Linear and Rotational Quartz Fiber Accelerometers for Geophysical and Inertial Use

B. BARTHOLOMEW,* B. BLOCK,† AND J. DRATLER JR.‡
DIAX Corporation, La Jolla, Calif.

Theme

THREE quartz fiber accelerometers are being developed for geophysical and inertial use. Prototype models of the vertical and horizontal instruments exist and are undergoing tests. A rotation sensor capable of measuring rotational accelerations about a single axis is being designed. While most of the data gathered to date pertains to geophysical phenomena, these instruments may be used directly in any application requiring sensitive, low drift accelerometers.

Contents

The heart of each accelerator is a flat plate supported by a quartz fiber.[1–4] The ends of the fiber are clamped to the instrument frame while the mass is attached at the center and allowed to swing freely. In the vertical accelerometer (Fig. 1) the mass is held in a horizontal plane by torsion in the fiber and responds to vertical accelerations like a simple harmonic oscillator. The mass in the horizontal accelerometer hangs vertically to form a simple pendulum while the fiber serves as an elastic pivot with an extremely small restoring torque. The rotation sensor (Fig. 2) is similar to the horizontal accelerometer, but the mass consists of two dynamically balanced plates. The fiber axis lies along the principle axis of inertia of the mass, which therefore responds to rotational accelerations about the fiber axis, but not to linear accelerations.

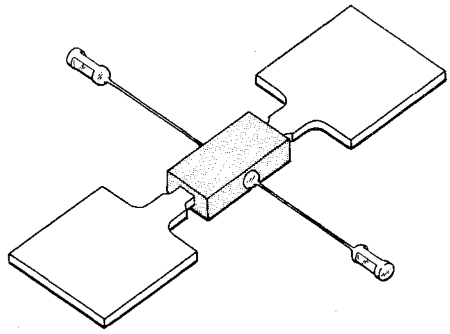

Fig. 2 Mass-fiber system for rotation sensor. Dynamically balanced inertial element, supported by quartz fiber along the principal axis of inertia, responds to rotational accelerations only. Fiber is less than 4 in. long.

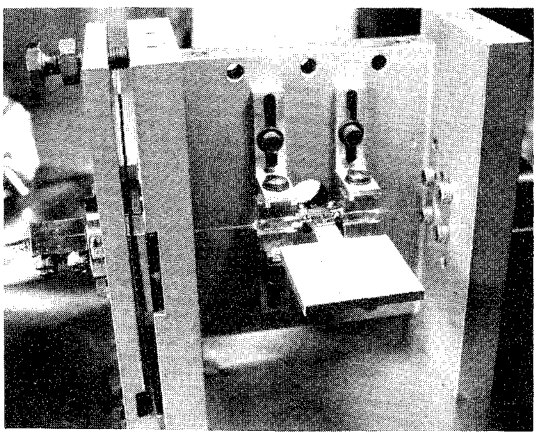

Fig. 1 Mass-fiber system for prototype vertical accelerometer. Mass is held in horizontal plane by torsion in fiber. Height of frame is 4.5 in.

The position of the plate or plates relative to the instrument's frame of reference is detected using a differential capacitive position transducer and phase sensitive detection. With these transducers the measured sensitivity of the vertical is 10^{-10} g in a 1 sec averaging time while the horizontal can resolve tilts as small as 10^{-10} rad in a 1 sec averaging time.[1] The rotation sensor will measure deflections about the fiber axis of 2×10^{-9} rad at 1 sec periods.

Rigid internal control of both pressure and temperature is a design feature of all of these instruments.[1–4] The mechanical sensors are mounted in stainless steel vacuum cans sealed at a pressure less than 10^{-7} torr to eliminate the effects of convection, variable buoyancy and humidity. Because of the strong temperature dependence of the elastic properties of quartz, a system of passive thermal insulation and active thermostatic control is used to keep the fiber temperature constant. For the vertical instruments the temperature is regulated within 10^{-6} °C over 100 sec periods to maintain a sensitivity of 10^{-10} g. The horizontal and rotational instruments also require temperature regulation but they are approximately 1000 times less sensitive to temperature fluctuations because the fiber is not initially stressed to support the mass or masses against the pull of gravity. The constant temperature environment also removes spurious signals that might be due to thermal expansion of the instrument frame.

A standard phase sensitive detector (i.e., lock-in amplifier) detects the output signal of the mechanical sensor. Because the capacitive transducer measures the position of the mass, this signal contains acceleration information at all frequencies from d.c. to the resonant frequency of the mass-fiber system. The output of the lock-in amplifier is then selectively filtered to emphasize phenomena in various bandwidths. Finally the data is digitized and stored on magnetic tape from which it can be fed directly into a digital computer for analysis.

Several years of data exist from the prototype vertical and horizontal instruments. Geophysical phenomena such as solid

Presented as Paper 72-822 at the AIAA Guidance and Control Conference, Stanford, Calif., August 14–16, 1972; submitted August 14, 1972; synoptic received February 6, 1973; revision received March 26, 1973. Full paper available from AIAA Library, 750 Third Avenue, New York, N.Y. 10017. Price: Microfiche, $1.00; hard copy, $5.00. **Order must be accompanied by remittance.**

Index category: Research Facilities and Instrumentation.

* Physicist.

† President. Member AIAA.

‡ Physicist.

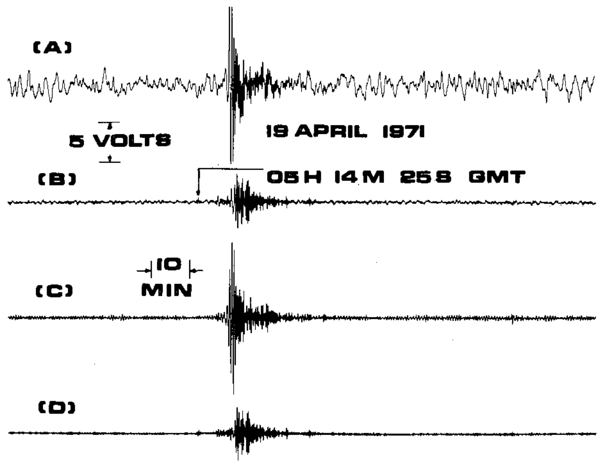

Fig. 3 Data from horizontal (A) and vertical (B) instruments for small (magnitude $m_b = 4.9$) earthquake in Galapagos Islands on April 19, 1971. Data were filtered to emphasize bandwidth from 5–200 sec periods. 1 v corresponds at 20 sec periods to about 5×10^{-9} g for vertical accelerometer and 10^{-8} g for horizontal. Transfer functions are given in Refs. 1 and 4. Traces (C) and (D) are data of horizontal and vertical, respectively, after application of digital high-pass filter which cuts sharply at 45 sec periods.

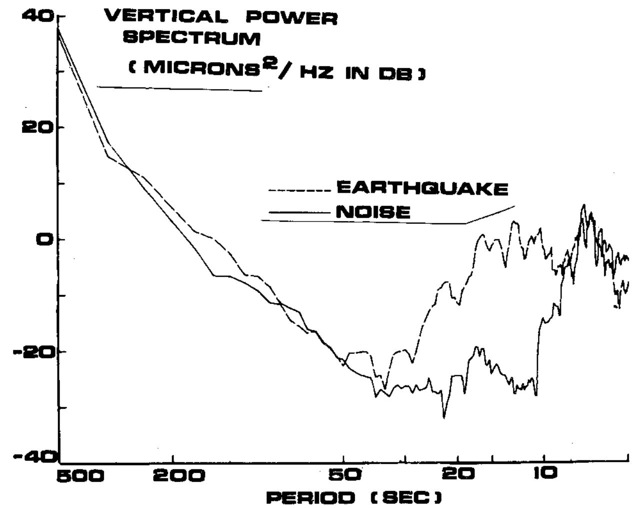

Fig. 4 Power spectra of Earth ground noise and small (magnitude $m_b = 4.7$) earthquake near Oaxaca, Mexico on June 6, 1971. Note peaks in noise spectrum near 15 and 6 sec periods. To convert to power spectral density of acceleration in g^2/Hz multiply by $1.6 \times 10^{-11}/T^4$ when T is periods in seconds.

Earth tides,[1] free oscillations of the Earth and seismic events[1,5] are clearly observed. One continuous eight month stretch of data set an upper bound on the drift rate of the vertical of 10^{-10} g/day.[1] Data from the horizontal show similar drift figures and it may thus be used as a sensitive tiltmeter to study long term tilting of the Earth's surface.

One problem of general interest in the fields of geophysics and inertial guidance is the amount of time that coherent signals due to earthquakes exist above the average level of background geophysical noise. Investigations[6] using data from the vertical instrument show that roughly 16% of the time such signals exist. Figure 3 shows one such event, and Fig. 4 shows a power spectrum of a similar event and the spectrum of the ambient noise before the earthquake. Note the two peaks in the noise spectrum near 15 and 6 sec periods (the microseism peaks), and how most of the energy of the earthquake is concentrated in this region.

The broad bandwidth, high sensitivity and low drift properties of these instruments make them ideal for monitoring the input to inertial platforms. Derivative feedback may be applied to the mass allowing the instrument to be used in high g environments without deteriorating performance. The dynamic range of the position transducer, defined as the maximum measurable deflection divided by the sensitivity, is 10^8. The new instruments are $4\frac{3}{4}$ in. in diameter, 9 in. long and weigh less than 15 lb so they may be deployed conveniently with any inertial system.

References

[1] Dratler, J., Jr., "Quartz Fiber Accelerometers and Some Geophysical Applications," Doctoral thesis, Sept. 1971, Univ. of California at San Diego, San Diego, Calif.

[2] Block, B. and Moore, R. D., "Tidal to Seismic Frequency Investigations with a Quartz Accelerometer of New Geometry," *Journal of Geophysical Research,* Vol. 75, No. 8, March 1970, pp. 1493–1505.

[3] Block, B. and Dratler, J., Jr., "Improvements in the Wideband Vertical Quartz Torsion Accelerometer," *Journal of Geophysical Research,* Vol. 77, No. 17, June 10, 1972.

[4] Dratler, J., Jr. and Block, B., "A Wide Band Horizontal Accelerometer with Preliminary Earth Normal Mode and Seismic Investigations," *Geophysical Journal of the Royal Astronomical Society,* Vol. 27, 1972, pp. 337–367.

[5] Block, B. and Dratler, J., Jr., "A Review of Earth Normal Mode and Seismic Data from Quartz Fiber Accelerometers," *Geophysical Journal of the Royal Astronomical Society,* Vol. 31, Dec. 1972, p. 239.

[6] Whorf, T., "Teleseismic and Earth Noise Monitoring with the Block-Moore Accelerometer," *Geophysical Journal of the Royal Astronomical Society,* Vol. 31, Dec. 1972, p. 205.