Available online at www.sciencedirect.com
ScienceDirect
Optics Communications 278 (2007) 81–89
OPTICS COMMUNICATIONS
www.elsevier.com/locate/optcom

Estimation of thermal contact resistance and thermally induced optical effects in single-coated optical fibers

Yu-Ching Yang *

Department of Mechanical Engineering, Kun Shan University, Tainan 710-03, Taiwan, ROC

Received 26 January 2007; received in revised form 4 June 2007; accepted 4 June 2007

Abstract

In this study, a conjugate gradient method based on an inverse algorithm is applied to estimate the unknown time-dependent thermal contact resistance in a single-coated optical fiber, which is subjected to transient thermal loading. While knowing the temperature history at the measuring position, no prior information is needed on the functional form of the unknown contact resistance. The temperature data obtained from the direct problem are used to simulate the temperature measurement. The influence of measurement errors, initial guess values, and measurement locations upon the precision of the estimated results is also investigated. Results show that an excellent estimation on the time-dependent thermal contact resistance, temperature distributions, thermally induced microbending loss, and refractive index changes can be obtained for the case considered in this study.

Keywords: Inverse problem; Thermal contact resistance; Conjugate gradient method; Optical fibers; Microbending loss; Refractive index changes

1. Introduction

The conventional optical fiber for telecommunication is usually constructed of silica glass fiber coated by two or three layers of polymeric coatings [1,2]. However, when silica fibers with polymeric coatings are stressed in a humid environment, strength degradation occurs after a long period of time due to slow crack growth. To solve this problem of moisture attack, inorganic coatings such as oxides, carbides, and carbon are being considered [3,4]. On the other hand, metallic coatings such as aluminum, indium, copper, tin, etc. are also applied on optical fibers [5–7]. Some of these fibers exhibit higher resistance to moisture attack and show higher strength than polymeric-coated fibers.

On the other hand, thermal stresses are important in multi-layer structures such as optical fibers, since they cause increased transmission loss in the optical fibers. Thermal stresses occur in the optical fibers at a low temperature, which are due to the mismatches of thermal expansion properties of fiber and coating material [8,9]. Since thermal stresses affect the performance of the optical fibers, they have been extensively studied [10–15]. Nevertheless, to the author's knowledge, there was no work in the literature investigating the effect of interlayer thermal contact resistance in such layered construction as optical fibers. In addition, the thermal contact resistance can neither be measured nor calculated directly. However this problem can be solved by the technique of *Inverse Heat Conduction Problem* (IHCP).

A direct heat transfer problem is concerned with the determination of temperature at interior points of a region when thermophysical properties and initial and boundary conditions are specified. In contrast, an inverse heat transfer problem considered in this study involves the determination of the unknown time-dependent thermal contact resistance from the knowledge of the temperature measurements taken within the body. Many methods of solving the inverse heat transfer problem have been

* Tel.: +886 6 2050496; fax: +886 6 2050509.
E-mail address: ycyang@mail.ksu.edu.tw

0030-4018/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.optcom.2007.06.013

Nomenclature

E	Young's modulus (GPa)
h	convection coefficient ($\text{Wm}^{-2}\,\text{K}^{-1}$)
J	functional
J'	gradient of functional
k	thermal conductivity ($\text{Wm}^{-1}\,\text{K}^{-1}$)
q	direction of descent
R	thermal contact resistance ($\text{m}^2\,\text{KW}^{-1}$)
r	radius (μm)
T	temperature (°C)
T_0	initial temperature (°C)
T_∞	surrounding temperature (°C)
t	time (s)
u	displacement radial component (μm)
Y	measurement temperature (°C)
Γ	microbending loss (dB/km)
Δ	small variation quality
Δn_r, Δn_z, Δn_∞	refractive index changes
α	thermal diffusivity ($\text{m}^2\,\text{s}^{-1}$)
β	step size
Γ	conjugate coefficient
ε_θ	strain tangential component
η	very small value
θ	temperature drop (°C)
λ	variable used in adjoint problem
ν	Poisson's ratio
σ	standard deviation
σ_r	stress radial component (MPa)
σ_z	stress axial component (MPa)
σ_θ	stress tangential component (MPa)
τ	transformed time (s)
ω	thermal expansion coefficient (K^{-1})
ϖ	random variable

Superscript

K	iterative number

developed. In this article, we present the conjugate gradient method (CGM) [16–23], which converges very rapidly and is not sensitive to the measurement errors, to estimate the time-dependent thermal contact resistance of a single-coated optical fiber by using the simulated temperature measurements. Subsequently, the temperature distributions, thermally induced transient microbending loss, and refractive index changes of the optical fiber are also calculated.

The conjugate gradient method derives basis from the perturbational principles and transforms the inverse problem to the solution of three problems, namely, the direct problem, the sensitivity problem, and the adjoint problem, which will be discussed in detail in text.

2. Direct problem

To illustrate the methodology of developing expressions for use in determining the unknown time-dependent thermal contact resistance, $R(t)$, in a single-coated optical fiber, we consider the following transient heat conduction problem.

Fig. 1 shows the geometry of a single-coated optical fiber, which is composed of a silica glass fiber coated by a thin layer of coating, and has intermediate and outer radii, r_1 and r_2, respectively. Assume the single-coated optical fiber is initially at temperature $T_i(r,0) = T_0$, and for time $t > 0$, the fiber at its boundary surface $r = r_2$ is subjected to a convective thermal loading of the surrounding temperature T_∞, $T_\infty < T_0$. Here the subscript $i = 1$ refers to the region of glass fiber, and $i = 2$ refers to the region of coating, respectively. Then the mathematical formulation of this transient heat conduction problem is given by [20]:

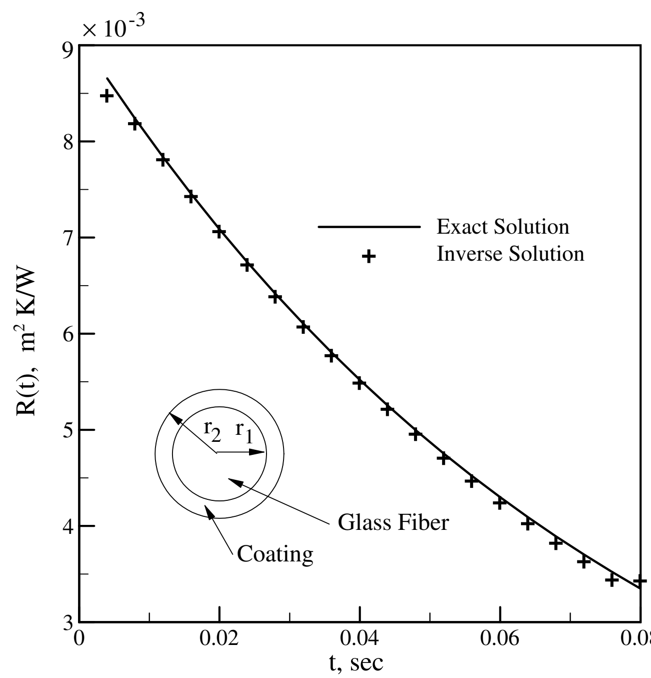

Fig. 1. Estimated thermal contact resistance at 20th iteration with initial guesses $\tilde{R}^0 = 0.003$, measurement error $\sigma = 0.0$, and measurement location $r_\mathrm{m} = 63$ μm.

$$\frac{\partial^2 T_i}{\partial r^2} + \frac{1}{r}\frac{\partial T_i}{\partial r} = \frac{1}{\alpha_i}\frac{\partial T_i}{\partial t}, \quad i = 1, 2, \tag{1}$$

$$\frac{\partial T_1(0,t)}{\partial r} = 0, \tag{2}$$

$$k_1\frac{\partial T_1(r_1,t)}{\partial r} = k_2\frac{\partial T_2(r_1,t)}{\partial r}, \tag{3}$$