



“Zero-Mass” Noninvasive Pressure Transducers

High-performance strain gauges are formed in sputtered thin films.

NASA's Jet Propulsion Laboratory, Pasadena, California

Extremely lightweight, compact, noninvasive, rugged, relatively inexpensive strain-gauge transducers have been developed for use in measuring pressures of fluids in tubes. These gauges were originally intended for measuring pressures of spacecraft-propulsion fluids, but they are also attractive for use in numerous terrestrial applications — especially those involving fluids that are extremely chemically reactive, fluids that must be isolated for hygienic purposes, fluids that must be allowed to flow without obstruction, and fluid-containing tubes exposed to severe environments.

A basic pressure transducer of this type comprises one or more pair(s) of thin-film strain gauges integral with a tube that contains the fluid of interest. Following established strain-gauge practice, the gauges in each pair are connected into opposite arms of a Wheatstone bridge (see figure). Typically, each pressure transducer includes one pair (the active pair) of strain gauges for measuring the hoop stress proportional to the pressure of the fluid in the tube and another pair (the dummy pair) of strain gauges that are nominally un-

strained: The dummy gauges are mounted on a substrate that is made of the same material as that of the tube. The substrate is welded to the tube at only one spot so that stresses and strains are not coupled from the tube into the substrate. The dummy strain gauges measure neutral strains (basically, strains associated with thermal expansion), so that the neutral-strain contribution can be subtracted out of the final gauge reading.

The active strain gauges are oriented to obtain an adequate response to hoop strain while minimizing the response to torsional and bending strains, which can be induced by mechanical coupling between the tube and other components of the fluid-handling system. The precise optimum orientation for this purpose depends on the Poisson's ratios of the materials used; a representative approximate optimum orientation is specified as an angle of 61.3° between the gauge axis and the tube axis.

The strain gauges are formed by sputter deposition of a dielectric film directly on the tube, followed by sputter deposition of a film of a suitable piezore-

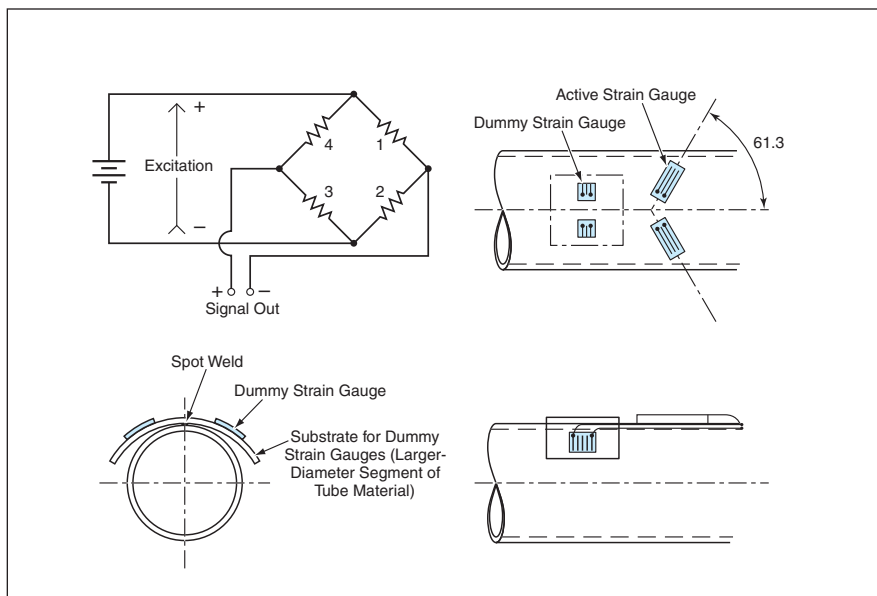
sistive material (typically, a nickel-chromium alloy), followed by laser cutting of strain-gauge grid lines into the piezoresistive film. These gauges have been characterized by the term “zero-mass,” which is not entirely an exaggeration: the sputtered layers are so thin that when one accounts for tube material removed by polishing in preparation for sputtering, one could find that the net mass of the tube plus pressure transducer is equal to or less than that of the plain tube.

The connections between the strain gauges and the external parts of the Wheatstone bridge are made with thin-film flexible electrical leads. A thin film of dielectric material can be sputtered over the strain gauges and bridge wiring to protect the gauge circuitry, to prevent outgassing, and/or to prevent chemical reactions between the strain gauges and the environment.

In addition to the advantages already mentioned, these pressure transducers offer several advantages over prior pressure transducers, including those based on strain gauges bonded to tubes by use of adhesives:

- The intimate coupling between strain gauges and tubes increases the magnitudes and speeds of gauge responses, simplifies accounting for thermal coefficients, reduces thermal-response times, and diminishes long-term drifts and zero shifts.
- A pressure transducer of this type is essentially part of the tube on which it is mounted, with little or no protuberances or additional mass, with high resilience in the face of shock and vibrational loads.
- The high dissociation temperatures of the dielectric and piezoresistive films enables operation at high temperatures, while the thin-film, intimate-coupling nature of the gauge structures extends the lower operating-temperature limit down to the cryogenic range.

This work was done by Frank T. Hartley of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-21194



The Active and Dummy Strain Gauges are used to measure hoop strain and neutral strain, respectively, in a tube that contains a pressurized fluid. The active gauges are oriented to minimize their response to bending and torsional strains.