Real Time Ultrasonic System for Resistance Spot Weld Inspection.
Integration in Assembly Line

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Resistance Spot Welding in Industry

Spot welding is highly automated today

Regular vehicle contains 3000-6000 spot welds
Spot Welding

Spot welding involves

- electrode forces: 500..2200 lb
- electric currents: 5000..13000 A
- temperatures: 70..3000 F

Some means of quality control are required to ensure uninterrupted automatic production.
Destructive Testing

**Peel test**

**Cross-section**

Cons: Selective testing; Time consuming; Labour intensive.

More than 99% of the parts are never checked. For this reason, at the design stage, additional spot welds are introduced into the assembly process.
Non-destructive Testing

Potential to inspect 100% of produced welds

When steel plates are heated, the sound speed drops from 5900 m/s at room temp. down to 4200 m/s at melting point and down to 3900 m/s in liquid state.
Real-time Ultrasonic Testing of Spot Welds

Ultrasonic probe built into electrode

Incident wave

Copper Electrode

Steel Plate 1

Steel Plate 2

Molten Nugget

Copper Electrode

Arrival time

Amplitude

Current ON

Arrival Time

Time, ms

*Transducer built into an electrode by Maev et al. US Patent 6297467

Impedance mismatch between solid and liquid steel provides reflection coefficient for longitudinal wave energy at level of \(~1.046\%\).

Acoustic impedance of the medium: \(Z = \rho \cdot c\)

Reflection coefficient at normal incidence:

\[
R = \left[\frac{Z_2 - Z_1}{Z_2 + Z_1}\right]^2
\]

Steel Properties at different temperatures
Real-time Ultrasonic Testing of Spot Welds

Real Acoustic Image

Pattern of interest

Weld geometry
Ultrasonic transducer parameters:
- central frequency: 10 MHz.
- bandwidth: 90%.

Sampling rate: 66.6 MHz
Pulse repetition: 3.0 ms
Radon transform can be considered special case of Hough transform

- Image is rotated around its center
- At every rotation angle, a projection of image on horizontal line is performed
- 1D projection amplitude becomes a vertical line in Radon image
Performance Example

Line going through the circle of random numbers of amplitude in the range -0.5..+0.5.

Line amplitude: 0.5.
Line slope: 22 degrees

Main Principle of Line Detection with HT

Parametrize image into angle and distance coordinates using

\[ \rho = x \cdot \cos(\theta) + y \cdot \sin(\theta) \]

Find maxima as indicators of the strongest directions on image

Convert parameters \( \rho \) and \( \theta \) back into \( x-y \) 2D image

After this processing stage, the segmented components are used by higher-level algorithms for pattern recognition and interpretation.
System Design
Welding Application with Ultrasonic Monitoring Station

- Robot controller
- PC
- Quality monitoring system
- Weld gun with ultrasonic probe
- Weld controller
- Remote Workstation (optional)
RIWA System

Discrete I/O device with USB cable
RIWA PC
Coax cable
AC adapter
Weld electrode with ultrasonic transducer inside
Approximately 20-25% more spots are welded to guarantee the integrity of the product. The average number of spot welds per car is 3000. This turns into 600-800 additional welds which can be eliminated if one can guarantee the quality of every single weld produced.
In this new design the ultrasonic probe is built into regular welding electrode.

Probe is submerged into cooling water stream which is used as a couplant.
Communication with Welding Equipment

RIWA

Part ID

Weld ID

Trigger

Quality

Robot and Welding Controller

Time

Idle

Trigger

PartID

WeldID

Current

Read BScan

PartID

WeldID

Trigger

Idle

Current

Read BScan
Communication with Welding Equipment

DIO

FIELDBUS

Robot Controller

Digital IO Device

RIWA PC

Robot and Welding Controller

Part ID  Weld ID Trigger

FieldBus; DeviceNet, Ethernet/IP

Quality
Data Representation
Data Representation
Communication Between Units
# Ultrasonic Hand-held Device Measurements

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RIWA real time measurements. Detected all 3 purpose failures.
Challenges

- The amount of data available for analysis is enormous
- There have never been performed so many measurements per robot
- 25,000 to 1 is the average ratio for real-time vs manual ultrasound inspections

What should we do with this data? Save? Discard?
- Perform statistical analysis
- Look for quality trends
- Create individual vehicle spot weld database
- Selective and random measurements are now replaced by about 100% production volume measurements
RIWA system detected cooling water tube failure

Screen image contains about 10,000 measurements collected in about 23 hours
8.35
Tip dress

Improvement, more greens

8.17
Tip dress

No improvement
No improvement

7.55 Tip dress

Improvement, more greens

7.22 Tip dress
Monitoring Water Overheat Dynamics as a Function of Tip Condition
Conclusions

The system development is unimaginable without involvement of one or few industrial partners who help in transition of the new technology from the lab into production environment.

The system provides quality evaluation to most of the welds being produced by the robot.

Feedback provided by the system can be used to perform any action desired (send alerts, send notifications to maintenance personal, stop the production line, etc.).

Collected information can be used in many different ways:
• statistics
• system performance charts
• customer satisfaction data recording