Pipeline Corrosion Monitoring by Fiber Optic Distributed Strain and Temperature Sensors (DSTS)

OZ Optics Limited

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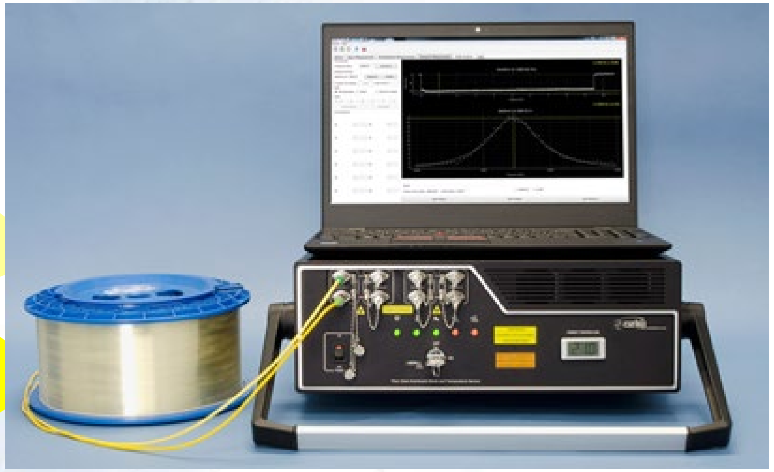

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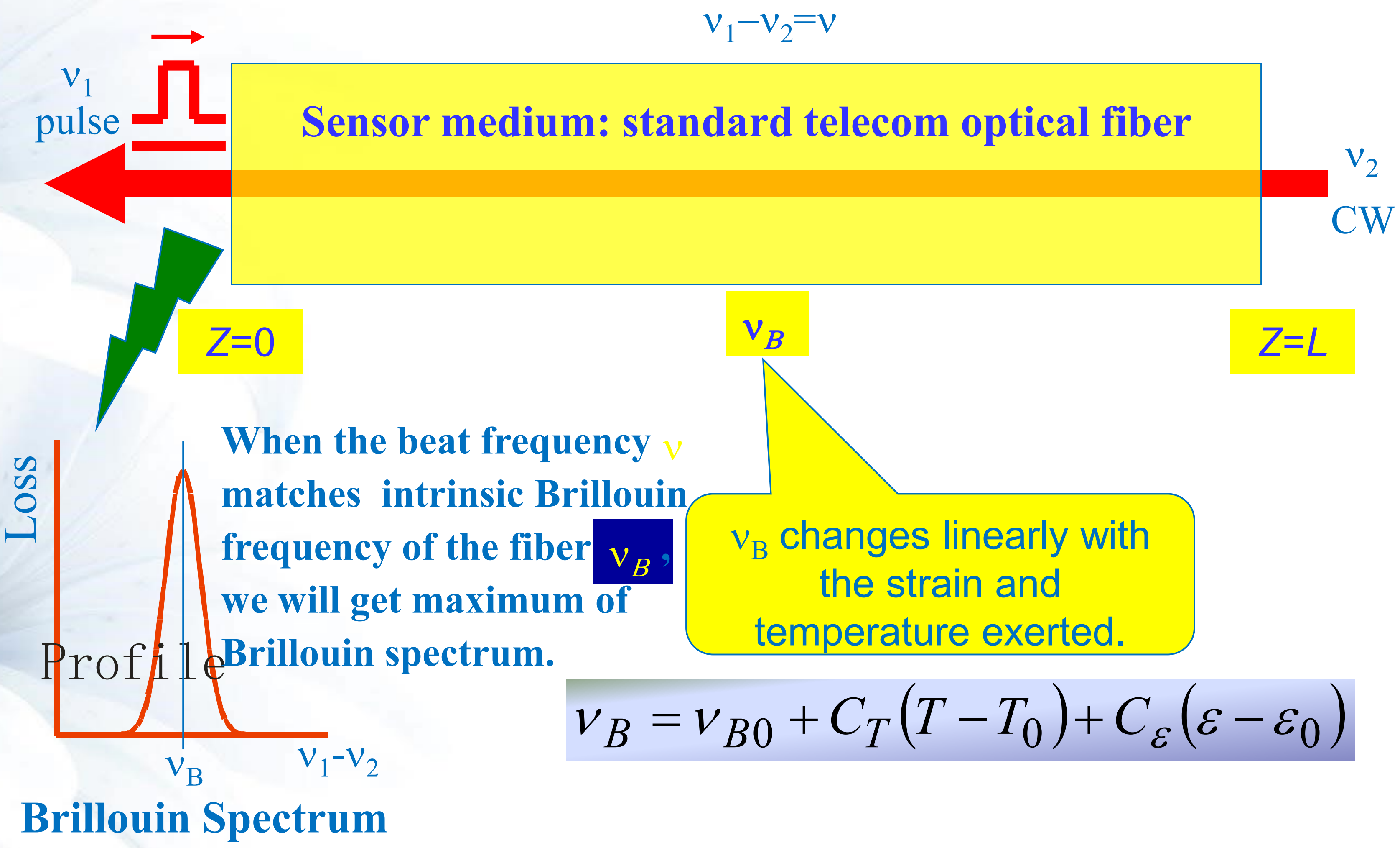
Fiber Optic Sensors

- Advantage of fiber optic sensors
  - Electrically insulating materials (no electric cables are required) — high voltage environments
  - Chemically passive, not subject e.g. to corrosion
  - Immune to electromagnetic interference (EMI)
  - Wide operation temperature range
- Fiber Bragg Grating Sensor
  - Strain resolution and accuracy: < 1 me
  - Non-distinguishable between strain and temperature
  - Point sensor
- Distributed Fiber Optic Sensors
  - Raman scattering based — only temperature
  - Brillouin scattering based — both temperature and strain

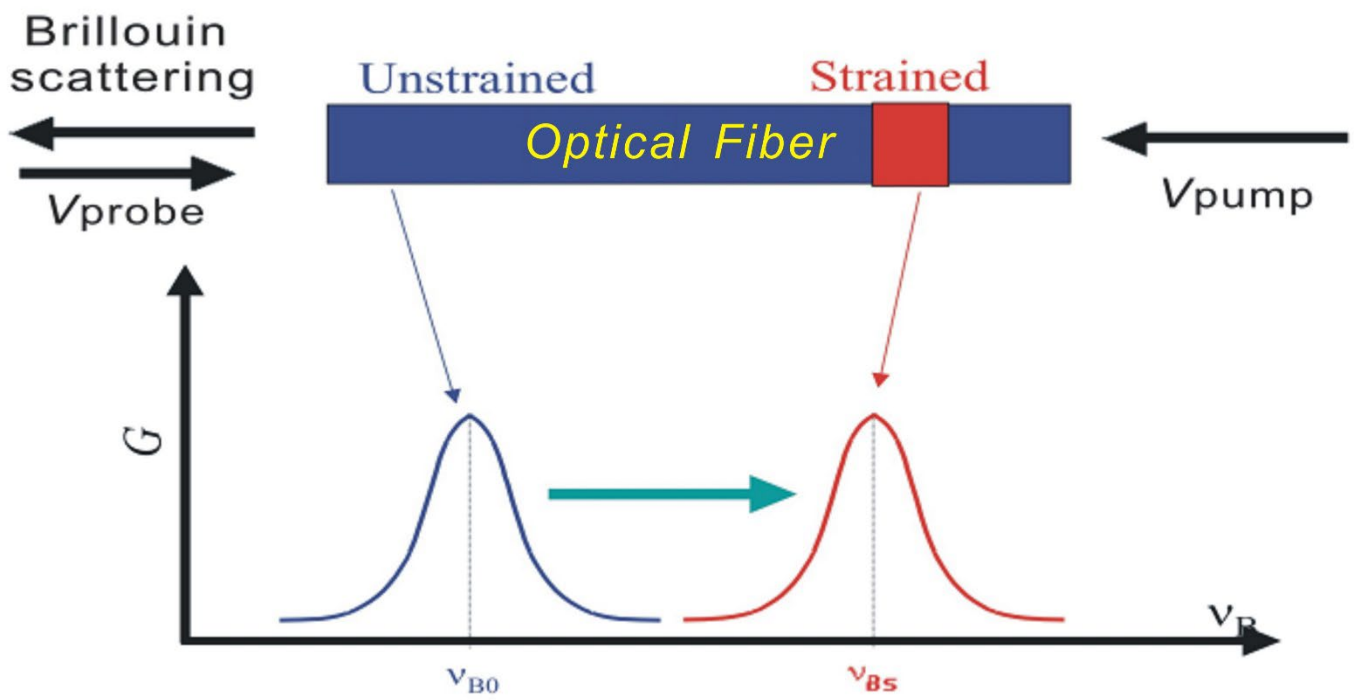
Working Principle — BOTDA

(Brillouin Optical Time Domain Analyzer)



$$\nu_B = \nu_{B0} + C_T\left(T - T_0\right) + C_\varepsilon\left(\varepsilon - \varepsilon_0\right)$$

Working Principle — BOTDA (cont'd)



$$\nu_B = \nu_{B0} + C_T (T - T_0) + C_\varepsilon (\varepsilon - \varepsilon_0)$$

Working Principle — Coherent interaction of pulse and pump lights

Numerical model of P/P-based Brillouin Fiber Sensor

$$\left(\frac{\partial}{\partial z} - \frac{1}{v_g}\frac{\partial}{\partial t}\right) E_p = i g_1 Q E_s + \frac{1}{2}\alpha E_p$$

$$\left(\frac{\partial}{\partial z} + \frac{1}{v_g}\frac{\partial}{\partial t}\right) E_s = -i g_1 Q^* E_p - \frac{1}{2}\alpha E_s$$

$$\left(\frac{\partial}{\partial t} + \Gamma\right) \overline{Q} = -i g_2 E_p E_s^*$$

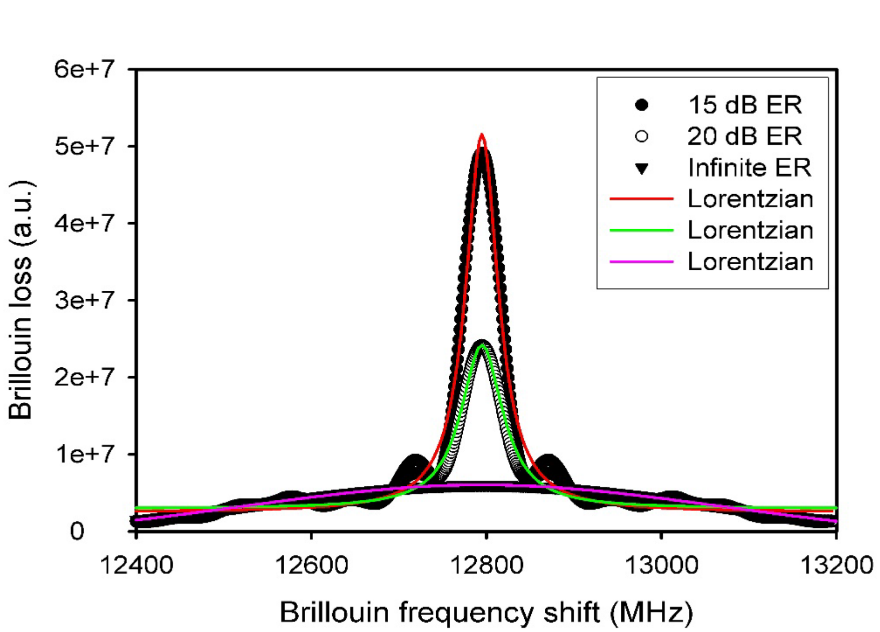
Three coupled differential equations:

* Two Maxwell's equations describing the propagation of the Stokes and pump laser beams

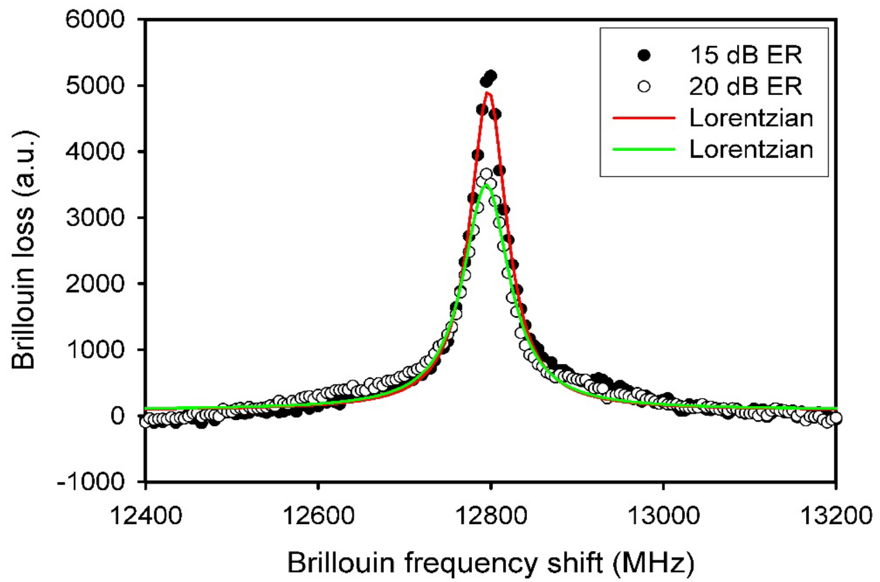
* A simplified Navier-Stokes equation describing the density wave

a = fiber absorption
E_p = pump field
E_s = Stokes field
Q = acoustic field
v_g = c/n
G = $G_1 + iG_2$
$G_1 = 1/2\tau$ damping rate
$G_2 = \omega - \omega_B$ detuning frequency
g_1, g_2: coupling constants
$g_B = 2g_1g_2/G_1$ Brillouin gain

Working Principle — Coherent interaction of pulse and pump lights (cont'd)



Numerical simulations
Pulse: 1.5 ns
Linewidth: 46, 58, and 952 MHz
for ER=15 dB, 20 dB, and infinite



Experimental results
Pulse: 1.5 ns
Linewidth: 46 and 56 MHz
for ER=15 dB and 20 dB

Applications

Oil and Gas Pipeline Monitoring

Dam Monitoring

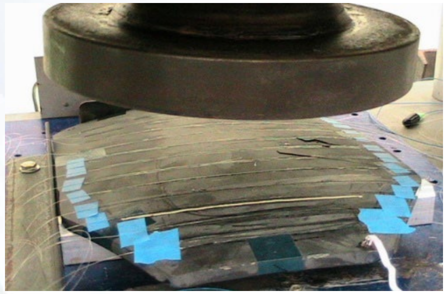
Oil and Gas Well Monitoring

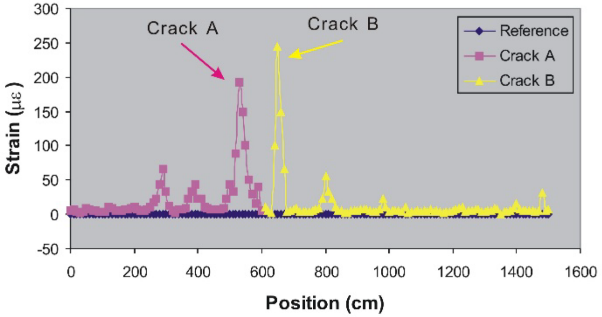
Bridge and Building Monitoring

Power Line Monitoring

Border Security Monitoring

Crack Detection

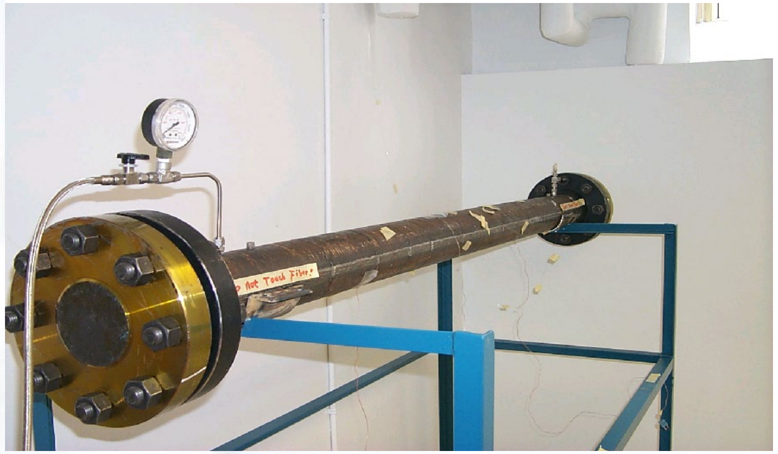


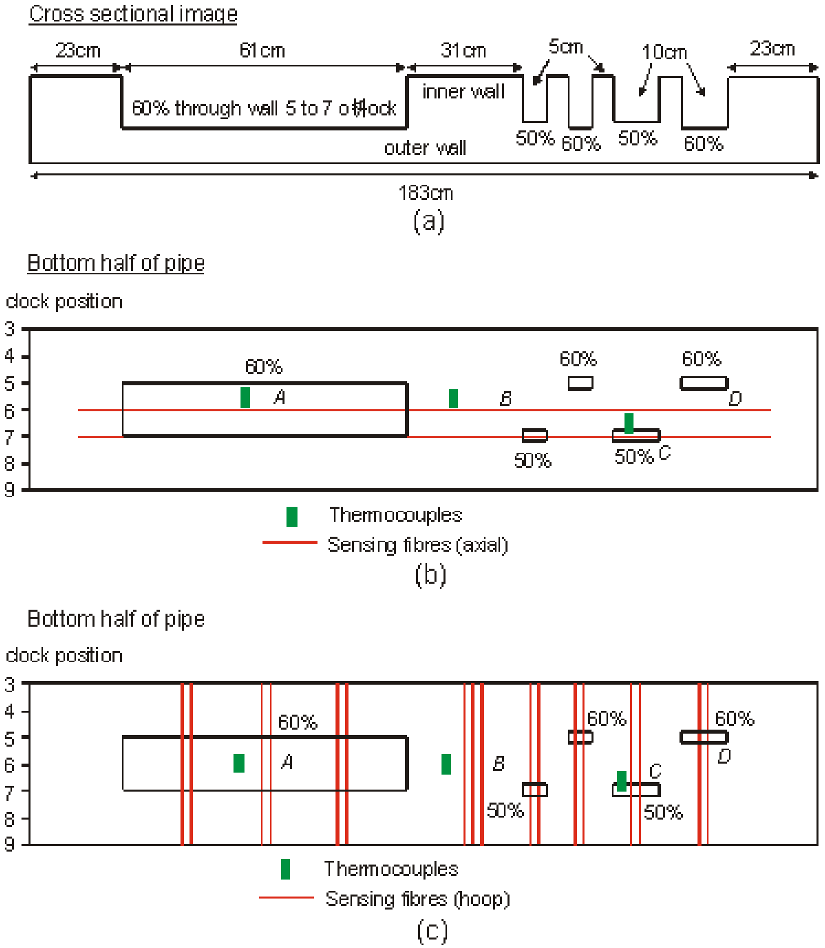


Optical fiber layouts & sizes of depleted regions

Parameters of cutouts (defects)

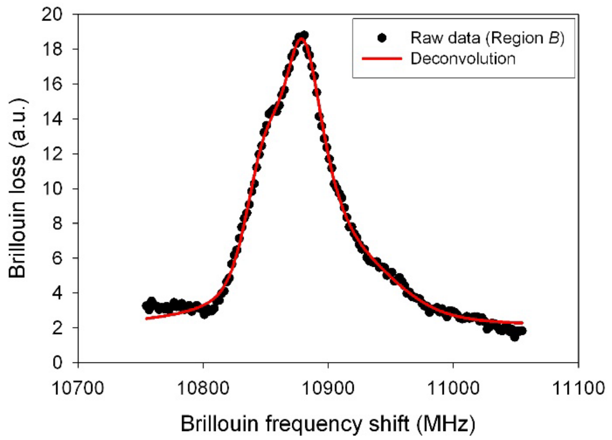
Cutout	Location (o'clock)	Reduced thickness (%)	Width (cm)	Length (cm)
A	5-7	60	5.3	61
C	7	50	1.3	10
D	5	60	1.3	10

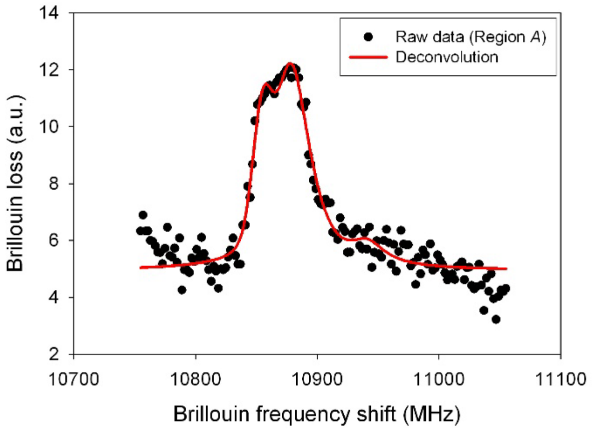




Spectrum Shape

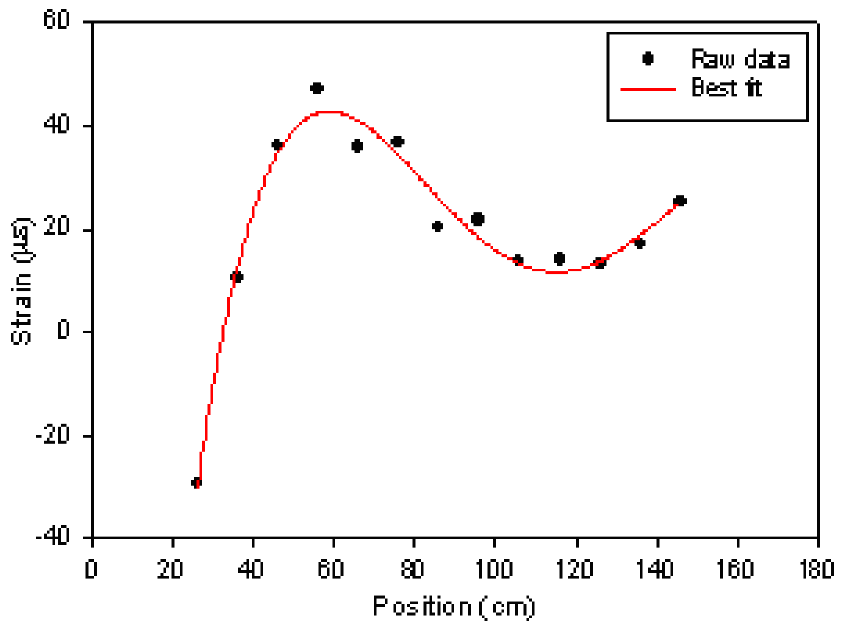
- The spectrum in the perfect region exhibits higher intensity
- Fiber experiences higher bending loss in defective region
- Coherent interaction of probe and pump lights produces complex spectrum
- These differences can be used to identify defective regions



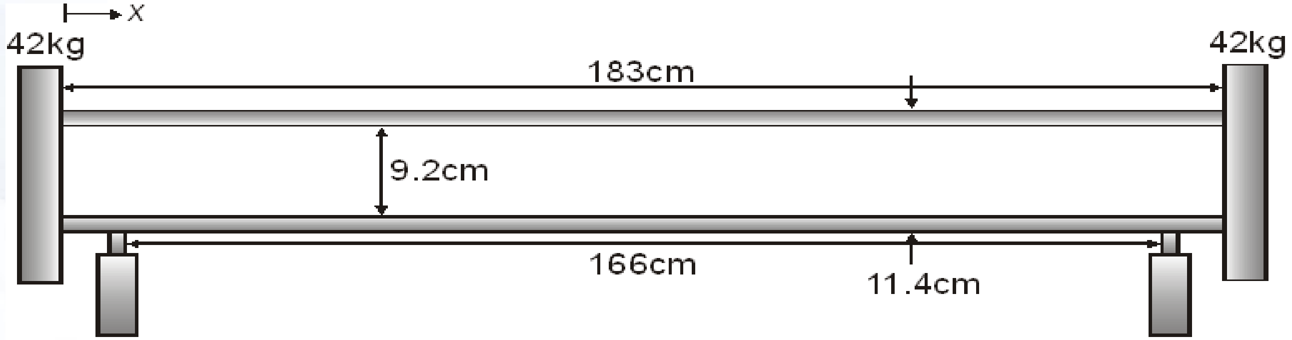


Axial strain distribution

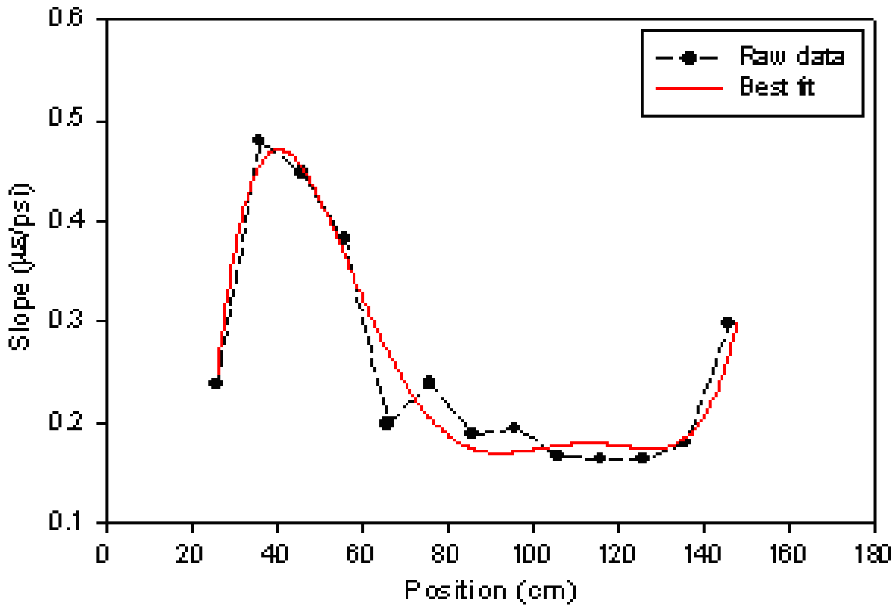
— along the pipe under 200 psi internal pressure



- Maximum strain (46 me) occurs in the middle of defect *A*.
- Minimum strain (14 me) happens in the middle of unperturbed region *B*.
- The support points, end-caps, asymmetric defect distribution affect axial strain distribution in both end of pipe.



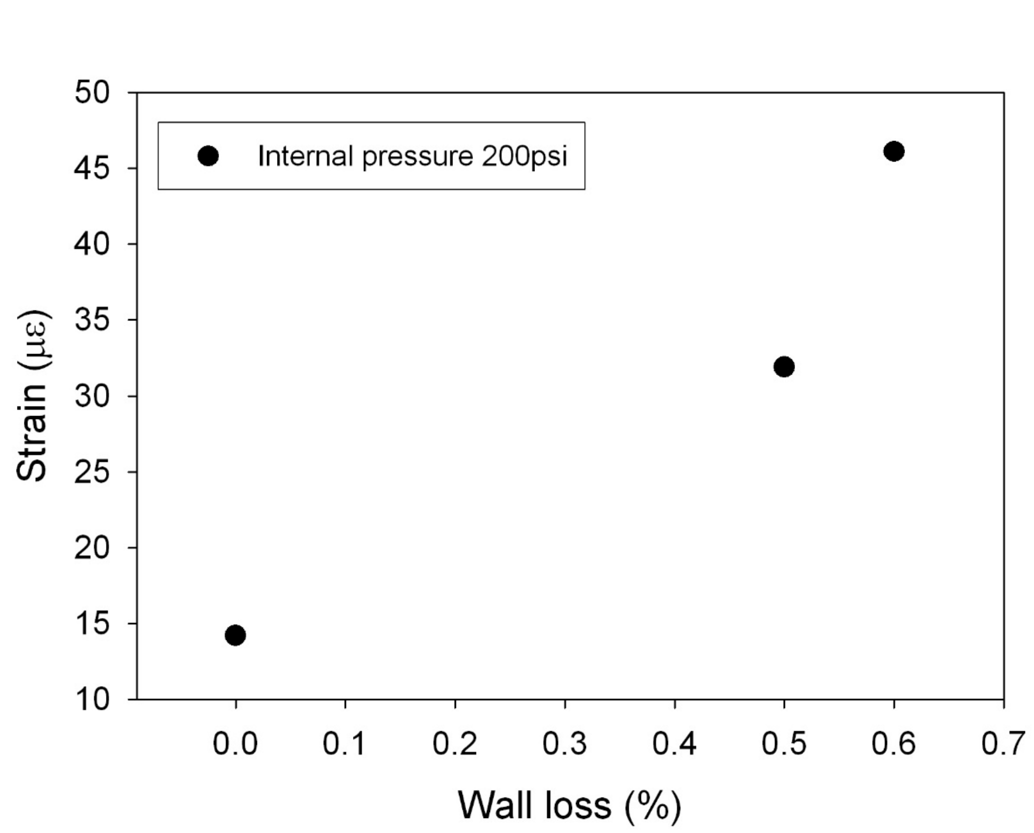
Axial strain-pressure slopes — along the pipe



- Maximum 0.48 me/psi near the middle decreases toward the edges of defect *A*.
- Slope remains constant at 0.16 me/psi near the middle of unperturbed region *B*.
- Local stress concentration and overlapping 13 cm pulse lead to ripple from 70 to 100 cm.

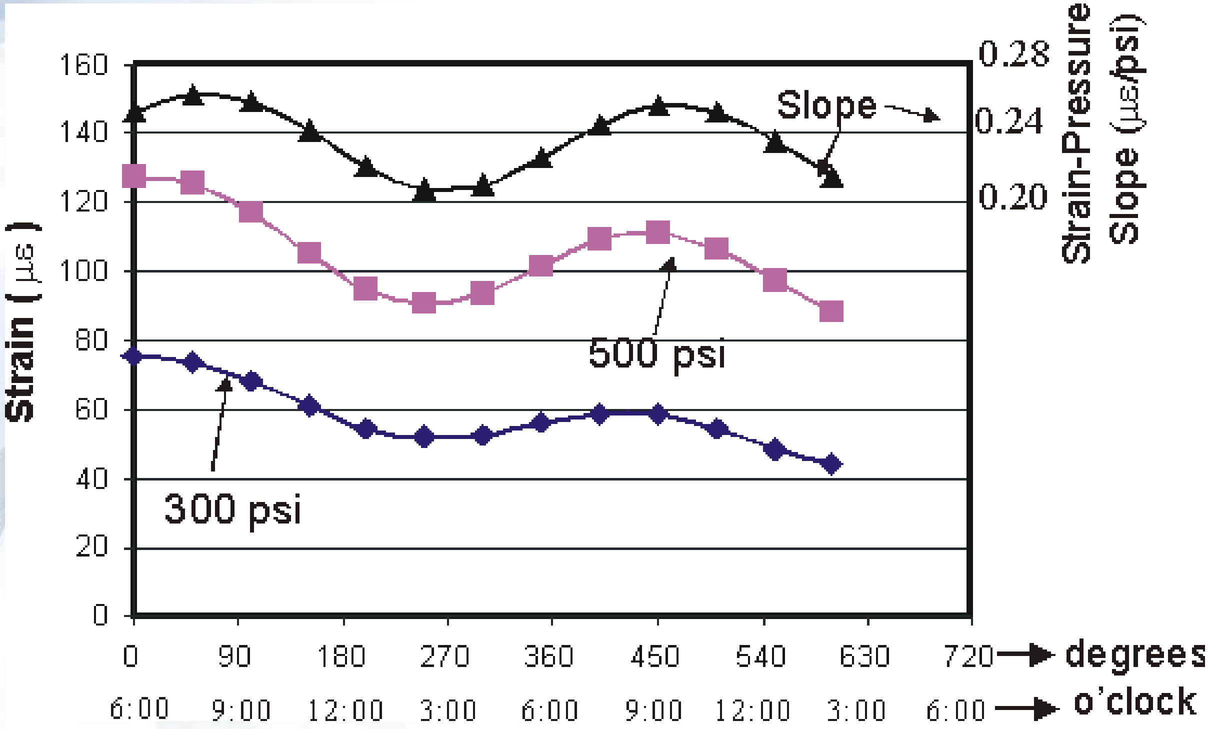
Comparison of axial strain

— Defects *A* (60%) & *C* (50%) & region *B* (0%)



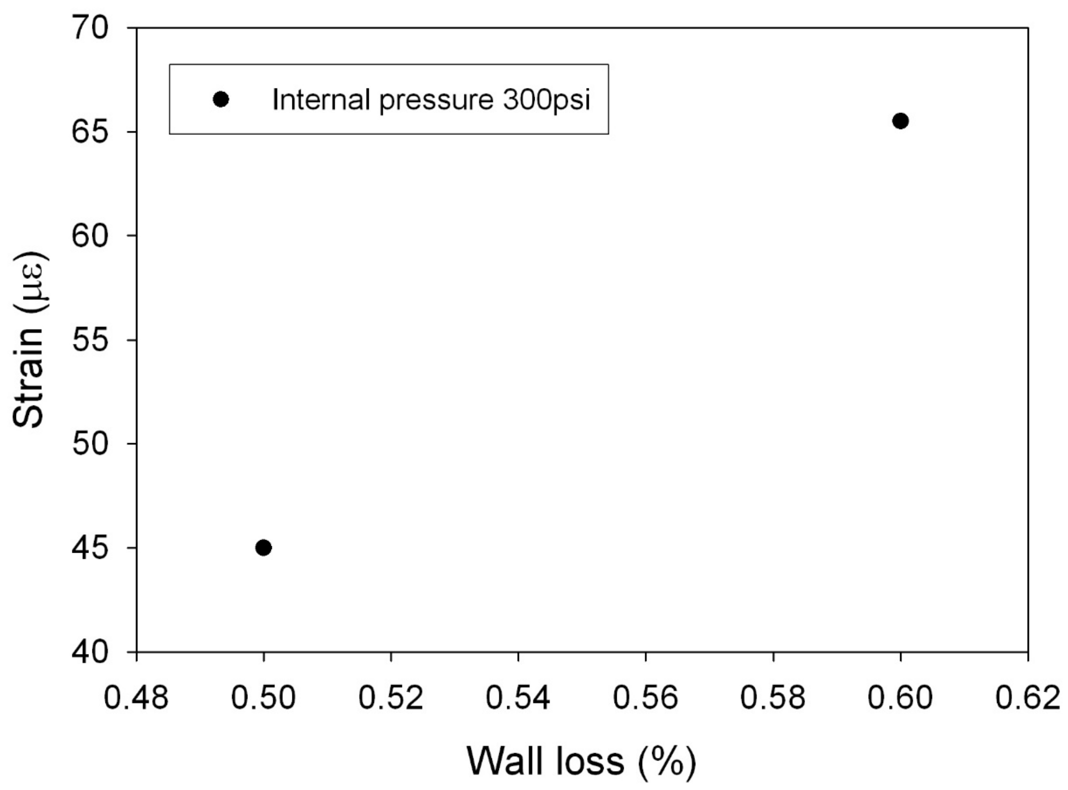
Hoop strain distribution

Hoop strain distributions around one pipe circumference encompassing defective region *A* (*60% depleted wall, 5.3 cm wide and 61 cm long*). Two maximal strains, corresponding to one complete loop, are observed.

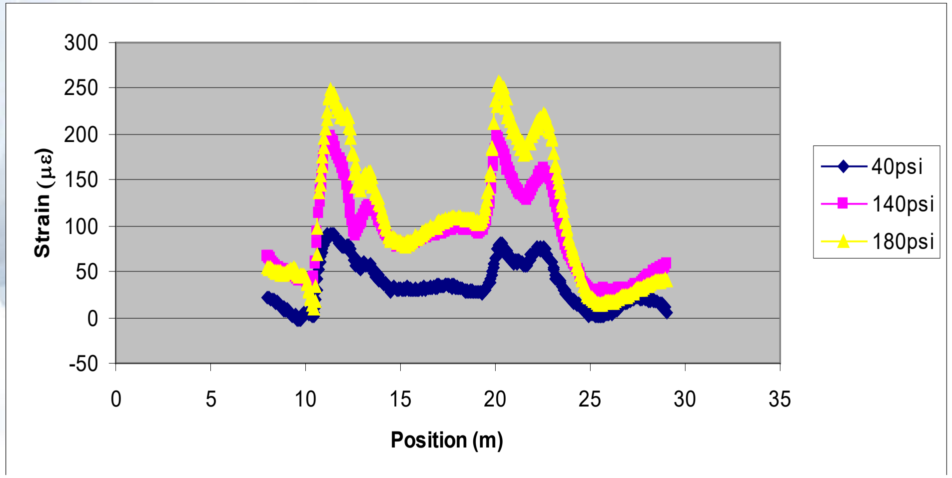


Comparison of hoop strain

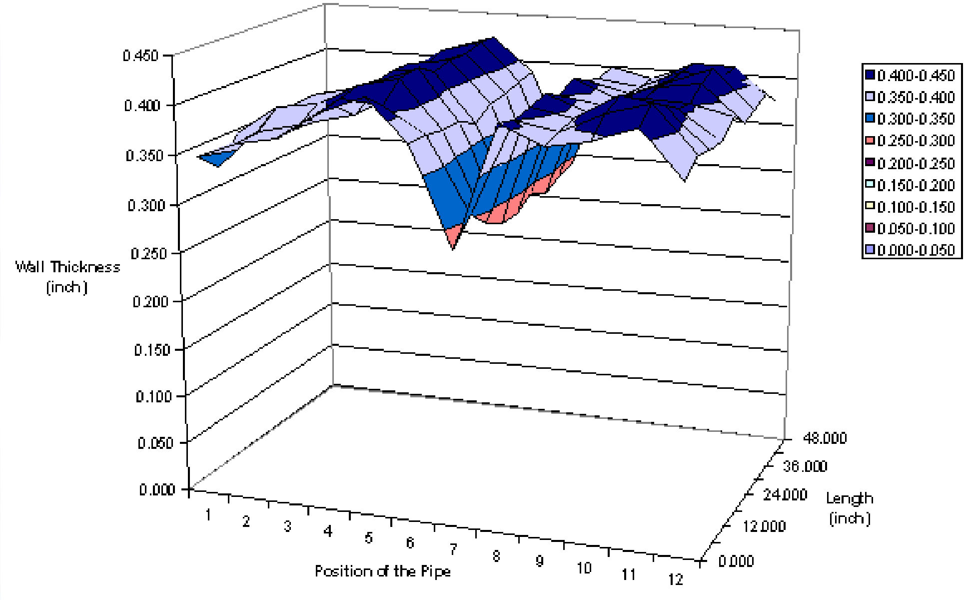
— around defects *C* (50%) & *D* (60%)



Pipeline erosion monitoring by DSTS



$$\varepsilon \propto \frac{p}{H}$$



Conclusion

- A fiber optic distributed strain and temperature sensor (DSTS) has been used to identify several inner wall cutouts in an end-capped steel pipe successfully.
- Larger strains are observed in the big defective region.
- Between the small defective regions, the 60% depleted wall experienced larger strains than the 50% depleted wall.
- DSTS has been used to identify wall thickness change of steel pipe caused by oil sand erosion successfully.

Acknowledgement

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