Monitoring and Control of the Hybrid Laser-Gas Metal-Arc Welding Process

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Outline

- Overview of Project
- INL Sensor and system development focusing on real-time ultrasonic inspection probe/methods
- EWI real-time Eddy-Current inspection
- Concluding

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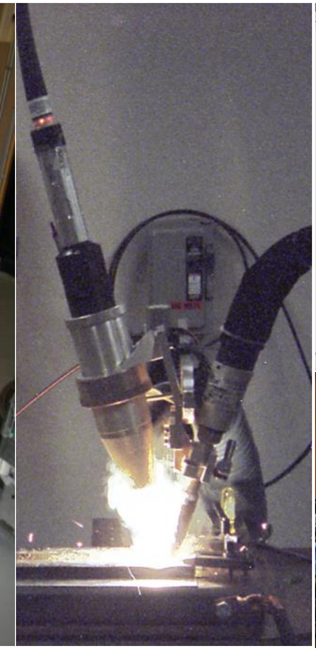
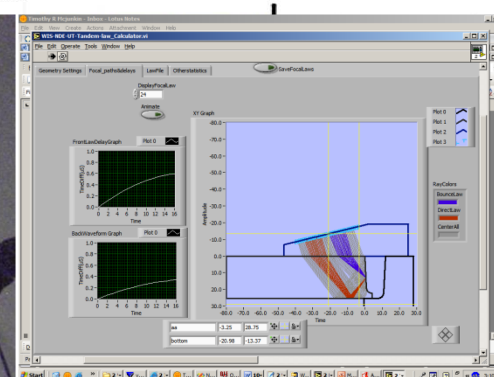




Enhanced technology for nuclear and industrial fabrication

- Advanced Manufacturing Methods (e.g. hybrid laser welding, spray forming).
- Efficiency through robotics, near real-time diagnostics, and intelligent systems.
- High throughput, minimized energy, and low waste processes.
- Remote capability in hazardous environments.

Building on the legacy of state of the art high temperature process research.

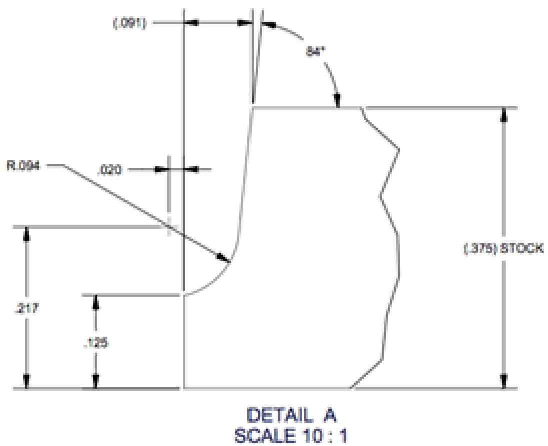
Towards effective real time feedback…

- With High Speed processes along with the potential for high productivity is the danger of high productivity of flawed welds
- Not necessarily detected by welder or system prior to post weld examination—possibly at an entirely different facility (i.e. radiography cave)
- Base goal: do in place evaluation of weldment in welding fixture
- Next goal: provide real time feedback is the ability to detect a flawed weld and shut it down to minimize the extent waste or repairs
- Ultimate goal: have a knowledge base so signature of a flaw or precursor to a flaw can be remedied without a start and stop
- Sensors tailored to producing near instantaneous feedback.
  - Weld electrical signals.
  - Ultrasonic methods
  - Electromagnetic (eddy current)

Choice of Welding Configuration / Lab Setup

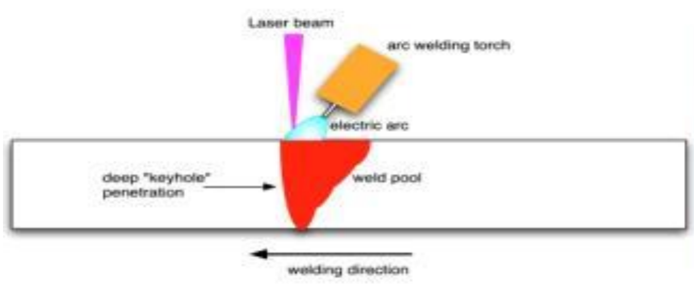
- High through put welds Hybrid/Laser
  - Laser and Hybrid laser allow a high speed process.
  - Focused laser leading GMAW.
  - Parameter variations of Laser power source is a convenient feedback input to system
  - Feedback mechanisms to remedy lack of penetration or excessive heat leading to weld pool leaking out.
- Weld Joint and Material for Initial Research
  - Chose 316L – EWI desired non-magnetic material
  - 3/8” thick material
  - Started with V-groove preparation with vertical root face and have moved to a J-groove with vertical root face.
  - Bounded welding parameters with available laser.
- Current limitations
  - 4KW laser limits root face to approximate 1/8”

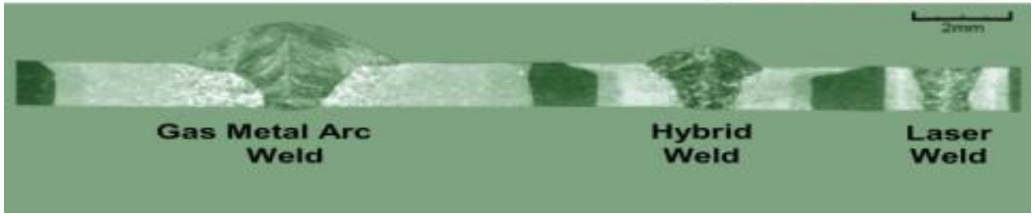
Joint Configuration



Laser Hybrid Welding Process

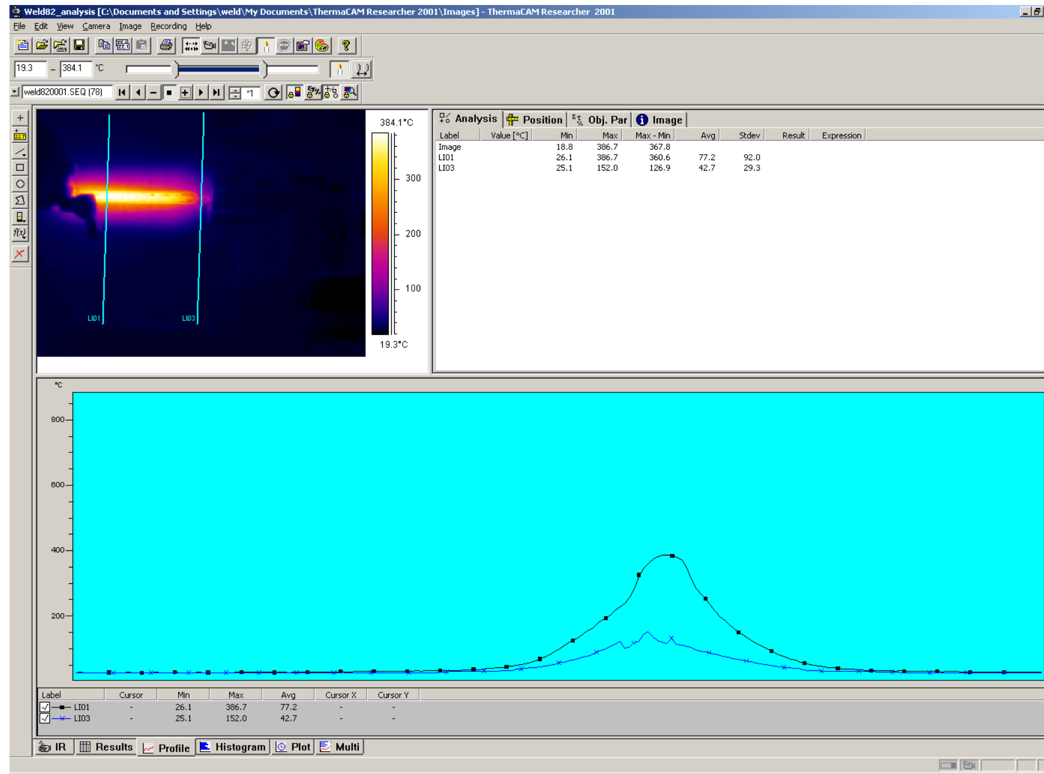
- Advantage
  - laser's penetrating power
  - Gas Metal Arc Welding (GMAW) bridges gaps mitigates tight fitup tolerance
  - Greatly increase welding speeds are achieved, but present new Challenges.
- Challenges
  - Fast feed rate make real time adjustments by welder more difficult. Automation is more important.
  - NDE can be optimized for inspection immediately after weld – i.e. not requiring moving part to radiography chamber to inspect.
  - Real time assessment and laser tracking correction based on NDE would be big a big plus to productivity.



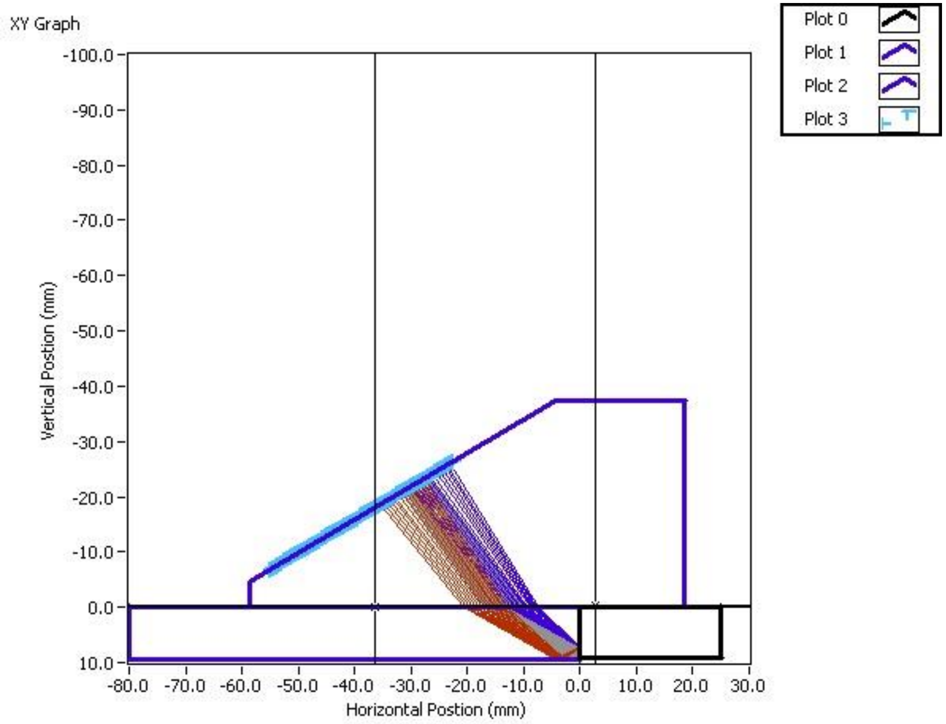


Heat Profile of Hybrid Laser Process

- Thermal Imaging Camera
- Relatively low temperature to the sides of the weld bead
  - Advantage of Laser/Hybrid
- INL and EWI using surface temperature as a design criteria for probes
- Less exotic coupling methods and wider choice of materials are possible in the design.

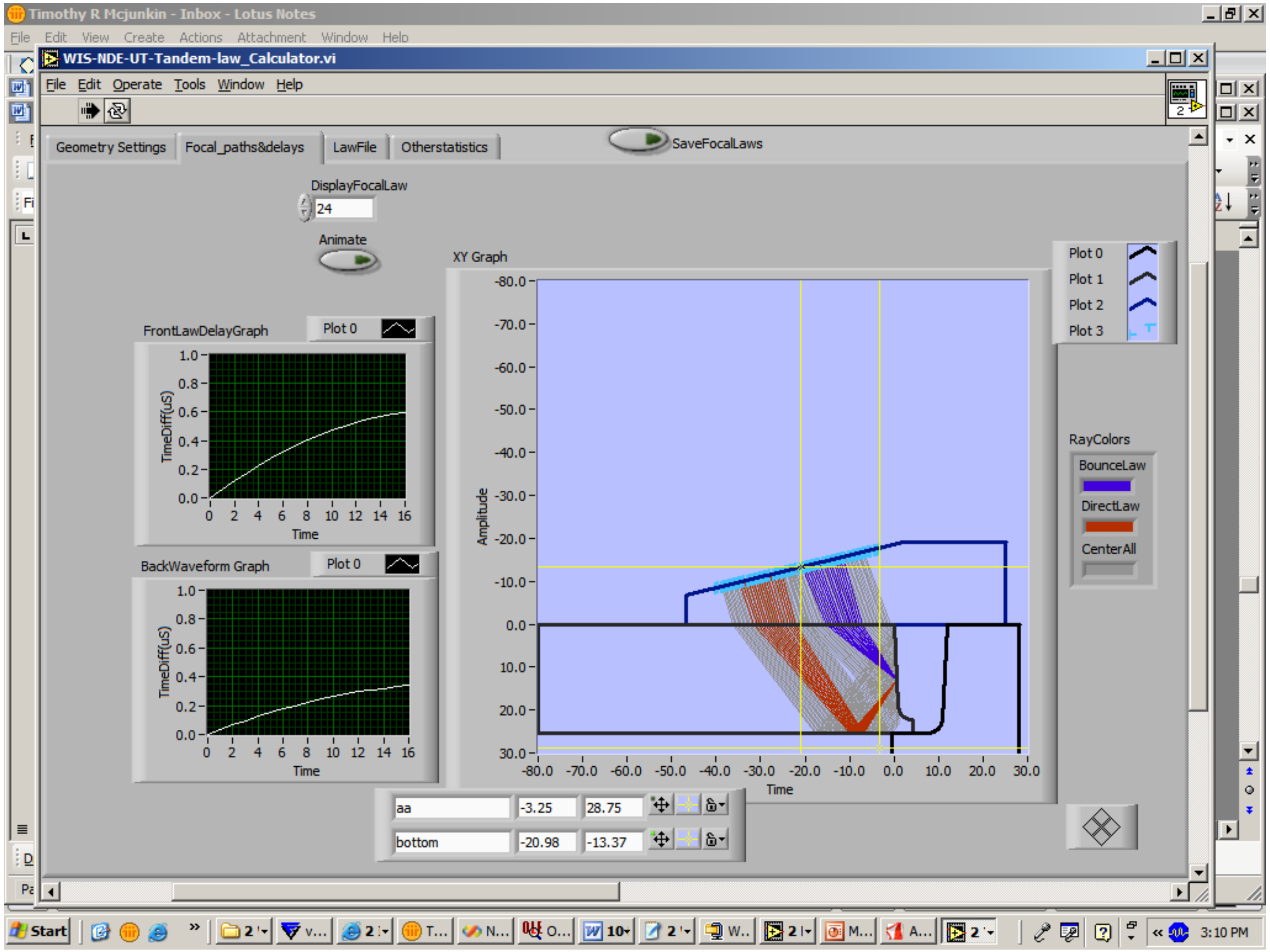


UT Phased Array Focal Laws

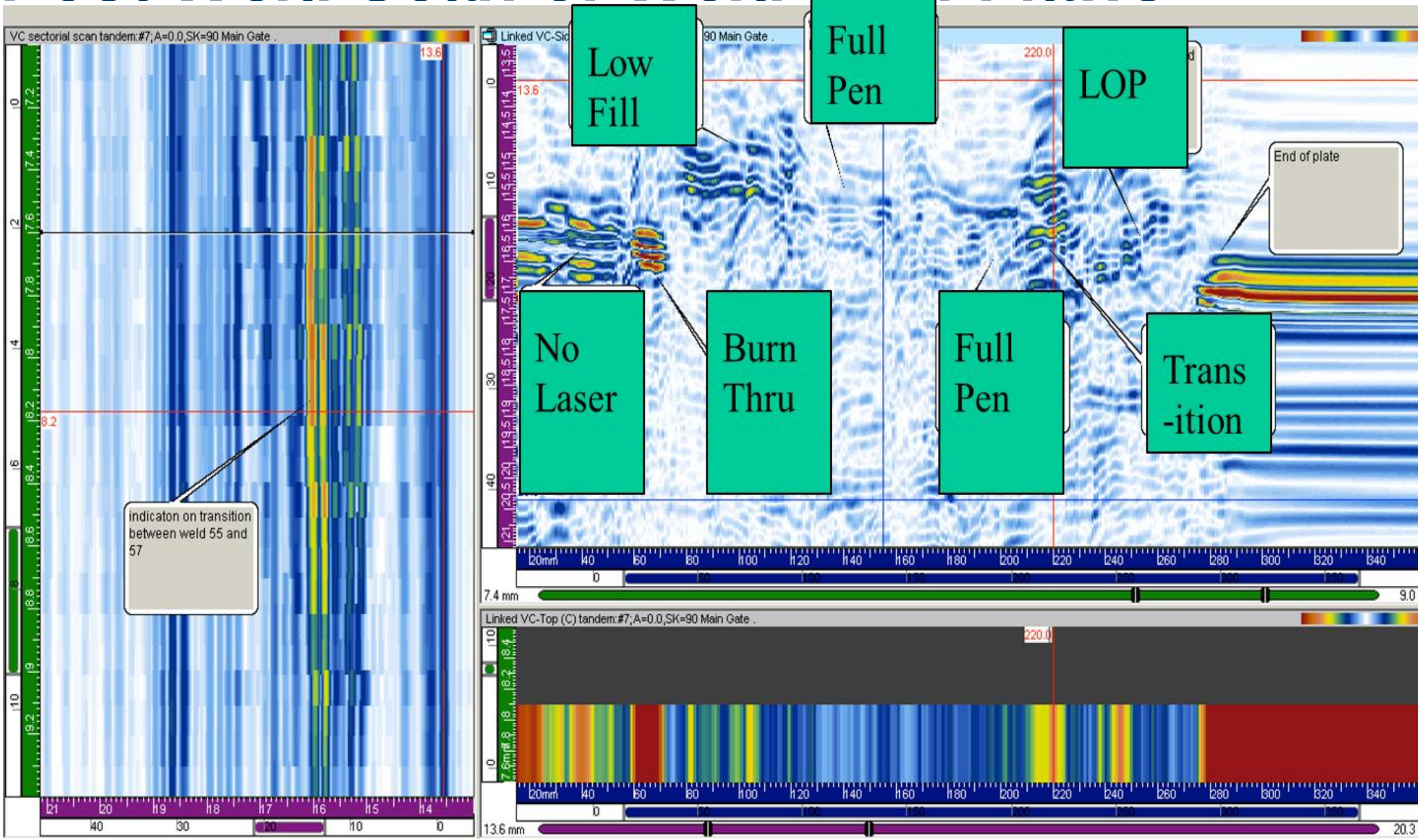


- Direct focus of transducer laws to the root and root face.
  - Detects a laser miss on the root face even when full penetration can be seen on the bottom surface
- Initial design used a commercial probe with modifications.

Adapted from Tandem (Pitch-catch) Find mid weld fusion defects

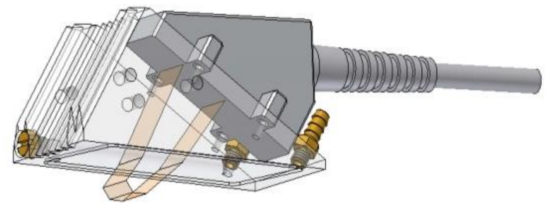


Real-Time Ultrasonics
Post Weld Scan of Weld With Flaws

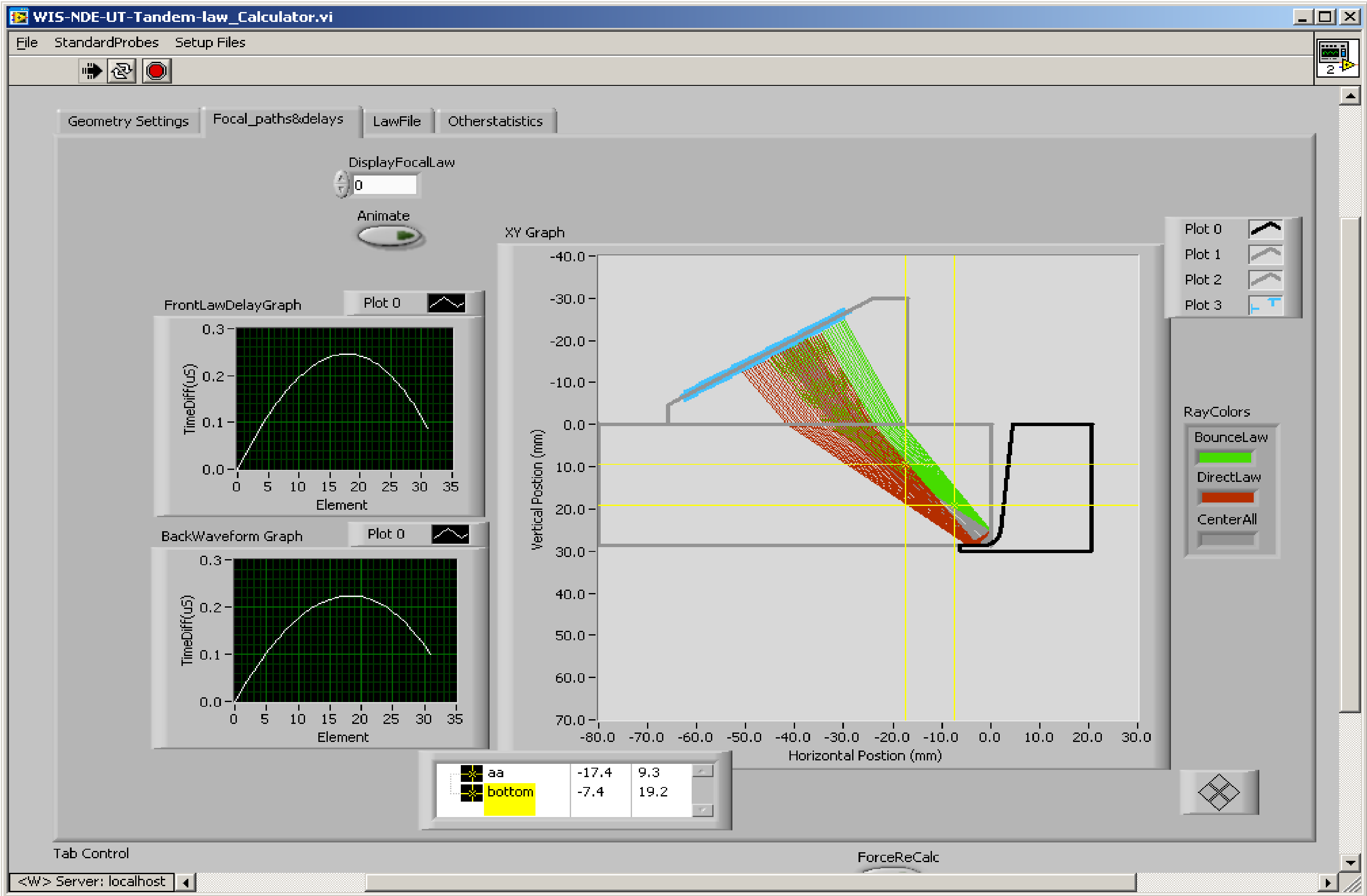


UT Probe Design

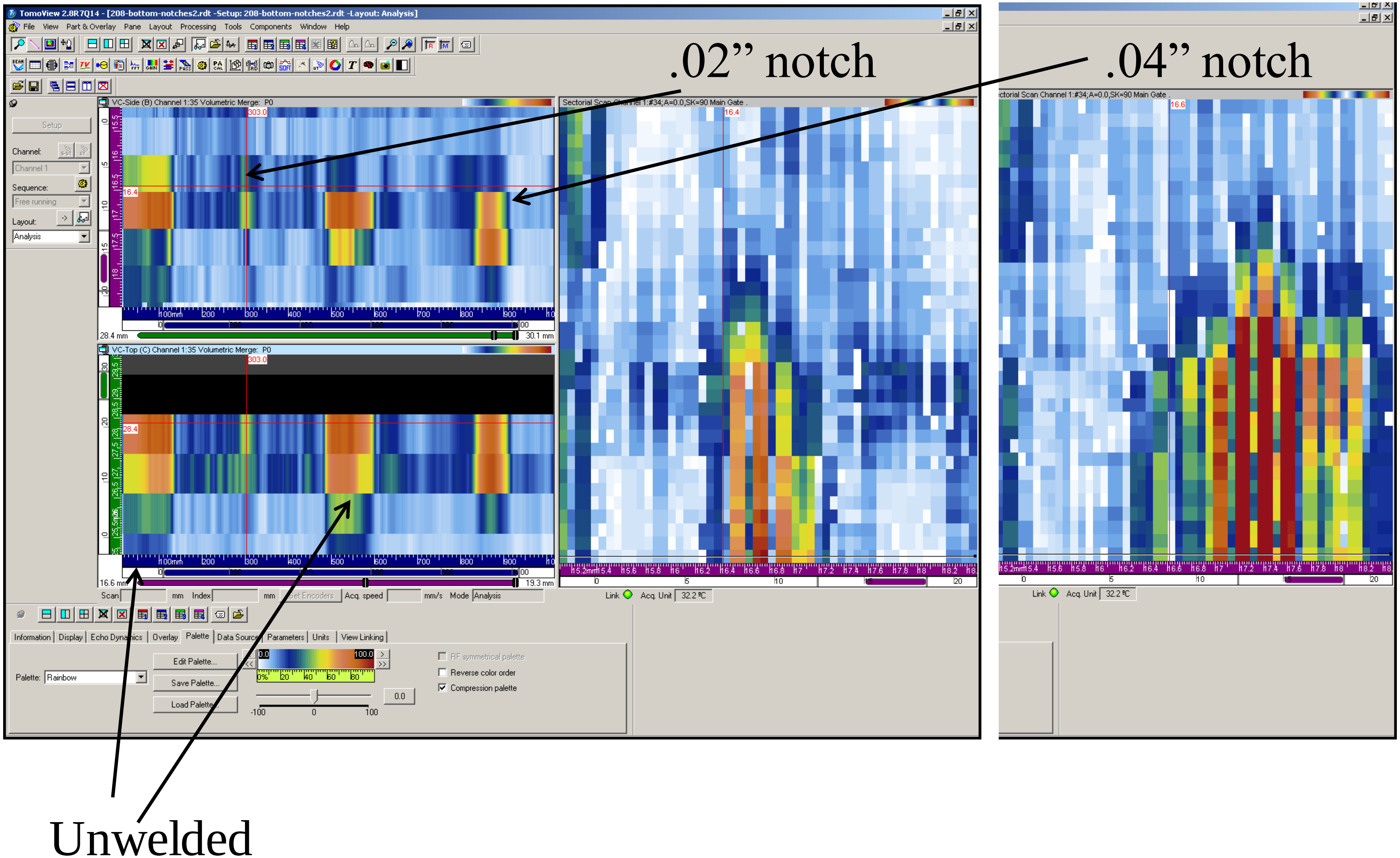
- Custom probe design
  - Shallow water path for coupling
  - Sound path designed to allow 10mm spacing to weld
  - Design viable for greater root thickness than current 3/8 inch plate
- Real-time testing completed in 2015
- Water cooled copper heat shield designed to protect probe material



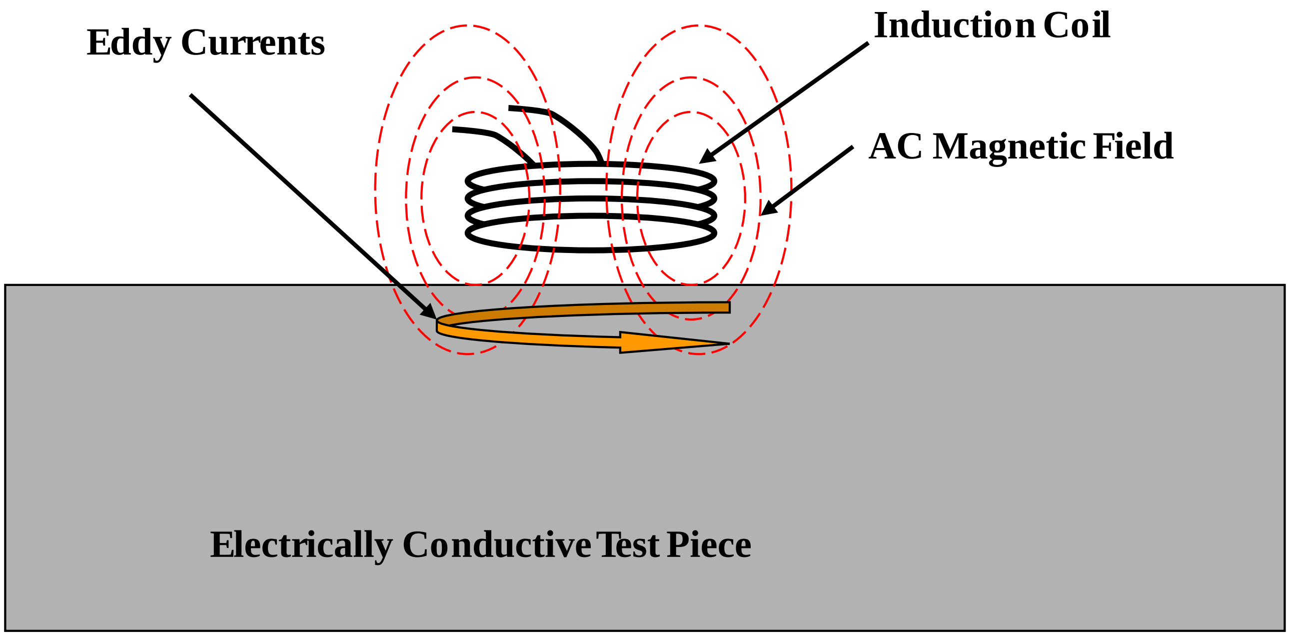
Focal Law Design for More Setback



EDM Notches Results



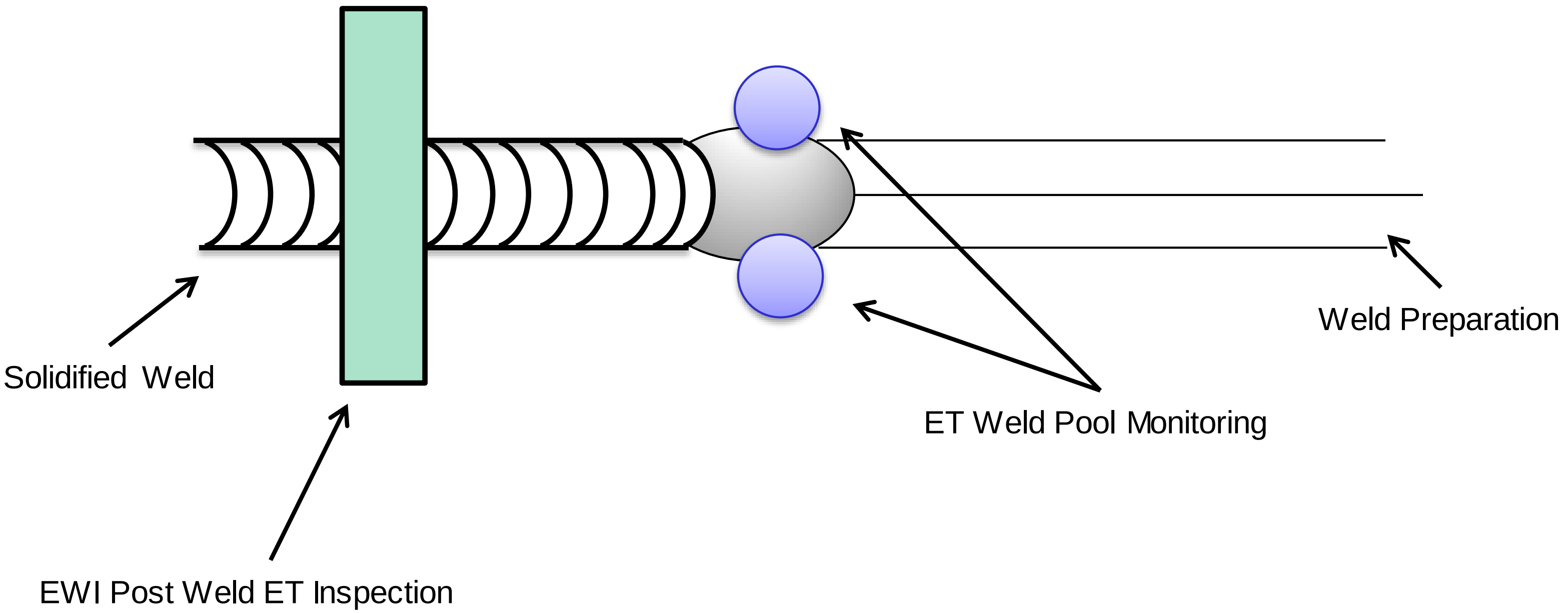
Eddy Current (ET) Inspection



Inspections Based on Electromagnetic Properties of the Test Material

Surface/Near Surface Inspection Due to Skin Effect and Limited Projection of Magnetic Field

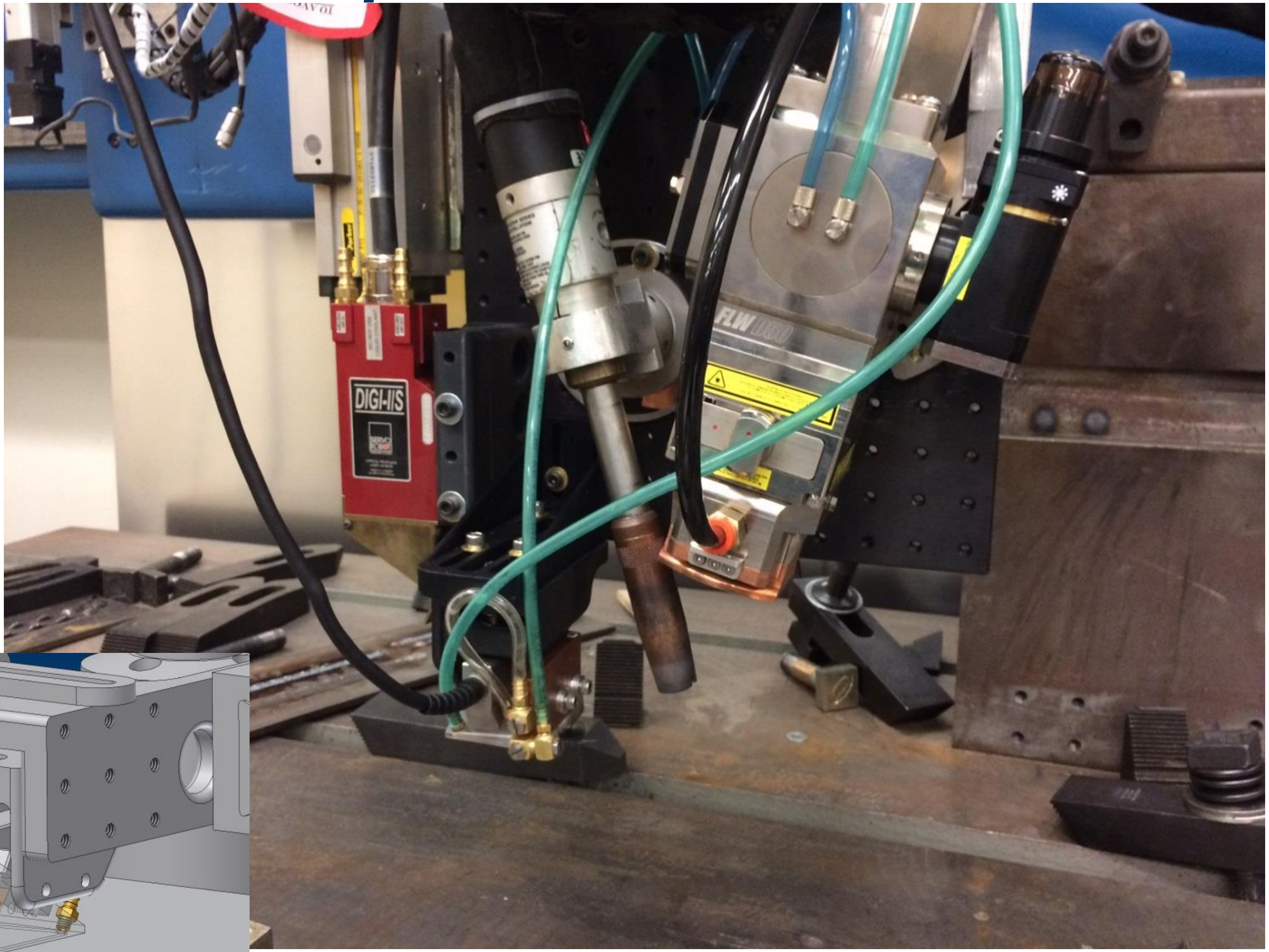
ET Weld Monitoring

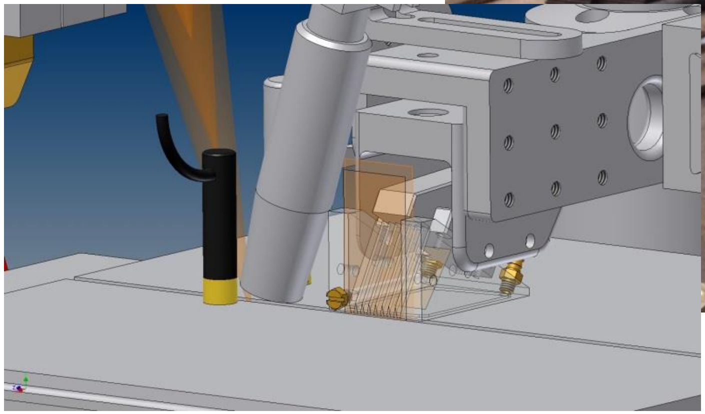


Side Beam Configuration – New Laser

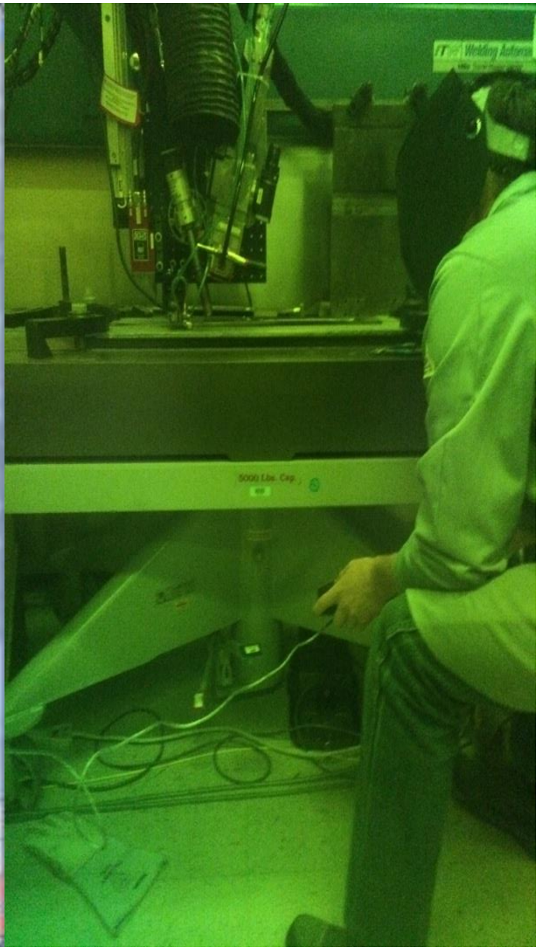
Longer welds for development/ demonstration

Sidebeam installed UT probe

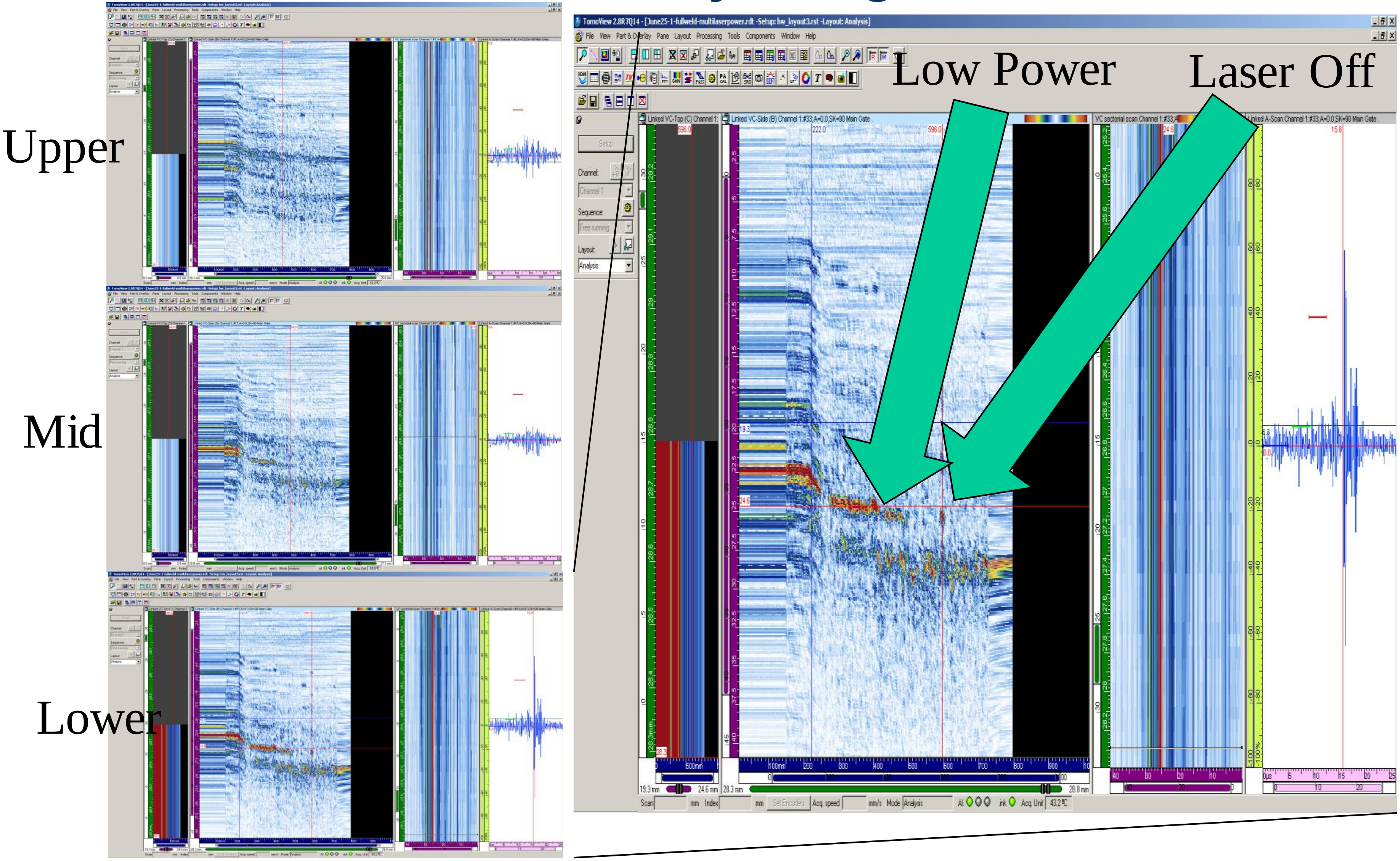




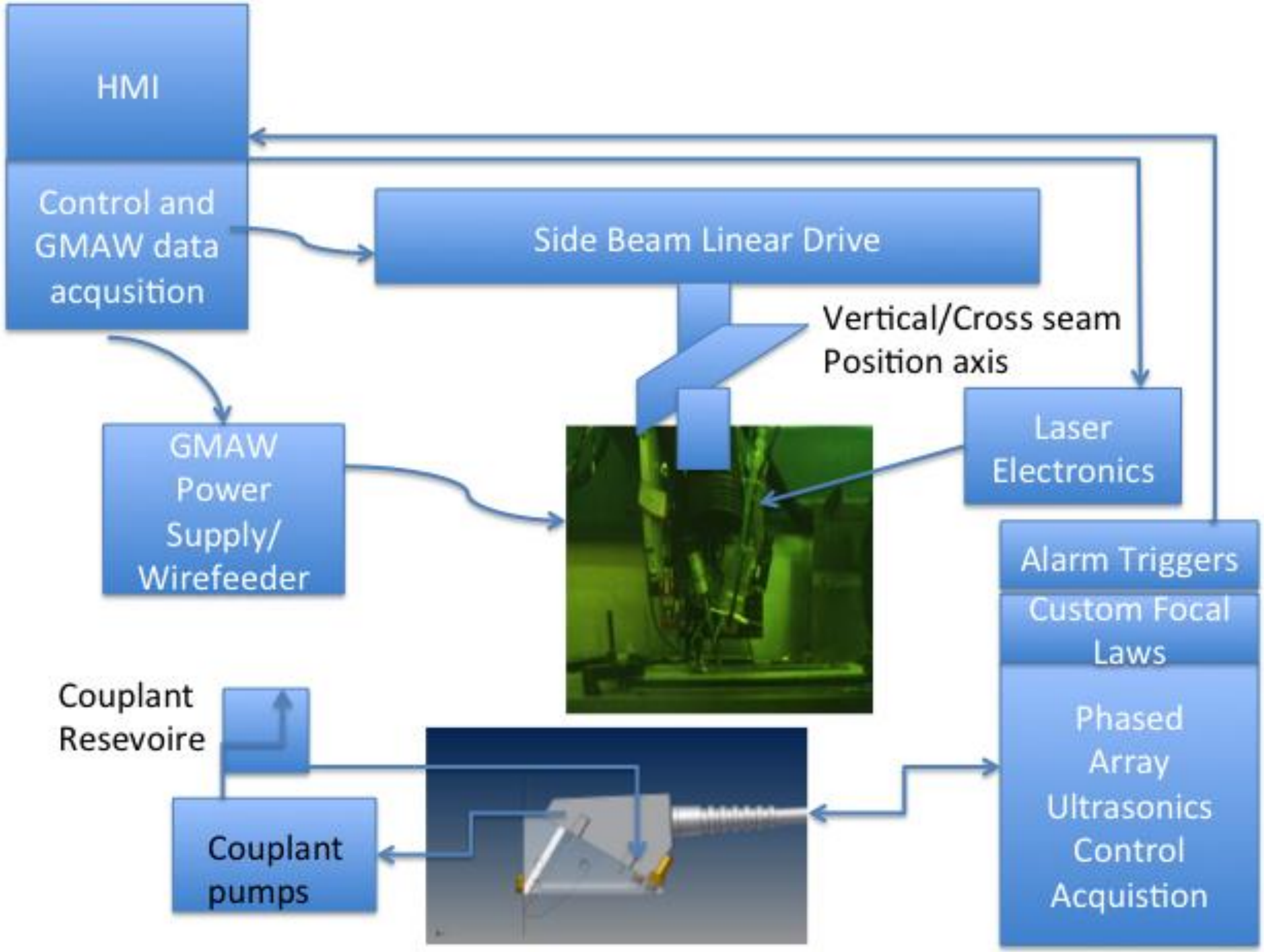
Results UT Sensor under test



Real-Time Data Summary – regions of root



System Diagram



Eddy Current Sensor Development for Monitoring and Control of Hybrid Laser/Gas Metal Arc Welding Process.

Advanced Methods for Manufacturing Workshop

29 September 2015

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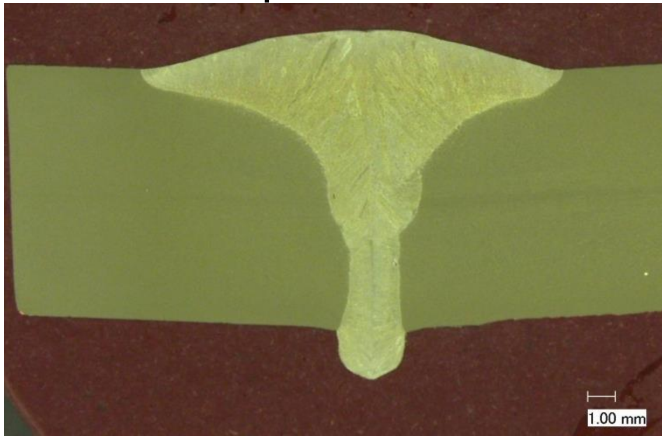
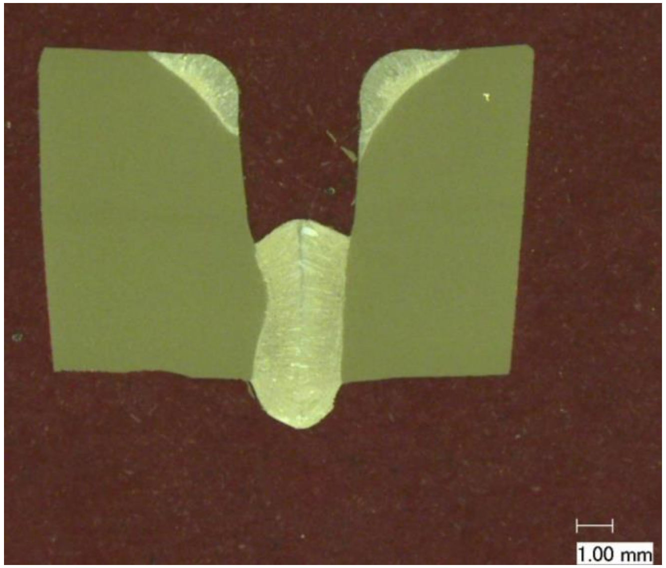
Background

Completed Weld



First Pass



- **Objectives**
  - Detecting surface and subsurface flaws in first, second and any subsequent layer
  - Only cap surface of each layer accessible
  - Narrow bead preparation - Limited access
  - Cap width may increase significantly for second (and subsequent) layers
  - Weld inspection done in one pass
  - Sensor follows weld head closely for real- or near-real time monitoring
    - High temperature components
    - Cooling features required
- **Approach**
  - Computer optimization modeling
  - Material selection and testing
  - Optimized design
  - Testing on actual weld system

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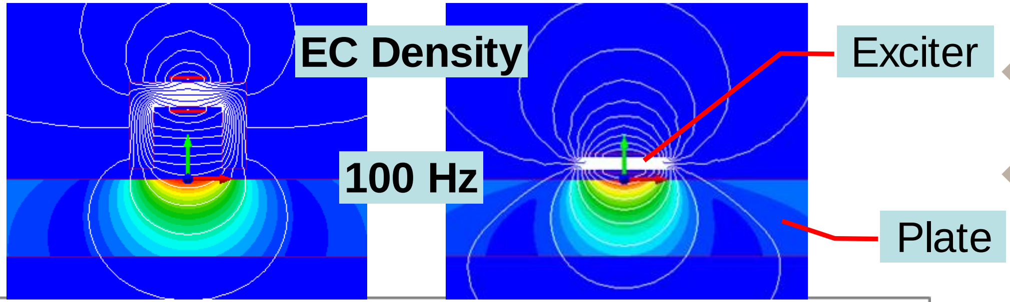
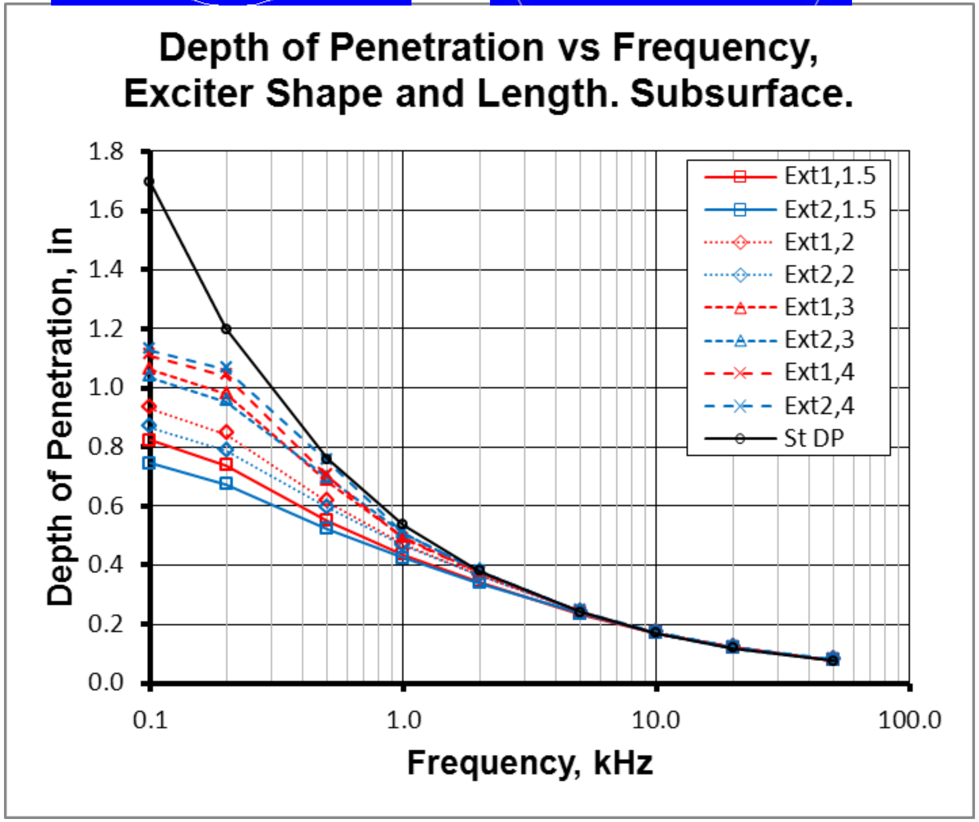
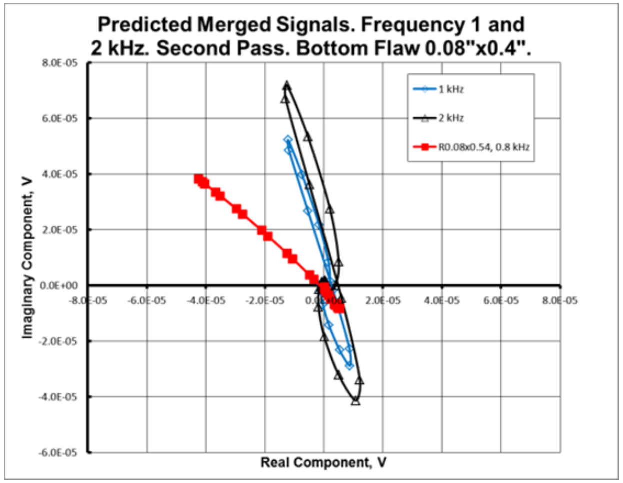
Depth of Penetration (DP) Optimization

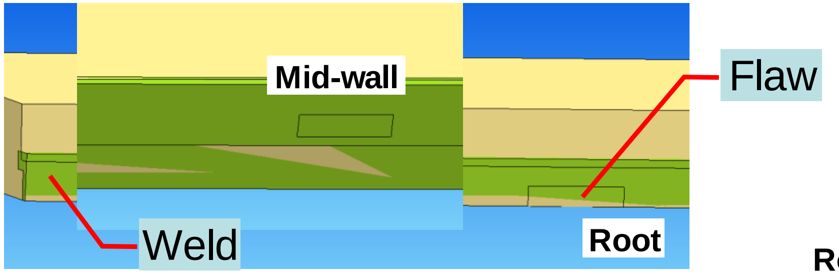




- **2D translational symmetry models used**
- **DP, EC surface extent and EC density investigated vs exciter shape, length and frequencies**
  - 2 exciters considered – U-(1) and Plate-shaped (2)
  - Length – 1.5”, 2”, 3” and 4”
  - Frequencies – 0.1 to 50 kHz
  - Plate thickness – 1.25”
  - Plate material – 316L
- **Length affected DP for frequencies lower than 2 kHz and DP smaller than 0.365”**
- **Good DP with reasonable exciter dimension**
- **U-shape exciter selected**

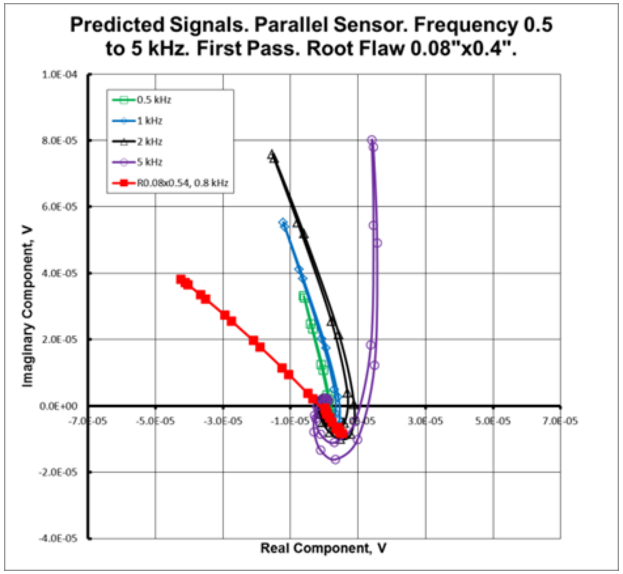
Interaction with Subsurface Planar Flaws. Summary.





Root

- Two receiver elements most promising – parallel (x) and normal (z)
- Surface and slightly subsurface pores larger than 0.06” expected to be detectable
- Planar flaws longer than 0.4” and height larger than 0.04” and 0.08” expected to be detected depending on depth
- Detection of planar flaws with height 1/16” would be in sensor range



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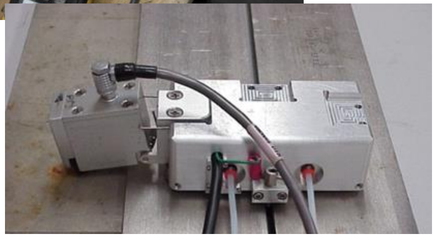
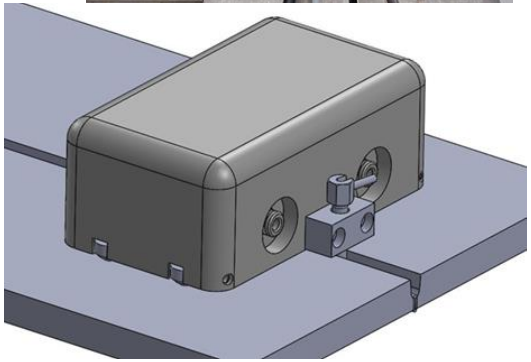
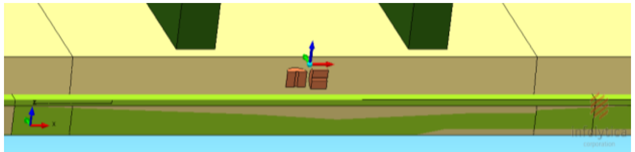
Design

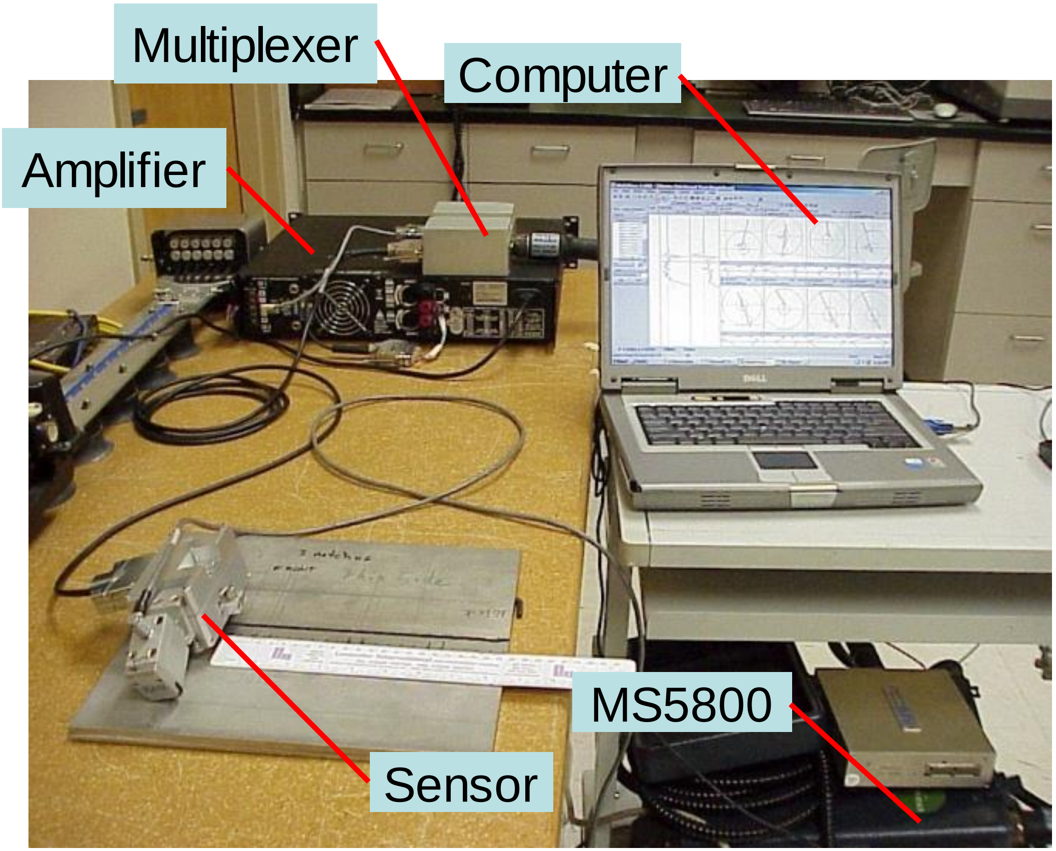






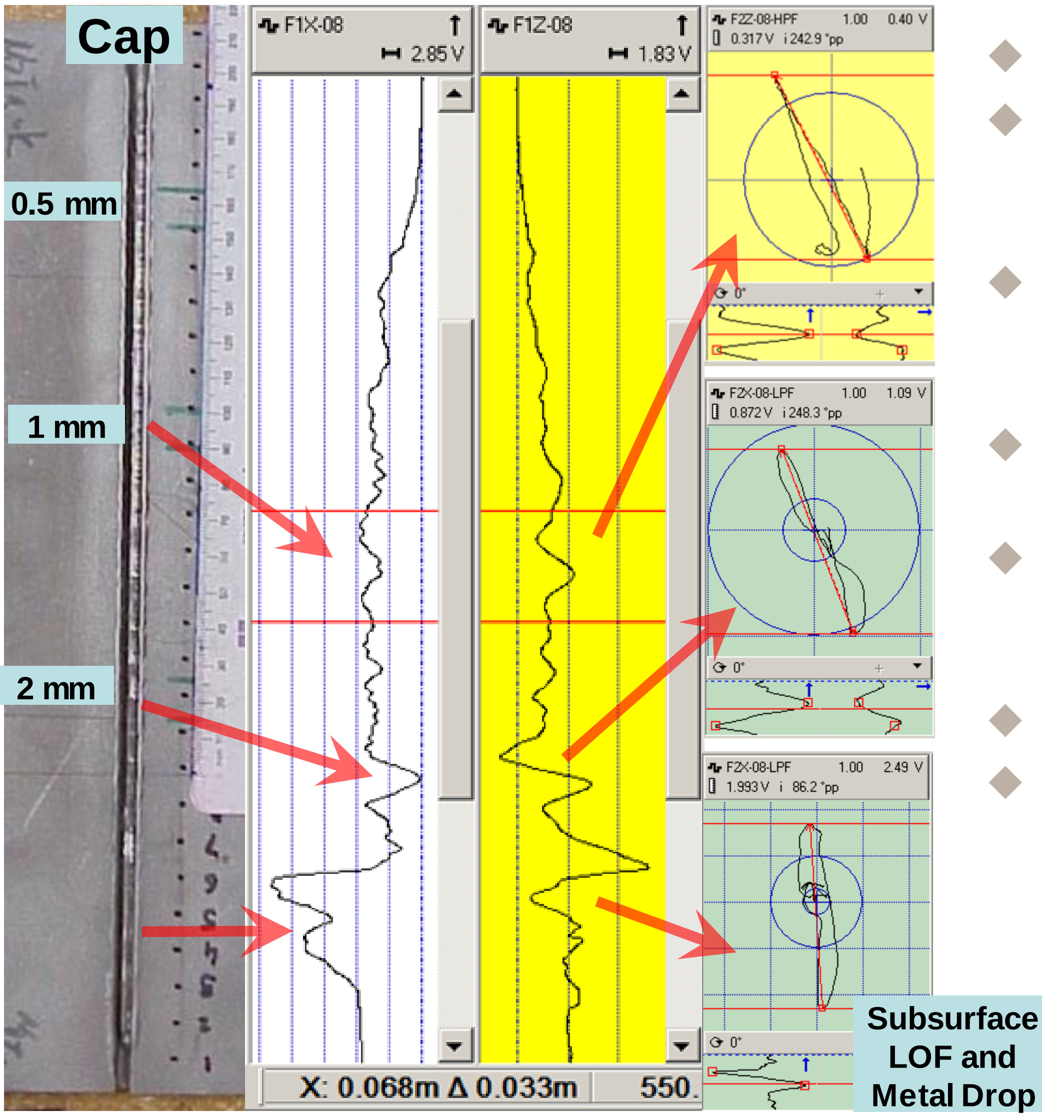
- Thermal testing conducted. Selected materials performed up to 200ºC without any adverse effects.
- All wires and insulation rated to 200ºC
- Sensor designed to work with single receiver element (first pass) and array arrangement (cap pass)
- Each receiver element – X and Z field
- Air cooling lines available if necessary
- Design features built for sensor centering and sliding over surface
- Testing conducted without mechanical contact between surface and receiver element

Laboratory Setup



- **Off-the-shelf equipment**
- **Single element**
  - Three frequencies F1-2.25 kHz, F2-4.5 kHz and F3-15.75 kHz
  - 12 processing channels with and without HP and BP filters and 2 orthogonal receivers
- **Array demonstrated at 14 kHz**

First Pass. Surface Flaws.



- Weld with root pass
- EDM notches 10 mm length and height 0.5, 1 and 2 mm at cap
- Long area with subsurface LOF at one specimen end
- Notches 1 and 2 mm detected
- Large area of LOF and root metal drop also detected
- Notch 0.5 mm missed
- Other natural features detected

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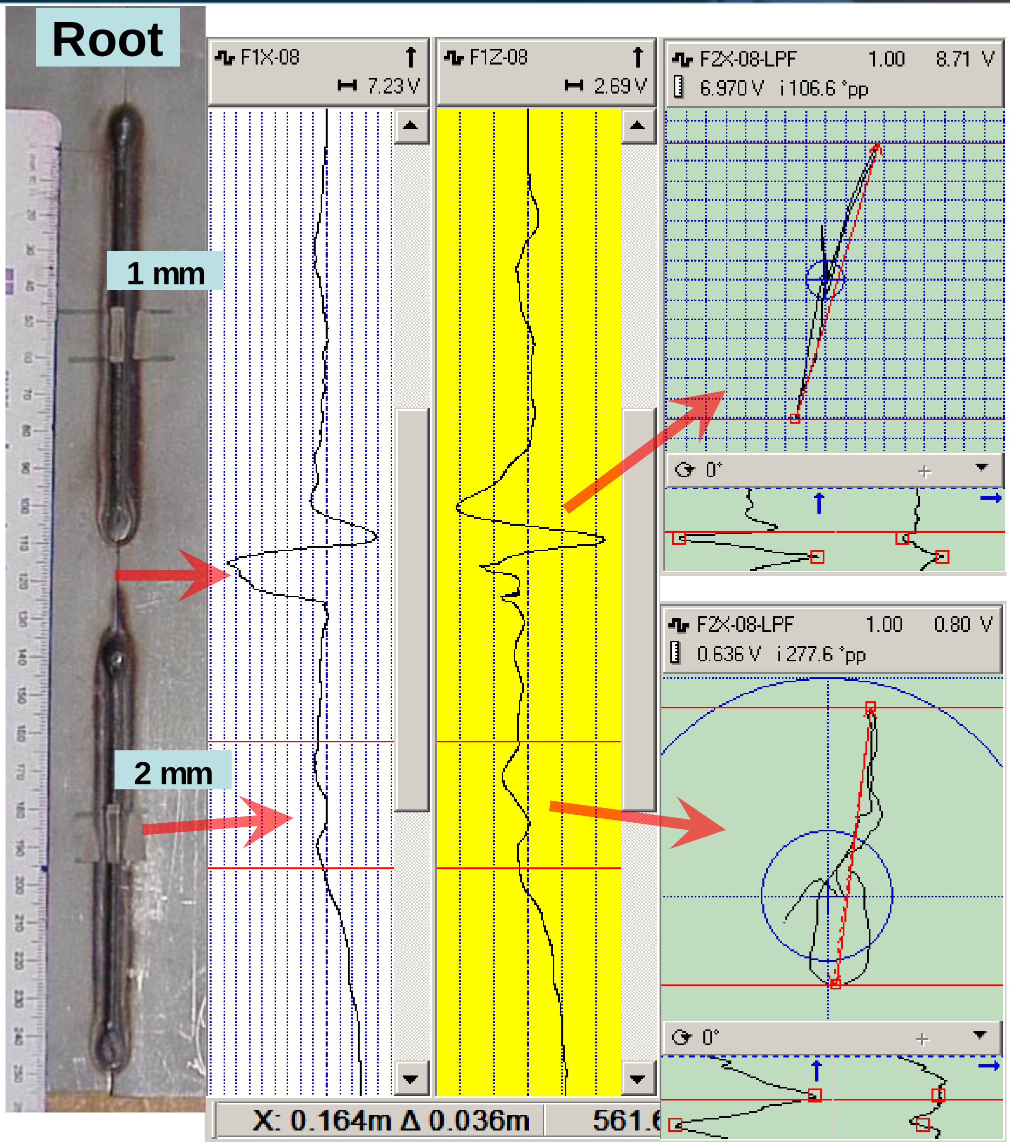
First Pass Subsurface Flaws.



- Weld with root pass
- EDM notches 10 mm length and height 1 and 2 mm at root
- Long area with surface and subsurface LOF at middle
- Notch 2 mm detected
- Large area of LOF and root metal drop also detected
- Notch 1 mm missed
- Other natural features detected

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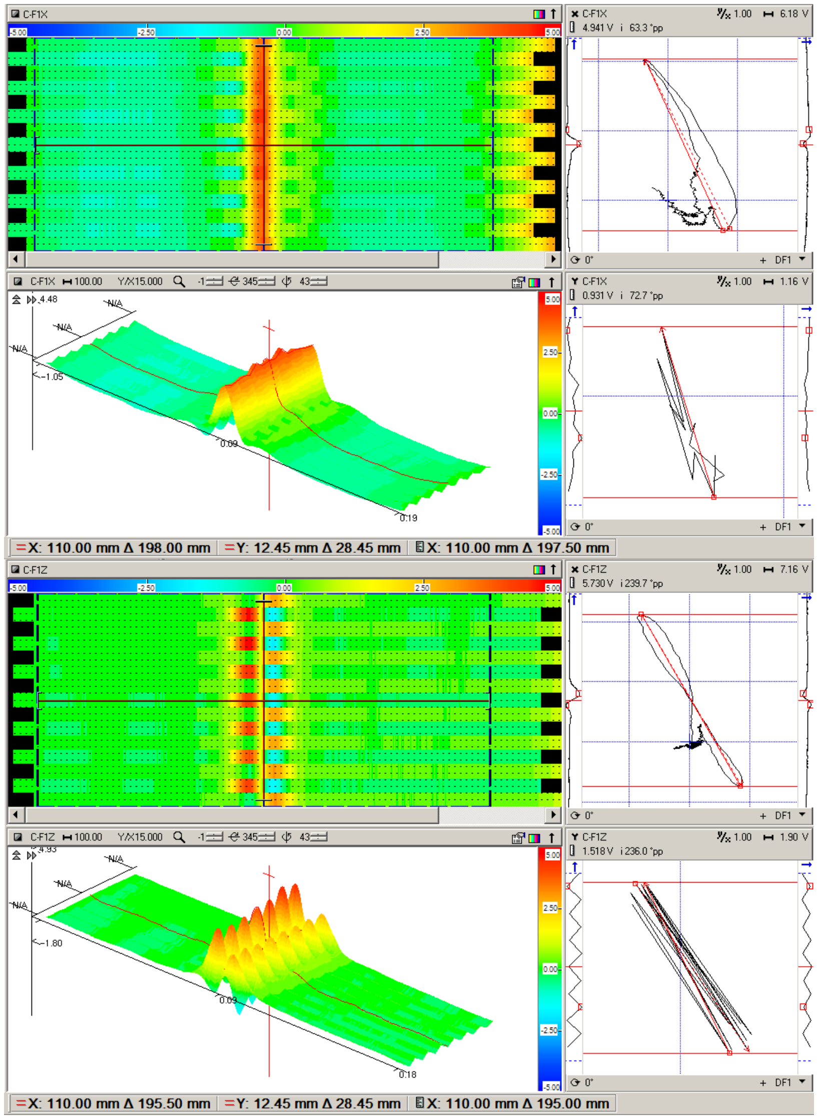
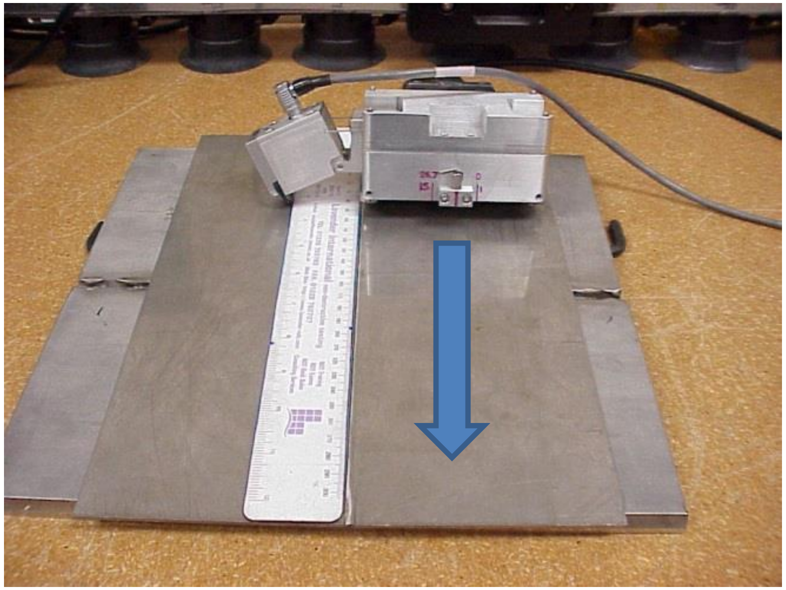
Array Inspection





- Array demonstrated with subsurface flaw under 1.8 mm thick sheet
- Frequency 14 kHz

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Conclusions

- Multipurpose eddy current sensor for weld monitoring designed and integrated
- Laboratory tests indicated very good sensitivity for surface and subsurface implanted and natural features in first weld pass
- Trials will conducted at INL to verify and demonstrate performance during welding on root and cap pass later this year

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Conclusions/Path Forward

- Satisfactory Results Out of Both EWI/INL probes on post weld inspections
  - EWI filed for provisional patent
  - INL evaluating intellectual property
- UT Probe system has undergone evaluation under welding conditions and performed satisfactorily
  - Water coupling work per conceptual design
  - Focal laws design provided expected mechanism to determine depth of laser penetration
  - Auto-Tuning of focal plane during setup would beneficial for more robust detection

Conclusion Path/Forward (more)

- Project extended to November 2015:
  - Support a combined demonstration with EWI with INL laser welding system
  - Provide opportunity for live evaluation of EWI Sensor additional evaluation of INL sensor
- To do list:
  - Submit draft publication
  - Explore commercialization opportunities

Thank you--Questions