Lightweight, Low-CTE Tubes Made From Biaxially Oriented LCPs

CTEs can be tailored by tailoring biaxial orientations.

John H. Glenn Research Center, Cleveland, Ohio

Tubes made from biaxially oriented liquid-crystal polymers (LCPs) have been developed for use as penetrations on cryogenic tanks. ("Penetrations" in this context denotes feed lines, vent lines, and sensor tubes, all of which contribute to the undesired conduction of heat into the tanks.) In comparison with corresponding prior cryogenic-tank penetrations made from stainless steels and nickel alloys, the LCP penetrations offer advantages of less weight and less thermal conduction. An additional major advantage of LCP components is that one can tailor their coefficients of thermal expansion (CTEs). The estimated cost of continuous production of LCP tubes of typical sizes is about \$1.27/ft (\$4.17/m) [based on 1998 prices].

LCP tubes that are compatible with liquid oxygen and that feature tailored biaxial molecular orientation and quasi-isotropic properties (including quasi-isotropic CTE) have been fabricated by a combination of proprietary and patented techniques that involve the use of counterrotating dies (CRDs). Tailoring of the angle of molecular orientation is what makes it possible to tailor the CTE over a wide range to match the CTEs of adjacent penetrations of other tank components; this, in turn, makes it possible to minimize differential-thermal expansion stresses that arise during thermal cycling.

The fabrication of biaxially oriented LCP tubes by use of CRDs is not new in itself. The novelty of the present development lies in tailoring the orientations and thus the CTEs and other mechanical properties of the LCPs for the intended cryogenic applications and in modifications of the CRDs for this purpose.

The LCP tubes and the 304-stainless-steel tubes that the LCP tubes were intended to supplant were tested with respect to burst strength, permeability, thermal conductivity, and CTE. The following conclusions were drawn from the tests:

- The thermal conductivities of the LCP tubes ranged from 0.21 to 0.40 W/(m·K) — 98 percent smaller than those of the corresponding 304-stainless-steel tubes.
- The CTEs of the LCPs were fully tailorable down to an exceptionally low value of 5.8×10^{-6} (°C)$^{-1}$.
- It was necessary to fabricate an LCP tube with a wall thickness of 0.080 in. (≈2.0 mm) to obtain a flexural strength equal to that of a 304-stainless-steel tube with a wall thickness of 0.028 in. (≈0.7 mm). Even with its greater thickness, the LCP tube weighed 53 percent less than did the stainless-steel tube.
- The LCP tubes exhibited exceptionally low permeability: The average rate of transport of oxygen though an LCP tube having dimensions typical of those of a cryogenic tank at a temperature of −183 °C was found to be of the order of 4×10^{-21} cm^3 (standard temperature and pressure) per day.
- All of the LCP tubes exceeded the hydrostatic-burst-strength requirement by at least 400 percent.

This work was done by Leslie Rubin, Frank Federico, Richard Formato, John Larouco, and William Slager of Foster-Miller, Inc., for **Glenn Research Center.**

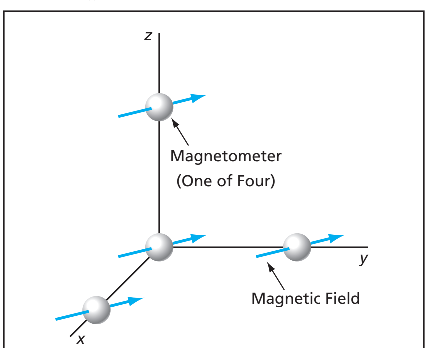
Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland Ohio 44135. Refer to LEW-16780.

Using Redundancy To Reduce Errors in Magnetometer Readings

Fundamental laws of electromagnetism impose constraints that can be exploited.

NASA's Jet Propulsion Laboratory, Pasadena, California

A method of reducing errors in noisy magnetic-field measurements involves exploitation of redundancy in the readings of multiple magnetometers in a cluster.



Four Magnetometers at corners of a cube provide noisy, redundant measurements of a magnetic field. The redundancy can be used to partly correct for the noise contributions.

By "redundancy" is meant that the readings are not entirely independent of each other because the relationships among the magnetic-field components that one seeks to measure are governed by the fundamental laws of electromagnetism as expressed by Maxwell's equations.

Assuming that the magnetometers are located outside a magnetic material, that the magnetic field is steady or quasi-steady, and that there are no electric currents flowing in or near the magnetometers, the applicable Maxwell's equations are

$$\nabla\times\mathbf{B} = \mathbf{0} \text{ and } \nabla\cdot\mathbf{B} = 0,$$

where **B** is the magnetic-flux-density vector. By suitable algebraic manipulation, these equations can be shown to impose three independent constraints on the values of the components of **B** at the various magnetometer positions.

In general, the problem of reducing the errors in noisy measurements is one of finding a set of corrected values that minimize an error function. In the present method, the error function is formulated as (1) the sum of squares of the differences between the corrected and noisy measurement values plus (2) a sum of three terms, each comprising the product of a Lagrange multiplier and one of the three constraints. The partial derivatives of the error function with respect to the corrected magnetic-field component values and the Lagrange multipliers are set equal to zero, leading to a set of equations that can be put into matrix·vector form. The matrix can be inverted to solve for a vector that comprises the corrected magnetic-field component values and the Lagrange multipliers.

The method was tested in computational simulations of random noise superimposed on readings of a dipole magnetic field by four magnetometers in a cluster like the one shown in the figure. The numerical results of the simulations showed that errors in the magnetometer readings were reduced by values ranging from about 20 to about 40 percent.

This work was done by Igor Kulikov and Michail Zak of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).NPO-40695*

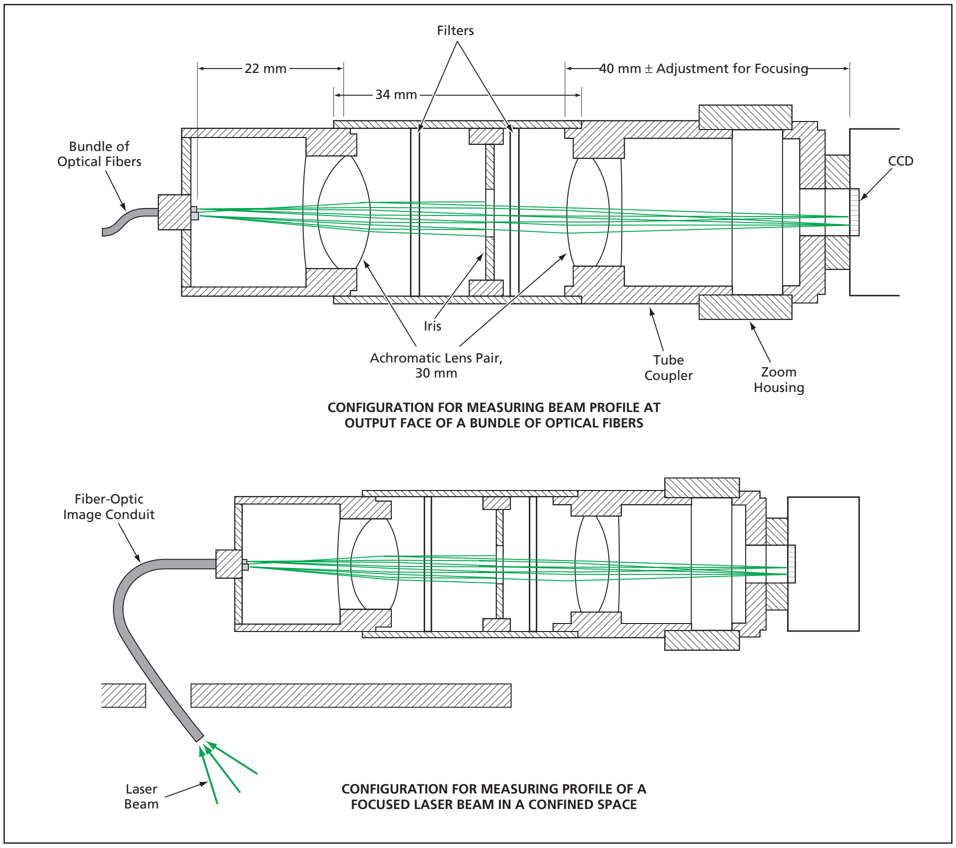
Compact Instrument for Measuring Profile of a Light Beam

A simple optical assembly is combined with a conventional CCD beam profiler.

Lyndon B. Johnson Space Center, Houston, Texas

The beamviewer is an optical device designed to be attached to a charge-coupled-device (CCD) image detector for measuring the spatial distribution of intensity of a beam of light (the "beam profile") at a designated plane intersecting the beam. The beamviewer-and-CCD combination is particularly well suited for measuring the radiant-power profile (for a steady beam) or the radiant-energy profile (for a pulsed beam) impinging on the input face or emerging from the output face of a bundle of optical fibers. The beamviewer-and-CCD combination could also be used as a general laboratory instrument for profiling light beams, including beams emerging through small holes and laser beams in free space.

There are numerous commercial beam-profiling instruments, but each is deficient in one or more respects that include, variously, low dynamic range, optomechanical complexity, large size, difficulty of alignment, and/or high cost. In contrast, the beamviewer is compact, easy to align, capable of operation over a wide dynamic range, and relatively inexpensive.



The **Achromatic Lens Pair** projects a magnified image of the cross section of a light beam onto a CCD for measurement of the spatial distribution of light in the cross section.

The beamviewer is designed to be attached to the optical mount on the CCD portion of any off-the-shelf CCD beam profiler. The figure depicts the beamviewer-and-CCD combination as configured for measuring the beam profile at the output face of a bundle of optical fibers. The beamviewer includes an achromatic lens pair arranged in a telecentric system, such that an image of the output face of the fiber-optic bundle is projected onto the CCD with a desired amount of magnification. An iris between the lenses can be used to control the light flux and the depth of focus. There are also spaces between the lenses for inserting neutral-density filters to attenuate powerful light beams to protect the CCD against damage and prevent saturation of its output. By using or refraining from using the iris, the neutral-density filters, and the electronic control of the CCD gain and shutter speed of the off-the-shelf beam profiler, it is possible to attain a dynamic range of 10^{10}.

The beamviewer configuration for measuring the profile of a beam at a plane other than the output face of a fiber-optic bundle is the same as that described above, except for the input coupling. In this case, the output face of a fiber-optic image conduit (a fused fiber-optic bundle with polished end faces that consists of 3-µm fibers, each fiber acts like a pixel) is placed at the input focal plane of the telecentric lens system, and the input plane of the fiber-optic image conduit is placed in the plane where the beam profile is to be measured. The light-intensity distribution at the input face of the conduit is reproduced (with some attenuation) at the output face, then imaged on the CCD as described above.

This work was done by Valeri Papanyan of Lockheed Martin Corp. for **Johnson Space Center**. *For further information, contact the Johnson Commercial Technology Office at (281) 483-3809.*
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