SOFC Quality Control and the Role of Manufacturing Defects on Stack Longevity (FE0023478)

Atrex Energy

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- NREL Fuel Cell Manufacturing Project,

  Michael Ulsh, Peter Rupnowski, Bhusan Sopori
- Atrex Energy Engineering Team

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Acumentrics
Advanced Power Solutions

ATREX ENERGY
POWERFUL POSSIBILITIES

Acumentrics
Trusted Power Innovations

>480 SOFC units Shipped

60,000+ RUPS™ units shipped

Commercial SOFC LPG and NG

2U Lead Acid or Li-ion 2kW RUPS

JP8 fueled SOFC Prototype

1U Li-ion 1.5kW RUPS

Atrex Energy fact sheet

“Powder to Power”

- – **250W to 10kW**+ power generation products and prototypes, based on Solid Oxide Fuel Cell (SOFC) technology
- – Natural gas, LPG and Jet fuel for deployment in remote applications
- – Reliable, efficient and clean
- – Field Replaceable stack

- **> 480 Commercial Units** deployed in North America
- Accumulated **>5 Million hours** run time of the commercial NG and LPG generators
- Units running in remote environments for **>35,000hrs**
- **FC1 certification** from the Canadian Standards Association (CSA)
- Completed world first demonstrations of a packaged fuel cell generator working on high sulfur JP8/F24

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Project Motivation and Goals

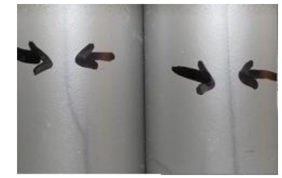
I. Experimental investigation of cell "imperfections"; do they cause rapid degradation/failure at high temperature?

1. Mini-cell testing (similar to button cell testing)
2. Single cell testing
3. Stack testing (20 cell stacks)
4. Microscopic characterization of imperfections

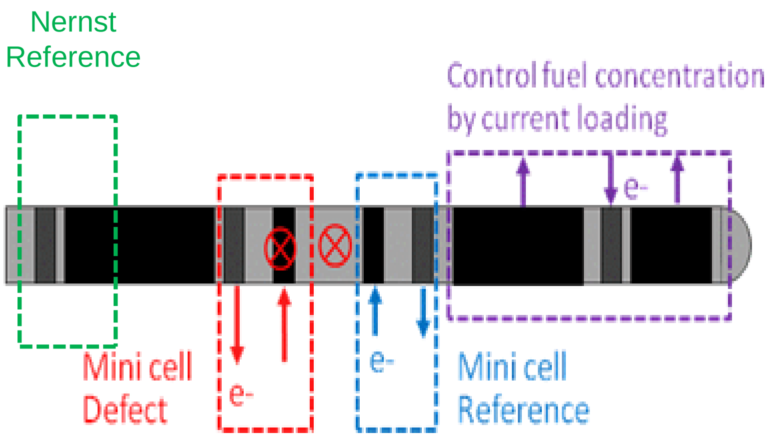
II. Development of automatable imaging techniques for identification of imperfections *with intelligent screening for defects*

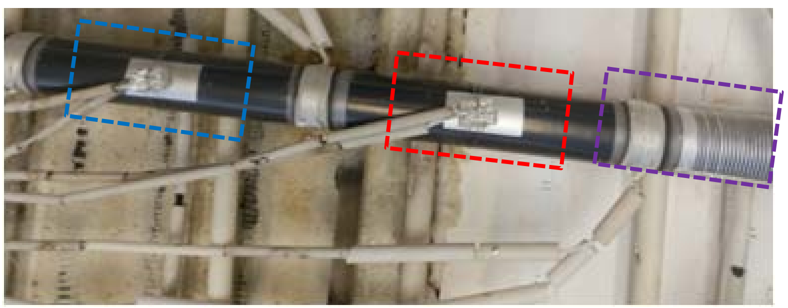
1. Screening of imaging techniques (NREL Fuel Cell Manufacturing project, Atrex)
2. Design and construct automated QC device (Atrex Energy)

Visually Conspicuous Defects

Description	Example	Description	Example
Contamination caused pit (<1mm)		Crack formed in processing	
Anode material agglomerate pop-out (~1mm)		Crack visualized by dye	
Crack (1~10mm) formed in green state processing		Pinhole (~μm) visualized by chemical etching	
Surface electrolyte scratch (1~10mm) (handling)		Pinhole (~μm) visualized by dye	
Coating agglomerate (slurry quality) (1~5mm)			

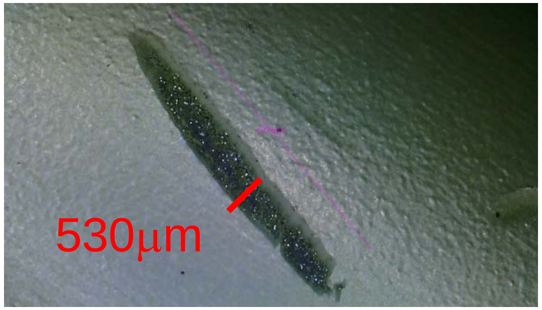
Mini Cell Testing

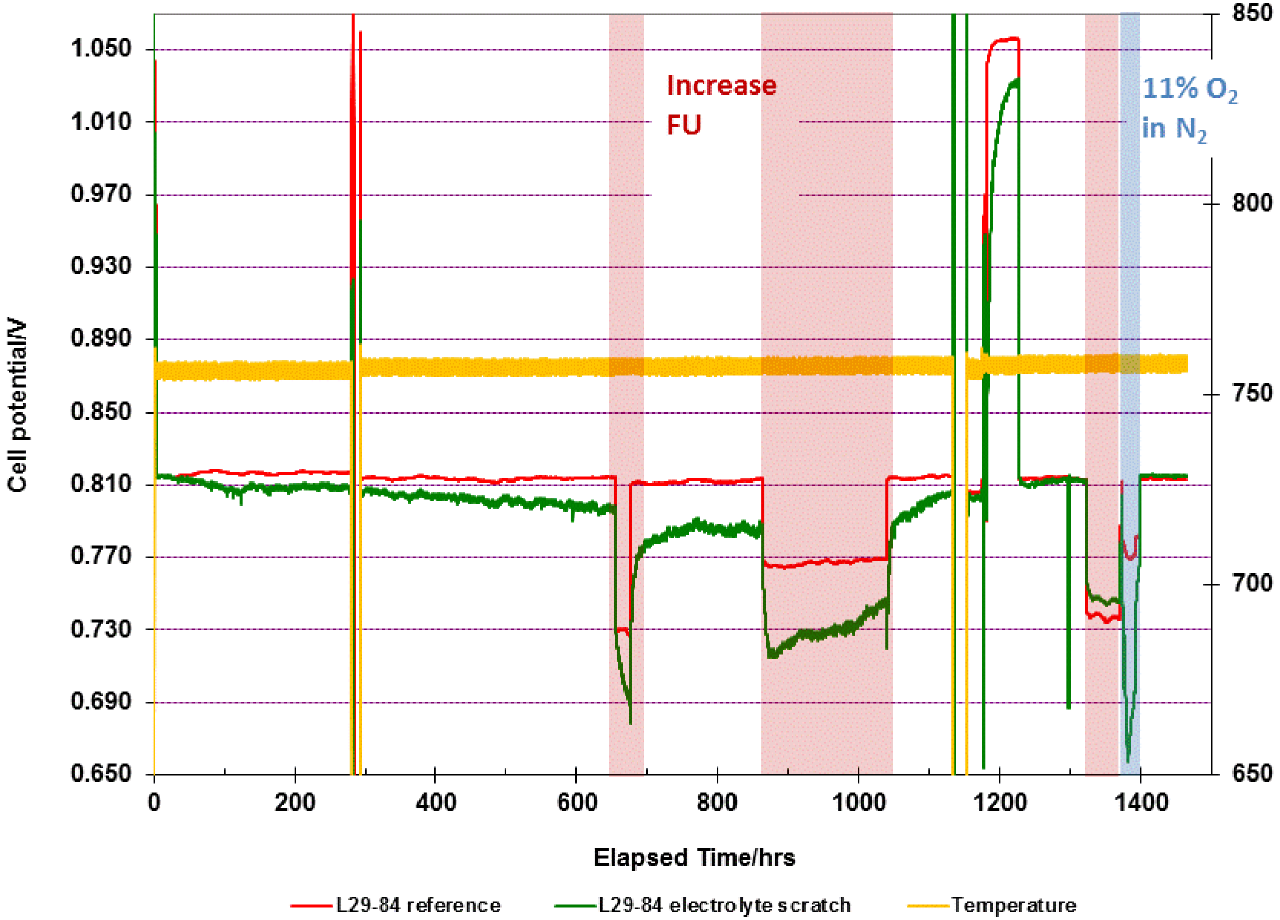


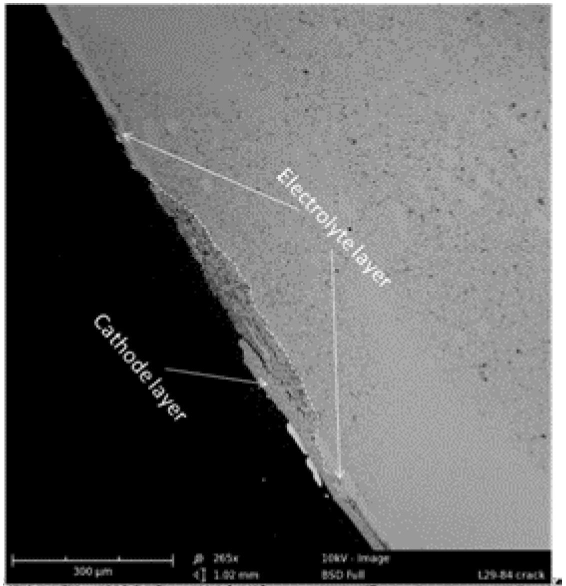


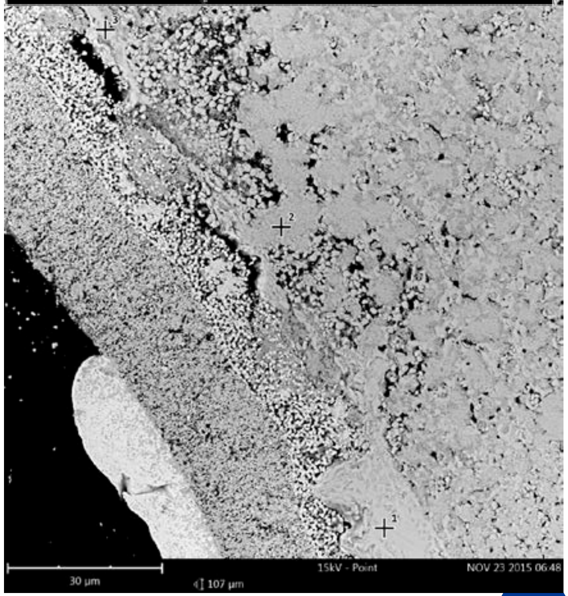
- Possible environment of a cell defect in a stack
  - Temperatures 680-830°C (however all testing at 750C to date)
  - Cathode atmosphere 21%-13% O_2
  - Anode atmosphere commensurate with 0-75% FU
  - Local current densities 150-700mA/cm^2
- Possible transients
  - Thermal and load cycling

“Natural” Scratch 530μm wide

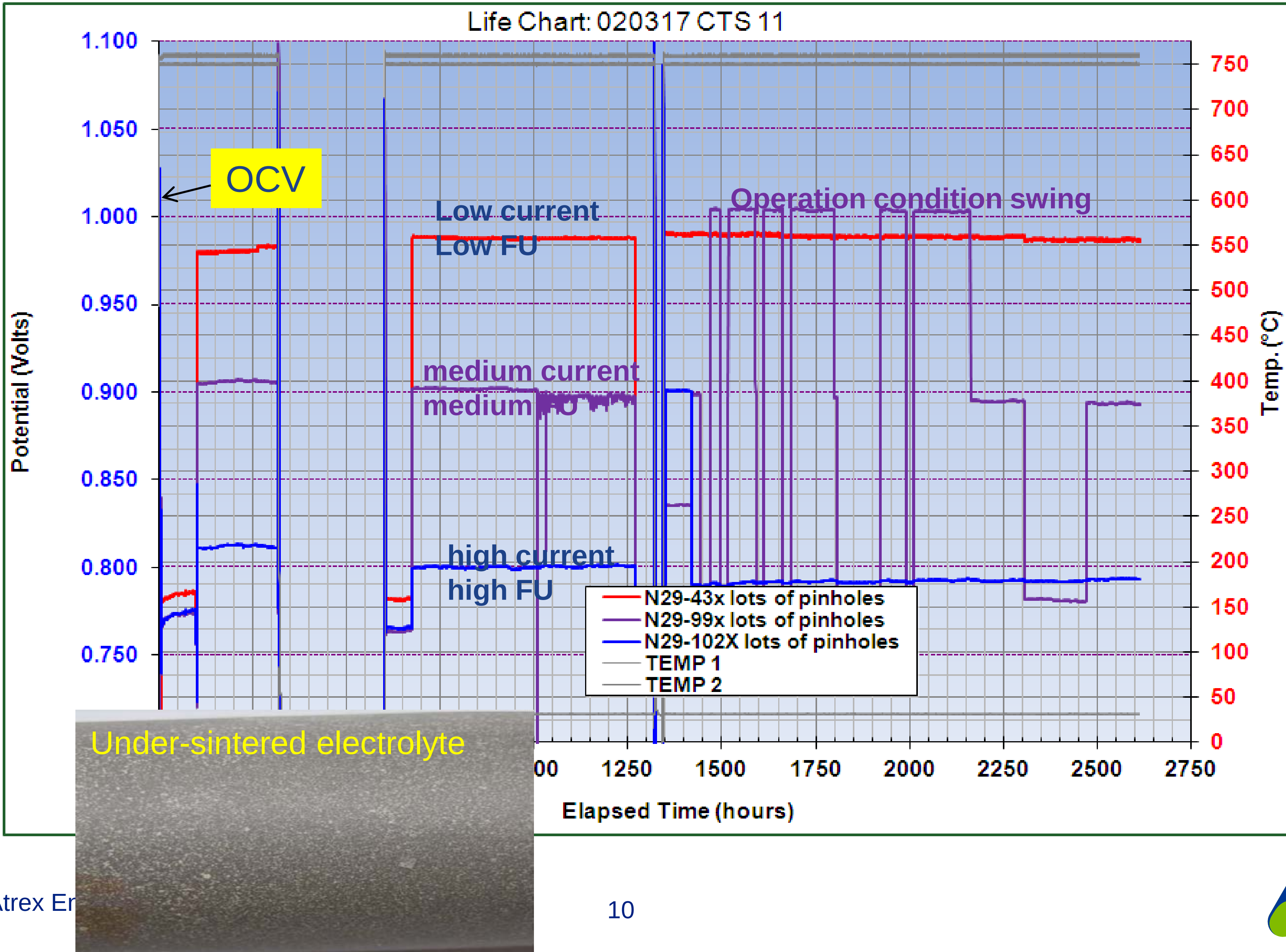






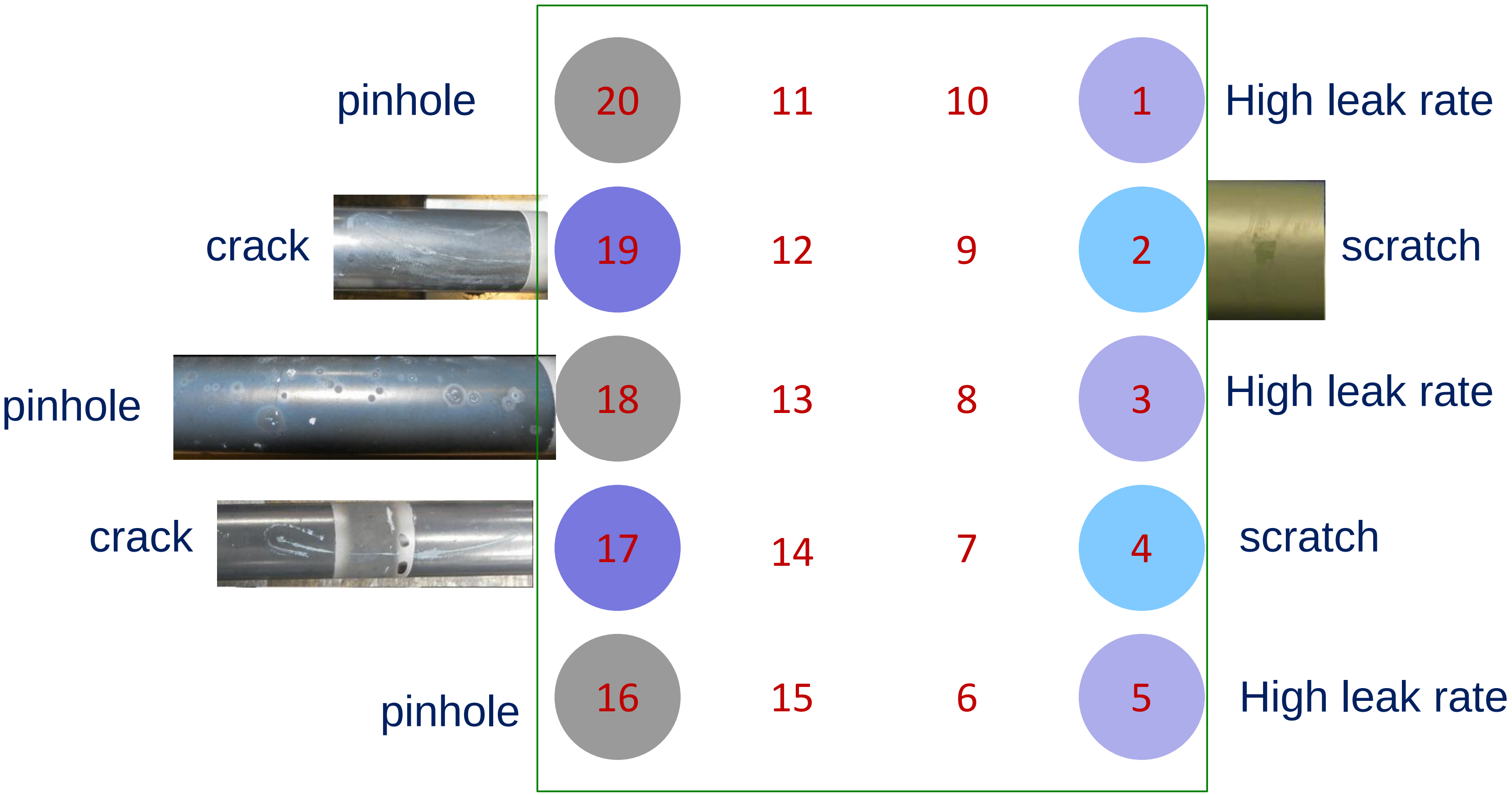


Electrolyte with high pinhole population

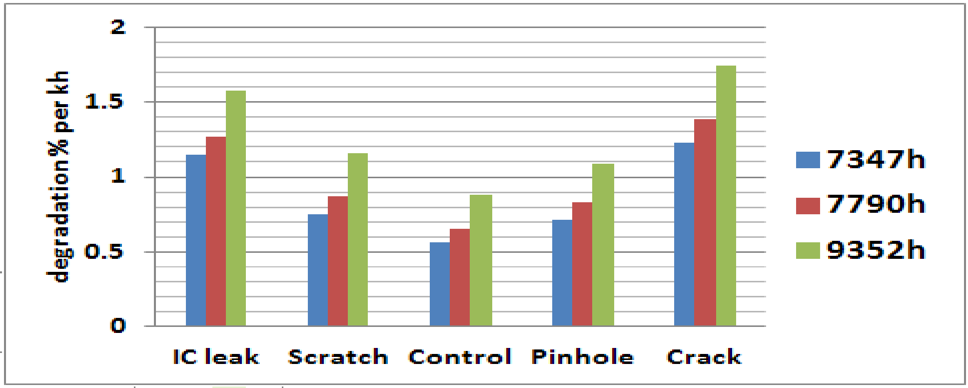


Stack Testing CT-1: **Placement Key**

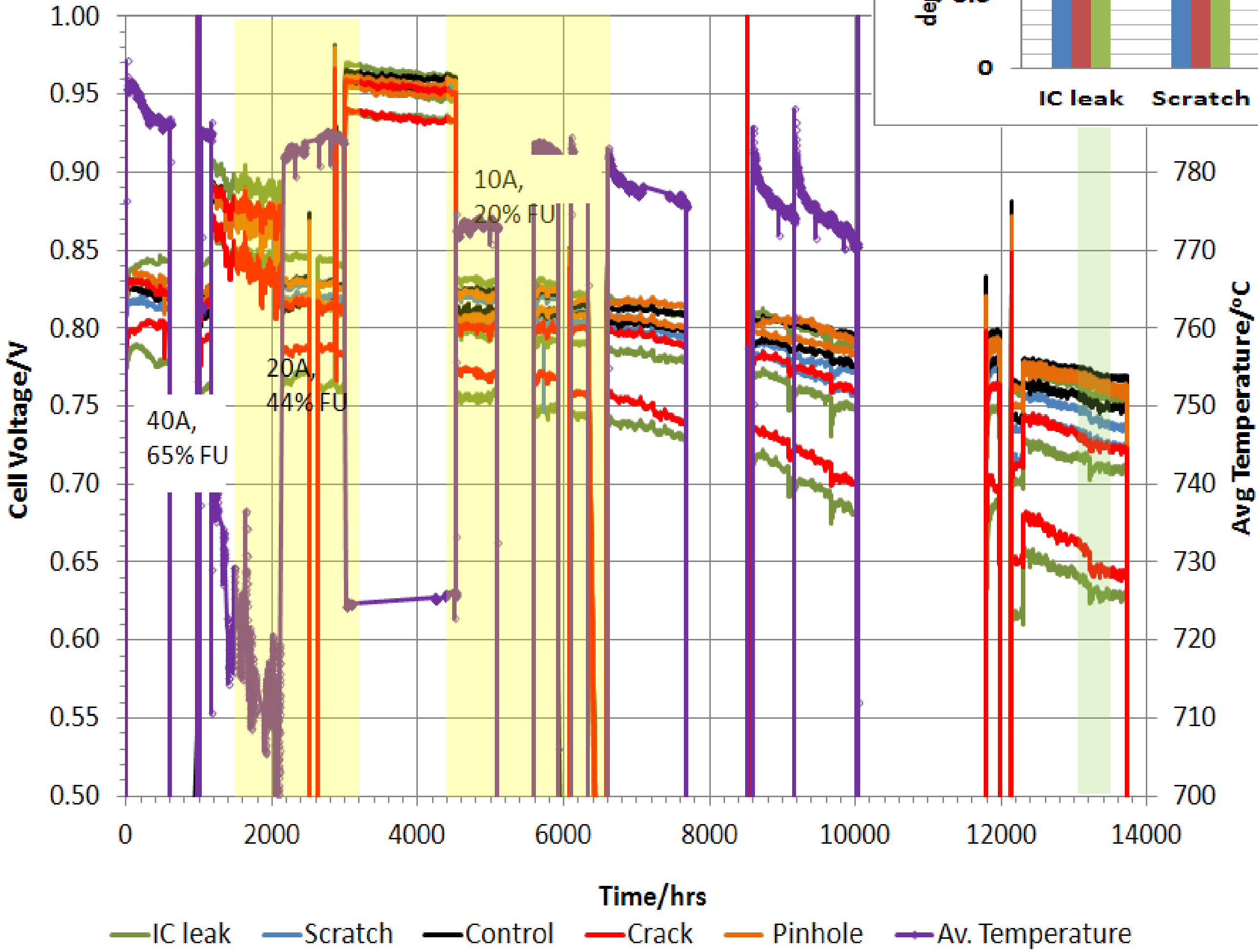
Instrumented bundle



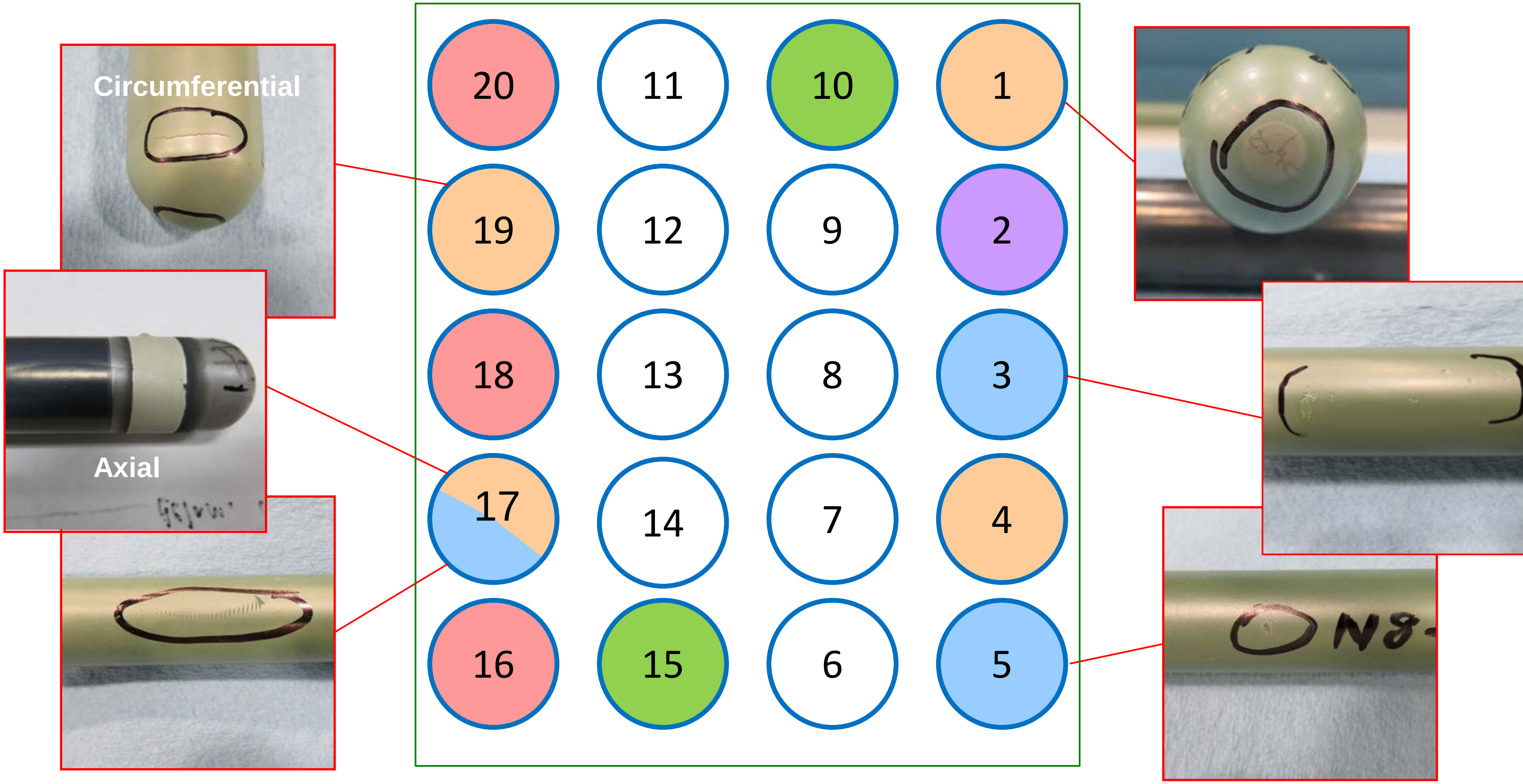
Stack Testing CT-1



>15 thermal cycles!

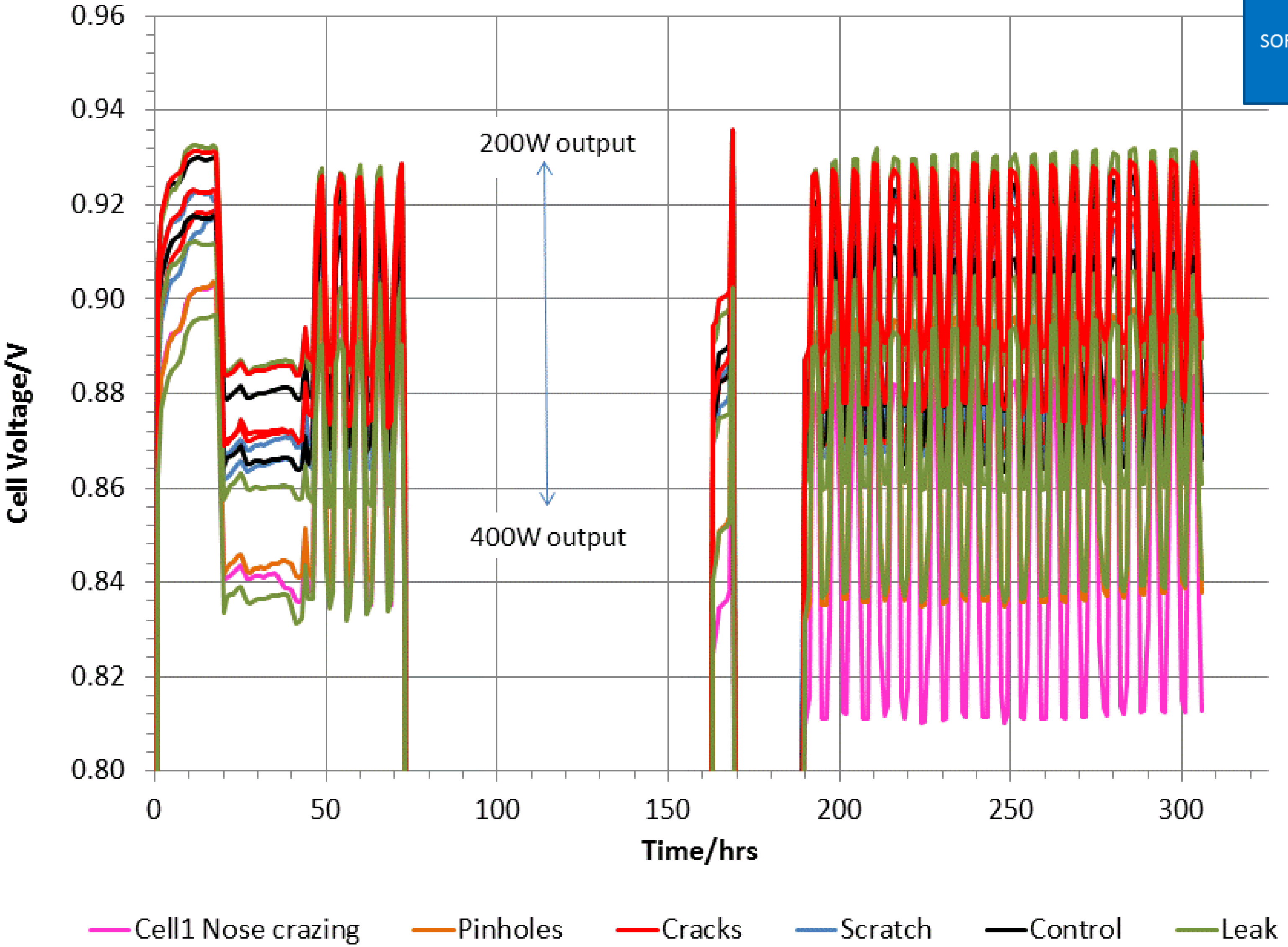


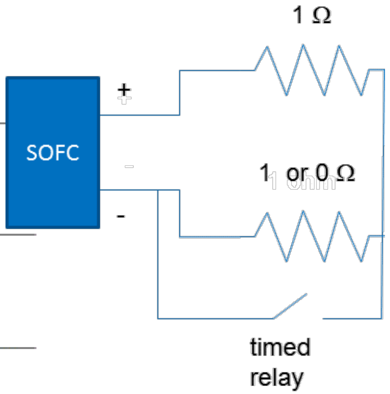
CT-2 Stack Test, **Defect Placement Key**

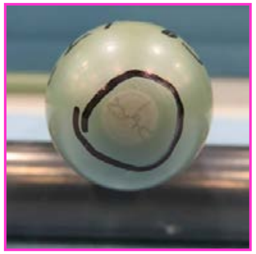


- High QC leak rate (pink)
- Pinholes (purple)
- Control (green)
- Scratch defect (blue)
- Crack (orange)

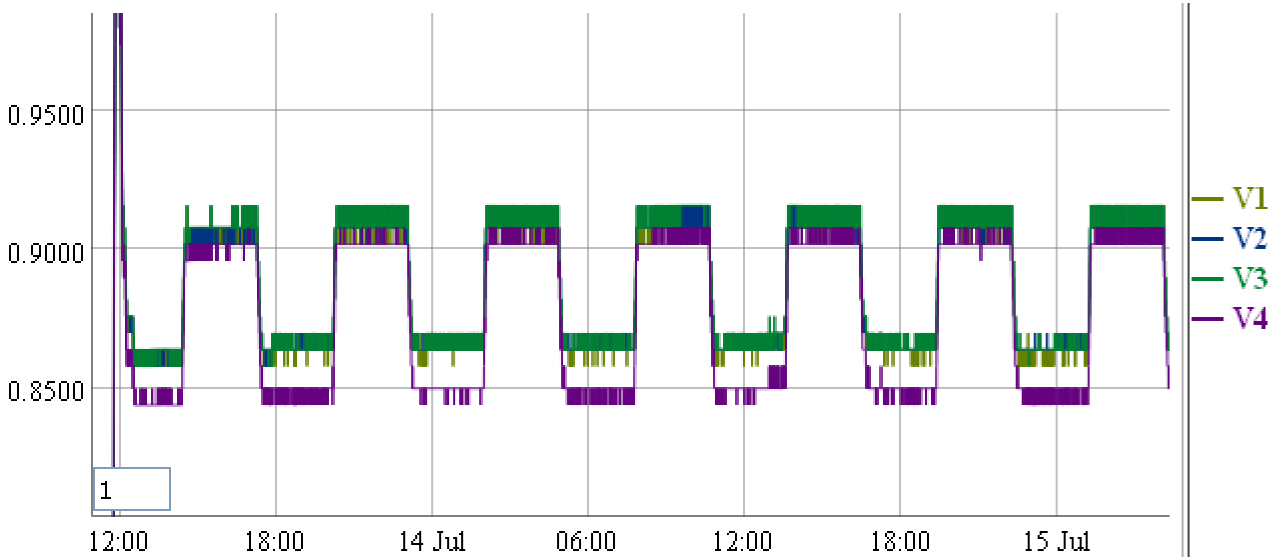
Load cycling of “imperfect” stack (CT-2)

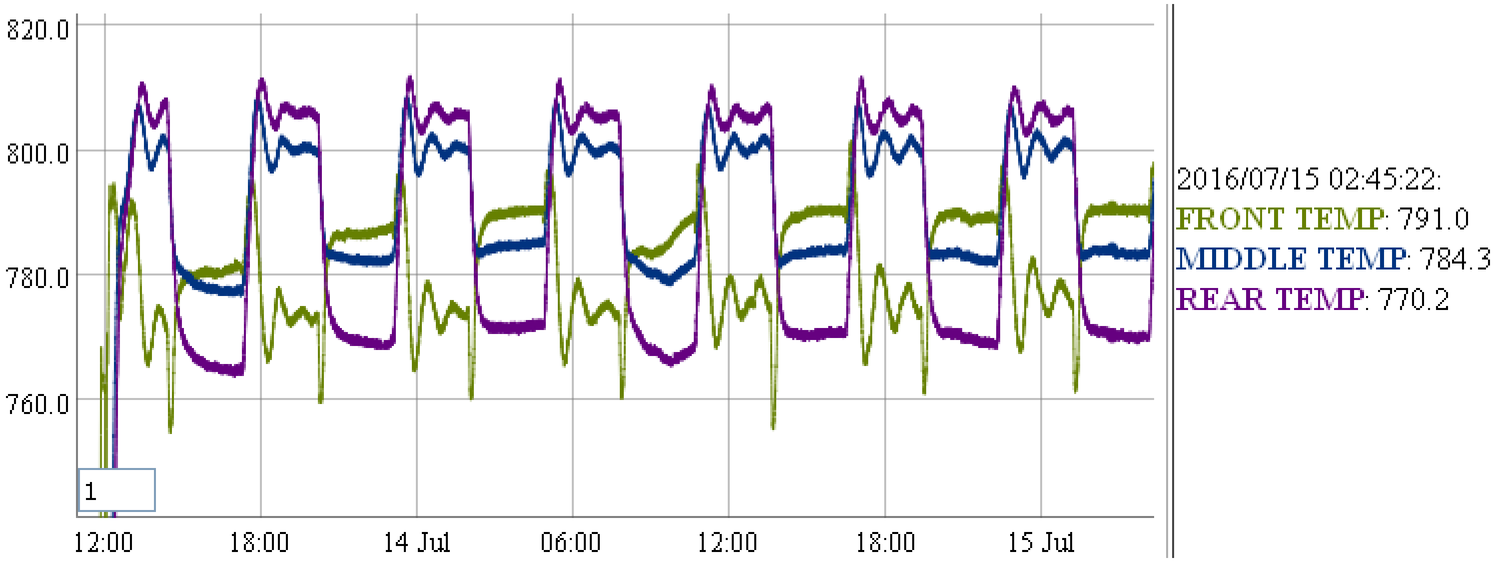




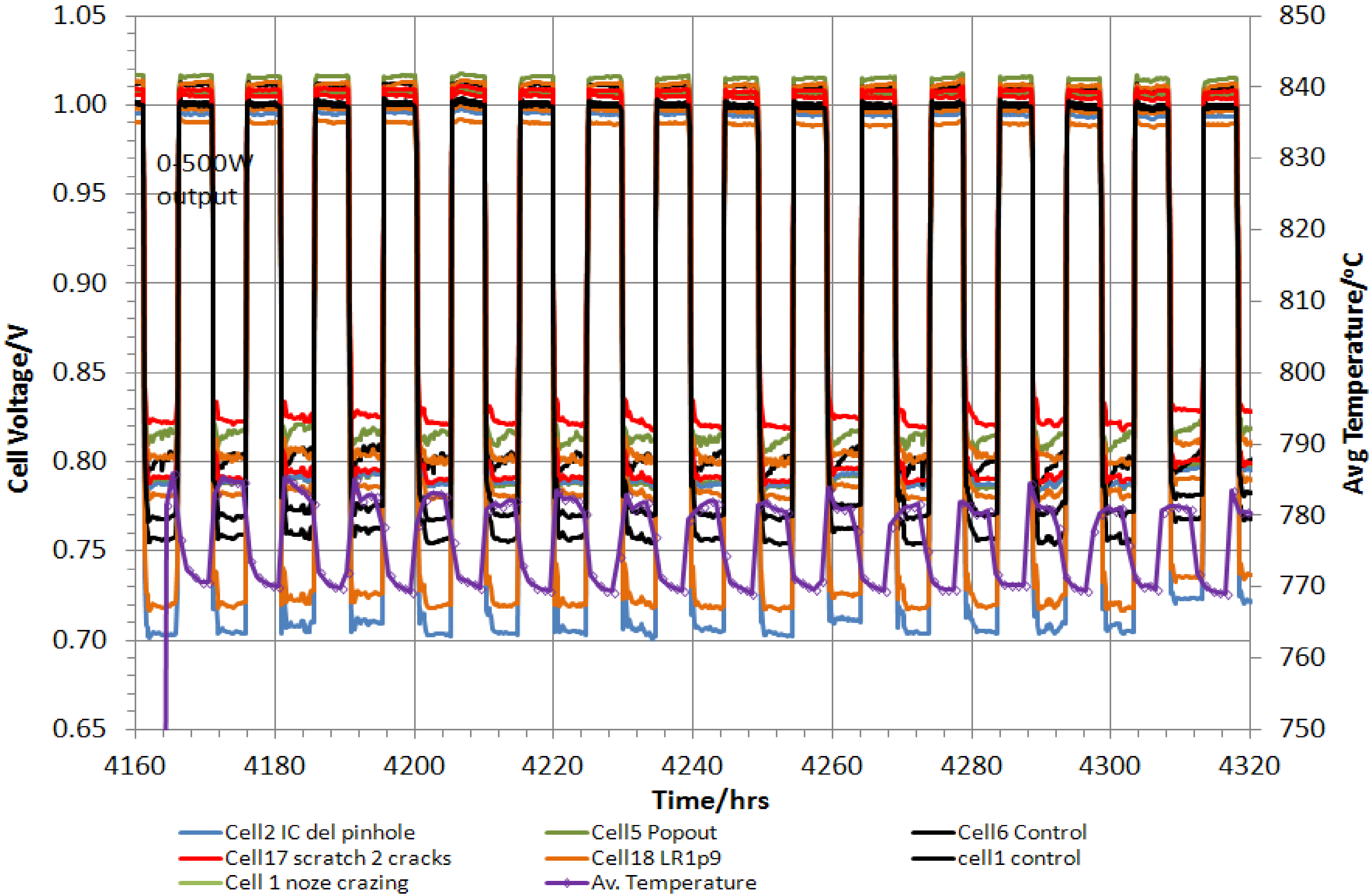


Load cycling → Temperature cycling

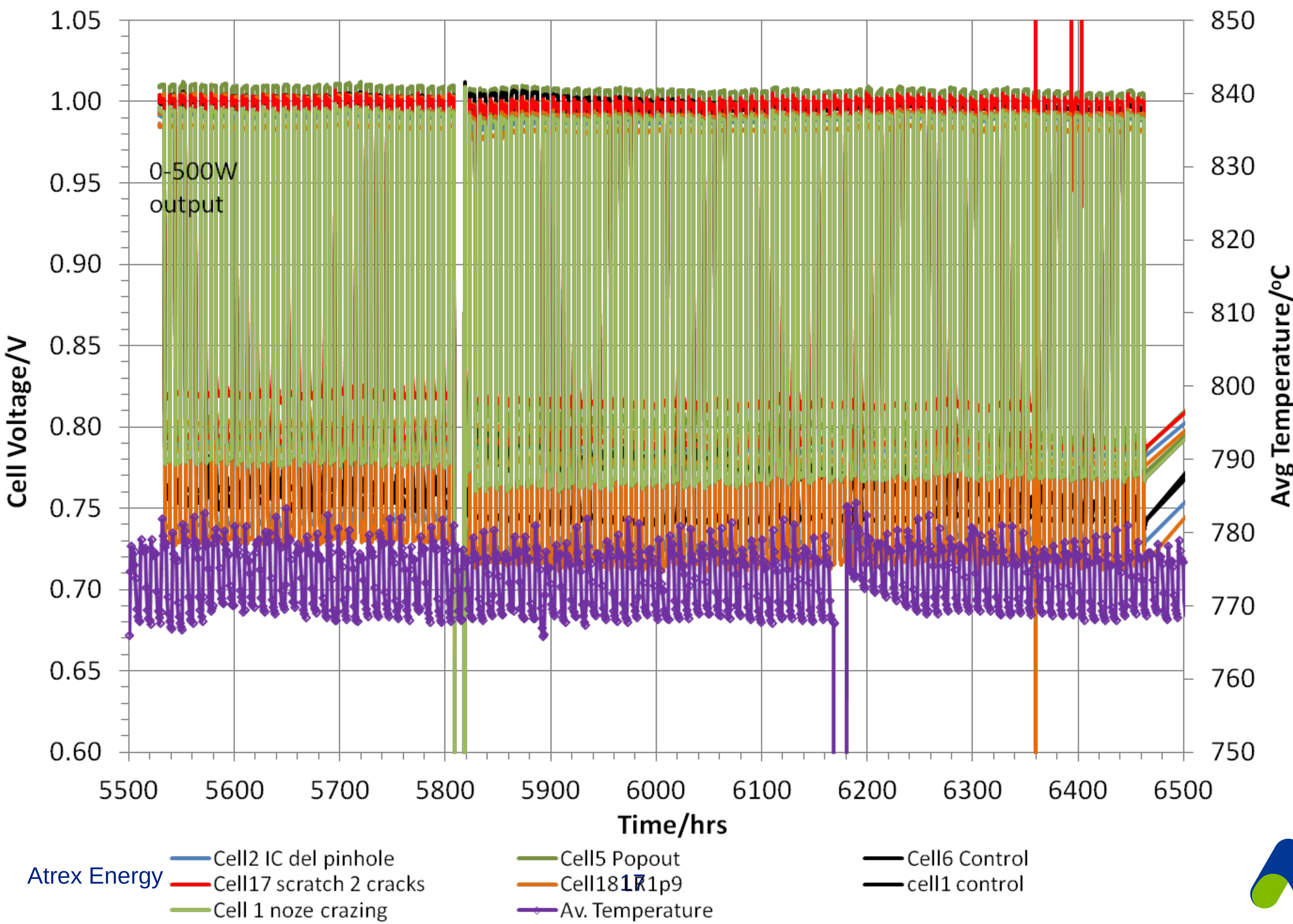




More Aggressive Cycling



More Aggressive Cycling



Ranking Defects

- Build *stress-defect-interaction* matrix
- Interaction metrics: failure mode, time to failure (TTF), degradation rate, etc.

IMPERFECTION CATEGORY	STRESS TYPE			
	Power cycling	High fuel utilization	Thermal cycling	Other types
High leak rate				
Crack				
Pop out				
Scratch				
Pinhole				
Other types				

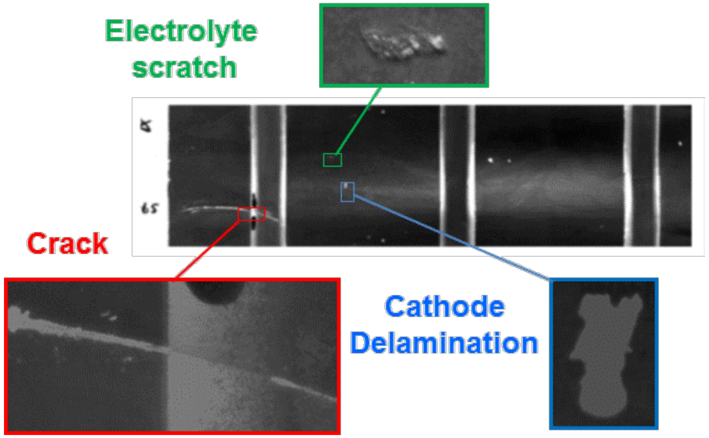
Automated Quality Control System

NDT Techniques Evaluated

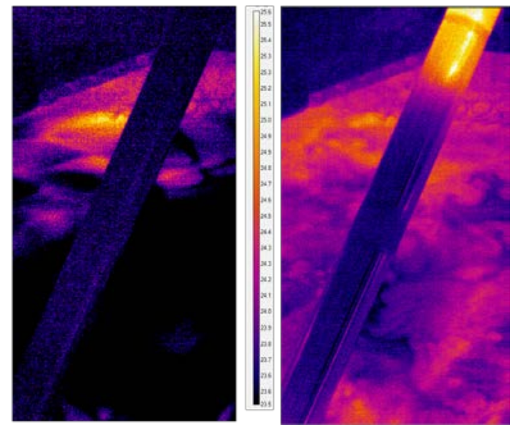
- IR Imaging
  - with thermal activation - for surface/subsurface non-homogeneities (Thermal Scanning)
  - with voltage excitation – for electrical shorts
  - with CO_2 pressurization– for cracks
  - with ultrasound excitation for cracks, separations
- Ultrasonic
- Optical Reflectance Imaging – surface anomalies
- 2D/3D Laser Profile – For topographical defects.

Imaging of Imperfections

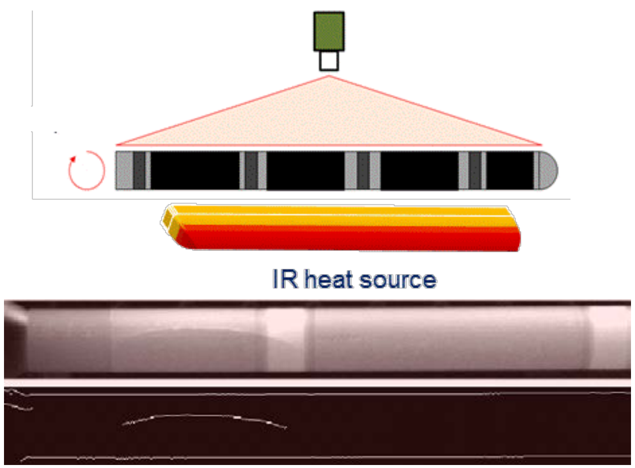
Optical Reflectance



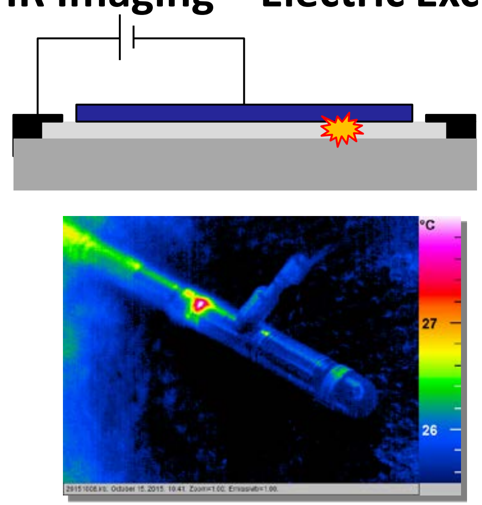
Thermal IR Imaging – Ultrasound Excitation



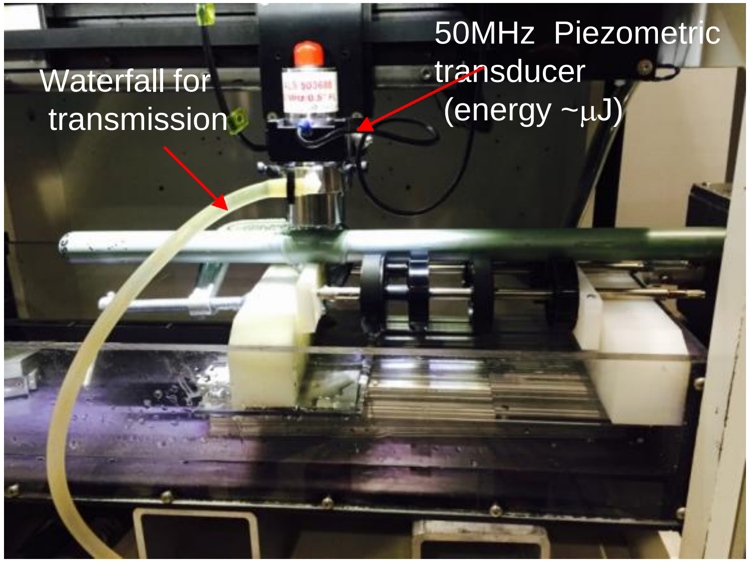
Thermal IR Imaging – Thermal Excitation



Thermal IR Imaging – Electric Excitation



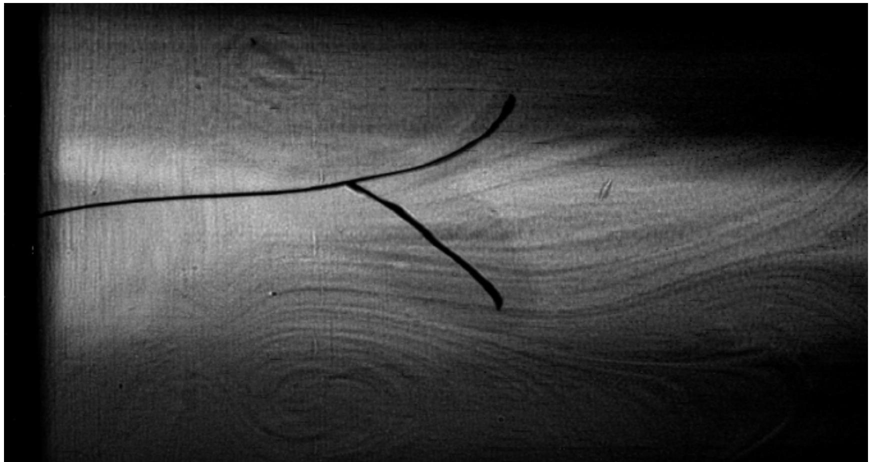
Acoustical Microscopy at Sonoscan, Inc



Preliminary experiments using acoustic microscopy

Ultrasound does not travel through air gaps and is reflected at the air/solid interface

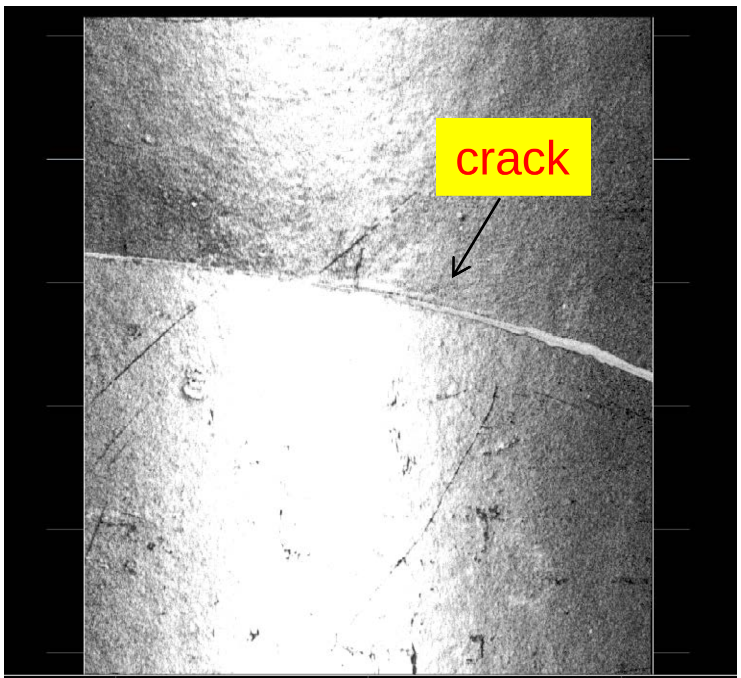
3D Tomography is possible using C-SAM software



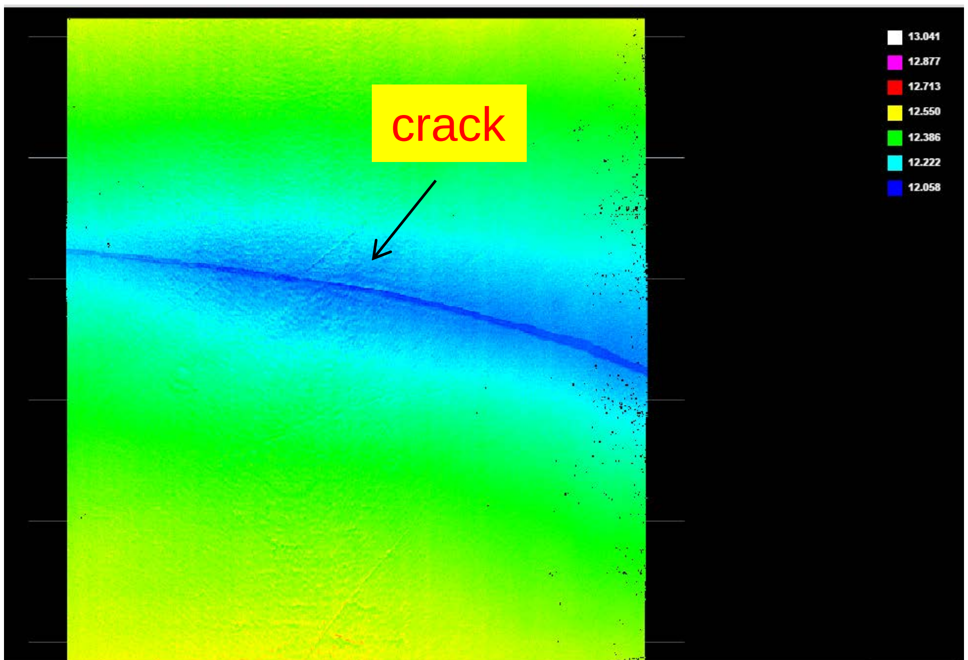
AM 2D reflected from *inner* diameter of tube

3D-2D Laser Profile Sensor

- Fast data acquisition: surface speed 35.8mm/sec
- Z axis resolution of 1.8 – 3 microns, X axis resolution of 14 – 21 microns
- 3-D capability, thickness measurement, tube off-straightness, etc



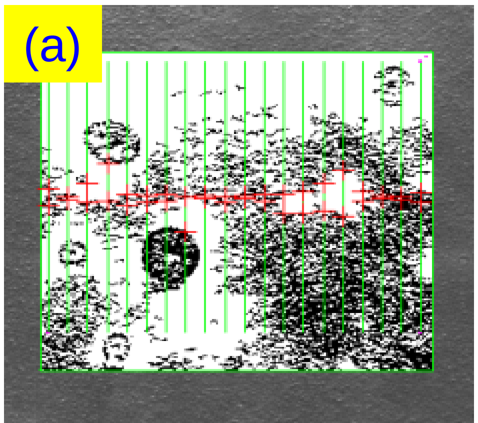
Grey scale 3-D height image



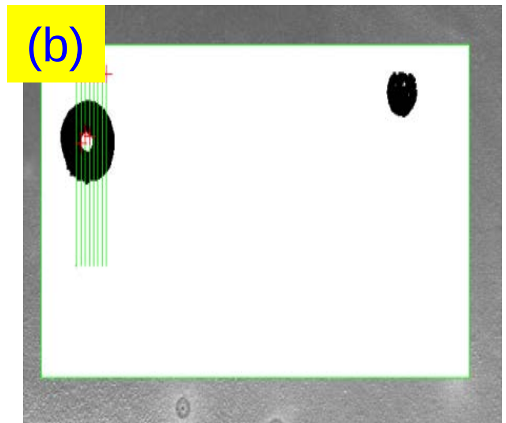
Color 3-D surface height image

Image processing software

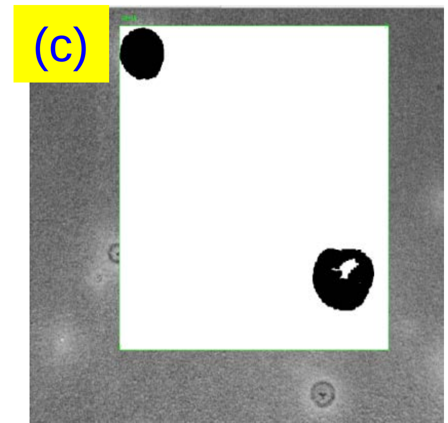
- Determine the ease and feasibility of detecting the defects in these images automatically with the tools available in the machine vision



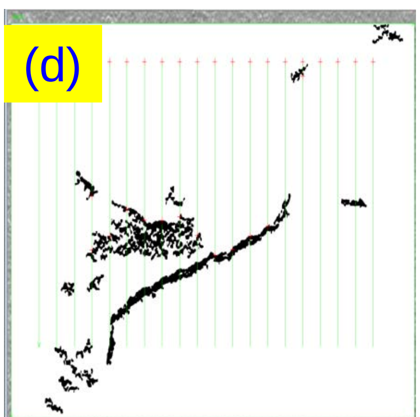
Line scan image/6 tools



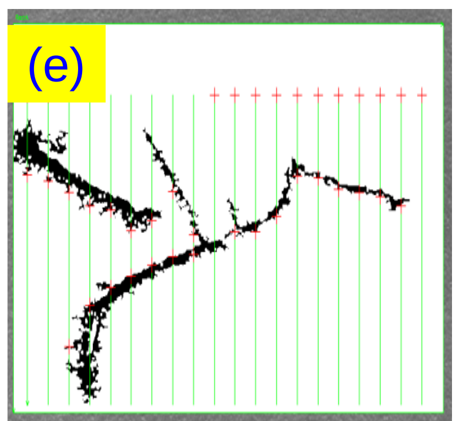
Line scan image/2 tools



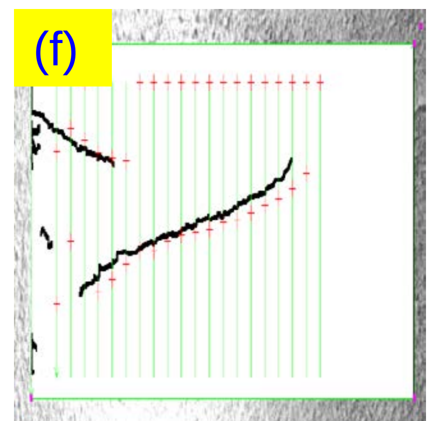
Laser scan image/2 tools



Line scan image/6 tools

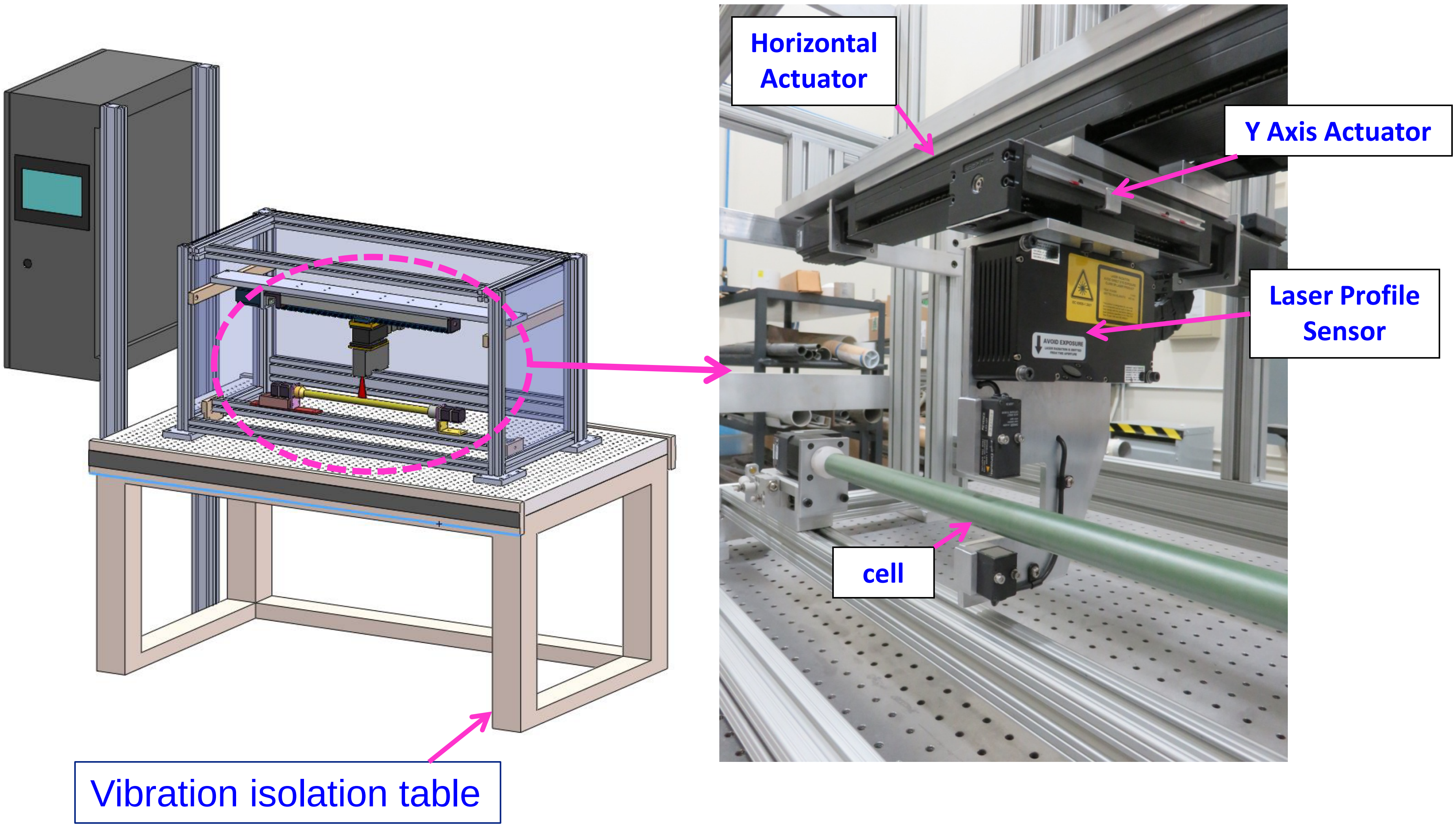


Line scan image/5 tools



Line scan image/2 tools

Defect Screening System: in progress



Future works

- Finish up cell and stack testing
- Conduct microanalysis of defects
- Build and implement automatable QC device

Video clip for Atrex ARP unit:

https://vimeo.com/191661007/807843bf0e