Optical Fiber Instrumentation for Slagging Coal Gasifiers

Motivation

- Coal gasification is considered to be a good candidate for clean fossil energy
- Operation of coal gasification needs real time on site monitoring of a series of parameters
- Temperature and wall thickness are among the important parameters list

Objectives

To develop an optical fiber based sensing system to monitor refractory wall thickness and temperature inside a slagging coal gasifier

Researchers

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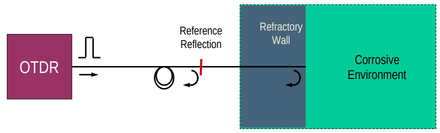
1 Thickness Monitoring Overview:



OTDR: Optical Time Domain Reflectometry

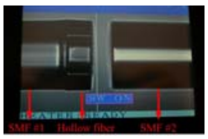
Silica based fiber is buried inside refractory of coal gasifier. A short time duration pulse from OTDR is launched into fiber link. Detector in OTDR records time passes until a reflection is received. Delay difference between two reflections, from reference point and sensing point, gives thickness of the refractory wall, assuming light velocity in fiber is known.

Resolution is determined by time duration of light pulse, timing accuracy of OTDR, software algorithm, and quality of reference point. In this project, we use OFM130 by Opto-Electronics with a resolution of 0.01% or 3mm, whichever is larger.

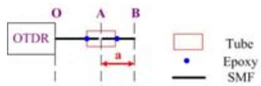
2 Creating Reference Reflection

Quality and intensity of reference reflection are critical to measurement accuracy. A good reference reflection should give a strong reflection while keeping optical loss as low as possible.

Fabrication methods include:



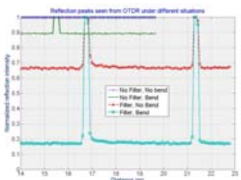
Hollow core fiber



Capillary tube alignment

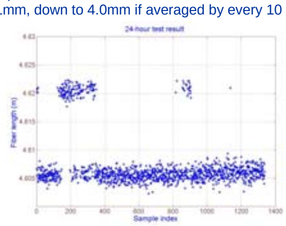
3 Test Results at 1000°C

Methods to mitigate black body radiation: optical filter and physical bending



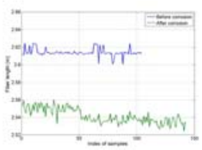
OTDR: 1308nm with 5dB bandwidth 10nm; Filter: 1314nm with 5dB bandwidth

A 24-hour test is performed to test long-term stability of measurement. 1337 samples are acquired in 24 hours and 15 minutes. Data has a standard deviation of 5.1mm, down to 4.0mm if averaged by every 10 samples.



Corrosion test is carried out to simulate wall thickness deduction by coal slag. Sodium carbonate is used as corroding source. This test is done at 900°C

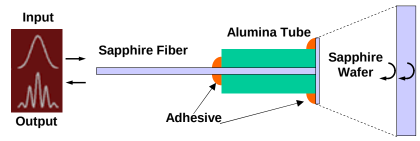
Alumina tube protects fiber inside Crucible with sodium carbonate powder before heating up furnace

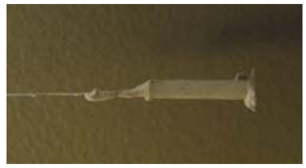


Standard deviation:
4.4mm before corrosion
8.2mm after corrosion

4 Principles of High Temperature Measurement

Extrinsic Fabry-Perot interferometer (EFPI) formed by the reflections from both polished surfaces of a single-crystal sapphire wafer.

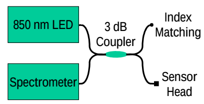




Sapphire wafer
- Thickness: 50um
- Orientation: C-plane
- Surface: Both side polished

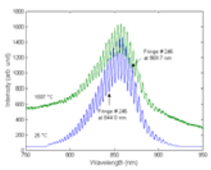
Sapphire fiber
- Diameter: 75um
- Orientation: C-plane
- Surface: 1°polished on wafer side flat polished and spliced to 105/125 multimode silica fiber on the other side

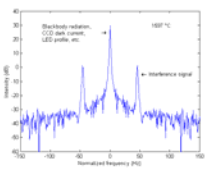
5 Temperature signal processing



$$I_t = I_B(\lambda) + I_D(\lambda) + I_{LED}(\lambda)\left(r_{couple} + r_{end} + r_{s1} + r_{s2}\right) - 2I_{LED}(\lambda)\sqrt{r_{s1}r_{s2}}\cos\frac{4n(T)d(T)\pi}{\lambda}$$

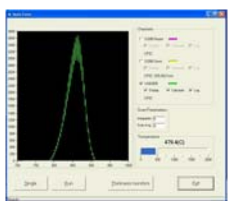
White-light is used as light source. Frequency of interferometric signal is decided by refractive index and thickness of sapphire wafer, which are both dependent on temperature.

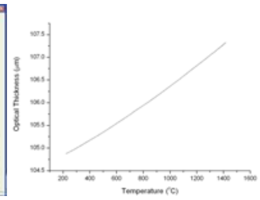




6 Sensor Calibrations

A software algorithm is able to tell the frequency of interferometric signal precisely even with 2πphase shift, given a calibration curve is pre-acquired. Since optical path difference (OPD) is the product of refractive index and thickness, we calibrate OPD to the third power of temperature.





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