

In-Process Monitoring: Monitoring the Health of a Manufacturing Process

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Nonlinear System Identification in Structural Health Monitoring

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Presentation Outline

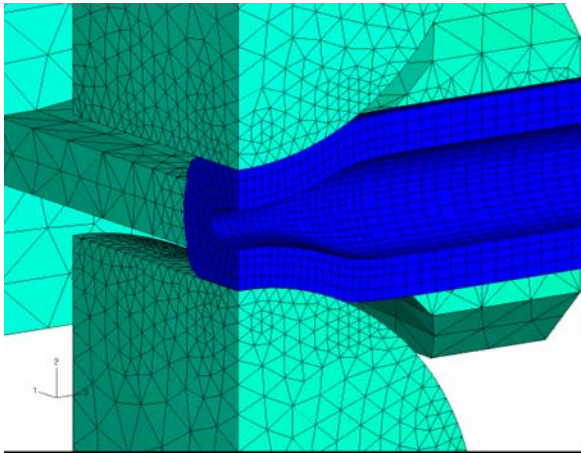
- Motivation:
 - What is In-Process Monitoring?
- Applications:
 - Gas tungsten arc welding
 - Pinch Welding
 - Machining
- Conclusions



In-Process Monitoring

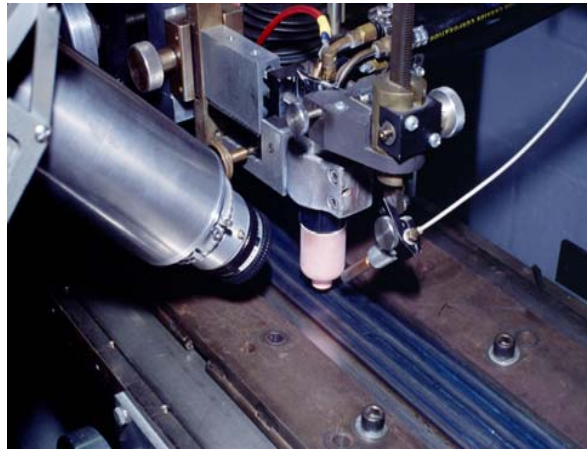
In-Process Monitoring is the application of sensors and data analysis techniques to provide continuous, real-time, and in-process feedback of the health of a manufacturing process.

RSW



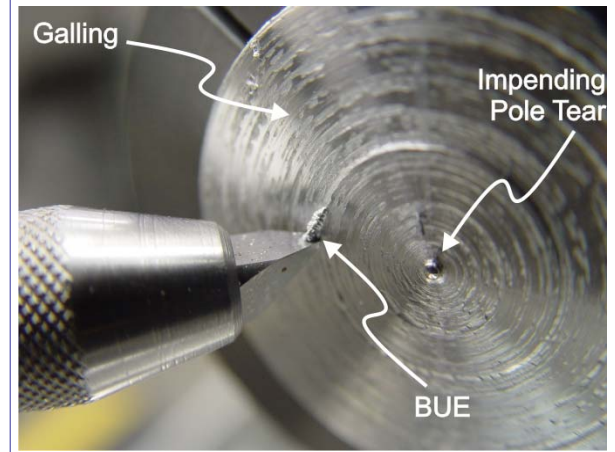
Monitor dynamic resistance and AE and infer metallurgical bond integrity.

GTAW



Monitor the heat source-to-material interaction by measuring the light reflected off of the weld pool's surface and infer depth of penetration.

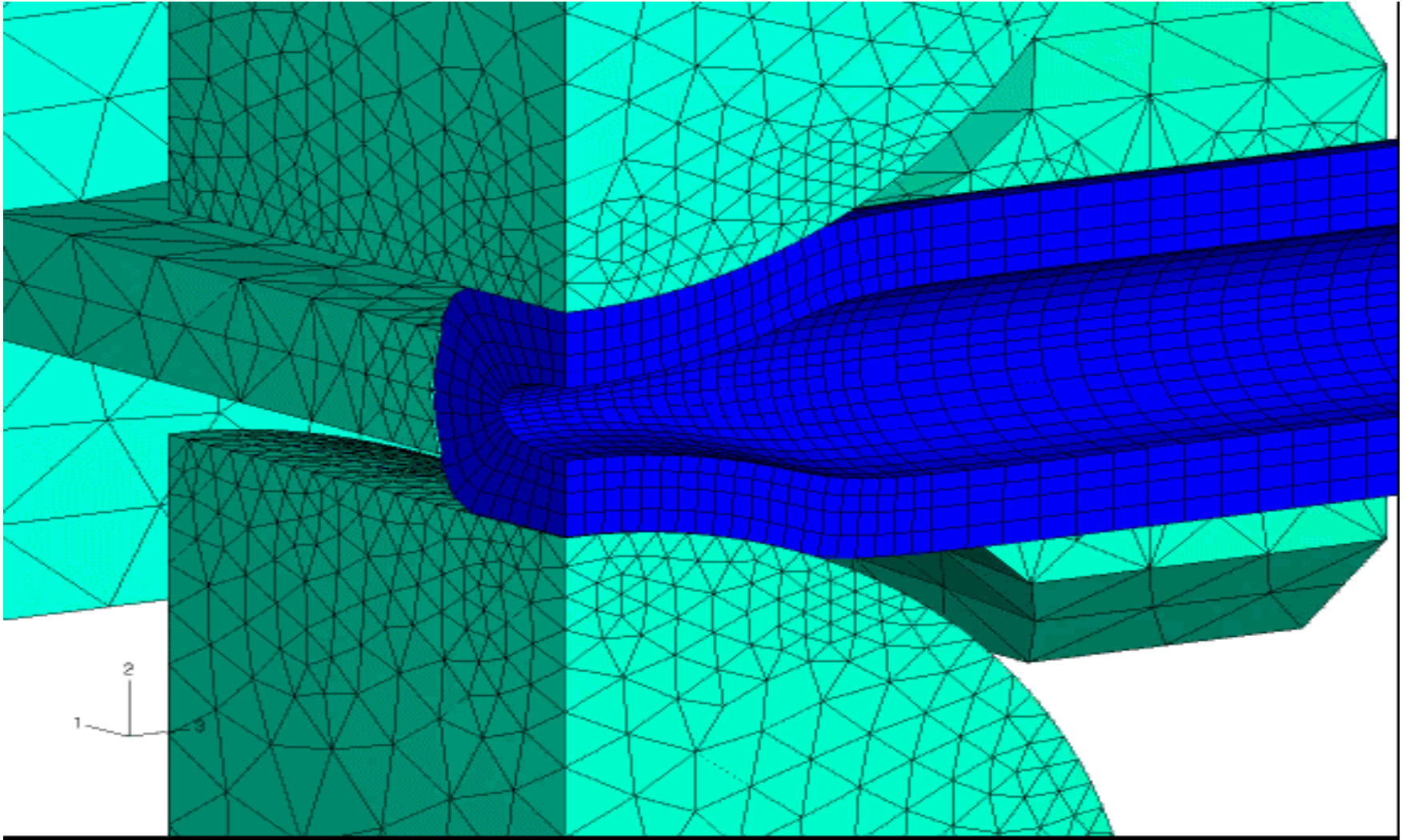
Machining



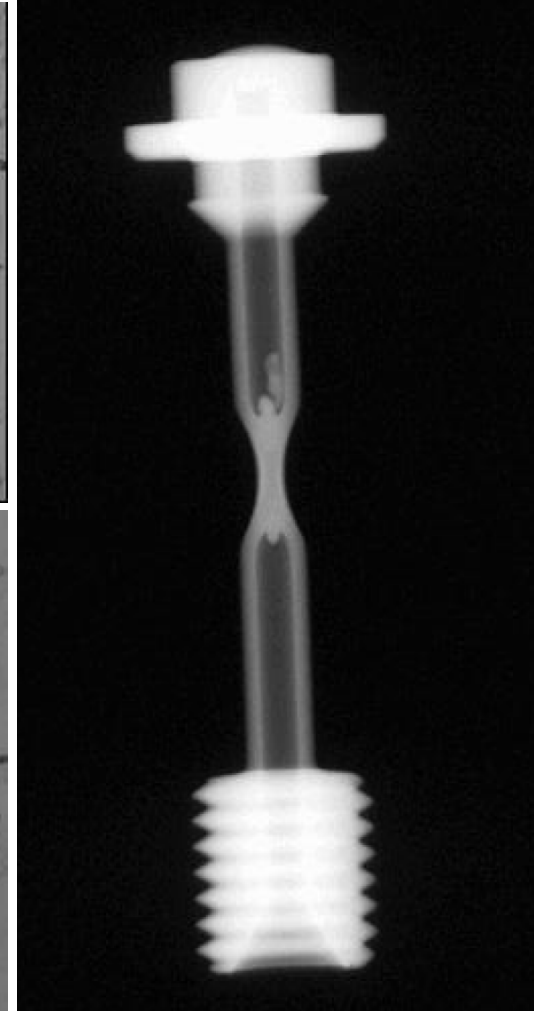
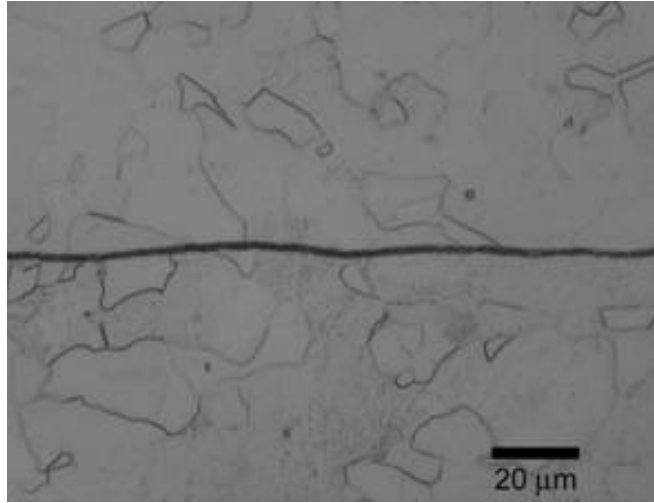
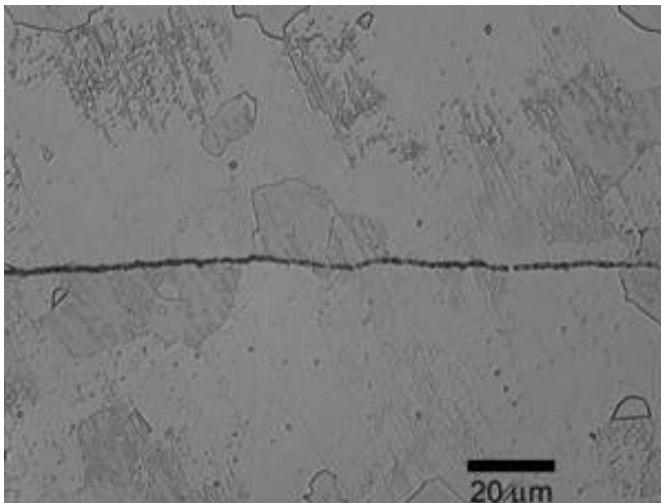
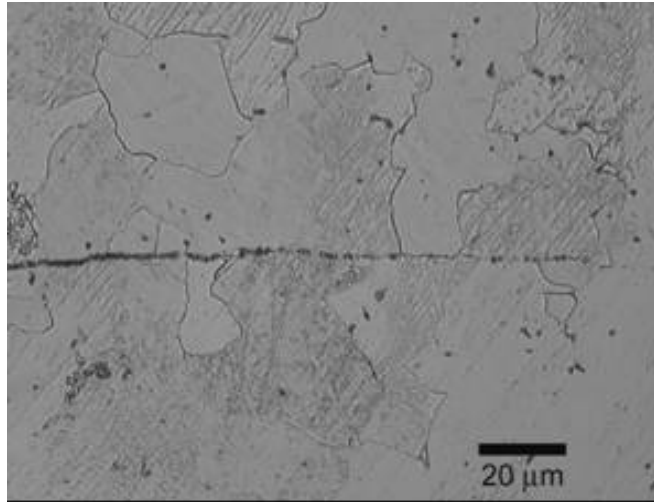
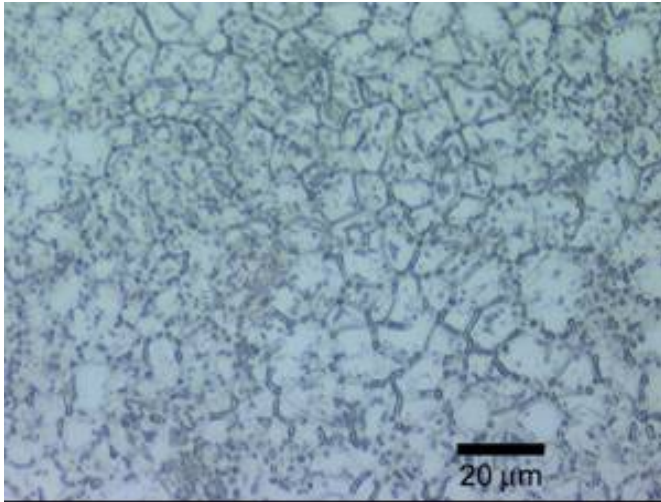
Monitor the tool-to-material interaction (vibration and force) and infer cutting performance and part quality.



Resistance Spot Welding: Process



Resistance Spot Welding: Process



Resistance Spot Welding: Methodology

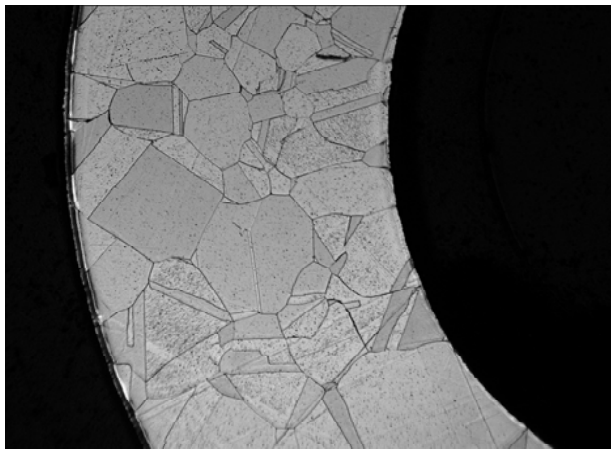
- *Apply a physics-based understanding of the resistance spot welding (RSW) process to collect, analyze, and classify acoustic emission data according to the weld's metallurgical bond quality.*
- *Monitor the dynamic resistance (a response variable) to infer interfacial heating to ensure a good bond.*
- *“Listen” to the weld on-cooling to quantify physical phenomena determining metallurgical bond quality.*



Resistance Spot Welding: Nonlinear Dynamics

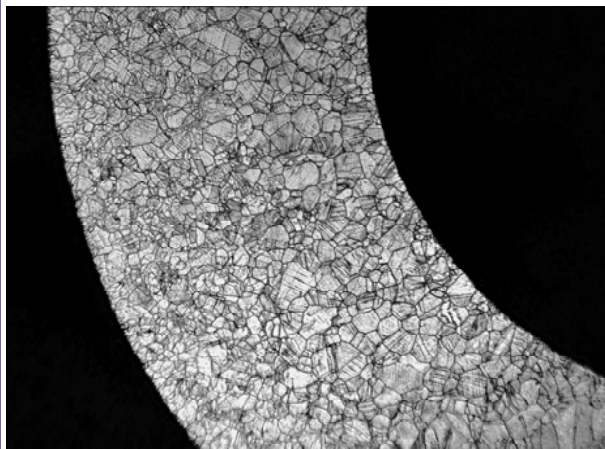
Different material properties can result in fundamentally different bond qualities under identical welding parameters.

HRB 64



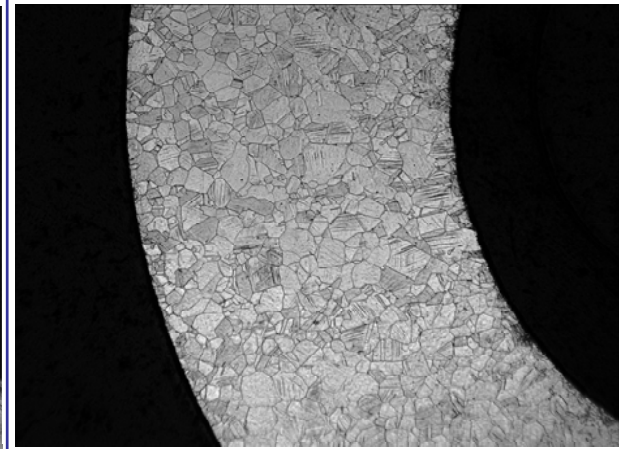
Fully Annealed

HRB 96



Partially Annealed

HRC 24

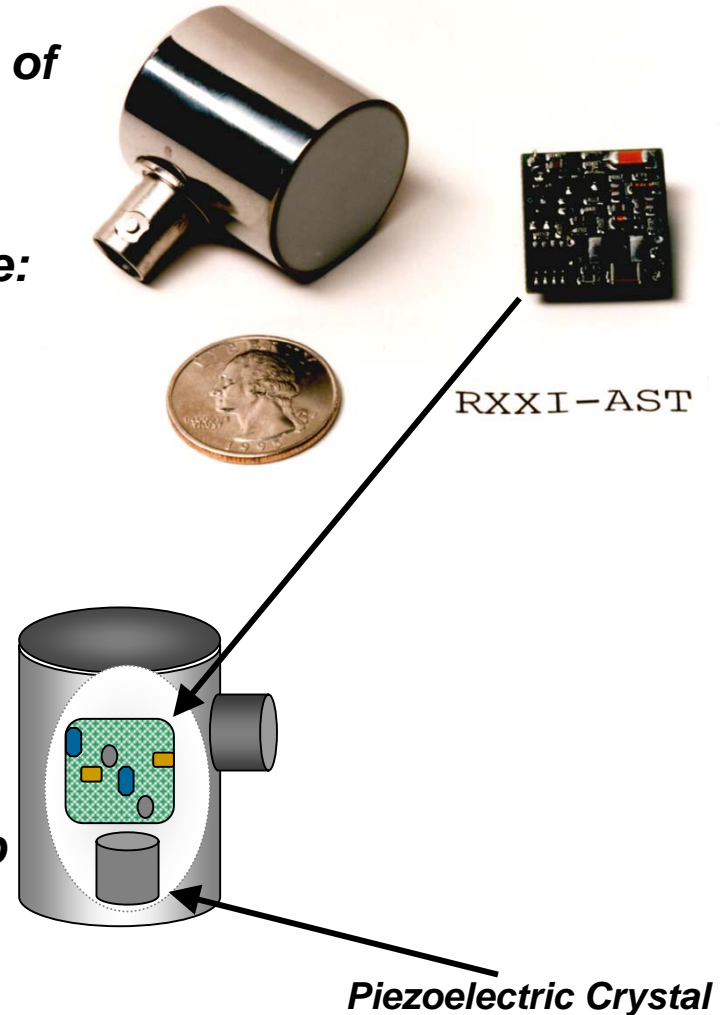


As-Received



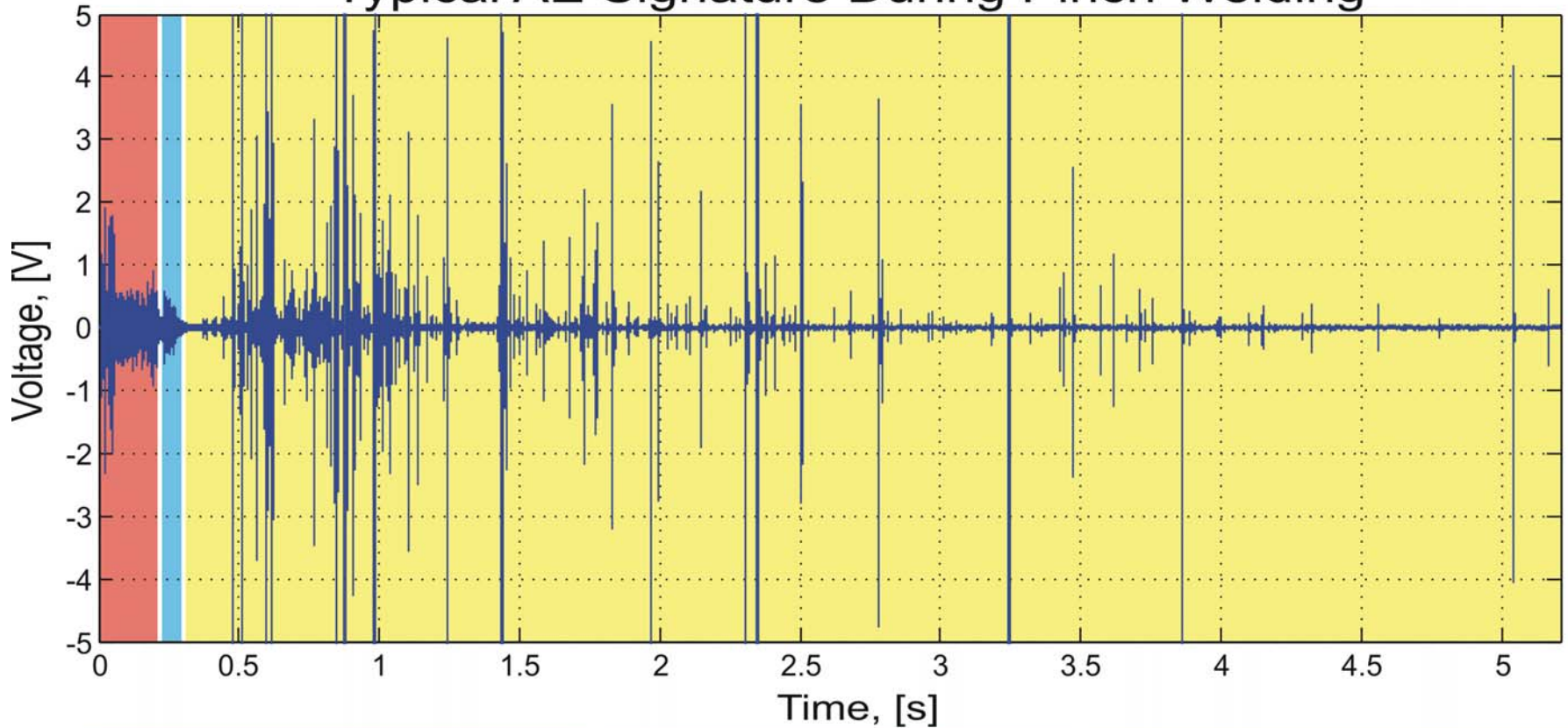
Resistance Spot Welding: Acoustic Emission

- **Acoustic emission (AE) is the rapid release of transient elastic waves from localized sources within a material.**
- **Common sources of AE (for metals) include:**
 - **Dislocation movement that is accompanied by plastic deformation**
 - **Initiation or extension of cracks in a structure under stress**
- **Other sources of AE include:**
 - **Melting**
 - **Phase transformation**
 - **Thermal stresses**
 - **Cool down cracking and stress build up**
 - **Twinning**



Resistance Spot Welding: Acoustic Emission

Typical AE Signature During Pinch Welding



"On-Heating"

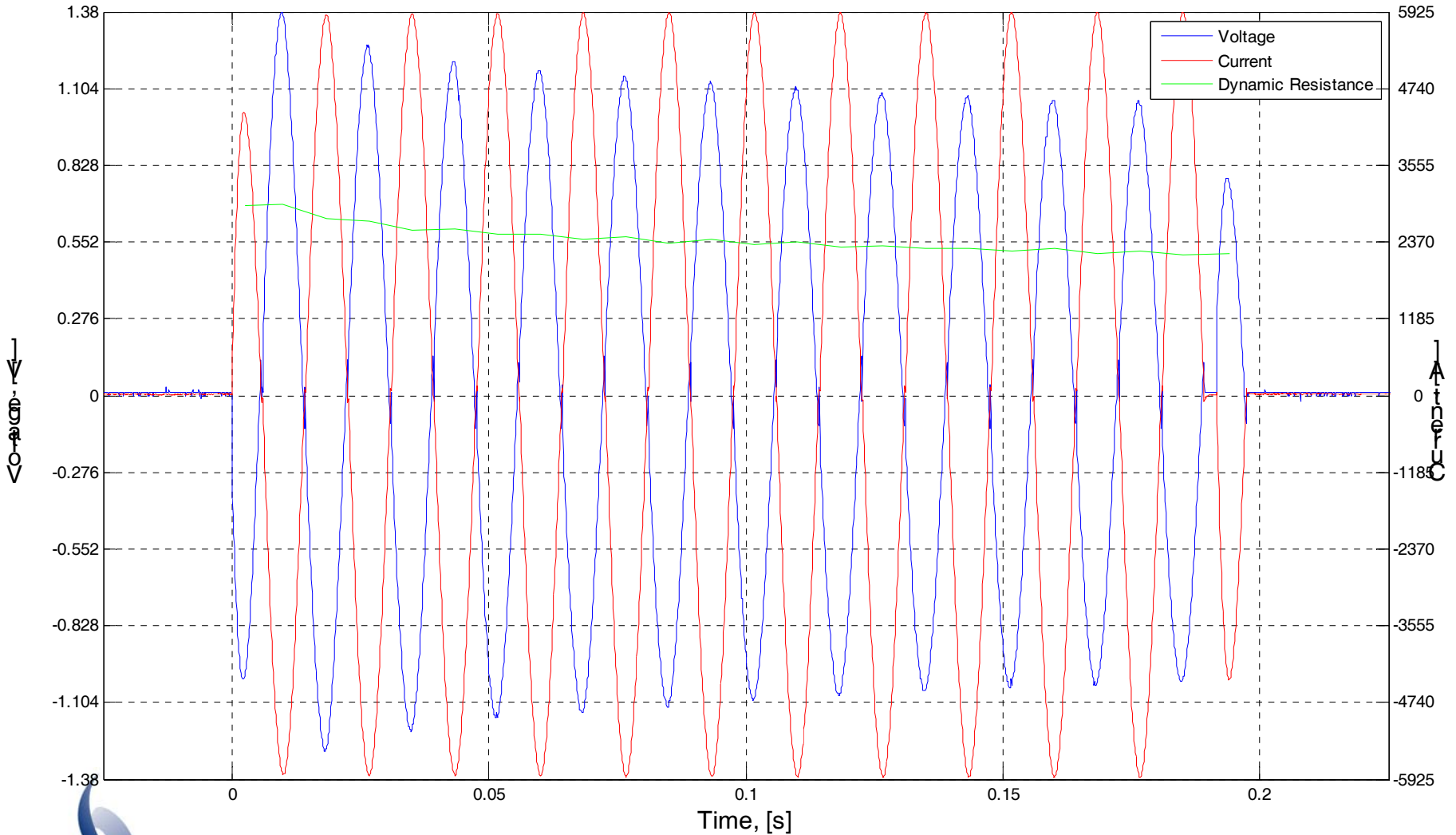
"On-Cooling"

"Relaxation"

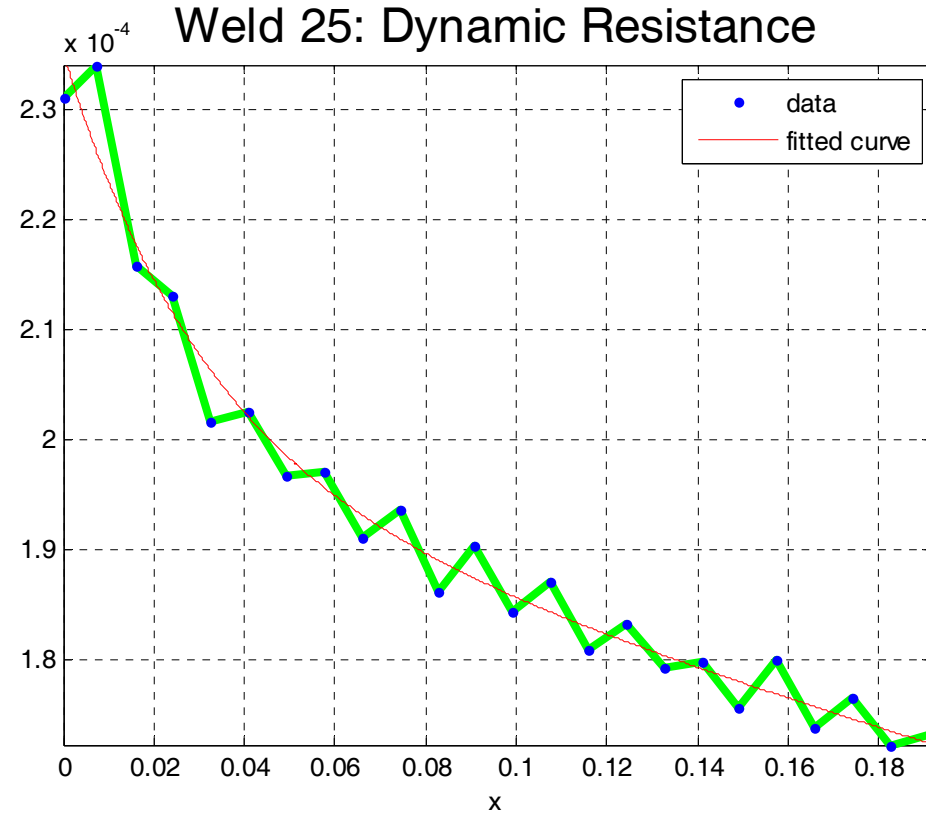
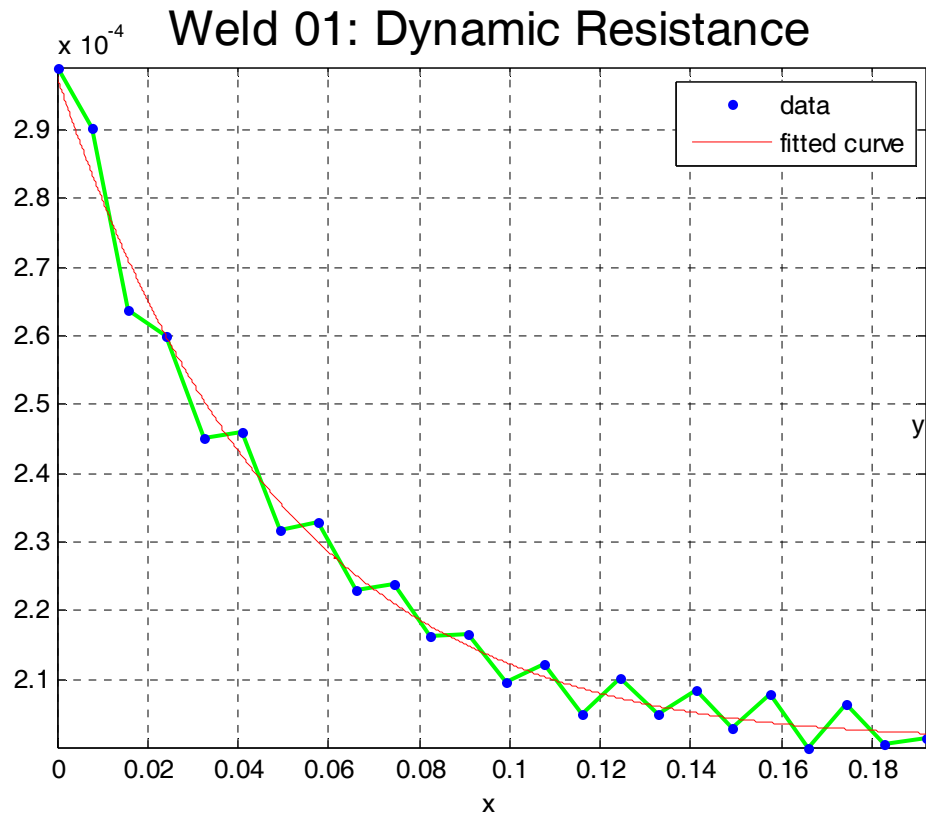


Resistance Spot Welding: Dynamic Resistance

Weld 25

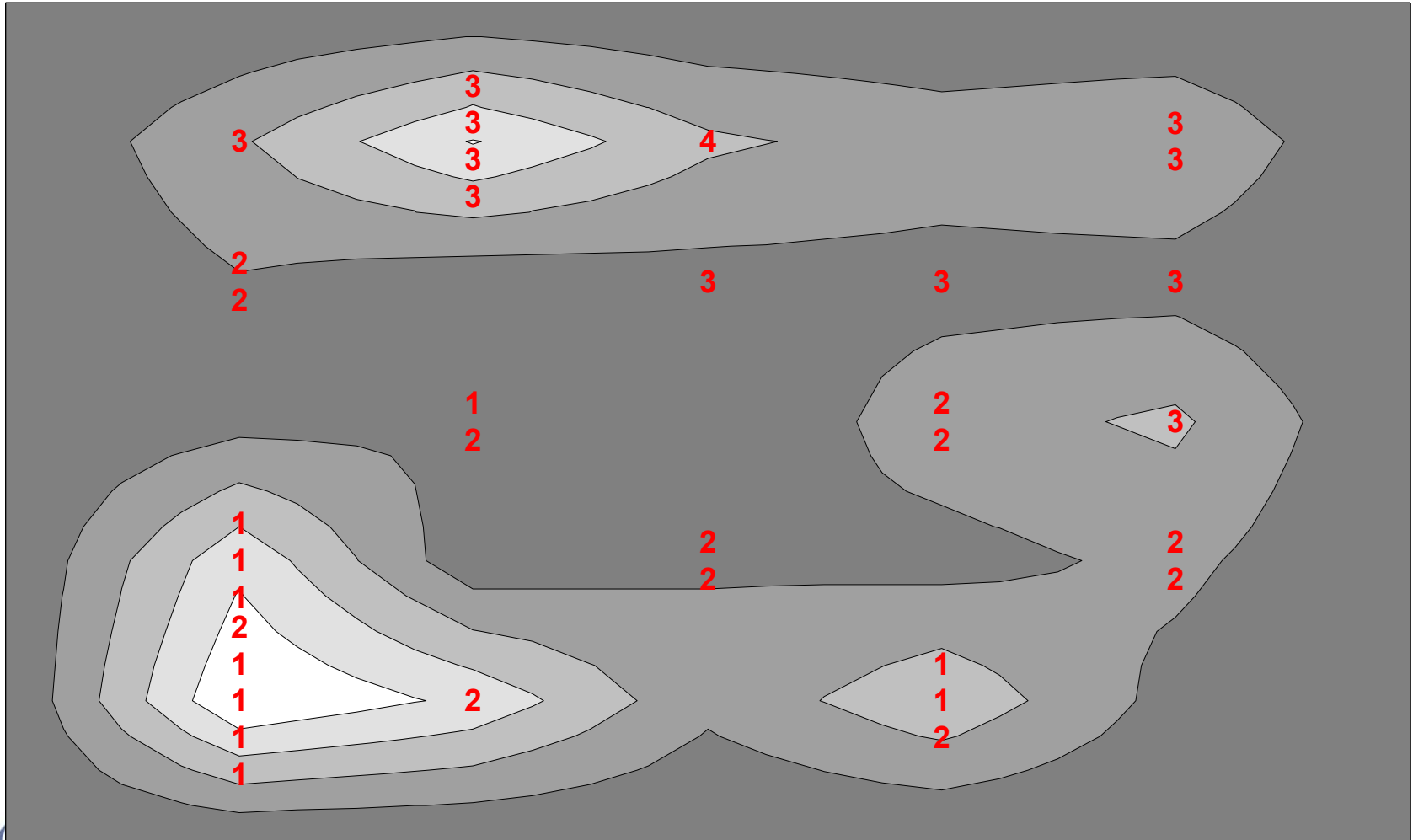


Resistance Spot Welding: Dynamic Resistance

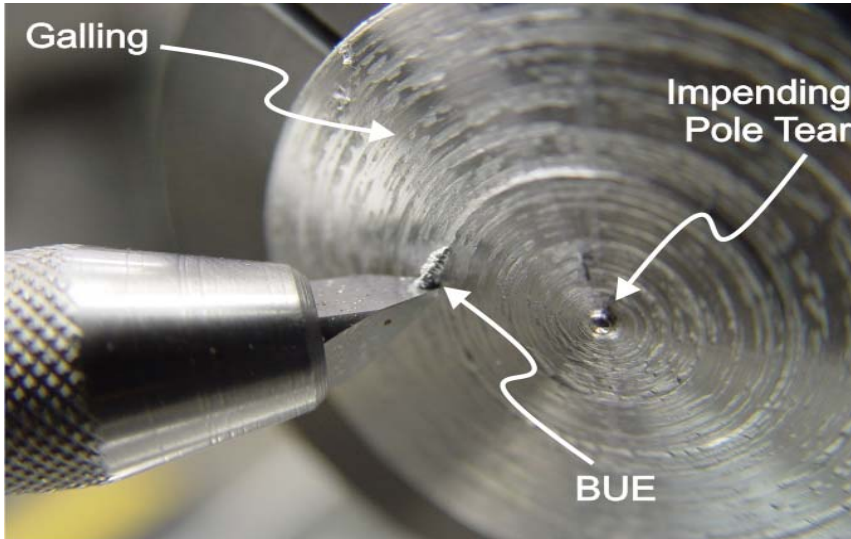


Resistance Spot Welding: Dynamic Resistance

Self Organizing Map



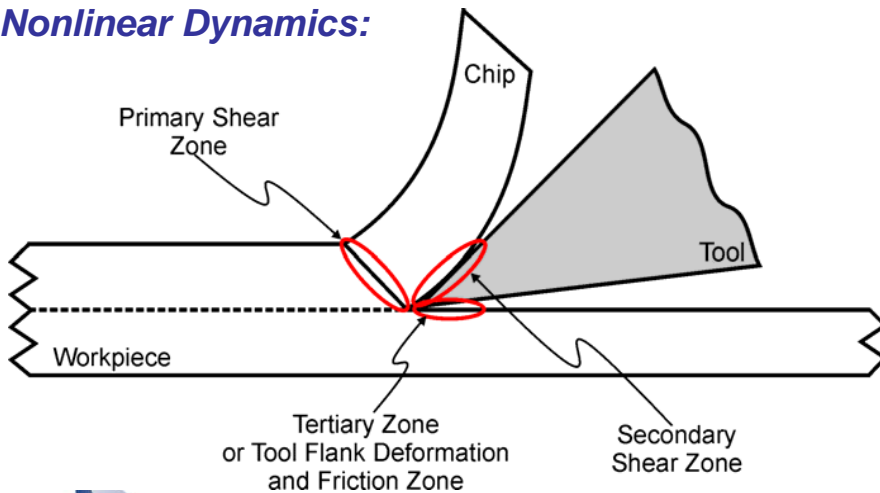
Application: Machining



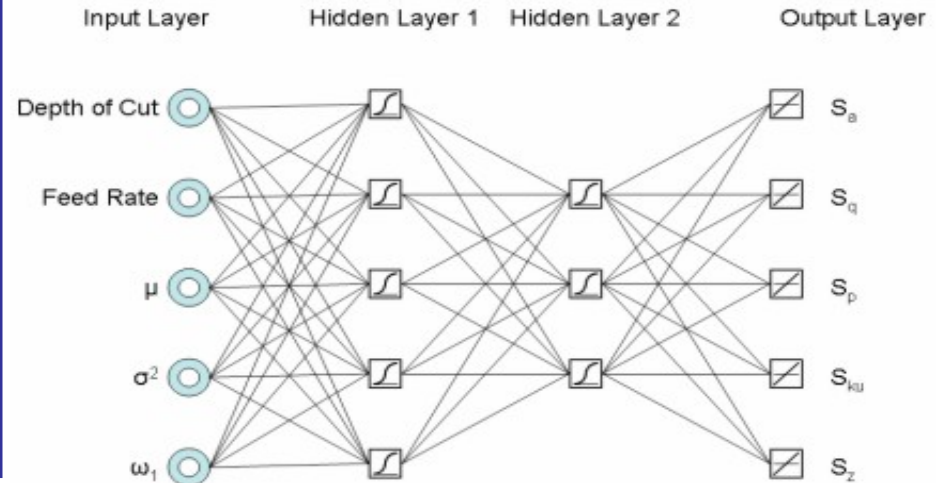
Methodology:

- Apply a physics-based understanding of the machining process to properly instrument, collect, analyze tool vibration data.
- “Listen” to the machining process and correlate in-process data to cutting performance and product quality in ***real-time***.

Nonlinear Dynamics:

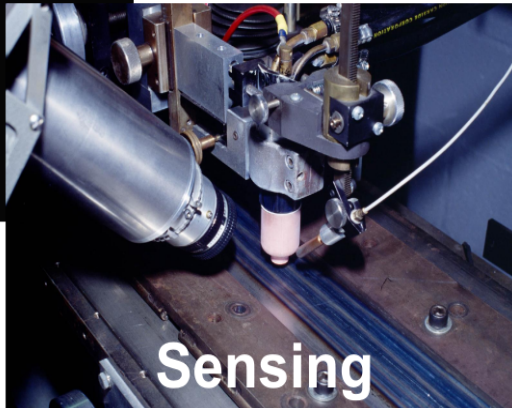
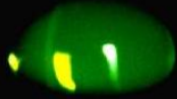


Approach:



Application: Gas Tungsten Arc Welding (GTAW)

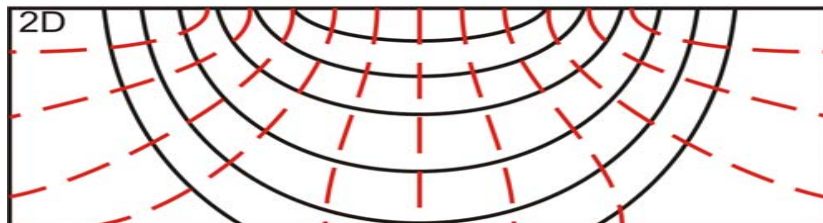
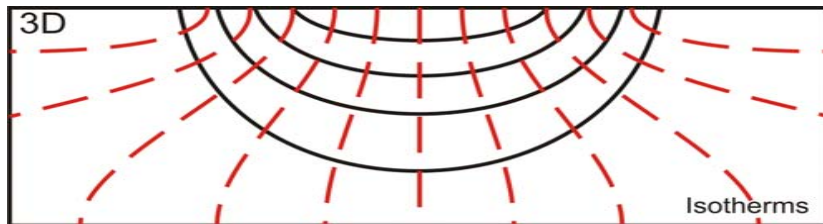
Process Physics



Time of One Oscillation:

$$t = \frac{\sqrt{\frac{3prV}{g}}}{\sqrt{n(n-1)(n+2)}} \text{ sec}$$

Nonlinear Dynamics:



Methodology:

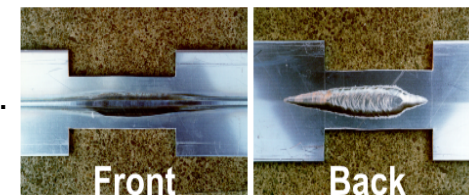
- The weld pool's natural resonant frequency is used to infer the volume, and hence the depth, of the molten metal.
- Provides top-side penetration control which is otherwise problematic.
- Lack of fusion due to variations in joint fit-up, joint geometry, and fixturing results in in-services failures of life- and safety-critical components.

Approach:

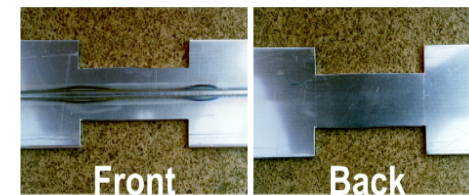
- A fuzzy logic system is capable of modeling nonlinear, time-varying, and asymmetric problems.

Flat Plate Demonstration

Control: Off



Control: On



Conclusions

- Investigation and knowledge discovery are not the same as production applications (e.g., relational databases) or traditional statistical analysis.
- Nonlinear system identification (and neural networks in particular) is well-suited for problems in which we don't know what we are looking for or how to measure it.

