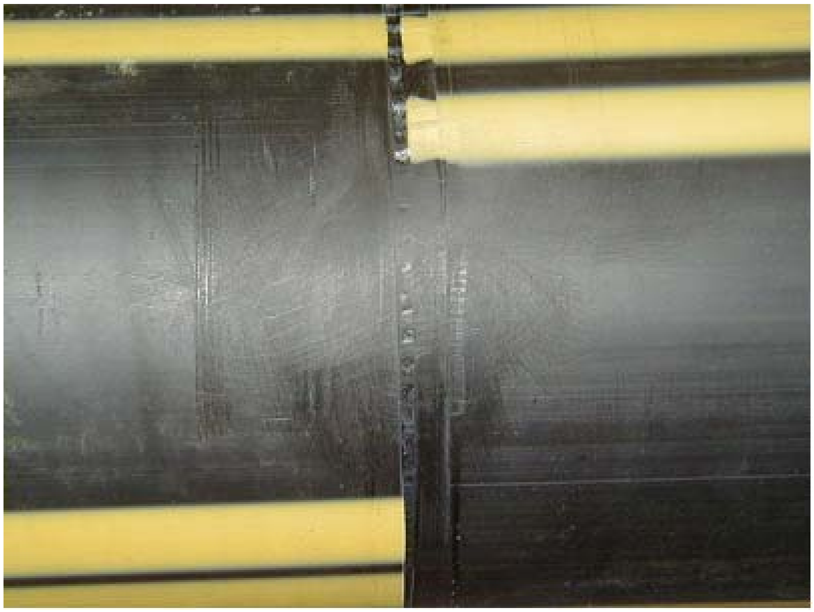
Calibrate
The first button on the software UIR (user interface) is labeled Calibrate. Press this button to begin calibration of the Laser Unit. When this button is pressed, the Laser Unit will move into position and start displaying a red line on the UIR. You will also see a green box on the UIR. Using the know on the front of the Laser Unit, adjust the laser height up and down until you see the red line go inside the green box. The Laser Unit height has been set and the system is now calibrated.

Heating Time
Before you start an inspection, make sure you have selected the correct Heating time using the Heating Time button on the UIR. This will depend on which density pipe you are using. Remember, HDPE is usually yellow and MDPE is usually Black. Set the Heating Time slider to HDPE or MDPE depending on the type of pipe you are inspecting. HDPE will heat for 19 seconds. MDPE will heat for 9 seconds.

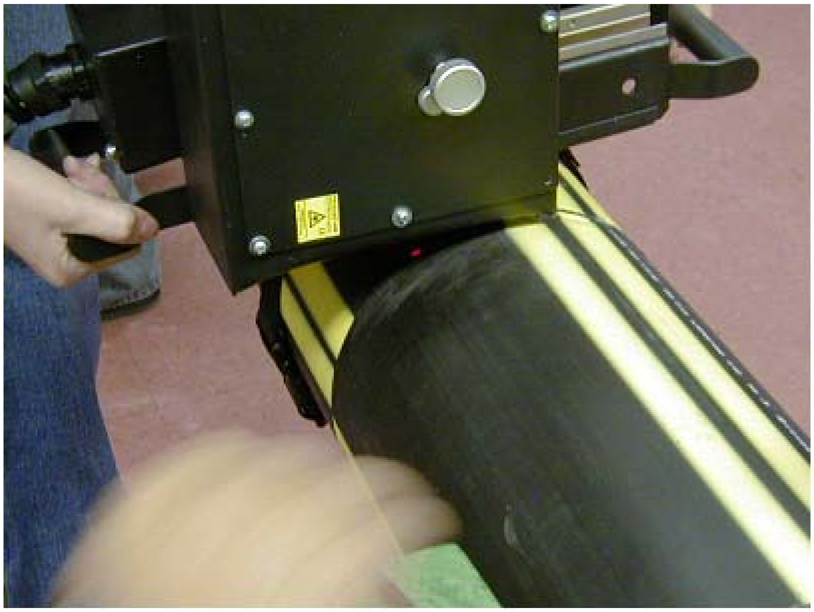
Start
The START button on the software UIR will begin the inspection process. Press this button to begin an inspection. Once this button has been pressed, the Halogen light source will illuminate for either 9 or 18 seconds. Observe that the UIR indicates how many seconds remain until the light source will be turned off. After the heating cycle, the Laser Unit will move into position and begin inspecting the part. Observe that the UIR indicates that the laser is scanning. Once the laser has completed the scanning (about 20 seconds), the Laser Unit will move back into the starting position. At this point, the UIR will indicate the laser is inspecting.

View the inspection result
Once completed, the UIR will change into a RESULTS screen which includes a picture of the scanned pipe surface, graphs of a single laser scan across the surface and a message indicating Pass, Fail or Undecided. The WZIM Inspection System automatically creates a report for each inspection, names the report and saves it to the laptop computer. The system then returns to the Main UIR screen and is ready for a new inspection.

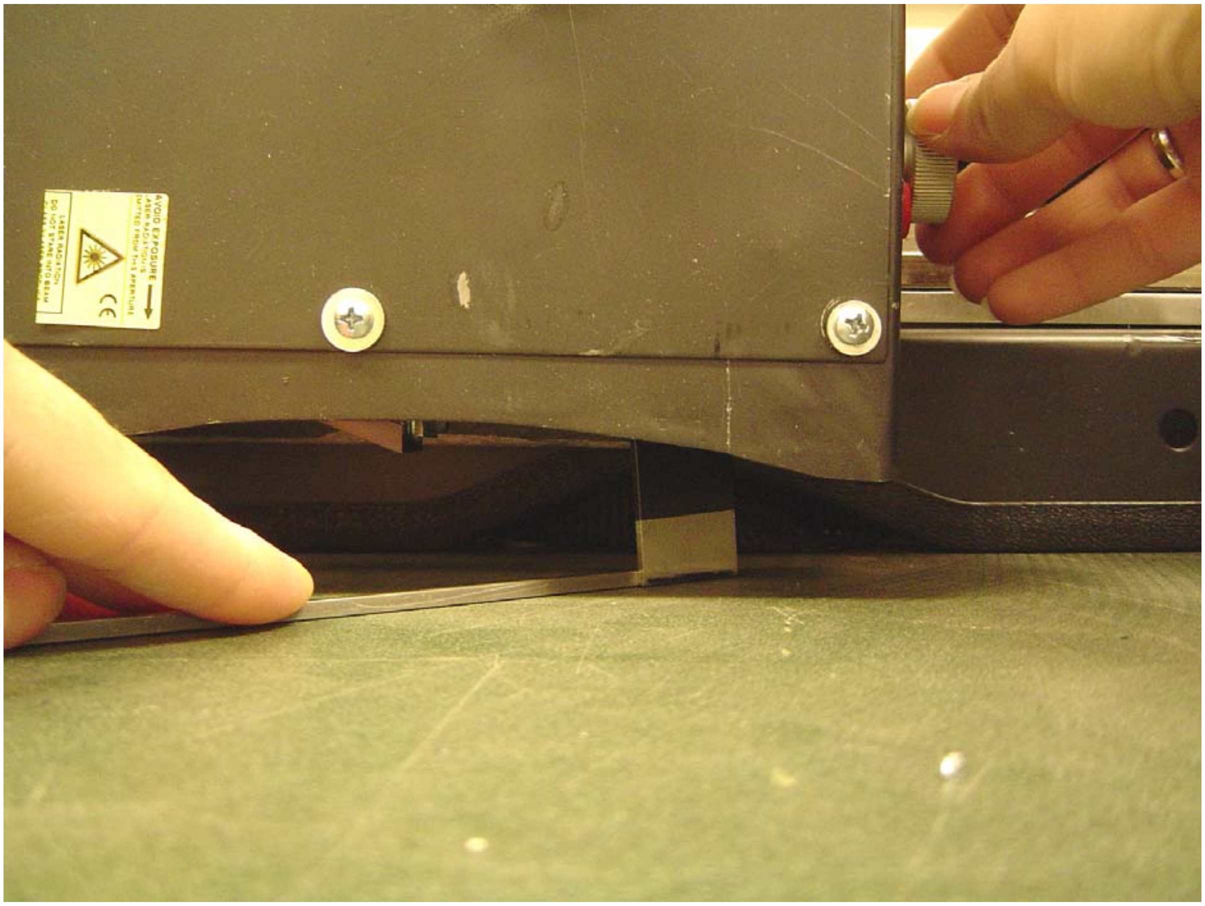
Step-by-Step Instructions



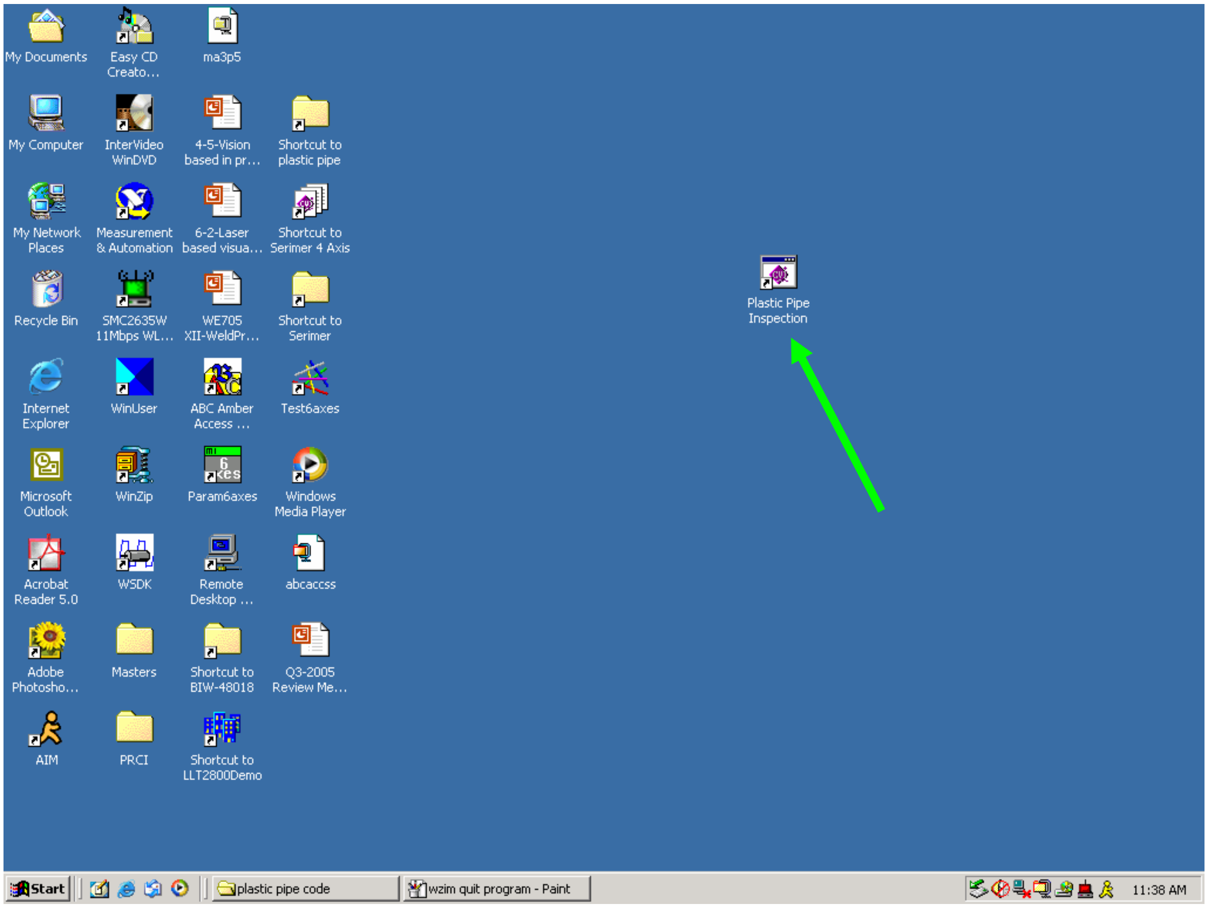
- **Prepare the pipe surface for inspection**



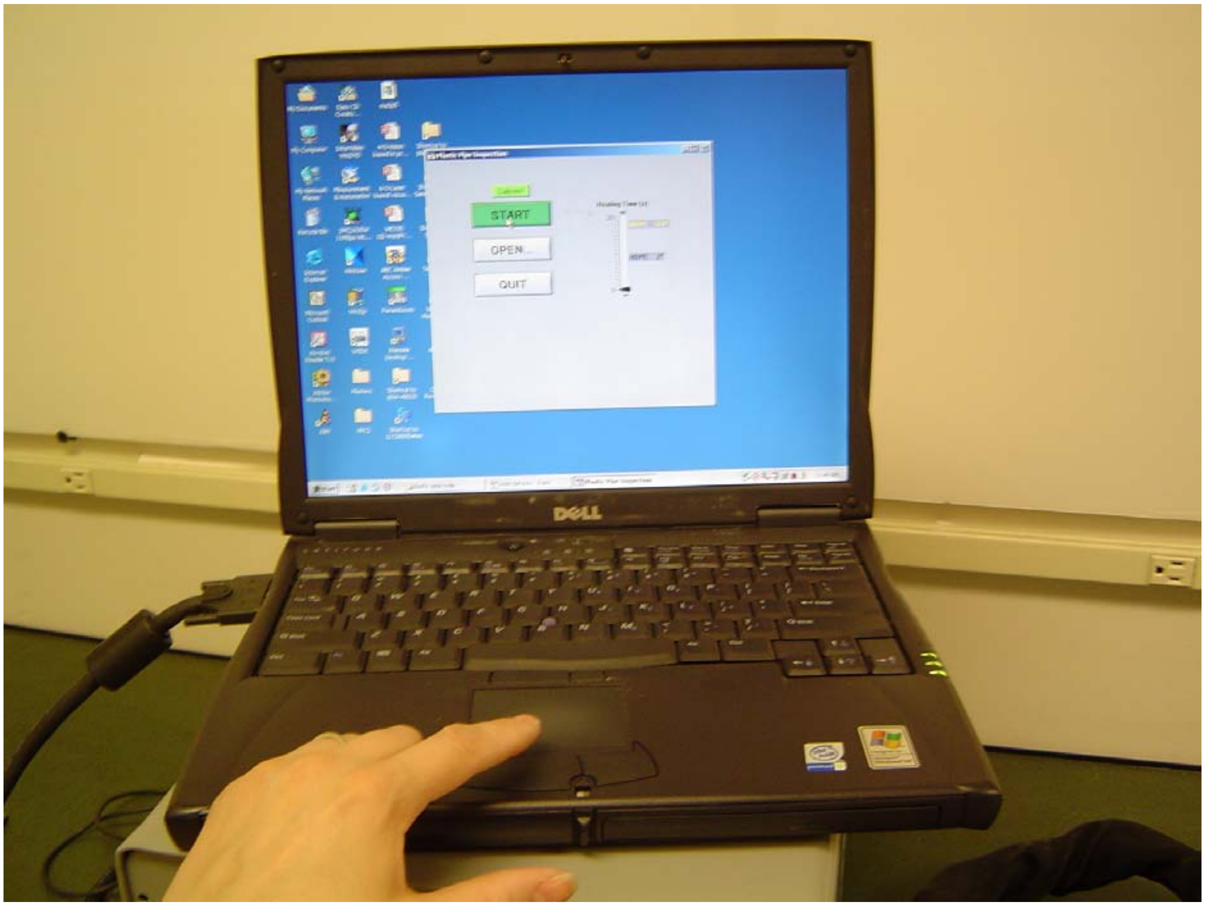
- **Place the unit onto a pipe**



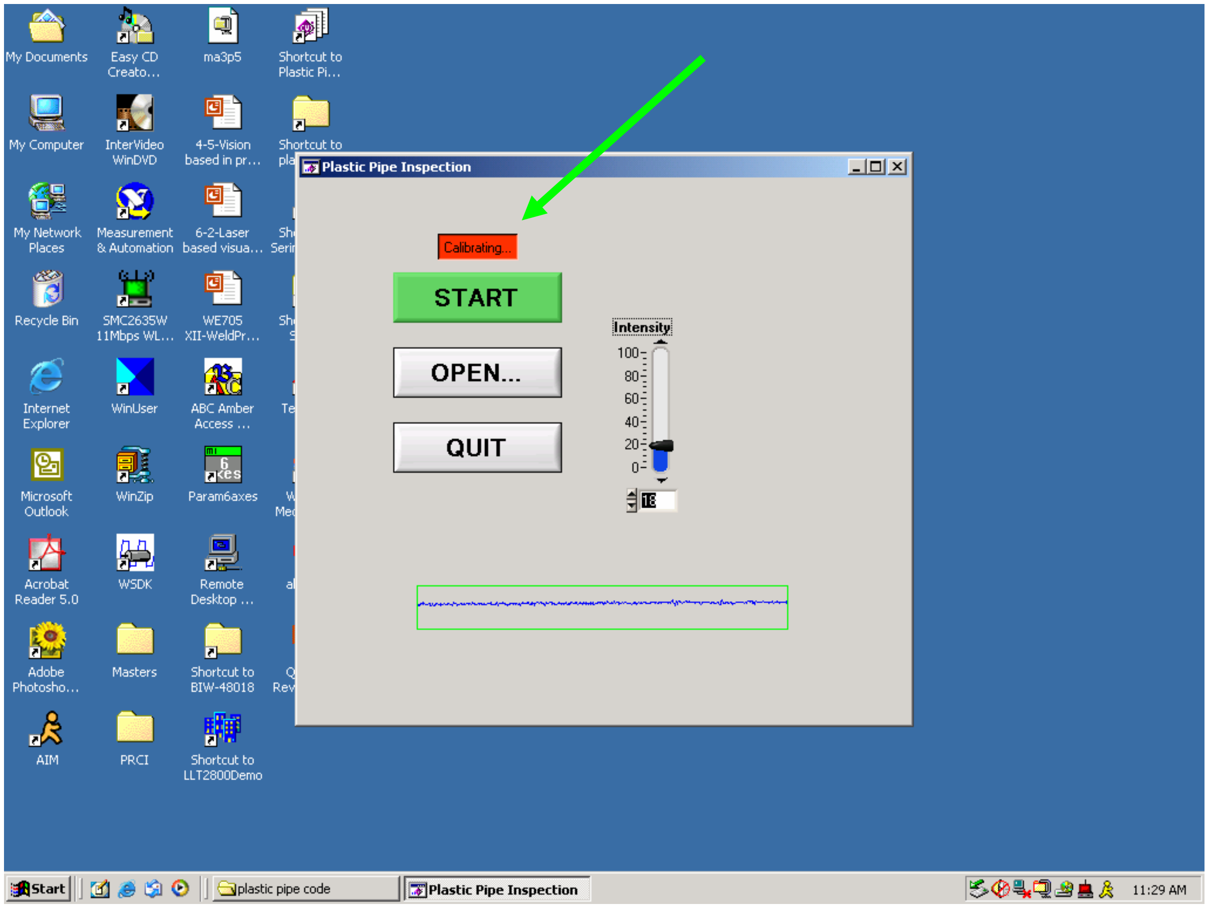
- **Set height of heating element**



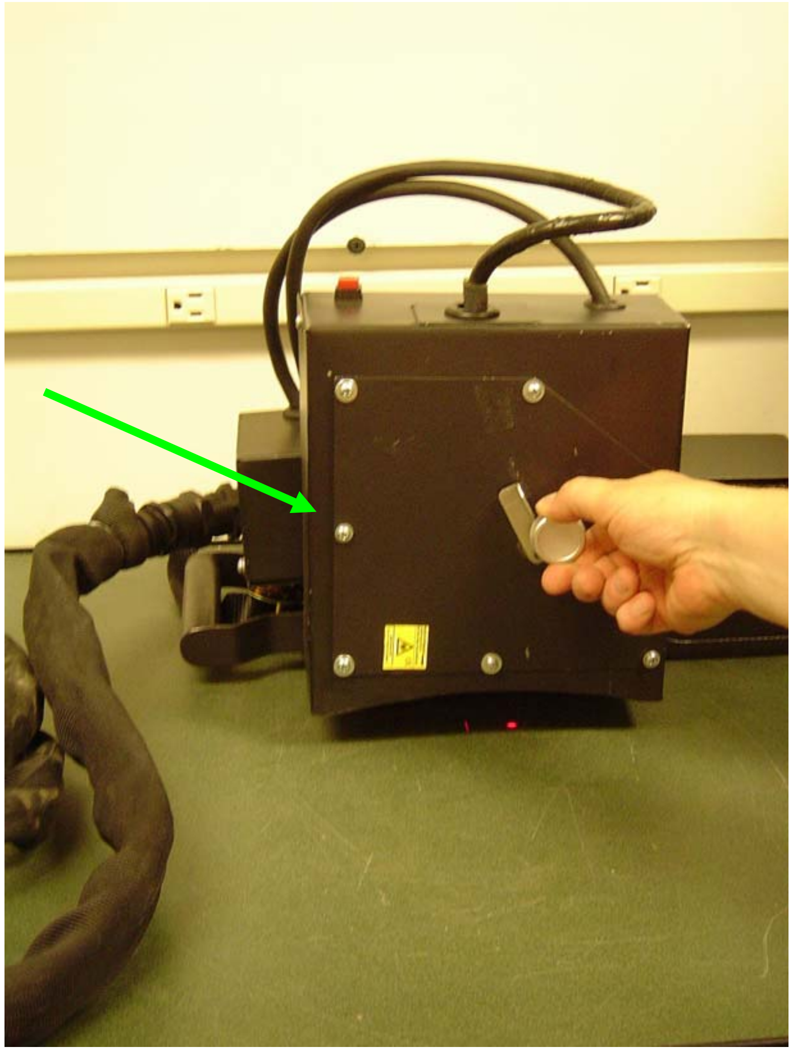
- **Start the software program**



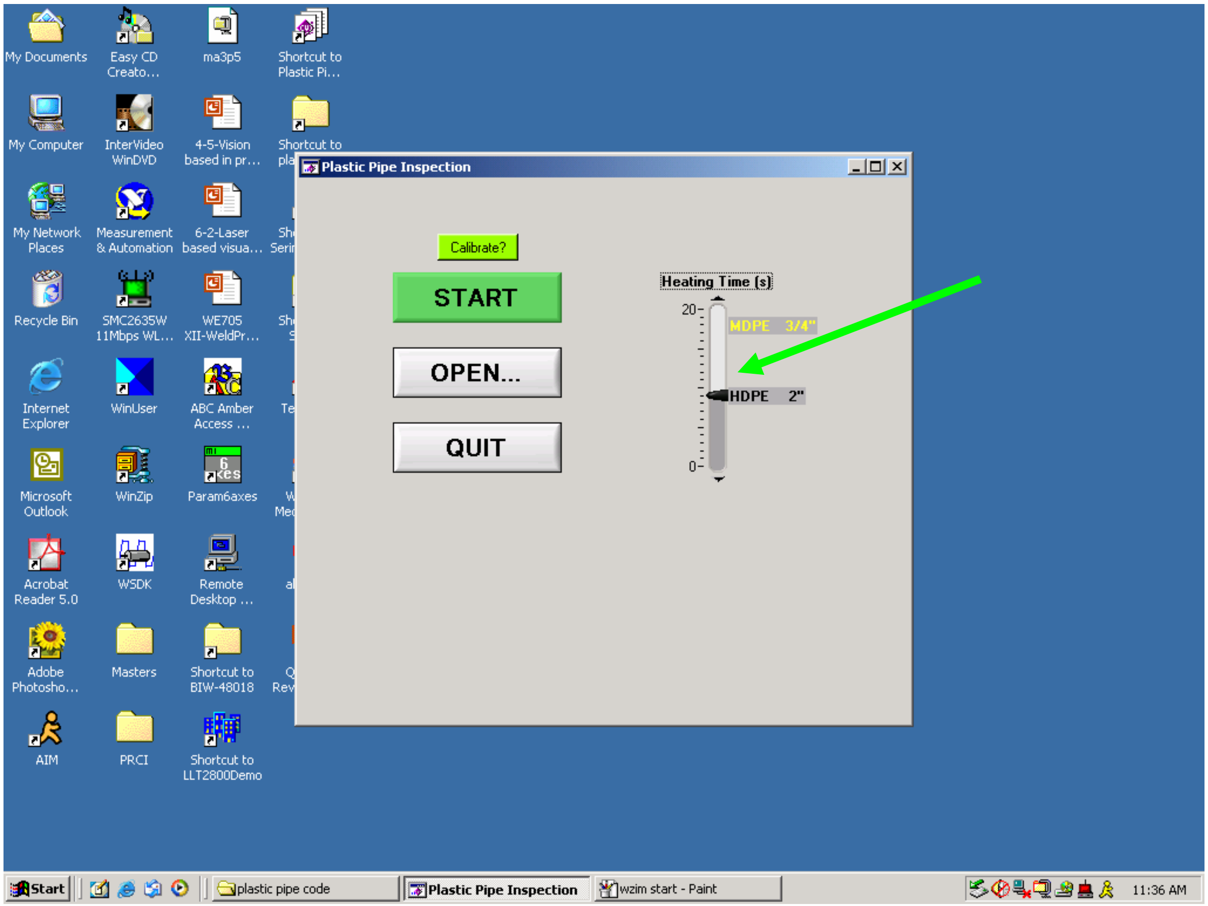
- **Perform an inspection starting at the MAIN Screen**



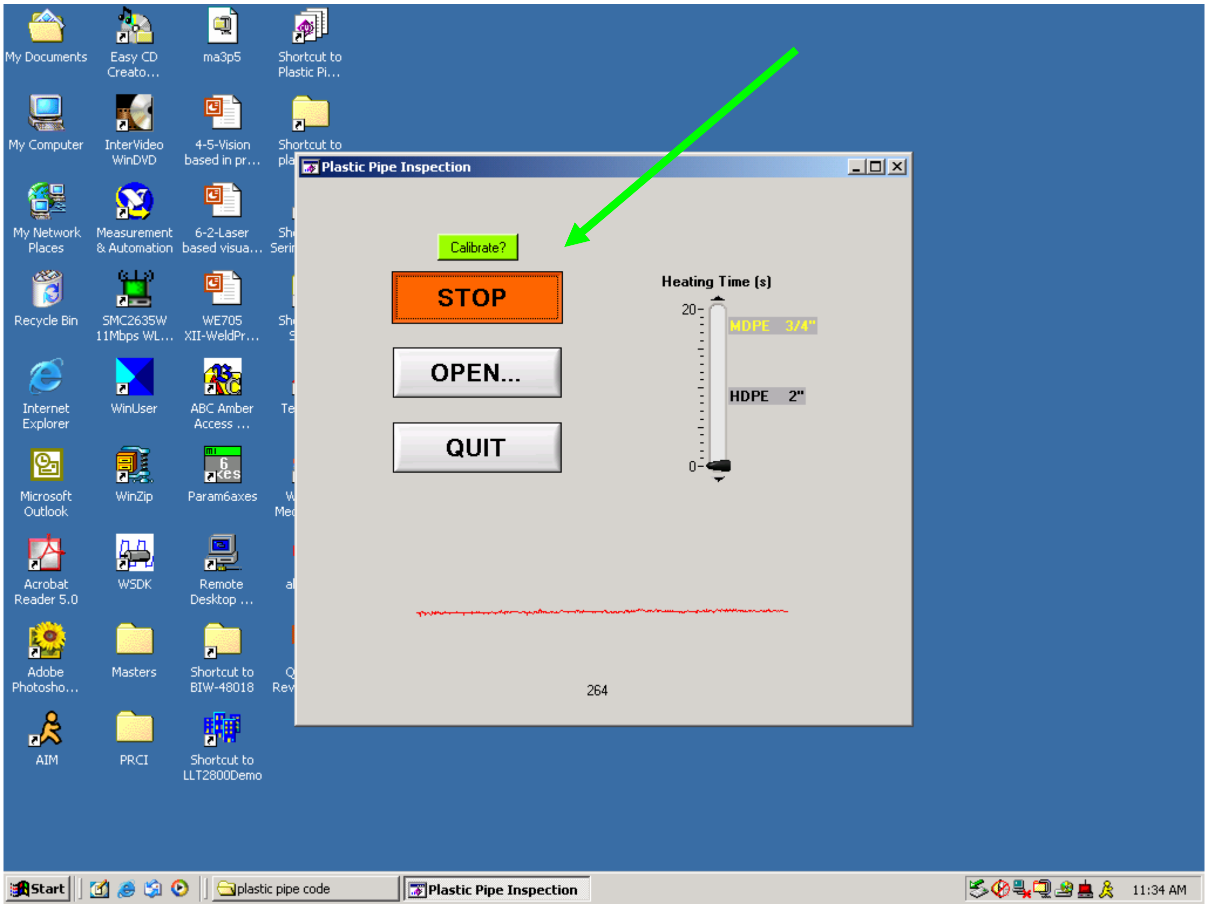
- **Push Calibrate Button**



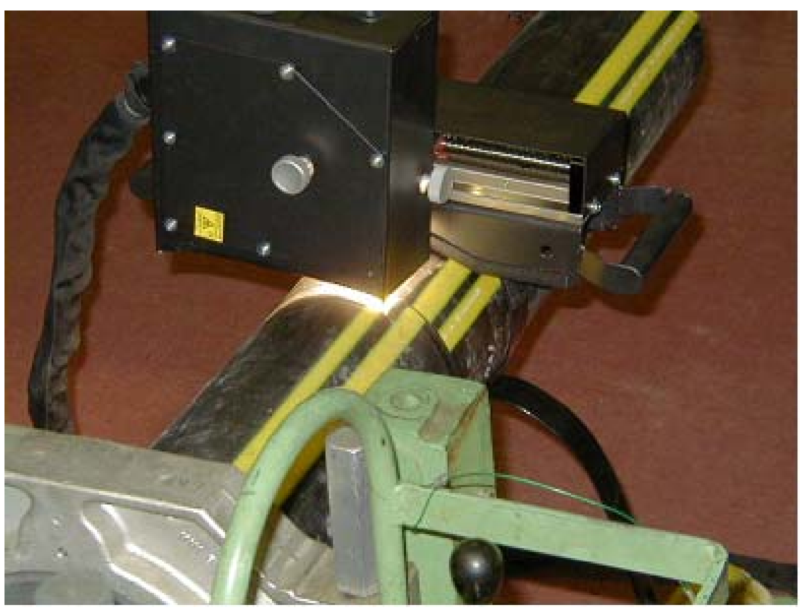
- **Manually adjust laser height during calibration**



- Set Heat Time Button depending on pipe density

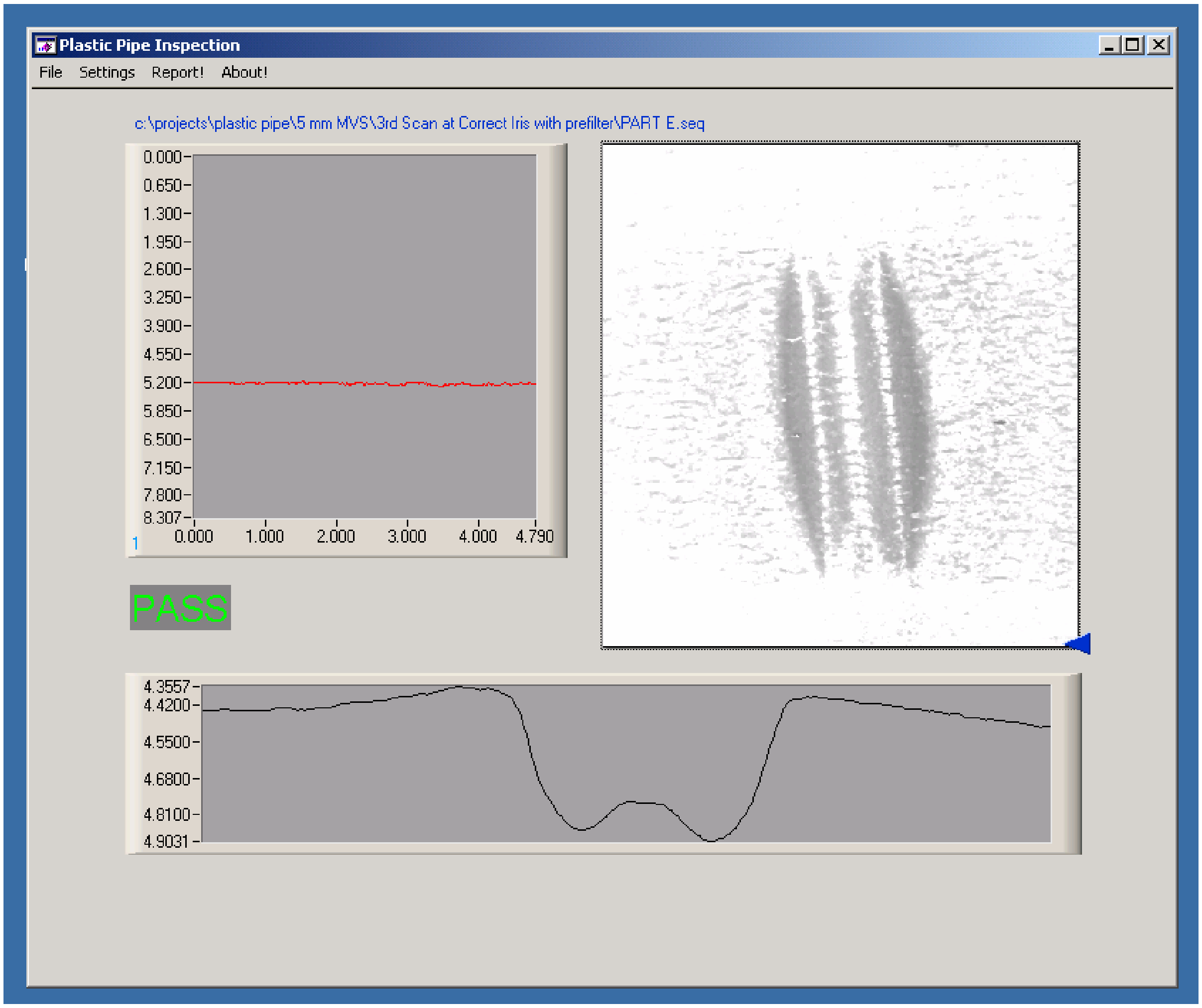


- **Push Start Button**

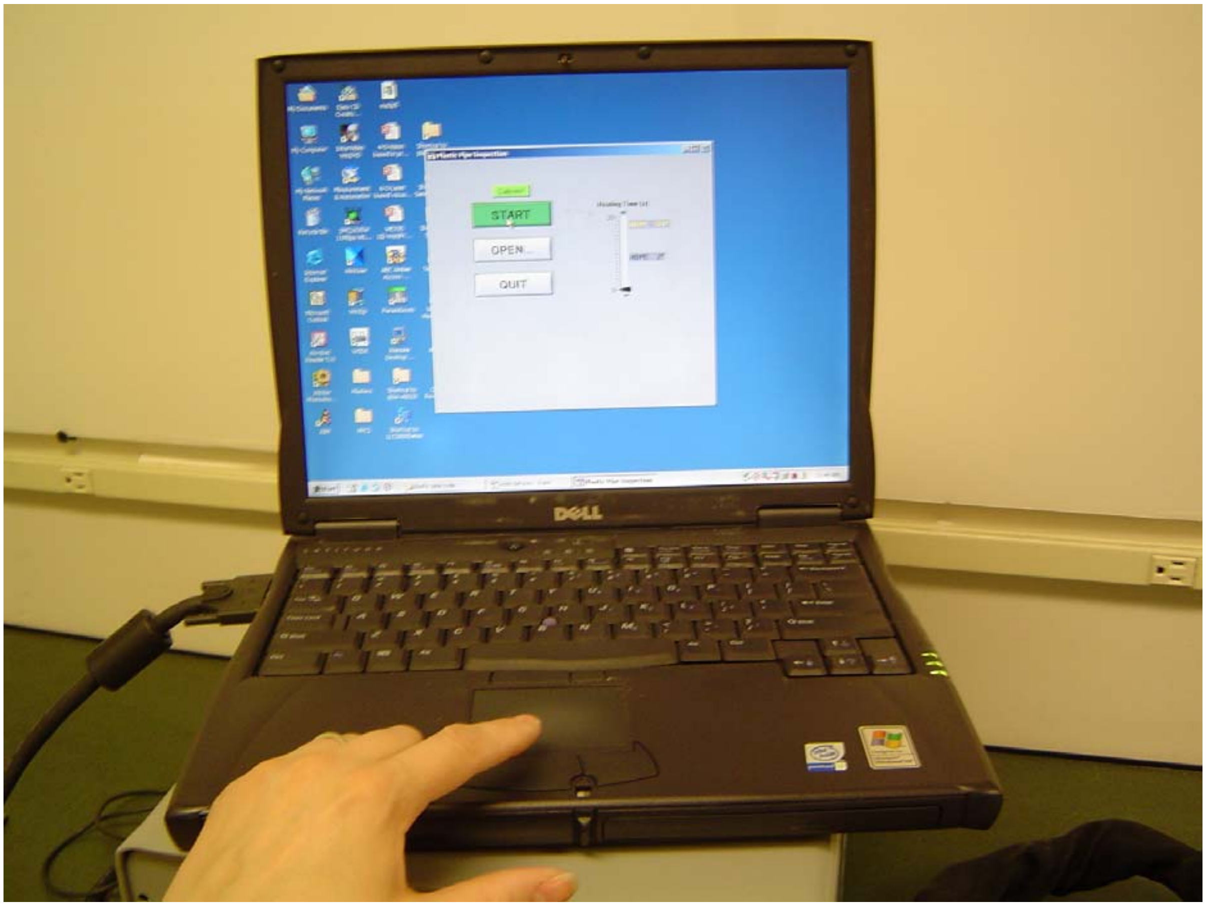


- **WZIM Unit performs local heating**

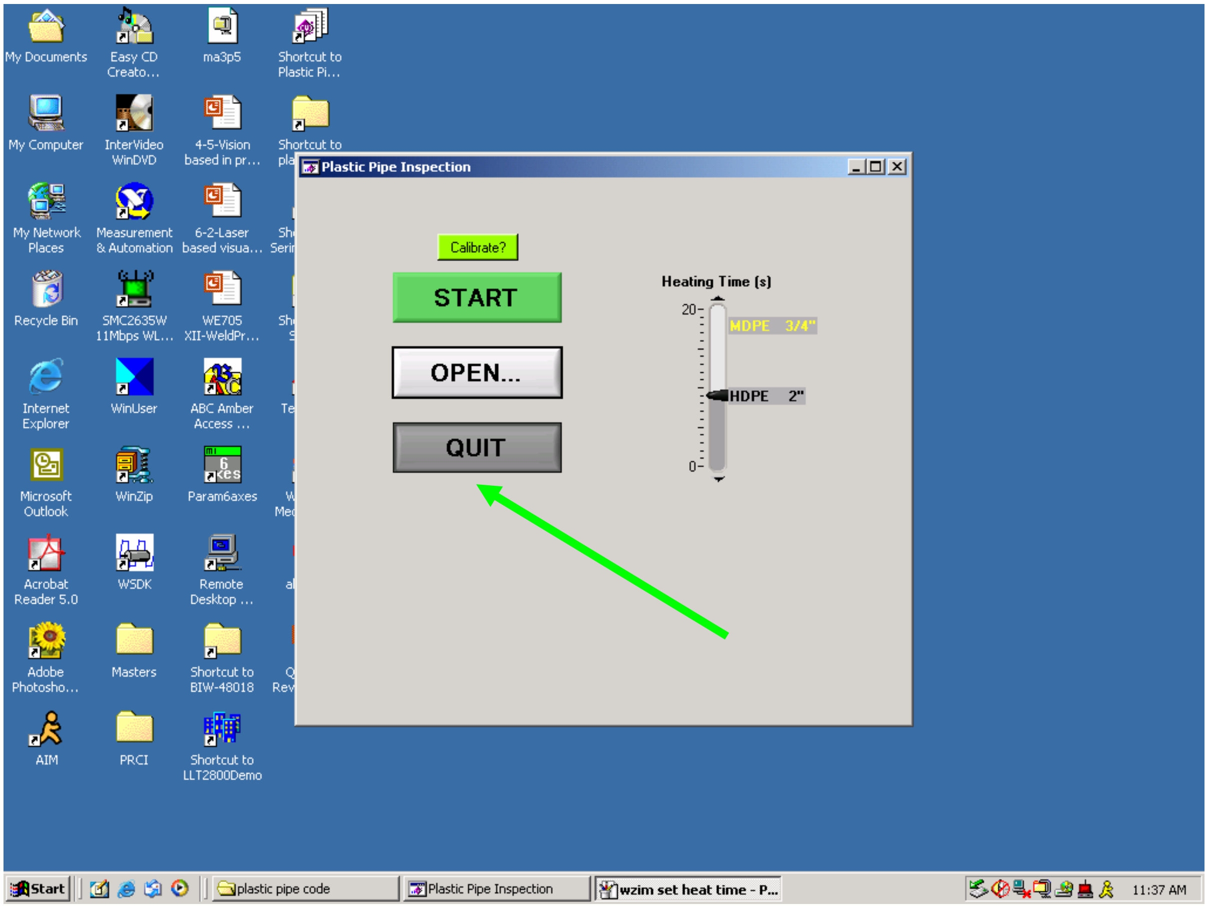
- **WZIM Inspection System performs laser scanning**



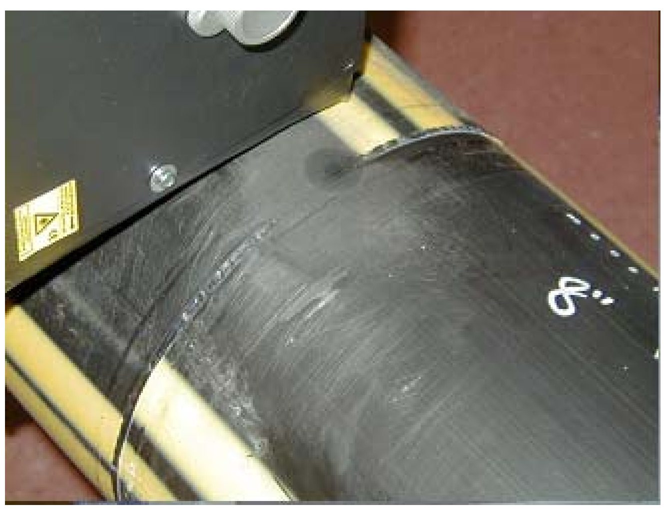
- **WZIM Unit displays Inspection Result**



- **WZIM Unit returns to MAIN screen when finished**



- Push Quit Button to exit the software program



- **Remove WZIM Unit from Pipe**

Section 4. Operating the WZIM Inspection System Software

Instruction Pages

This section describes how to use the WZIM Inspection System Software.

MAIN UIR Screen

The MAIN user interface screen is displayed when you first start the software. This screen has 4 buttons that you can select.

- Calibrate Button
- Heating Time Button
- Start Button
- Open Button
- Quit Button

Calibrate Button

The first button on the MAIN UIR is labeled Calibrate. Press this button to begin calibration of the Laser Unit. When this button is pressed, the Laser Unit will move into position and start displaying a red line on the UIR. You will also see a green box on the UIR. Using the knob on the front of the Laser Unit, adjust the laser height up and down until you see the red line go inside the green box. The Laser Unit height has been set and the system is now calibrated.

Heating Time Button

Before you start an inspection, make sure you have selected the correct Heating time using the Heating Time button on the UIR. This will depend on which density pipe you are using. Remember, HDPE is usually yellow and MDPE is usually Black. Set the Heating Time slider to HDPE or MDPE depending on the type of pipe you are inspecting. HDPE will heat for 18 seconds. MDPE will heat for 9 seconds.

Start Button

The INSPECT button on the software UIR will begin the inspection process. Press this button to begin an inspection. Once this button has been pressed, the Halogen light source will illuminate for either 9 or 18 seconds. Observe that the UIR indicates how many seconds remain until the light source will be turned off. After the heating cycle, the Laser Unit will move into position and begin inspecting the part. Observe that the UIR indicates that the laser is scanning. Once the laser has completed the scanning (about 20 seconds), the Laser Unit will move back into the starting position. At this point, the UIR will indicate the laser is inspecting.

Open Button

An inspection result can be viewed at any time by pressing the Open button the MAIN UIR. This will change the UIR into the RESULTS screen which will prompt you which file you want to open and view. The RESULTS screen includes a picture of the scanned pipe image, graphs of a single laser scan across the surface and a message indicating Pass, Fail or Undecided. Any previous inspection completed by the WZIM Inspection System can be opened this way.

Quit Button

Pressing this button will cause the WZIM Inspection System software to Quit, making the UIR screens disappear until the software is started again.

RESULTS UIR Screen
The RESULTS user interface screen is displayed after a joint has been scanned by the Laser Unit and it is going to be inspected. This can be done automatically during the inspection process or you can open any previous laser scan and view the results. The RESULTS UIR has a menu bar at the top of the screen that allows you to select from the following menu items:

- File Menu Item
- Settings Menu Item
- Report! Menu Item
- About! Menu Item

File Menu Item
The File menu item has a sub-menu that is shown when you select File. The sub-menu items are Open and Quit. Press Open if you want to open a previous inspection file and start the analysis. Press Quit if you want to exit from the RESULTS UIR screen and go back to the MAIN UIR screen.

Settings Menu Item
The Settings Menu Item has a sub-menu that is shown when you select Settings. The sub-menu items are Show Analysis and Automatic Index. Press Show Analysis if you want to see the results of the geometrical calculation of the weld zone area displayed on the UIR. Press Automatic Index if you want to change to Automatic Mode.

Report Menu Item
The Report Menu Item will create a report of the current inspection results displayed on the RESULTS UIR screen. This report will be created in Microsoft Word and will include a picture of the scanned are of the weld, the result of the inspection and the name of the file that includes the inspection. See the APPENDIX for an example of the report.

About Menu Item
The About Menu Item displays a message indicating information about the software program.

Change Default Settings

There are several default settings in the software for the WZIM Inspection System. The following items can be changed by using command line arguments with the software executable file.

- Automatic Mode
- Spreadsheet Mode
- Display Mode
- Manual Mode
- Stationary Mode

Automatic Mode

This setting automatically performs all the steps involved with the inspection such as saving the laser inspection file, analyzing the inspection file, making and saving a report and then returning to the MAIN UIR ready for the next inspection. The default condition for this Mode is on.

Spreadsheet Mode

This setting will automatically save a data measurements of the weld surface into a file that can opened in Microsoft Excel. The default condition for this Mode is off.

Display Mode

This mode allows you to see all the data measurements of the weld surface calculations displayed on the RESULTS screen. Each laser profile will have calculations completed and displayed on the screen as you step through the profiles. The default condition for this Mode is off.

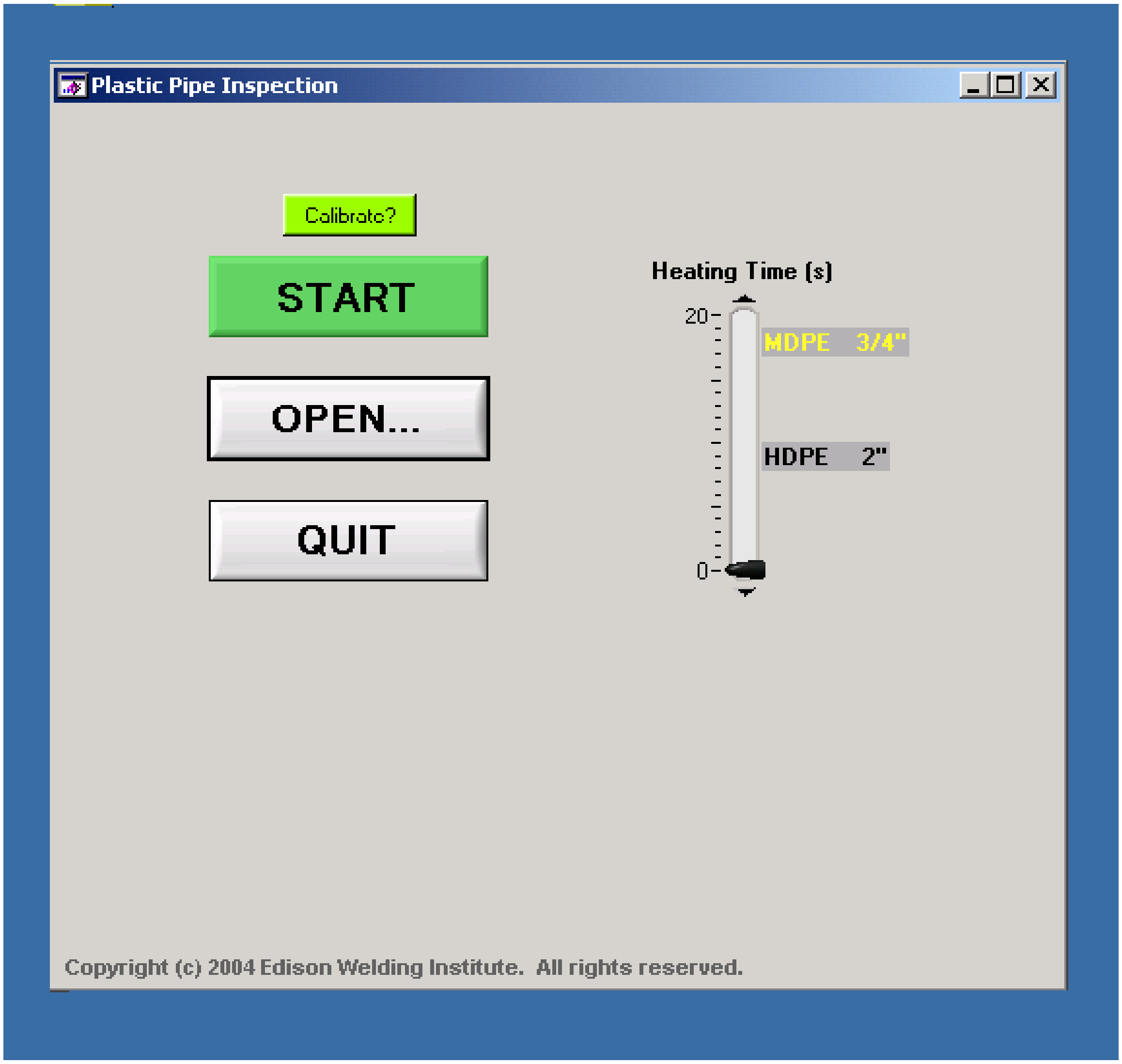
Manual Mode

This setting allows you to complete the steps of the inspection process yourself. After the laser has scanned the joint, you will be prompted to name the inspection file. If you want to analyze the inspection file, you will have to select the Open button on the MAIN UIR screen and then select the File-Open menu item to select the laser scan file you just created. You will have to create your own report using the Report menu item on the RESULTS UIR screen. You will be asked to name you report and save it to your laptop computer. This is the same as setting the Automatic Mode button to off. The default condition for this Mode is off.

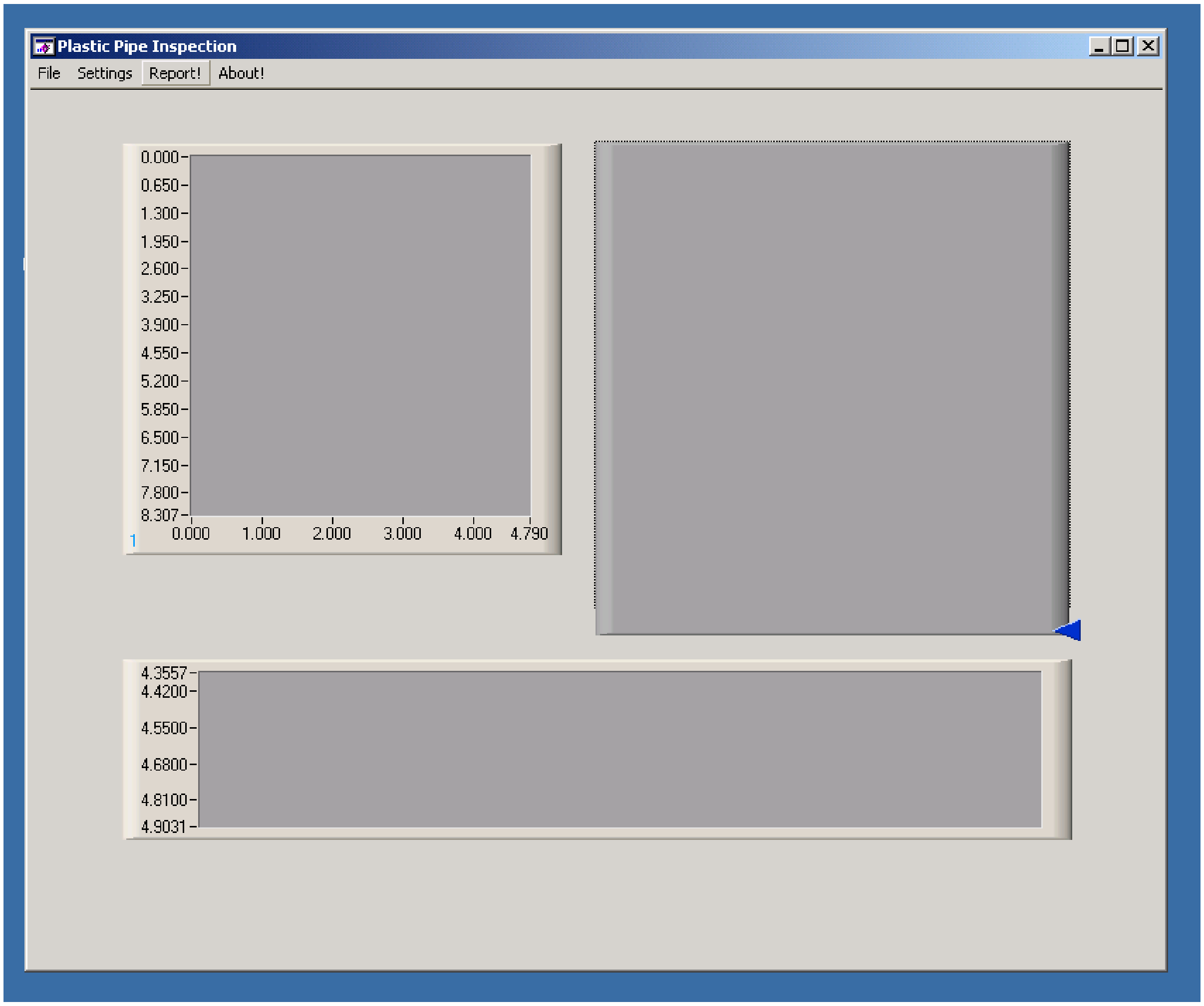
Stationary Mode

This setting will prevent the Laser Unit from moving during the inspection process. Use this setting if you don't want the Laser Unit to move. It is useful if you want to inspect a previously heated pipe section or if you are using the unit on a flat plate and do not need to apply heat. The default condition for this Mode is off

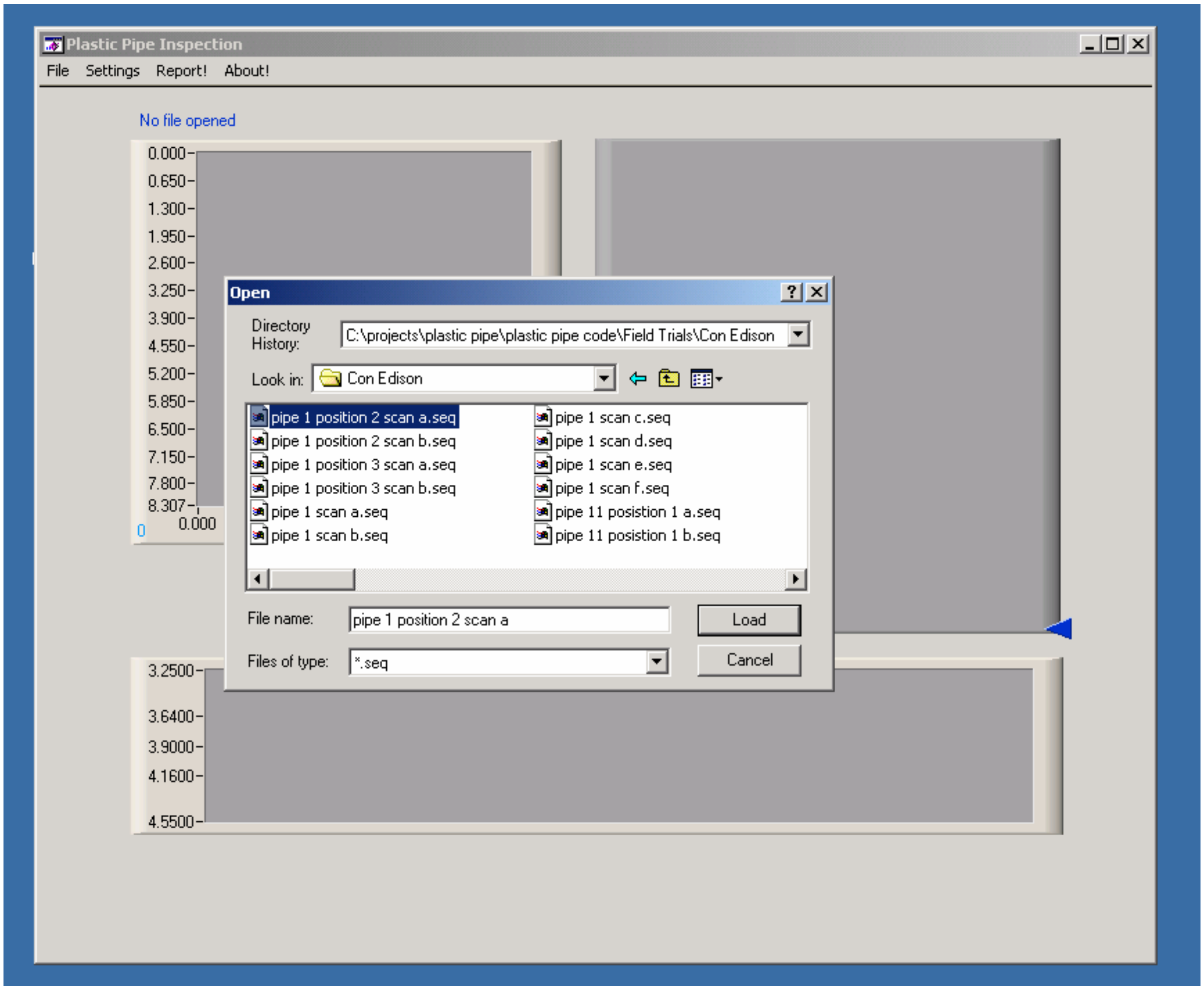
Step-by-Step Instructions



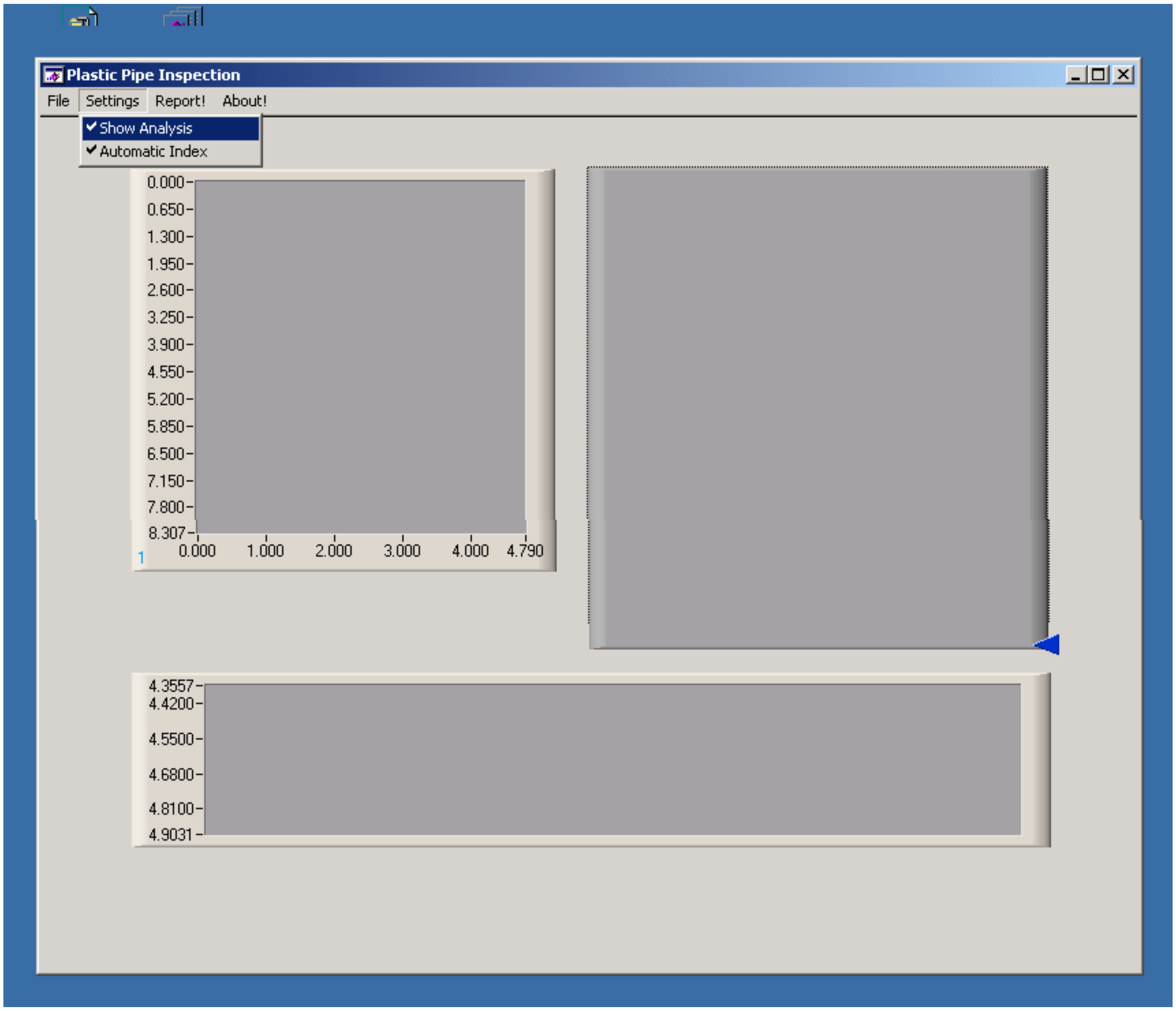
- **MAIN UIR Screen**
  - Calibrate Button
  - Heating Time Button
  - Start Button
  - Open… Button
  - Quit Button



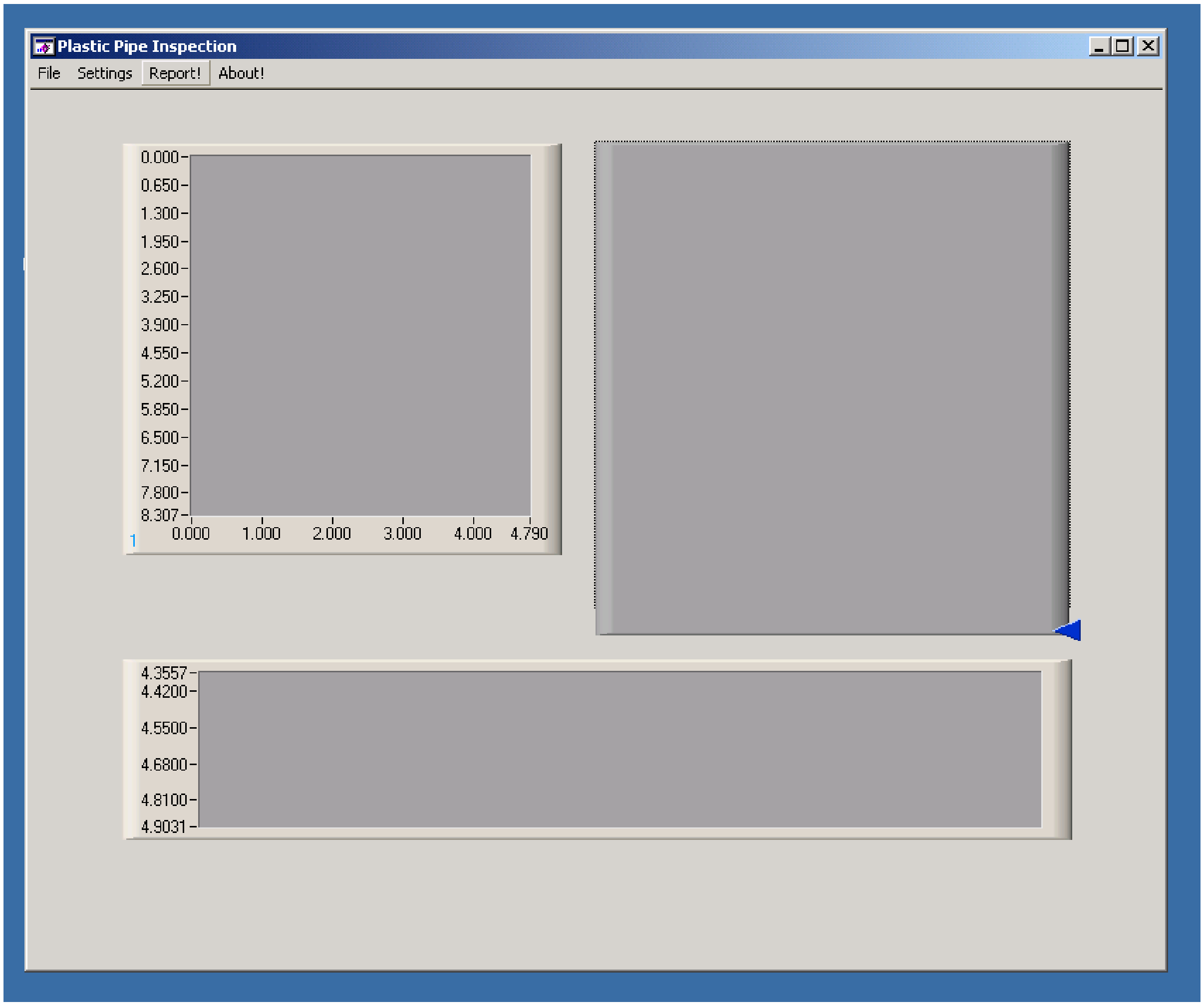
- **RESULTS UIR Screen**



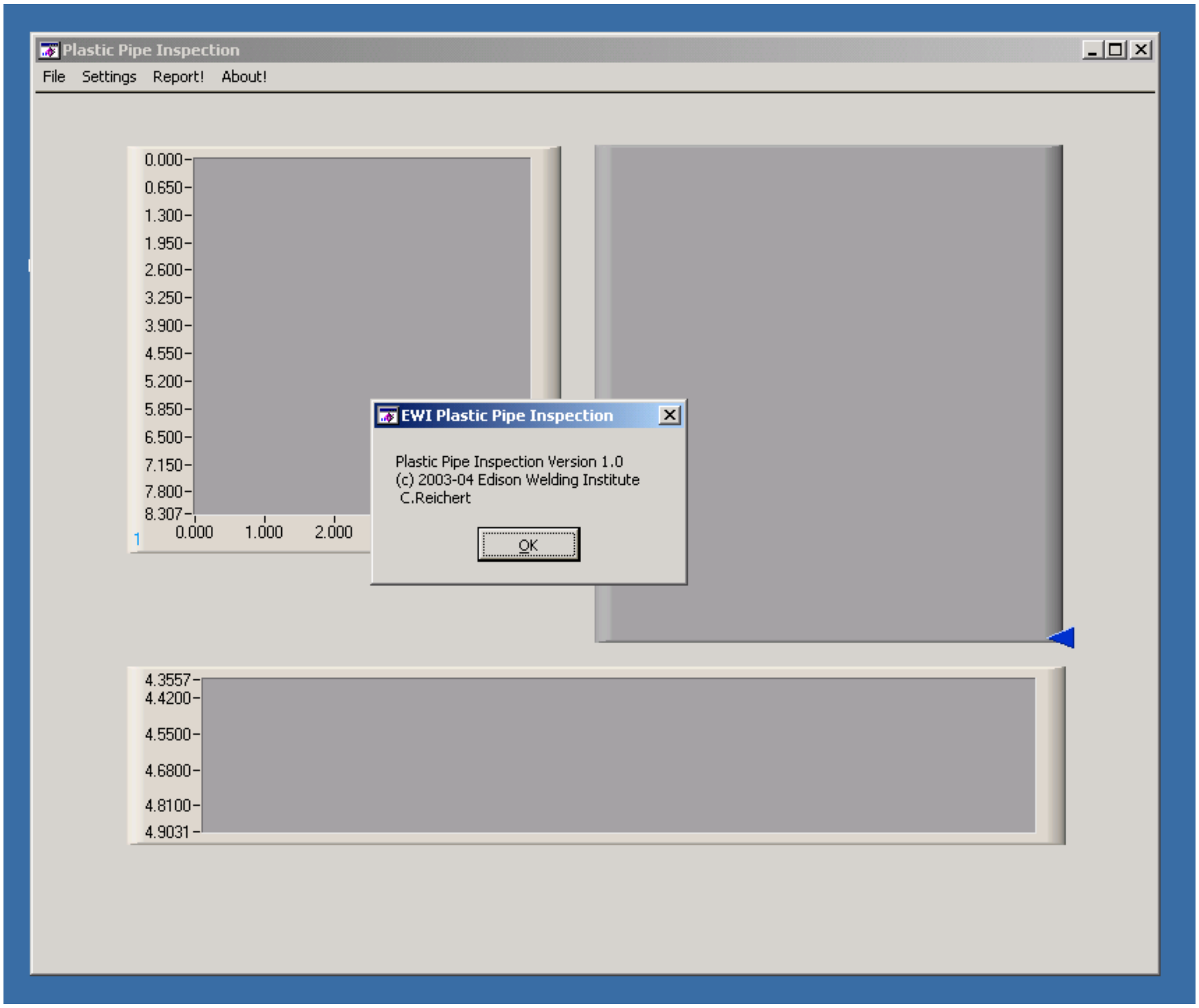
- o File Menu Item



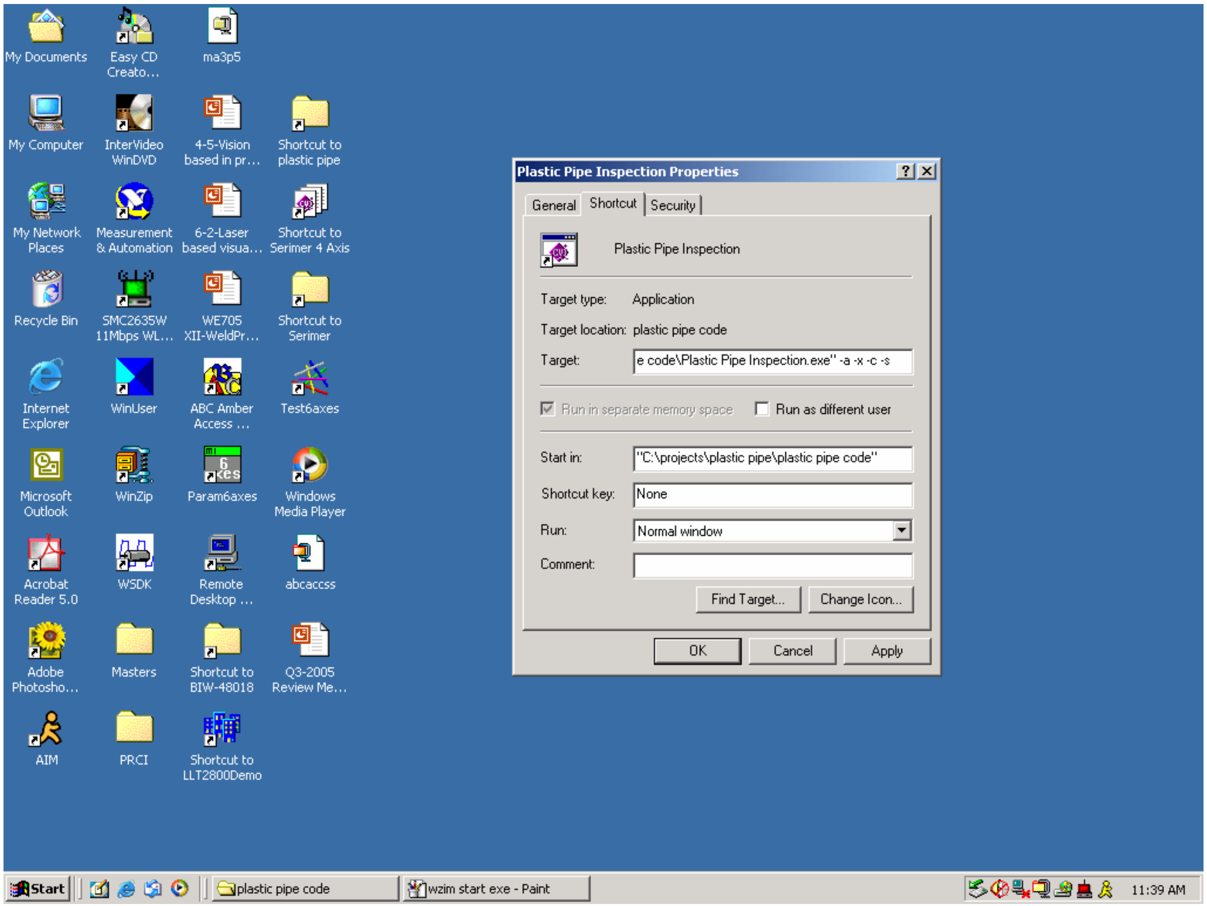
- o Settings Menu Item



- o Report! Menu Item



- About! Menu Item



- **Change software default settings**
  - o Automatic Mode
  - o Spreadsheet Mode
  - o Display Mode
  - o Manual Mode
  - o Stationary Mode

Section 5. Shut Down and Disconnect the WZIM Inspection System

Instruction Pages

This section will describe how to power down the WZIM Inspection System and disconnect the parts.

Power Off the WZIM Inspection System

The system can be powered off by using the Main Power Switch on the back of the Control Box. The main power switch will not be illuminated when power has been disconnected from the Control Box. Use the Emergency Stop Switch to make sure you have cut power to the components inside the box. Once you have made sure the Main Power Switch is off and the Control Box has been powered down, then you can begin to disconnect the connections.

Disconnect the Control Box from the Laser Unit

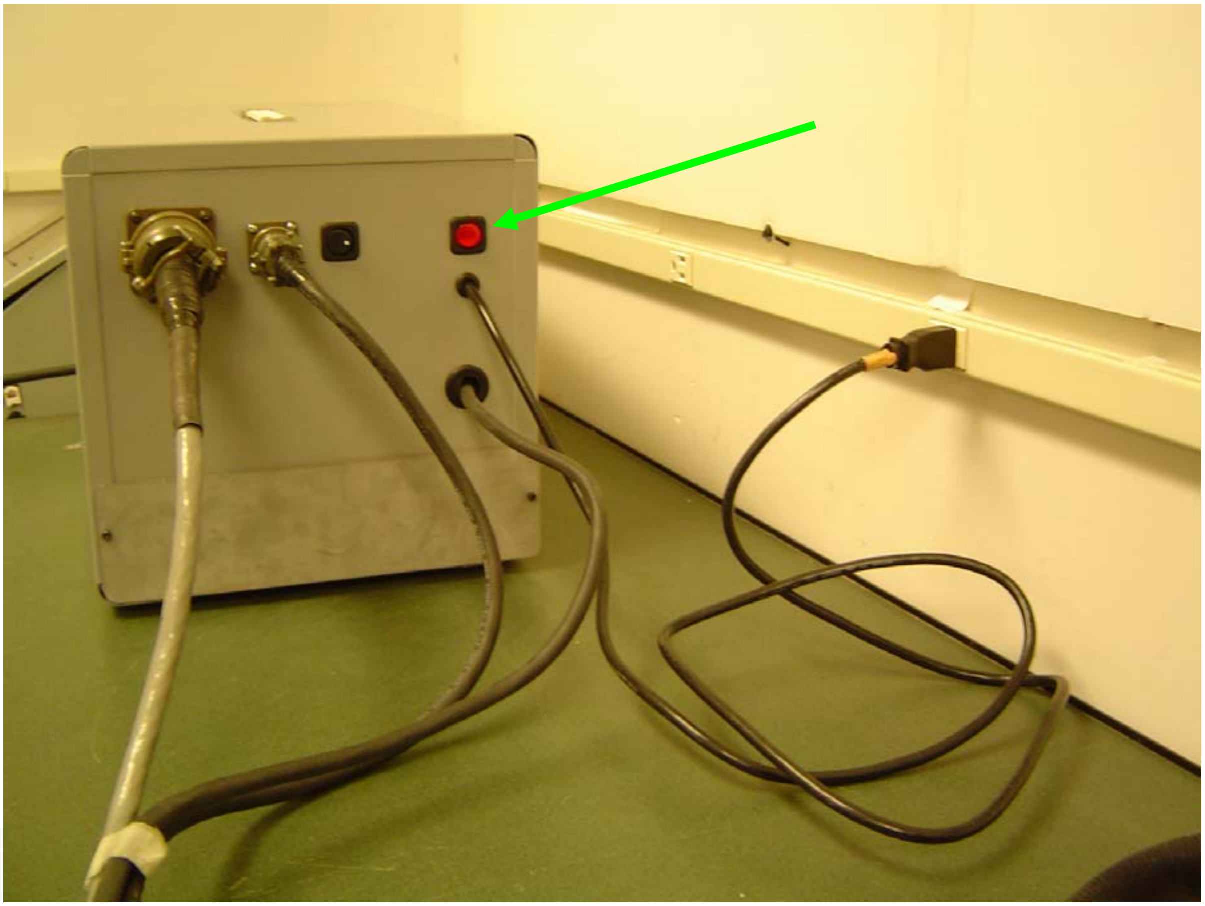
Unplug the Main Power Plug on the Control Box from the wall outlet. Disconnect the following cables from the Control Box:

- Main Signal Connection
- Heating Element Connection
- Laser Signal Connection
- Main Power Plug

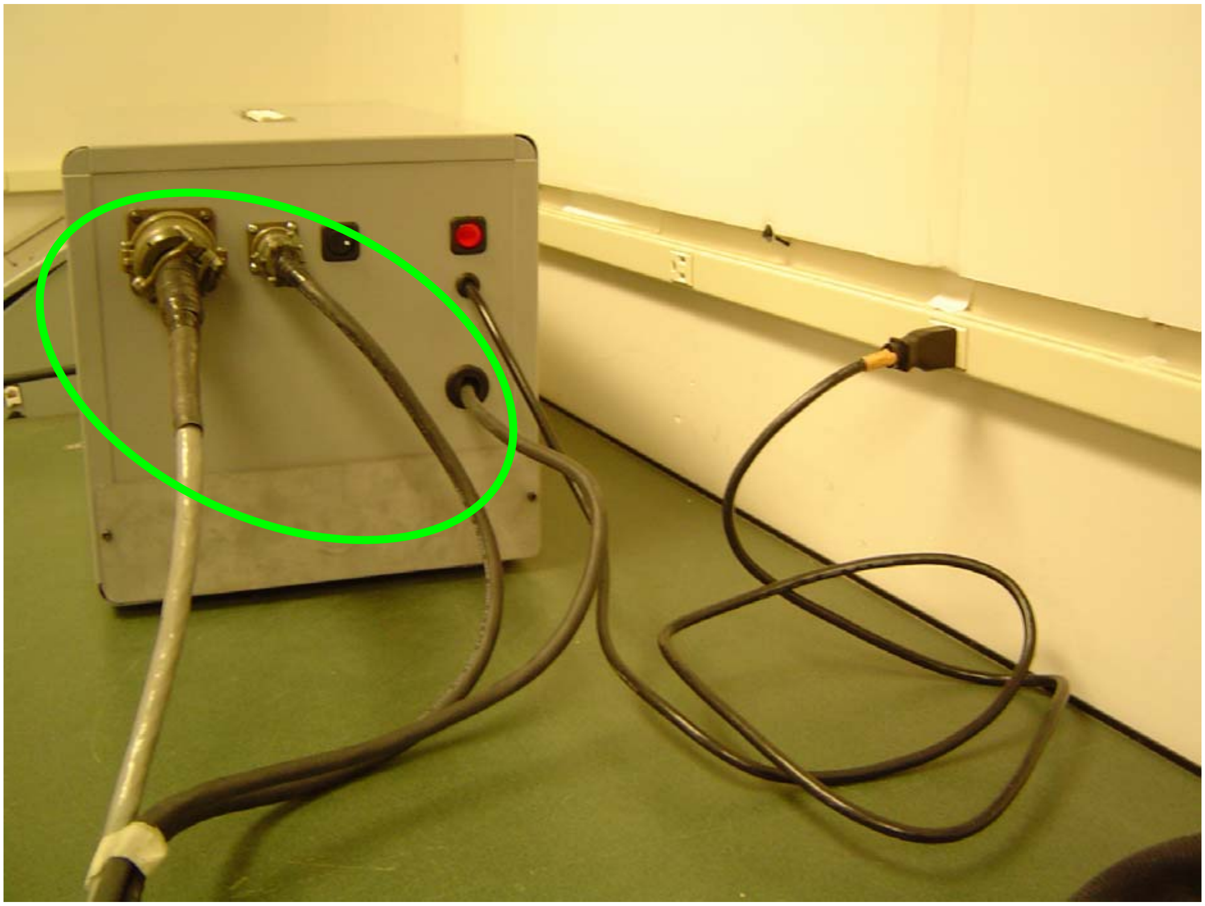
Disconnect the laptop computer from the system

Disconnect the serial connection from the laptop computer to the back of the control box. Disconnect the PCMCIA card connection from the laptop to the front of the Control Box.

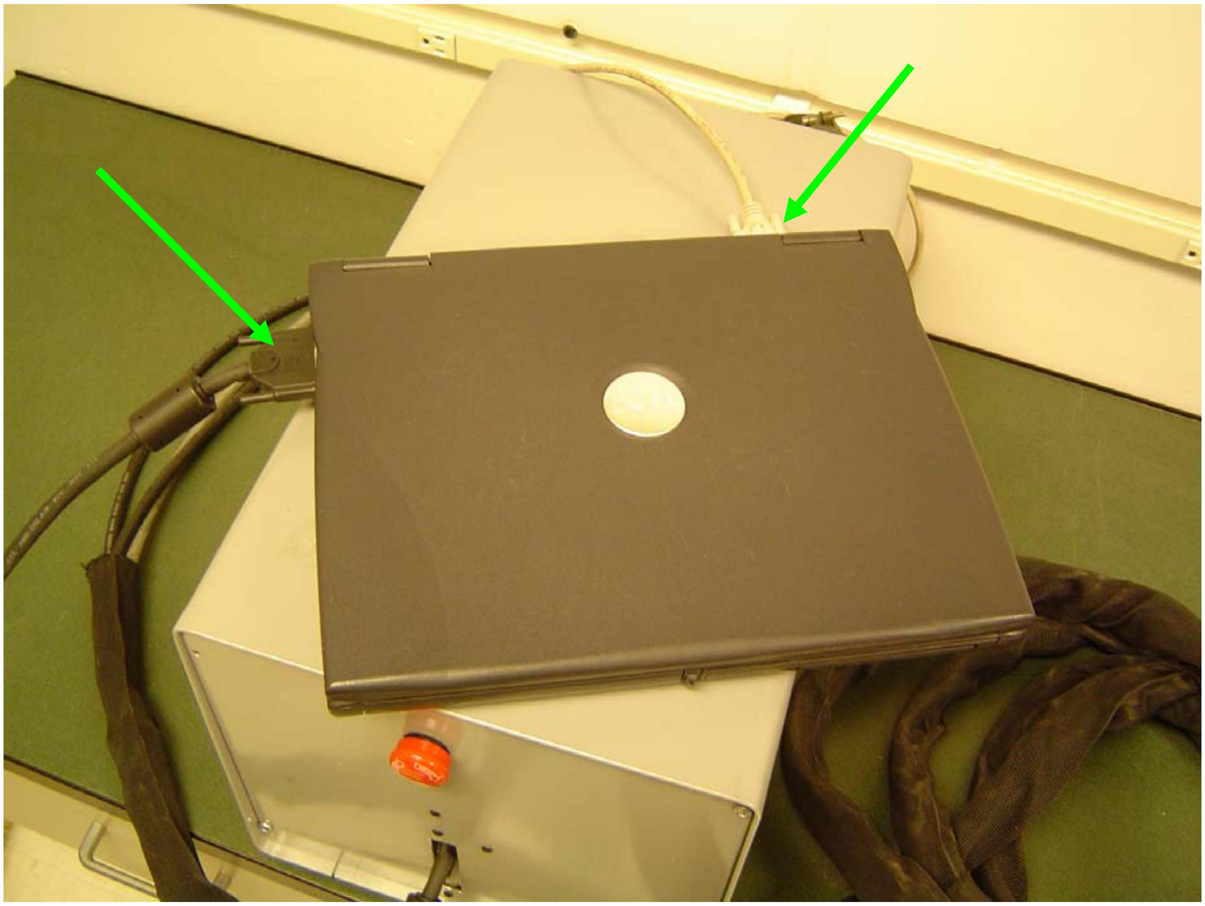
Step by Step Instructions



- **Power Off the WZIM Inspection System**



- **Disconnect the Control Box and the Laser Unit**



- **Disconnect the laptop computer from the system**

Glossary

UIR – User interface is the name given to the software screen that accepts user inputs via buttons on the screen, keyboards or other user input

WZIM – Weld Zone Inspection Method. A method developed and patented by EWI that uses localized heating at the bond interface on PE butt fusion weld to reveal cold weld or lack of fusion defects.

MDPE – Medium density polyethylene.

HDPE – High density polyethylene.

References

ANSI Z136.1For Safe Use of Lasers

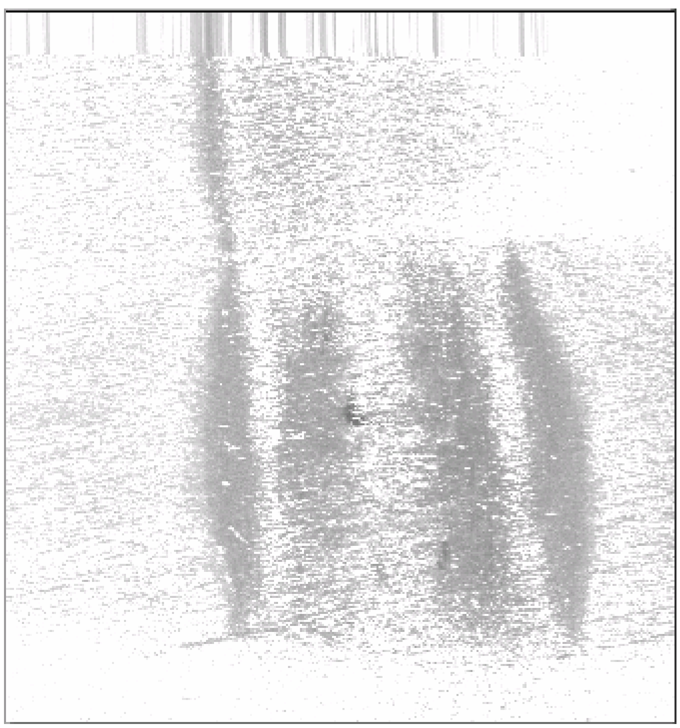
APPENDIX

EDISON WELDING INSTITUE
1250 Arthur E. Adams Dr.
Columbus, OH 43221

Laser Based Inspection Report

PASS

PART C.bmp



Appendix E

WZIM Field Tool Evaluation by NYSEARCH

WZIM Tool Evaluation
October 29, 2004
Con Edison, Bruckner Pipe Fusion Lab

Attending:
Phil Fowles (Con Ed)
Orlando Francini (Con Ed)
Paul Lonseth (Con Ed)
Joe Napoli (Con Ed)
Mario Smith (Con Ed)
Dominick Santomassimo (Con Ed)
Alex Savitski (EWI)
Connie LaMorte (EWI)
Angelo Fabiano (NYSEARCH)

Purpose:
To demonstrate and obtain user/advisory feedback on WZIM prototype field tool and the early version of software programming designed interpret joints. EWI provided an overview of testing done to date, including short term tensile and long term tests performed by TWI. The early prototype/software uses a pass/fail criteria based on laser profile imaging and an analysis of the average light intensity generated by scanned image.

Note: The results should be viewed taking into consideration that WZIM has progressed beyond the “proof of concept” and that joint profile signatures are in the process of being developed. EWI has already proven that when a bondline appears a joint of lesser quality is produced. We need to better understand the characteristics of a bondline and its impact on its in-field service life.

Joint Samples (total 6 joints to be prepared)

1-3) 4, 6, and 8-in. standard joint- Need to record the heat soak time for each.
4) 4" HD pipe - low temp at 75% of standard temp with standard heat soak time
5) 6" HD pipe - insufficient pressure 50% of standard with standard heat soak time
6) 8" HD pipe - high temp at 550°F, apply heat soak time obtained above

Results:
The prototype tool performed well for a first prototype of its kind. It appeared to be field rugged enough and relatively easy to use. The software interpretation of the joints appears to be progressing well, but more work is needed before individual company field tests can be performed.

Comments:
1) An additional category of uncertain (U) needs to be added to software, at least in its early evaluation stages. This information will be analyzed further to determine appropriate category and/or predicted service life.
2) Need to continue tests to determine the “true” bondline signature from other profiles. For example a 6-in. pipe samples tested produced a defined ridge and it was not clear if this joint was considered to be P (pass) or R (reduced in quality).

3) Our original understanding of WZIM was that for a joint to be good there was no line or ridge in the center of the fusion area. Based on the demo it appears that other ridge anomalies may exist that could produce an acceptable joint. Is this really the case?
4) The software's light intensity graph may need to consider both (+) peaks and (-) peaks/valleys that could denote the appearance of a bondline. In short, EWI needs to do more work in this area, particularly discerning the difference between "good" and reduced quality joints.
5) Suggestion: The process to determine the final joint rating should consider both the "light intensity" graph and the laser profile graph. EWI should consider analyzing the individual profile images and scanning for failure signatures.
6) Additional long term (LT) tests need to be performed, whether they are LT Creep Rupture Tests (TWI) or LT pressure tests in a heated bath. The limited TWI testing has not provided adequate results to validate the extent of reduced service life for joints that have reduced quality.
7) TWI/EWI needs to better explain the TWI test data. For example:
    a. Why were two of the eight TWI samples having less than 30% brittle failure found to be invalid?
    b. What is the service life "O" test sample (standard joint)? Can you explain why it did not perform as well as other joints that were fused out of standard (example joint N)?
    c. Did the testing confirm that the joints with or without beads removed have a similar or acceptable service lives? Need more detailed explanation?
8) Future Tool Improvements – Beta design
    a. WZIM to be more light and compact
    b. Needs new pipe strap design or eliminate the need for straps by designing a handheld application.
    c. Expand the tool to NDE the entire joint by rotating around the pipe.

Appendix F

Inquiry to Retrofit Laser for Longer Line Length

MVS5From: meta-mvs.com]
Sent: Monday, February 14, 2005 3:47 PM
To: Reichert, Connie
Subject: Fw: MVS5

Hello Connie,

It has been a while and thanks for getting in touch. The project looks like it's taking shape and ready to move off prototype to production.

Below is a summary of the conversation that I had with Pierre Lessard. Essentially, to move to a 10-mm sensor is not as simple as changing the laser diode. We will have to build a new sensor and supply a different interface box. In summary these MVS cameras are fast approaching extinct as far as new builds are concerned.

You should be taking a look at our newer sensor - the triple stripe.

Looking forward to your feedback.

Sincerely,

Pierre

It would be a completely new sensor (body, optics, camera and laser diode). The parts we could use from the MVS-5 would be the laser controller board and the filter.

She couldn't use the interface box with that sensor. She would need a CLPS like the one she has for the MVS-30 sensor.

Pierre L

Pierre,

So that I understand, Connie wants to convert the 5-mm FOV to a 10-mm FOV. Does this mean changing the optics and camera or just the laser diode ?

We can't convert a 5- to a 10-mm. The MVS-5 was designed to be a 5-mm only. It's true for all the MVS sensors line

To build a 10-mm, I can have the missing machine parts done. I would need to buy the optic lenses. I don't have a working camera. I have two defective one that I could send for repair.

Pierre L.

Pierre,

What parts do you require to convert the 5- to a 10-mm ?
We have absolutely nothing left in parts ?

1 } Can we still make the MVS 5 ? I could build one more MVS-5 sensor. I have one camera left. If EWI wants more it would have to be MLP1/05 sensors.

2 } Can we retrofit the current camera to an MVS5-10 mm ? No. It's impossible. We can't build a 10-mm either. No more parts. It would have to be a MLP1/10 sensor.

Regards

Pierre L
Two questions :

1 } Can we still make the MVS 5 ?

2 } Can we retrofit the current camera to an MVS5-10 mm ?

Thanks,

Pierre

----- Original Message -----
From: Reichert, Connie
To: pierre.huot@meta-mvs.com
Sent: Friday, February 11, 2005 4:48 PM
Subject: MVS5

Hi Pierre-

It has been a long time since we spoke- I hope all is going well for you. I have attached a picture of our plastic pipe system where we used the MVS5 you made for us last year. We have had a successful Phase 1 and Phase 2 over the past 1½ years. We are ready to begin Phase 3 which is field trials in March. I was wondering if the laser you made for us (MVS5 and controller box for manual/software control) could be retrofit with a 10-mm-wide laser in place of the 5-mm laser? In future units we will need to use a 10-mm-wide laser at least and I wanted to see if we could squeeze in getting a 10 mm for this last phase of our project. I hope to hear from you soon.

Kind regards,
CTR
Connie Reichert
Senior Engineer
Edison Welding Institute
Ph. 614-688-5247
Fax. 614-688-5001
Constance_Reichert@ewi.org

<<DSC01065.jpg>> <<DSC01063.jpg>>