

**DOE Sensors & Automation
2005 Annual Portfolio Review**

**The advancement in surface quality
assurance for hot rolled steel bars**

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Project Description

- This SQA program is to solve the major surface quality problems for the US special quality steel bars and rods industry and their customers.
 - The problem accounts for roughly 50% of the rejects.
 - The sporadic nature cannot be addressed based on sampling techniques.
- The goal is to develop & demonstrate an SQA™ prototype that
 - Enables efficient steel bar rolling process control of surface quality;
 - Is capable of automatic accurate-marking of the residual surface defects for downstream removal.

Project Description

Core Technology:

- In-line, real-time imaging based visual inspection;
- Modal based vibration reduction;
- Advanced data analysis for process signatures and root cause identification;
- Predictive process control to prevent surface defects;
- A new business paradigm based on defect detection, marking and removal.

Project Description

- Initial Application:
Steel bar/rod rolling mills
- Key Project Deliverable(s)
 - A reliable and accurate HotEye™ surface inspection system.
 - An effective, non-contact vibration reduction device.
 - A methodology for rolling process signature identification.
 - An integrated prototype of an on-line automatic root cause identification system.
 - A system for automatic defective segment removal.

Barriers and Pathways

■ Barriers

- Lack of a reliable surface defect detection system;
- Lack of a means for accurately registering/tracking defects, and
- Lack of the comprehensive knowledge of the complex rolling process.

■ Pathways

- Improved in-line surface defect detection capability;
- Integrated database systems (mill operation + surface defect data);
- Advanced pattern extraction models;
- New logistics for steel bar delivery; and
- Intensive on-site test and refinement.

Energy Savings

- Energy be saved through reduced steel mill scrap
- Based on the assumption that
 - the surface defect scrap rate can be reduced by **80%** in the special bar quality production,

The advancement in technology from 2003 expects to save

- **749,000 MMBTU / Year by 2010**
- **5,800,000 MMBTU / Year by 2020**

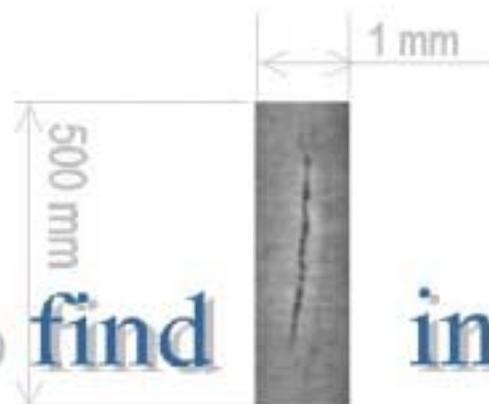
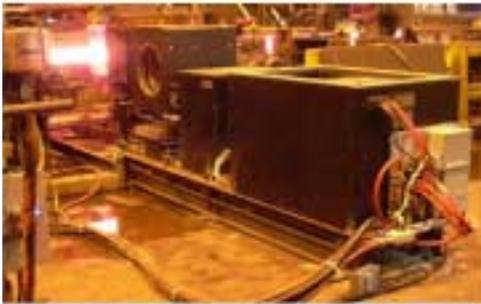
Other Important Metrics

- Decrease defect detection false positive accuracy to 2%, from ~20% prior to the project.
- Improve the capability of inspecting small bar to $\phi 5$ mm ($\phi 13/64$ ", state-of-the-art rolling capability), from $\phi 8$ mm capability.
- Improve the defect position registering (speed measurement) accuracy to 0.2%, from ~2%.
- Decrease the surface defect caused rejection rate to 2.5%, from ~5% as in 2003.

Accomplishments to Date

- Achieved the target surface detection accuracy of the in-line surface detection system.
- Demonstrated the target speed measurement accuracy on rods as small as $\phi 9$ mm.
- Demonstrated the capability of in-line pattern identification for selected surface quality faults.

Surface Defect Detection Accuracy



Surface Defect Detection Accuracy

Ability to detect and differentiate:

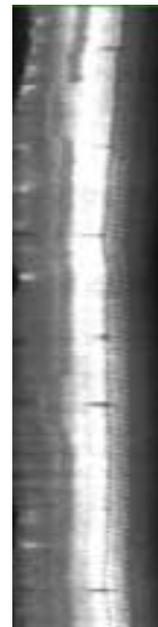
- Seams/laps
- Slivers/scabs/checking
- Overfills
- Scratches
- Roll cracks (periodic)
- Fluttering (periodic)
- Tool marks



Seam



Roll cracks



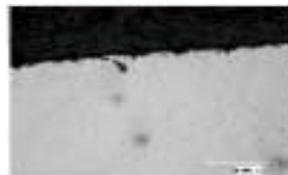
Overfill



Scratch

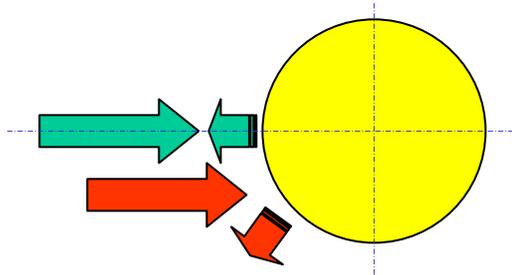


Heat crack

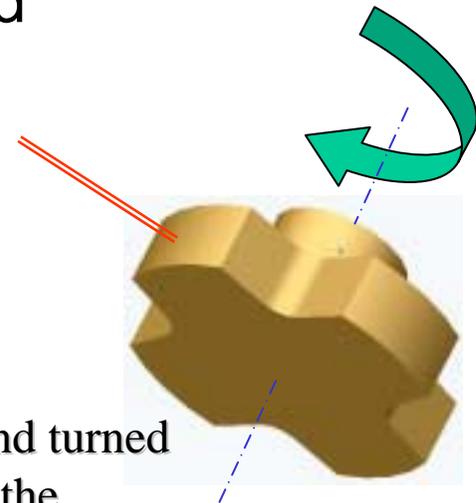


Speed Measurement Accuracy

- Base technology: Laser Doppler Velocimeter
- Issue: Difficult to maintain perpendicularity to the surfaces of long products
- Solution: Special signal processing to extract the good measurements
- Tested accuracy: 0.02% of the speed



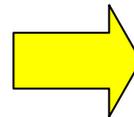
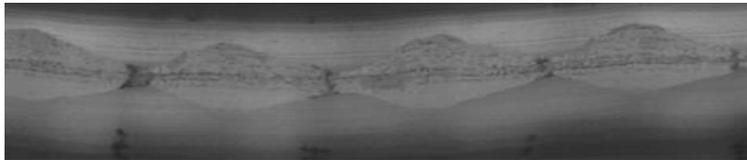
Part made and turned
on a CNC lathe



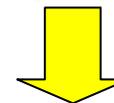
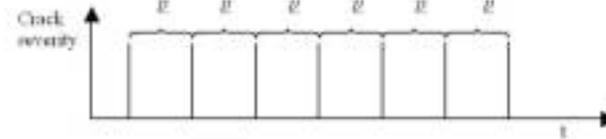
In-line Repeating Pattern Identification

Ideal Case

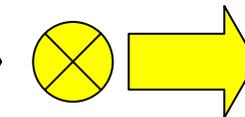
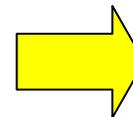
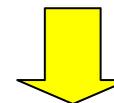
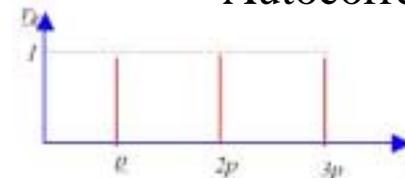
In-line Images



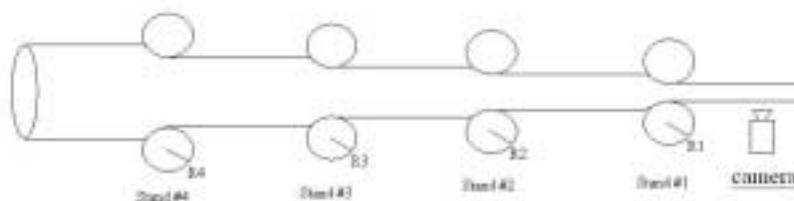
Repeating Pattern



Autocorrelation



Symptom /
Problem
Location

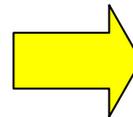
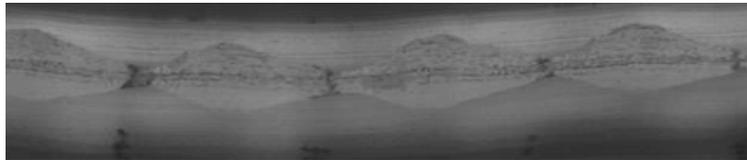


Roll Pass Parameters

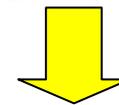
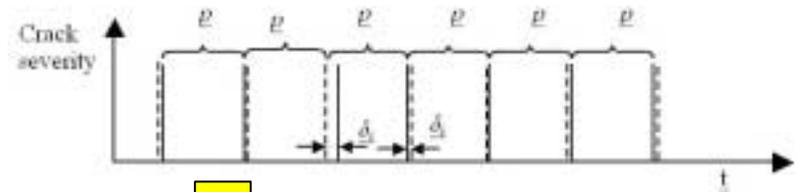
In-line Repeating Pattern Identification

Real Case

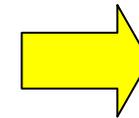
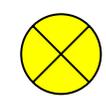
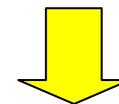
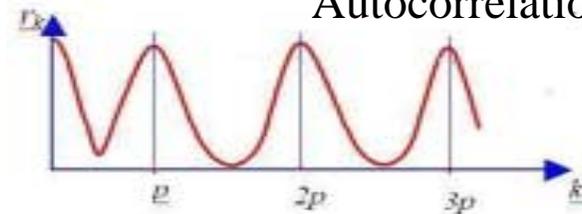
In-line Images



Repeating Pattern

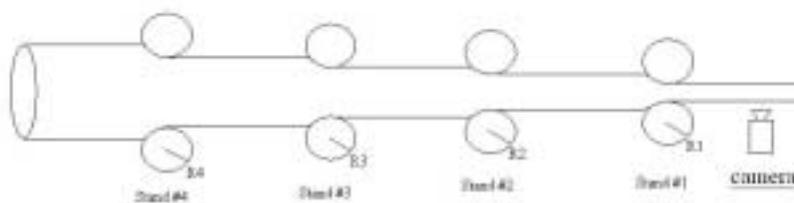


Autocorrelation



**Symptom /
Problem
Location**

- Contact/non-contact in subsequent rolling stands
- Quantization error due to fast computing needs
- Signals from multiple repeating sources
- Localized noise sources



Roll Pass Parameters

Next Project Steps

For each technology developed,

- Proof of on-site stability with a 6-month trial of production usage at beta site.
- Integration of the developed technologies into the base HotEye™ sensor system.
- Documentation of performance and benefits.

Future Milestones

- Demonstrated surface detection capability for wire (smaller than $\phi 8$ mm, or $\phi 5/16$ "") rolling lines by 12/31/2005.
- Demonstrated off-line process diagnosis for rolling process faults that result in surface defects by 12/31/2005.
- Demonstrated near-real-time on-site process diagnosis for rolling process faults that result in surface defects by 12/31/2006.
- Demonstration of surface defect marking, tracking, and removal by the end user of the steel bars by 12/31/2006.
- Demonstration of 80% surface defect reduction (baseline defect rates prior to this project) by 12/31/2007.

Continuation after ITP-Sponsored Project

- The technology developed will be marketed directly.
- In fact, the following items are already integrated into the base sensing product:
 - Accurate surface defect detection algorithms
 - In-line repeating defect pattern identification
- More development may be necessary for other applications
 - Planned project blocks to lower entry barrier
 - Seeking possible matching funds

Value Proposition for End User

- Improved productivity
- Improved quality
- Improved efficiency
- Expected payback of at least \$1M / year
- Example Case:

The developed technology has helped a mill reduces its monthly average mill setup rejects from ~150 tons to ~10 tons.

Commercialization Plan

- **Current market status**
 - **Steel industry is in its best period for years**
 - **No competing imaging technology in the long product sector**
- **Marketing objective**
 - **Solution provider to long product rolling mills for surface quality**
- **Marketing activities**
 - **Nine steel companies visited the project host site since March 2004**
 - **Exploring next step with a rolling equipment provider**
 - **More than 10 outstanding business proposals**
- **Current market position**
 - **The only proven in-line seam/overflow detection system for bars and rods**
 - **Close cooperative relation with most US SBQ mills**
 - **Seeking worldwide patent protection**
 - **Established market in Asia**
- **Broaden Applications**
 - **Started a contract for rail inspection**
 - **Negotiating a contract for billet inspection**

Commercial/Technical Risks Remaining

- **Complex causal relationship for sporadic defects**
Results to date are not intuitive and yet to be further delineated.
- **Uncertain on-site schedule**
The test hosting sites are running their production schedule, which always takes the priority.
- **Global market**
Such global appearance is a good opportunity, with a potential risk to OGT.
- **Potential steel price instability**
Decreased profits may prohibit the bar mills to limit their investment on capital equipment.
- **Difficult 1st sales into the secondary applications**
The industry has a special sense of “risk” when it comes to adopting new technologies.