matters arising

Strainmeter technology

WE agree with Sydenham[1] that many problems remain to be investigated with strainmeters and that many results obtained so far are ambiguous or contradictory. Measurements of strain (especially long period strain) are beset by a host of problems not found in such areas as magnetometry, so it may, therefore, be unreasonable to expect strainmeters to be as simple as magnetometers. Further, it may be time to opt for a smaller number of higher performance instruments and to reconsider the continued deployment of more and more strainmeters in a given area.

Although the measurement of strain is in principle differential, in practice the long term nature of most strain measurements requires great stability in the reference length, the realisation of which is tantamount to constructing a length standard.

Conventional materials, such as fused silica, have coefficients of expansion of about 10^{-6} °C^{-1} so that thermal fluctuations must be held to less than 10^{-4} °C over the entire length of the instrument if the thermally induced strain signal is to be kept below 10^{-10} (in order to measure a particular component of the Earth tides to an accuracy of 1%, for example).

Sydenham has shown[3] that this can be done for very short strainmeters (10 m) in the laboratory. The ancillary apparatus required to achieve microdegree stabilities is, however, far from simple, even for 10-m instruments, and difficulties in stabilising longer instruments can be expected to increase more than linearly with length.

The length of fused silica strainmeters also depends on the ambient humidity in a nonlinear manner (F. Homuth, unpublished thesis). Thus, stabilisation of the humidity is also required. That could be accomplished, at least to the first order, by enclosing the instrument in an evacuated pipe, in which case, of course, it would look exactly like a laser strainmeter.

By way of contrast, saturated absorption stabilisers routinely achieve stabilities and reproducibilities of 10^{-11} or better without any sort of thermal or environmental isolation. These data on stability and reproducibility are obtained by direct comparison between two independently stabilised devices.

It is true that the interferometer comprising the heart of the laser strainmeter is sensitive to fluctuations in atmospheric pressure and temperature, the fractional change in the optical path length being 2×10^{-10} per mtorr. A simple mechanical pump can easily evacuate the interferometer to a few mtorr and can maintain the pressure at that level indefinitely. The temperature dependence of the index of refraction at a few mtorr is negligible.

Until the advent of saturated absorption stabilisers, attempts to measure long term strain accumulations with conventional strainmeters were severely limited by the signals produced by various environmental effects. There is no question that conventional strainmeters can be used for conventional seismology and even for normal mode work (periods of less than about 1 h). In fact, many of the best normal mode data come from quartz rod strainmeters[4]. But for periods of longer than 1 h it becomes more and more difficult to isolate adequately the reference length.

Thus, our conclusions are quite different from those of Sydenham. We feel that there is no 'best' overall strainmeter, and that each instrument has advantages and shortcomings.

Laser strainmeters are usually faulted for their high cost and low reliability. But neither the cost nor the sophistication of a laser instrument increases very much with length, so that long instruments are quite a bit cheaper per metre than are short ones. We suggest that the opposite may be true for instruments requiring good thermal stability over their entire length. If, as Homuth (unpublished) suggests, stabilisation of the ambient humidity turns out also to be necessary, the cost of the total system will be even higher, and the reliability, presumably, lower.

J. LEVINE

Time and Frequency Division,
National Bureau of Standards,
Boulder, Colorado 80302

[1] Sydenham, P. H., *Nature*, **252**, 278–280 (1974).
[2] Levine, J., and Hall, J. L., *J. geophys. Res.*, 77, 2595–2609 (1972).
[3] Sydenham, P. H., *J. Phys. E.*, **6**, 572–576 (1973).
[4] Smith, S. W., *J. geophys. Res.*, **71**, 1183–1193 (1966).

SYDENHAM[1] has failed to appreciate that problems exist in studies of Earth strain which will not be solved by producing the 'ultimate' strainmeter. Strain signals cover a wide frequency range, and signal sources and noise vary across the spectrum. The correct way to assess instrument performance is to examine noise levels as a function of frequency (see ref. 2, for example). An early invar wire strainmeter designed and constructed by Sydenham[3] achieved signal-to-noise ratios of up to 100 on tidal peaks and although the instrument had defects, a poor signal-to-noise ratio was not the most important. As Sydenham has never published any power spectra it is not possible for others to compare the behaviour of their instruments with his. His interest in drift and stability amounts to an avid concern with only the lowest frequencies of the spectrum. Using drift as a criterion for comparison, however, it is interesting to note that Sydenham's early instrument has exhibited less long term drift than he now claims for quartz instruments[4] although even that level is too high to permit a strainmeter to compare in the long term (more than 1 yr?) with geodetic techniques for determining secular strain.

Sydenham's discussion of tensor arrays is also misleading. Given six instruments and a good site, a tensor array will not usually give maximum useful information. Geophysically important results (different examples are given in refs 5–9) can be obtained using single instruments or linear arrays of horizontal strainmeters and these also reveal site effects[7,10,11]. Should a site prove to be badly chosen perhaps it is best to go elsewhere.

No published data suggest that mechanical strainmeters are universally better than optical strainmeters (or vice versa). We register surprise that since Sydenham favours borehole instruments he makes no comment on the borehole dilatometer developed at the Carnegie Institution, Washington[12] or the Geotech borehole strainmeter[13].

G. C. P. KING
R. J. BEAVAN
J. R. EVANS

Department of Geodesy and Geophysics,
Cambridge University,
Cambridge, UK

[1] Sydenham, P. H., *Nature*, **252**, 278–280 (1974).
[2] Berger, J., and Levine, J., *J. geophys. Res.*, 79, 1210–1214 (1974).
[3] Bilham, R. G., Evans, J. R., King, G. C. P., Lawson, A., and McKenzie, D. P., *Geophys. J. R. astr. Soc.*, **29**, 473–485 (1972).
[4] Sydenham, P. H., *Geophys. J. R. astr. Soc.*, **38** 377–387 (1974).
[5] Frank, F. C., *Phil. Trans. R. Soc.*, **A274**, 183–184 (1973).
[6] King, G. C. P., Bilham, R. G., Campbell, J. W., McKenzie, D. P., and Niazi, M., *Nature*, **253**, 420–423 (1975).
[7] Bilham, R. G., King, G. C. P., and McKenzie, D. P., *Geophys. J. R. astr. Soc.*, **37**, 217–226 (1974).
[8] Beaumont, C., and Berger, J., *Geophys. J. R. astr. Soc.*, **39**, 111–121 (1974).
[9] Smith, S. W., *J. geophys. Res.*, **71**, 1183–1193 (1966).
[10] King, G. C. P., *J. R. Soc. N.Z. Bull.*, **9**, 239–247 (1971).
[11] King, G. C. P., and Bilham, R. G., *Phil. Trans. R. Soc.*, **A274**, 209–217 (1973).