OIL REFINERY MONITORING USING FIBER-OPTIC DISTRIBUTED STRAIN AND TEMPERATURE SENSORS

WHITE PAPER

Taha Landolsi and Alwyn Kaye*

*: Alwyn Kaye M.Eng, P.Eng. with Altech Engineering Inc.

COPYRIGHT

OZ Optics Limited, 219 Westbrook Road, Ottawa, ON, Canada, K0A 1L0
E-mail: sales@ozoptics.com | Toll free: 1-800-361-5415 | Tel: 613-831-0981

INTRODUCTION

The refining industry is of strategic importance to the economy of developed and oil-producing countries. The economic impact due to refinery downtimes for maintenance purposes, and the environmental hazard associated with accidental breakdowns are paramount. Therefore, oil and gas industries are relentlessly seeking more efficient and reliable proactive refinery monitoring technologies.

Refineries use reactors and pressure vessels to transform heavy oil into synthetic crude oil. One example of refinery applications is the upgrader reactors which are operated at very high temperatures, exceeding 500 °C. Due to the thermal stress exerted on the structure of the reactor, a wall-thinning problem might occur, resulting in conductive heat dissipation. Without the proper sensing technology, the refinery operator might prematurely shut down operations to perform untimely maintenance, or worse yet, the problem might go unnoticed, resulting in a catastrophic accident. In both cases, the financial losses to the operator are enormous.

Many monitoring solutions cannot withstand such high temperatures, while others are localized in nature and can only sense temperature gradients within a confined physical space. Therefore, the candidate technology that can address the refinery industry needs must be distributed, and capable of measuring a wide range of temperatures including extremely high ones, with good accuracy and resolution.

Fiber-optic distributed strain and temperature sensors (DSTS) use an optical sensing technology that is based on Brillouin optical time-domain analysis (BOTDA) to perform wall-thinning detection through continuous temperature monitoring. DSTS technology uses an entire optical fiber as the sensing element, thus achieving a true distributed sensing function. Due to the low fiber loss, the sensing range can reach many kilometers, easily allowing the fiber to wrap around the entire reactor structure.

This paper presents a brief description of the DSTS principle of operation, and discusses a plausible solution to the temperature monitoring of oil refinery reactors, using OZ Optics Ltd. DSTS products.

PRINCIPLE OF OPERATION

BRILLOUIN SCATTERING

Brillouin scattering stems from the density variations that dielectric materials exhibit in the presence of an electric field[1]. If an optical signal, called a probe, is injected into one end of an optical fiber, and a strong optical signal, called a pump, is injected into the other end, then the density variations induced by the electric field of the pump will result in a distributed refractive index grating inside the fiber. The distributed grating will, in turn, cause the probe to scatter in the backward direction, as shown in Figure 1.

---

[1] This phenomenon is called electrostriction.

The scattered signal is shifted in frequency by an amount ν_{B_0} called the Brillouin frequency shift. For standard single-mode fibers, operated at a wavelength of 1.55 μm, the Brillouin frequency shift is approximately $\nu_{B_0} \approx 11$ GHz. If a section of the optical fiber is stressed, either mechanically or thermally, the Brillouin frequency shift of the scattered light from that fiber section, noted as ν_{B_1}, will be different from the Brillouin frequency shift of the unstressed fiber. The amount of change in the Brillouin frequency shift is proportional to the change in temperature and/or strain. This linear dependency is typically written as:

$$\Delta\nu_B = \nu_{B_1} - \nu_{B_0} = C_t(T - T_0) + C_\epsilon(\epsilon - \epsilon_0)$$

where C_t and C_ϵ are the optical fiber temperature and strain coefficients, respectively. Because of the interaction between the pump and probe signal, the same frequency shift can be observed in the pump, albeit in the form of loss spectrum.

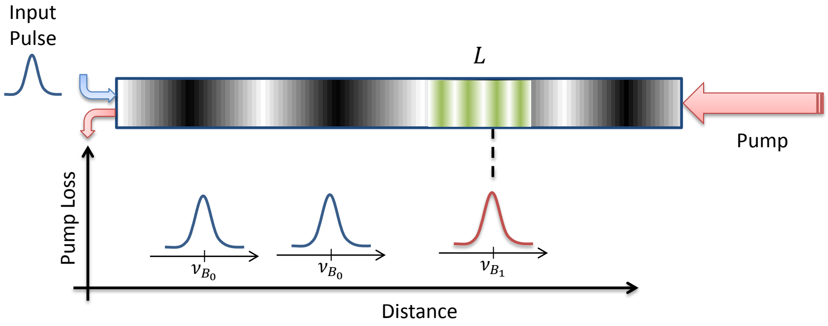

Figure 1. Brillouin scattering sensing principle.

BRILLOUIN OPTICAL TIME-DOMAIN ANALYSIS (BOTDA)

The BOTDA system, whose block diagram is shown in Figure 2, is based on the interaction, through Brillouin scattering, of a pulsed laser, acting as a probe, with a counter-propagating continuous-wave (CW) pump laser. The probe beam exhibits Brillouin amplification at the expense of the CW beam. The resultant power drop in the CW beam is measured while the frequency difference between two lasers is scanned, giving the Brillouin loss spectrum of the sensing fiber. The shift in the Brillouin spectrum of the fiber is used to calculate the temperature and/or strain change in the sensing fiber.

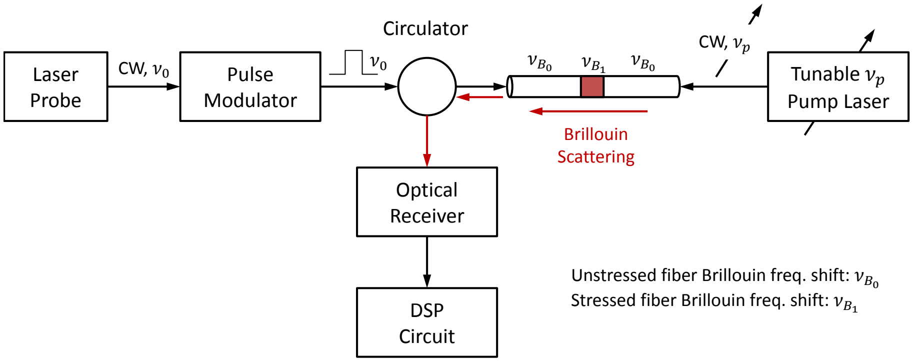

Figure 2. BOTDA block diagram.

If the measured Brillouin frequency shift is due to a change in temperature only, then the following relationship holds:

$$\Delta T = \Delta \nu_B / C_t$$

Therefore, a properly calibrated system with a known sensing fiber thermal coefficient C_t allows the translation of a Brillouin frequency shift into a temperature change. The BOTDA system has many features allowing it to resolve lengths as small as 10 cm, and to cover sensing lengths as large as 100 km. It can achieve high temperature and strain measurements accuracies of $\pm 0.1°C$ and $\pm 2\ \mu\epsilon$, respectively. Depending on the fiber cabling type, it can withstand temperatures exceeding 700°C.

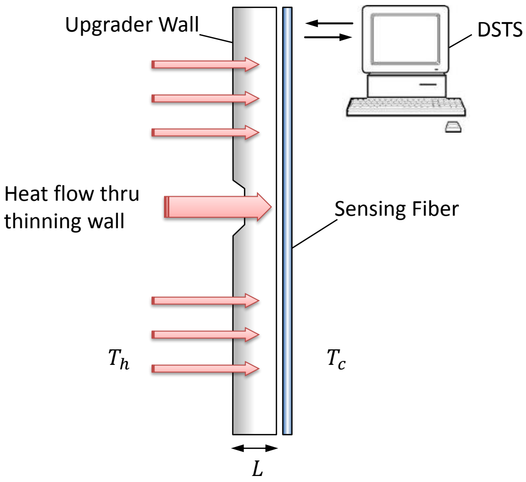

Figure 3. Reactor wall-thinning monitoring using DSTS.

In the case of an upgrader wall-thinning problem, shown in Figure 3, the change in heat flow due to conduction through the thinning part will result in a temperature change around the corresponding section of the sensing fiber, in accordance to thermodynamics laws:

$$T_c = T_h - \gamma L$$

where T_c and T_h are the respective outer and inner wall temperatures, and γ is a coefficient that depends on the wall area, its thermal conductivity, and the rate of heat transfer. Clearly, T_c will be larger in the presence of wall defects, because of the reduced wall thickness L, compared to T_c under normal operating conditions. Such increase in temperature will be sensed by the optical fiber through a Brillouin frequency shift.

CONCLUSION

Fiber-optic DSTS technology is a cost-effective solution for monitoring the temperature of reactors in refineries. Oil industries can leverage this technology and use it in proactive monitoring to reduce the downtime of their refineries, and maximize their profit through increased operation efficiency. The cost of equipment and installation are negligible compared to the potential loss of revenue due to unnecessary downtimes, and are expected to be paid for within the first few years of operations.