Technical Note:

DYNAMIC STRAIN MEASUREMENT USING PIEZOELECTRIC POLYMER FILM

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Piezoelectric polymers have been used to form the basis of dynamic strain gauges for the detection of stress waves. The linearity of response was tested using a split Hopkinson pressure bar arrangement. The results obtained illustrate the effectiveness of piezoelectric film strain gauges in the measurement of axial stress waves.

Key words: piezoelectric polymer strain gauge, split Hopkinson pressure bar, stress wave measurement, deconvolution, drag measurement

Introduction

A technique was developed recently at The University of Queensland for measuring the aerodynamic drag on models in high enthalpy shock tunnels where the test times are of the order of 1 ms (**1**).† Referred to as the stress wave force balance, the device consists of a test model attached to a long, hollow stress bar. The drag time history on the model is inferred from the time history of axial strain in the stress bar using deconvolution techniques.

Since the level of axial strain may be quite small for a typical balance geometry (<10 $\mu\epsilon$) and the deconvolution process tends to amplify noise, the typical signal-to-noise ratio from the strain sensor is important. The aim of this note is to demonstrate the use of piezoelectric film as a dynamic strain sensor, particularly in the measurement of axial stress waves where bending compensation improves signal output.

Polymer films based on polyvinylidene fluoride have piezoelectric properties that are particularly useful for dynamic strain sensing. The charge generated is directly proportional to an applied strain. Piezoelectric polymer is light, flexible and can be simply mounted to either electrically conductive or non-conductive surfaces. The sensitivity of piezoelectric polymers is high while the temperature dependence is low, especially when compared to semiconductor strain gauges.

Piezoelectric strain gauges

The basic operation and construction of piezoelectric polymer strain gauges was first illustrated by Belova *et al.* (**2**). The arrangement used here to achieve bending compensation is illustrated in Fig. 1.

In the arrangement shown, the surface of the stressed component and the piezoelectric film form the electrodes of the gauge. These are connected to a charge amplifier which had a frequency response of 0.3 Hz–180 kHz at the breakpoints of -3 dB. Note that the frequency range of the described gauge is 20 Hz–2 MHz, the upper limit arising from the requirement of smallness of dimensions of the sensing element as compared with the length of deformation wave, and the lower limit arising from the increase in capacitive reactance with frequency reduction. Bending compensation of the gauge results from the film being bonded around the circumference of the stressed component.

Stress wave measurement in a split Hopkinson pressure bar

A piezoelectric film gauge was mounted on the incident bar of a split Hopkinson pressure bar arrangement (refer to Fig. 1) to monitor the transmission, propagation and reflection of stress waves. The gauge was mounted approximately 5 diameters downstream of the contact surface. A mechanical impedance mismatch existed between the incident and striker bars, resulting in a complex time history of strain in the incident bar. The mechanical characteristics of the arrangement are summarized in Table 1.

Table 1. Mechanical characteristic of split Hopkinson pressure bar

	Striker bar	Incident bar
Material	Steel	Aluminium
Diameter (mm)	41.2	30.0
Length (mm)	300	1350
Elastic wave speed (m/s)	5155	5071
Transmission coefficient	5.41	0.19

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† *References are given at the end of this Note*

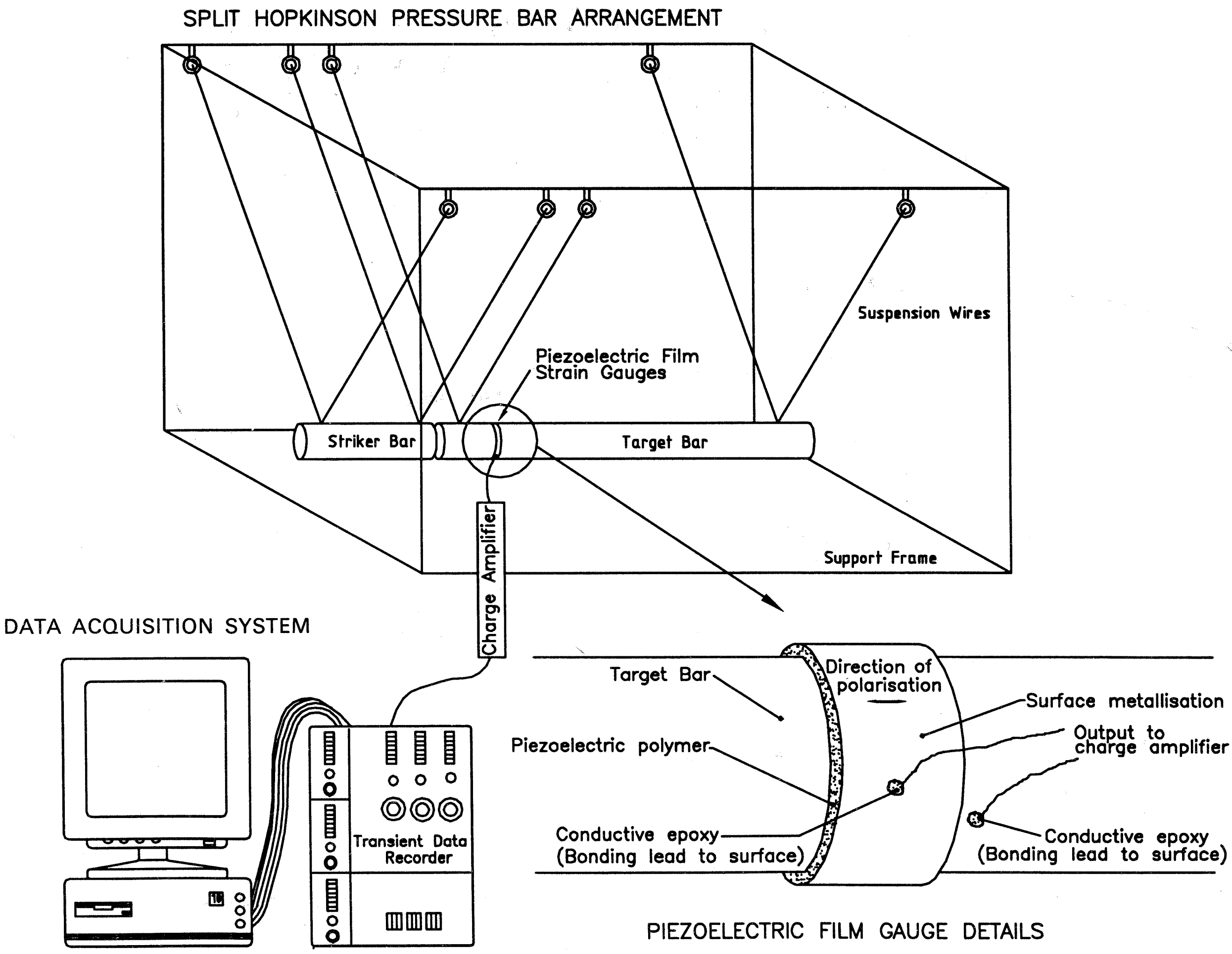

Fig. 1. Schematic of split Hopkinson pressure bar arrangement, data acquisition system and construction of the piezoelectric polymer film strain gauge

The history of strain in the incident bar was recorded for a variety of impact velocities. The results from each test were then compared to a predicted history of strain obtained from one-dimensional stress wave theory (**3**). A typical result is shown in Fig. 2.

The time history of strain presented in Fig. 2 illustrates the agreement between the piezoelectric film gauge measurements and the one-dimensional predictions in terms of both level and time history. The signal plotted is unfiltered and significantly less noisy than results obtained from either semiconductor or foil strain gauges using the same arrangement.

The relatively slow response to changes in stress measured by the piezoelectric film gauge occurred consist-

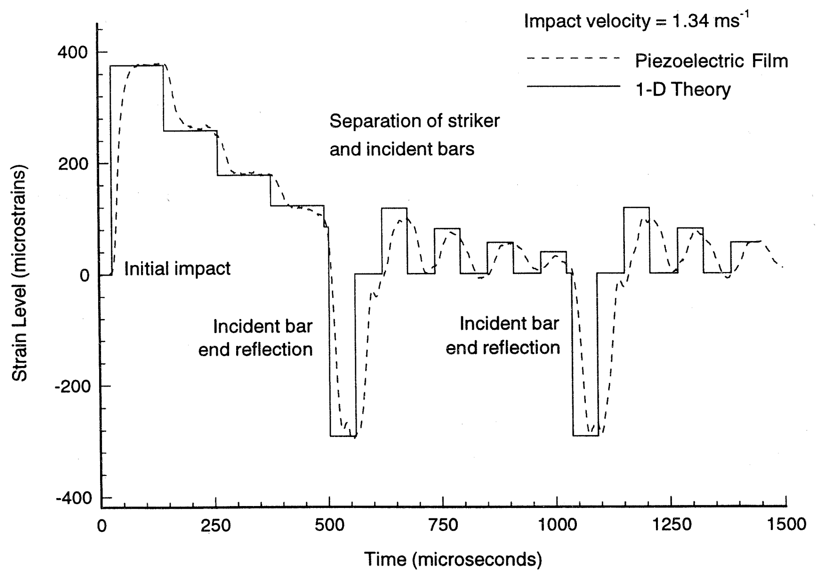

Fig. 2. Comparison of measured and predicted strain time history in target bar

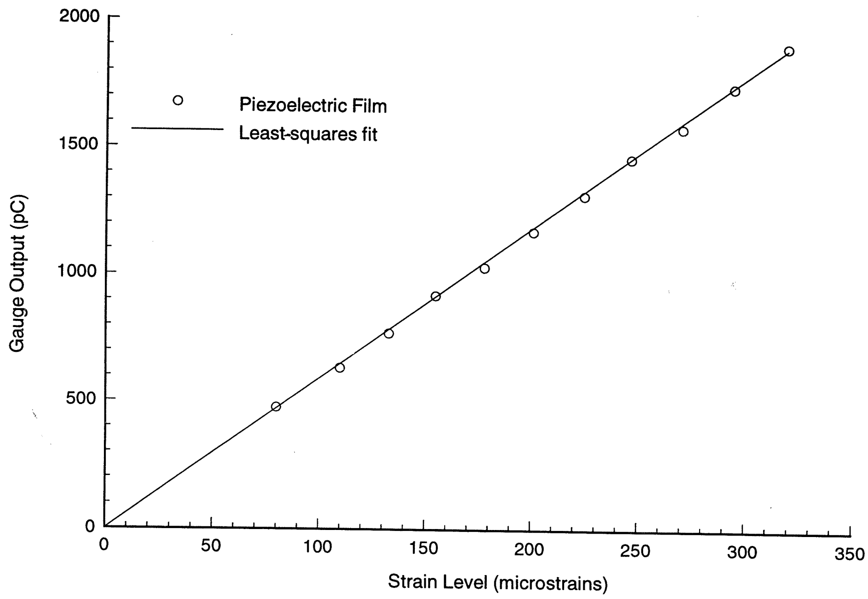

Fig. 3. Linearity of a piezoelectric film strain gauge to dynamic loading

ently throughout all tests. It is a result of radial inertia and the interaction of the stress waves with the external surface of the incident bar. Radial inertia is caused by the kinetic energy of the material flowing radially outward as the bar is being compressed by a stress wave. This apparent reduction in the mechanical response of this arrangement was first examined mathematically by Shalak (**4**). The model developed was verified experimentally using both conventional foil and semiconductor strain gauges by Smith (**5**).

The linearity of the response of the piezoelectric gauges was investigated by plotting the calibrated output against the initial strain level produced by increasing impact velocities. These data points were then used to calculate a line of best fit using a least-squares technique. The results appear in Fig. 3. The sample correlation coefficient was 0.9997.

In conclusion, piezoelectric film strain gauges have been used to obtain accurate measurements of axial stress waves propagating within the incident bar of a split Hopkinson pressure bar arrangement. The film was mounted in a bending compensation arrangement so that oscillations resulting from radial inertia did not affect the signal quality. This technique has improved the stress wave force balance by reducing the signal-to-noise ratio in the measured strain signals.

References

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