DISTRIBUTED FIBER OPTIC SENSOR FOR ON-LINE MONITORING OF COAL GASIFIER REFRACTORY HEALTH

DE-FE0005703

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Motivation

• Refractory health monitoring in slagging coal gasifiers:
  • Rapid corrosion of refractory materials.
    • High-temperature reducing environment.
  • Difficult to predict remaining refractory life.
    • Localized thinning, spallation and cracking.
  • Expensive to shut down gasifier for repair.
Impacts

• Current gasifier operation strategy:
  • Scheduled inspection & replacement of liners.
    • Conservatively short intervals – increased downtime
    • Difficult to predict wear rate.
  • Re-bricking takes up to 3 weeks and $1-2M, and
downtime costs even more.

• New technology will enable:
  • Early detection & location of hot-spots.
  • Estimation of remaining lifetime.
  • Allow condition-based maintenance model.
  • Reduced downtime & cost savings.
Gasifier Refractory Health Monitoring

- Refractory defect monitoring by temperature mapping

![Diagram of gasifier showing temperature mapping and refractory layers]

- Temperature (C)
  - 1326
  - 1200
  - 1000
  - 800
  - 600
  - 400
  - 200
  - 57

![Diagram of gasifier showing sensor network and health monitoring]

- Sensor network wrapped around gasifier between refractory layers
- Single entry/exit point
- To remote sensor control system

- Refractory Health Mapping: Distributed Fiber-Optic Sensor (proposed)

![Diagram of temperature difference and sensor readings]

- Temperature Between Refractory Layers (°C)
  - Direct Refractory Monitor
  - External Sensor
  - Temperature Difference: Δ=164°C
  - 5° Deep Crack: 39°C
  - 1° Deep Crack: 4°C
  - External Temperature (°C)
  - 260
  - 250
  - 18
  - 1080
  - 1060
  - 1040
  - 1020
  - 1000
  - 980
  - 960
  - 940
  - 920
  - 0
  - 0.5
  - 1
  - 1.5
  - 2
Sensing Mechanism

• A strong pulsed light as pump and a weak CW light as probe are injected into the sensing link, counter-propagating.

• The beat note of the pump induces a transient grating which scans along the sensing fiber via electrostriction effect.

• The signal light probes the travelling fiber grating and translates the temperature distribution along the fiber from spectral shift changes in time domain.
Optical Sensing System Designing

- 1550 nm source
- OC
- PC
- EOM
- EDFA
- PS
- OC
- Tunable filter
- PD
- Oscilloscope

- RF generator
- Pulse generator
- FUT

- 50%

- 50%
First Demonstration

• First demonstration of temperature sensing
• 5m spatial resolution and 10ºC temperature resolution achieved at 500ºC
Sensitivity Optimization: Spatial Resolution

- Width of pump pulse and intensity of probe light optimized with the help of theoretical analysis
- Spatial resolution improved from 5m to 1m (over the span of 230m, at 1000ºC)
Sensitivity Optimization: Temperature Resolution

- Temperature demodulation algorithm improved
- Test environment temperature stabilized
- Temperature resolution of 2.5°C achieved near 1000°C with 1m spatial resolution.
Challenges

- Fiber type: silica fibers
  - Must be single-mode fiber
- Silica devitrification at extremely high temperatures
  - Weaken in mechanical strength
  - Optical transmission loss increase
  - Refractive index and acoustic property change
Challenge 1: Packaging

• Inconel 600 alloy tubes
• No deformation
• Oxidation on surface only

Before annealing

After 1000ºC annealing
Preliminary Packaged Sensor Test

- 1m spatial resolution over the span of 600m achieved at 1000°C
- Sensor passed 36h annealing test at 1000°C
Challenge 2: Fiber Loss

- Minor loss increases over time when fiber is kept at temperatures at 1000ºC
- Increasing rate measured to be ~0.1dB/m/day for a properly packaged fiber at 1000ºC
Lab Test Environment Design

- Independent dual heating zone for temperature gradient simulation

Full cylindrical outer insulation with vestibule (ID: 21”; OD: 26”)

2” gap, blanket filling in between heater and outer insulation.

Inner insulation cylinder for fiber coiling (ID: 8.5”; OD: 13.5”; Length: 12”
Lab Test Environment Building

- Finished furnace assembly

Testing chamber

~60cm
Performance Demonstration: Spatial Resolution

- Fiber installing scheme designed to simulate a hot spot on the furnace inner-wall
- 1m spatial resolution over 550m measurement range
What’s Next

• Temperature resolution demonstration of packaged sensor in simulation environment

• Proposing of possible sensor installation schemes
THE END
THANK YOU!