LA-UR -86-1249
CONF-860511O--1

RECEIVED BY OSTI MAY 1 2 1986

TITLE: FIBER OPTIC APPLICATIONS IN HOSTILE ENVIRONMENTS

LA-UR--86-1249

DE86 010190

AUTHOR(S): PETER E. LYONS

SUBMITTED TO: OPTO'86
HELD IN PARIS, FRANCE, MAY 13-15, 1986.

Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

FORM NO 836 R4
ST NO 2629 5/81

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

FIBER OPTICS APPLICATIONS IN HOSTILE ENVIRONMENTS

Applications Des Fibres Optiques En Environnement Hostile

by

Lyons, Peter B.

Los Alamos National Laboratory
P. O. Box 1663 MS F617
Los Alamos, NM 87545
USA

I. Introduction

In 1983, 455,000 km of cabled fiber were produced in the U. S.[1], and this production increased to 1,465,000 km in 1985.[2] In that same year, the U. S. market[2] for fiber cable and related components reached $500M. While telecommunications have undeniably provided the impetus for this explosive growth, the ready availability of fiber optic technology has allowed fiber optics to be considered for diverse applications, far removed from conventional telecommunications.

This Conference focuses on applications of optical fibers in hostile environments. As the introductory paper in this Conference, this communication will trace the evolution of applications of fibers in hostile environments and explore some of the motivations for these applications. A few key examples will be used.

II. Key Attributes of Fiber Optics

Fiber optics offer a very high bandwidth transmission medium with multi-mode fibers providing capability well above 1 GHz over km lengths. Single mode fibers further increase the available bandwidth. For many applications, fiber optics cables are lower in cost than coaxial cables and if these costs are normalized in some manner for bandwidth capability, fiber optics are clearly a leader.

Cabled fiber optics are far lighter than coax cables and can occupy far less area per data channel then coaxial cable. Fibers present an all-dielectric data transmission medium providing immunity to electromagnetic interference. This attribute also prevents introduction of sparks into a protected area or provides lightning protection.

An obvious, but critical, attribute is that fiber optics transmit optical data. To the extent that a physical process can deliver an optical output, then that process may be directly detected through an optical fiber transmission line. Very few measurement parameters have resisted determined research efforts to develop a direct optical probe!

III. Evolution of Applications of Fiber Optics in Hostile Environments

Depending on the definition of a "hostile environment", the earliest application of fiber optics to such an environment can vary over a wide range. High loss optical fibers have been available for centuries! Many applications of such fibers for imaging detectors in high energy physics experiments are documented in the early 1950's.

As low-loss fibers were realized in the 1970's, applications in hostile environments sharply increased. The first optical fibers were used at the Nevada Test Site in 1976. The first international conference on the subject of Fiber Optics in Adverse Environments was sponsored by SPIE in 1981.[3] Two other SPIE conferences, in 1983[4] and 1985[5], focused on this subject with another SPIE conference scheduled later in 1986. Including the present conference and the three preceding ones, 107 papers have been presented from 8 countries. Over half of these papers have dealt with fiber optics in radiation environments, for applications in nuclear testing, accelerator experiments, nuclear power plants, and military environments. Other subjects with large numbers of papers have included EMI and thermal environments, blast and shock experiments, and space and airplane applications. Other related conferences and papers have stressed a range of manufacturing, chemical sensor, and utility distribution applications. Three International Conferences on Optical Fiber Sensors (OFS) have been sponsored by the IEEE and OSA with the Fourth Conference scheduled later in 1986. At the 1985 OFS conference, 55 papers treated many aspects of sensor operation. Furthermore, the SPIE has organized three conferences on "Fiber Optic and Laser Sensors", in 1983, 1984, and 1985. The latest conference in this series featured 64 papers on a very wide range of sensor systems, many characterized by hostile environments.

Each application has been driven by one or more of the attributes of fiber optics discussed in Section II. For example,

a) Nuclear testing - High bandwidth data must be transmitted over km distances to isolate instrumentation from blast and radiation interactions. Furthermore, many critical parameers can be sensed through optical phenomena.

b) Military applications: Light-weight, portable, rugged data transmission systems are frequently required. EMP resistance can protect critical components.

c) Nuclear power plants - Reliable communications in electrically noisy areas without risk of sparks are essential.

d) EMP testing - The transmission system must be immune from EMI.

e) Blast and shock testing - Freedom from sparks is essential in explosive environments and very compact sensors are sometimes required for minimum intrusion.

f) Air and space applications - Weight reduction, high temperature capability, inert sensors, and EMI resistance are needed in many systems.

IV. System Examples

From the many applications that have been demonstrated where fiber optics have played critical roles in problems involving hostile environments, four successful systems are discussed below.

a) Gas Centrifuge Diagnostics An operating UF_6 gas centrifuge presents a complex diagnostic challenge. Temperature and pressure of the gas are key variables, but any mechanical sampling system in the unit would destroy the centrifuge operation. Furthermore, the only stationary location in the centrifuge is on the axis, but rapid variation in gas pressure occurs in a thin layer at the high speed periphery.

An all-optical system provided an elegant solution. An optical signal was introduced on the axis with wavelength chosen to fluoresce the UF_6 gas. An optical system imaged different gas volumes into an array of optical fibers which exited the centrifuge on the axis. These fibers were coupled to detectors tuned to detect UF_6 fluorescence. Since the fluorescence intensity and decay time are functions of temperature and pressure, the resulting signals were used as a non-intrusive diagnostic.[6,7]

b) Blast and Shock Diagnostics

Electrical sensors for shock usually use shorting electrical pin detectors. With care, these electrical pins and the connecting coax cable can be made reasonably small, about 1 mm in diameter. However, even these dimensions, incorporated in large numbers, can seriously perturb a measurement. Furthermore, explosives are frequently the object under test and introduction of conductors into an explosive can lead to spark initiation.

An all-optical system has greatly simplified this poblem. A gas-filled micro-balloon on a fiber is used. Shock heating of the gas provides a luminous signal in the fiber. Any spark hazards are removed and the resulting sensor is far less intrusive[8].

c) Pulsed Current Measurements

Pulsed power research is conducted in areas with severe EMI and electrical sensors can be completely compromised due to this EMI. Fiber optic probes using the Faraday magneto optic effect offer an elegant solution to this problem and have been successfully used at Los Alamos for current measurements above 50 MA in explosive flux compression tests.[9]

d) Nuclear Testing Measurements

Multi-channel, high bandwidth, data recording requirements must be addressed in nuclear testing. Coaxial cables allowed most measurements to be accomplished, but with heavy and costly cable and at a reduced bandwidth. Fiber optic cables have been increasingly utilized in nuclear testing. Many innovative experiments have depended on the optical transmission properties of the fiber cables

Of particular note is a recent system that utilized a linear (1-D) array of fibers to transmit an image (2-D data). In this system, one spatial dimension was encoded on each fiber through variations in wavelength. Substantial reduction in fiber number was accomplished through this scheme.[10]

V. Radiation Effects

As summarized earlier in this paper, more than half the papers presented at conferences of this title have dealt with radiation effects, as do most of the papers at this particular conference. In addition to these conferences, two large working groups are devoted to these concerns, the U.S. Tri-Services Working Group on Radiation Effects in Fiber Optics and the NATO Task Group on Radiation Effects in Fiber Optics. The latter group is coordinating measurements on three test fibers to demonstrate consistency in radiation-induced absorption data among laboratories. Under the auspices of the NATO group, a standard set of test conditions is being developed.

References:

[1] Kessler (J.N.). - < Laser Focus/Electro-Optics >., 1984, p.14.

[2] Plasse (H.). - < Laser Focus/Electro-Optics >., 1986, p.62.

[3] ed by Lyons (P.B.). - < "Fiber Optics in Adverse Environments" >. SPIE., 1981, Vol. 296.

[4] ed by Boucher (D.) - < "Fiber Optics in Adverse Environments" >. SPIE., 1983, Vol. 404.

[5] ed by Greenwell (R.A.). - < "Fiber Optics in Adverse Environments" >. SPIE., 1986, Vol. 296.

[6] Caldwell (S.E.), Gentry (R.A.), White (P.W.), Allison (S.W.), - < "Measurement of gas density and temperature profiles in UF_6 using laser induced fluorescence." >. < "Sixth Workshop on Gases in Strong Radiation" >., Tokyo, Japan, 1985.

[7] Cates (M.R.), Allison (S.W.), Marshall (B.), Davies (T.J.), Franks (L.A.), Nelson (M.A.), Noel (B.W.), - < "Laser based data acquisition in gas centrifuge environments using optical fibers" >. SPIE., 1984, Vol. 506, p.64.

[8] Benjamin (R.F.), Mayer (F.J.), Maynard (R.L.), - < "Microshell^T - tipped optical fibers as sensors of high pressure pulses in adverse environments" >., SPIE 1984, Vol. 506, p.116.

[9] Veeser (L.R.), Caird (R.S.), Fowler (C.M.), Erickson (D.J.), - - "A fiber optic sensor for measuring multimegampere currents from flux compression generators" >., SPIE, 1984, Vol. 506, p.103.

[10] Iverson (C.F.), Nelson (M.A.), - < Remote Two Dimensional Radiation Image Transmission Using a One Dimensional Optical Fiber Array >., EG&G, Inc., 1983, rpt. 10282-2008, S-754-R