Comparison between Piezo Film Sensor, Strain Gauge, and Accelerometer on Bending Beam

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(abridged results from tests performed Jan 1987)

Introduction

Piezo film sensors can be used to measure strain in a similar way to conventional strain gauges, as long as the strain signal is dynamic. A change in length of the sensor element creates a charge or voltage signal across the electrodes, and the linearity and dynamic range are both exceptional. The operating bandwidth may also be very high, whereas conventional strain gauges are not normally used in high frequency applications. For this reason, the following description compares piezo film (used as a "dynamic strain gauge") with both a conventional foil resistive strain gauge, and a piezoelectric accelerometer.

Experimental Set-up

A shielded piezo film vibration sensor (similar to AMP P/N 1-1000288-0) was bonded to a cantilever steel beam rigidly supported at one end and driven by a vibration exciter at its free end. The sensor was fixed using double-coated adhesive tape, near to the clamped end. A single copper/nickel foil strain gauge was bonded using cyanoacrylate adhesive close to the piezo sensor, and connected in quarter-bridge configuration using a dummy gauge and precision resistors to a bridge amplifier with a gain of 60 dB. The gauge factor was 2.1, with excitation 1 V. A low mass accelerometer (B&K type 4374) was mounted at the driven end of the beam, and both this accelerometer and the piezo film sensor were monitored using B&K 2635 charge amplifiers with -10% frequency of 0.2 Hz.

Piezo Film compared with Strain Gauge

With an excitation frequency of 1 Hz, the outputs from the film sensor and the strain gauge were compared. Fig 1 shows a time record where the gauge peak-to-peak amplitude is around 2 mV (after +60 dB gain), while the open-circuit equivalent voltage response of the film sensor is 40 mV pk-pk.

Fig 2 shows spectral plots of the film sensor and strain gauge outputs, together with the calculated strain gauge amplifier frequency response (-3 dB at 18 Hz). The first beam resonance can be seen just below 100 Hz.

The piezo film sensor thus showed a sensitivity "advantage" of around 86 dB over the unamplified bridge output.

Piezo Film compared with Accelerometer

Higher bandwidth spectral plots are shown in Fig 3, with the magnitude and phase signals for both the film sensor and the low mass accelerometer. Note that a second resonance mode coccurs at 550 Hz, beyond which the film sensor and the accelerometer or on "different sides" of the node and therefore show a different phase relationship above this resonance compared with lower frequencies.

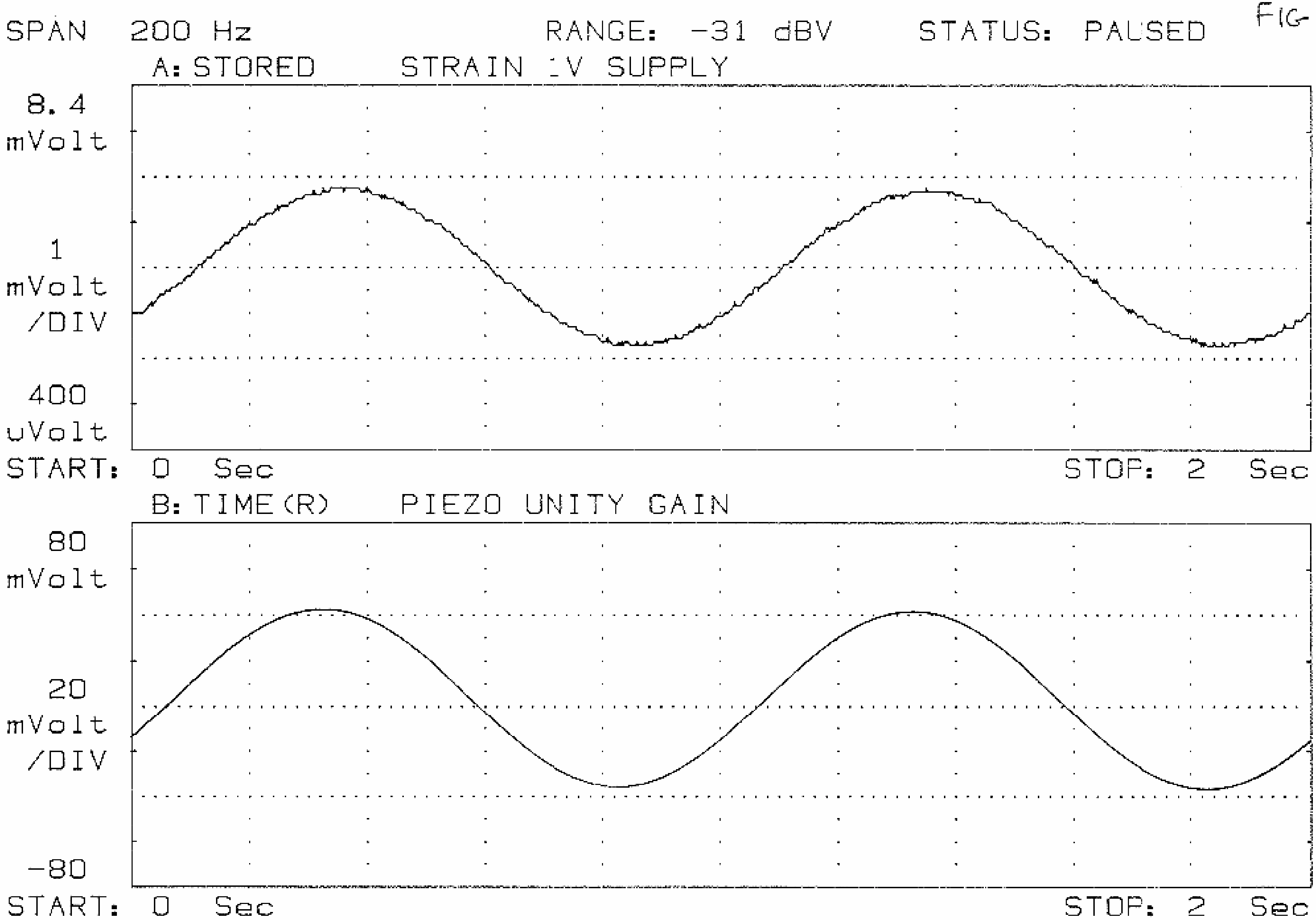
As a further comparison, the signal from the accelerometer was then integrated twice to obtain displacement, and this calculated result was compared with the surface strain signal detected by the piezo film sensor. For frequencies below the 550 Hz mode, the signals were in good agreement down to around 10 Hz, where the accelerometer signal level was dominated by noise. Fig 4 refers.

Finally, a much wider bandwidth measurement was made (Fig 5), showing useful information from the piezo film strain sensor even up to 10 kHz and perhaps beyond. At these higher frequencies, a better response could have been obtained using a smaller sensor, as the physical geometry of the film begins to become significant (minima in response curve where sensor length corresponds to a wavelength of vibration in the substrate, and subsequent multiples).

Key to Figures

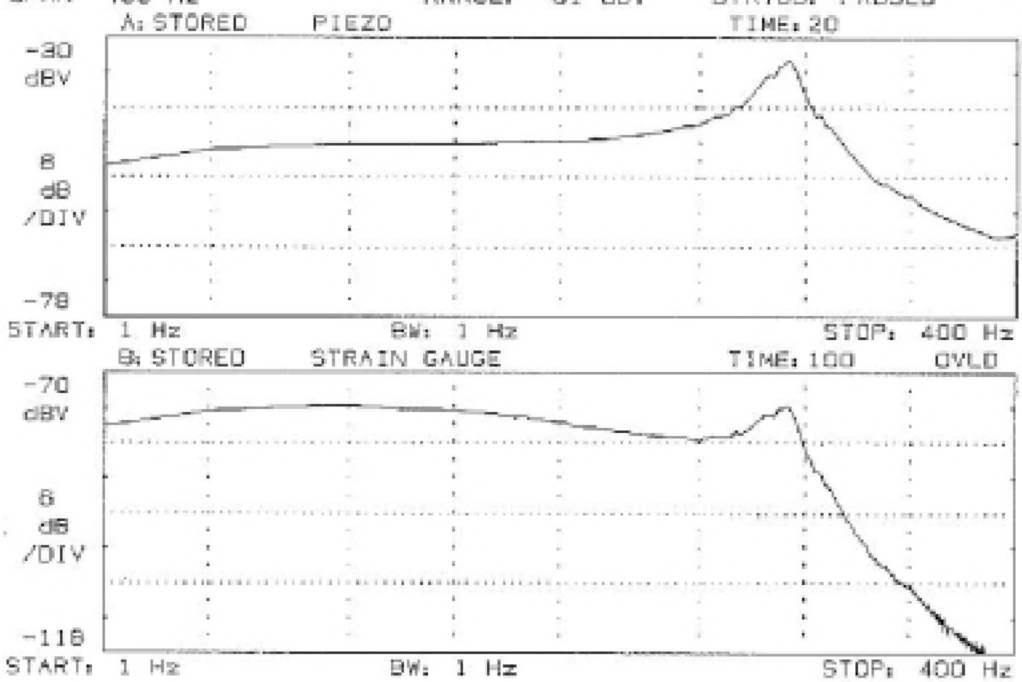
Fig 1 upper	Strain gauge output for 1 Hz beam excitation, using bridge amplifier (+60 dB), copper/nickel on Kapton strain gauge (factor 2.1) 1 V supply
Fig 1 lower	Piezo film sensor output under same excitation, open-circuit voltage response calculated from charge output measured with charge amplifier, from known capacitance source
Fig 2 upper	Piezo film and strain gauge spectra, for periodic pseudo-random excitation (400 Hz bandwidth)
Fig 2 lower	Bridge amplifier frequency response, calculated by division of the traces above
Fig 3 upper	Piezo film and accelerometer spectra compared, 1 kHz bandwidth, both showing two clear resonant modes from excited beam
Fig 3 lower	Phase plots corresponding to above spectra, showing change in phase relationship between piezo film sensor and accelerometer beyond second beam mode
Fig 4 upper	Piezo film spectrum, 1 kHz bandwidth, as Fig 3 but on log frequency scale
Fig 4 lower	Accelerometer signal integrated twice (by preamp) to yield displacement
Fig 5 upper	Accelerometer spectrum for 20 kHz excitation of beam
Fig 5 lower	Piezo film (dynamic strain) spectrum for same excitation

FIG ①



SPAN 200 Hz
RANGE: -31 dBV
STATUS: PAUSED
A: STORED STRAIN 1V SUPPLY
8.4 mVolt
1 mVolt /DIV
400 uVolt
START: 0 Sec
STOP: 2 Sec
B: TIME (R) PIEZO UNITY GAIN
80 mVolt
20 mVolt /DIV
-80
START: 0 Sec
STOP: 2 Sec

FIG 2


SPAN 400 Hz
RANGE: -51 dBV
STATUS: PAUSED
A: STORED
PIEZO
TIME: 20
-30
dBV
8
dB
/DIV
-78
START: 1 Hz
BW: 1 Hz
STOP: 400 Hz
B: STORED
STRAIN GAUGE
TIME: 100
OVLD
-70
dBV
6
dB
/DIV
-118
START: 1 Hz
BW: 1 Hz
STOP: 400 Hz

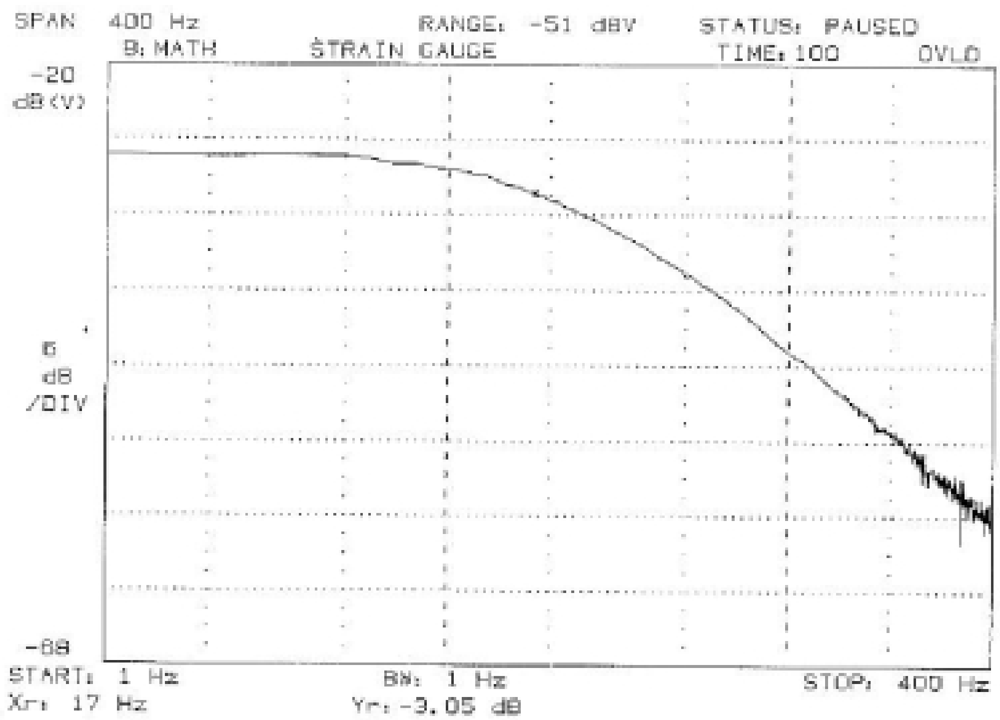
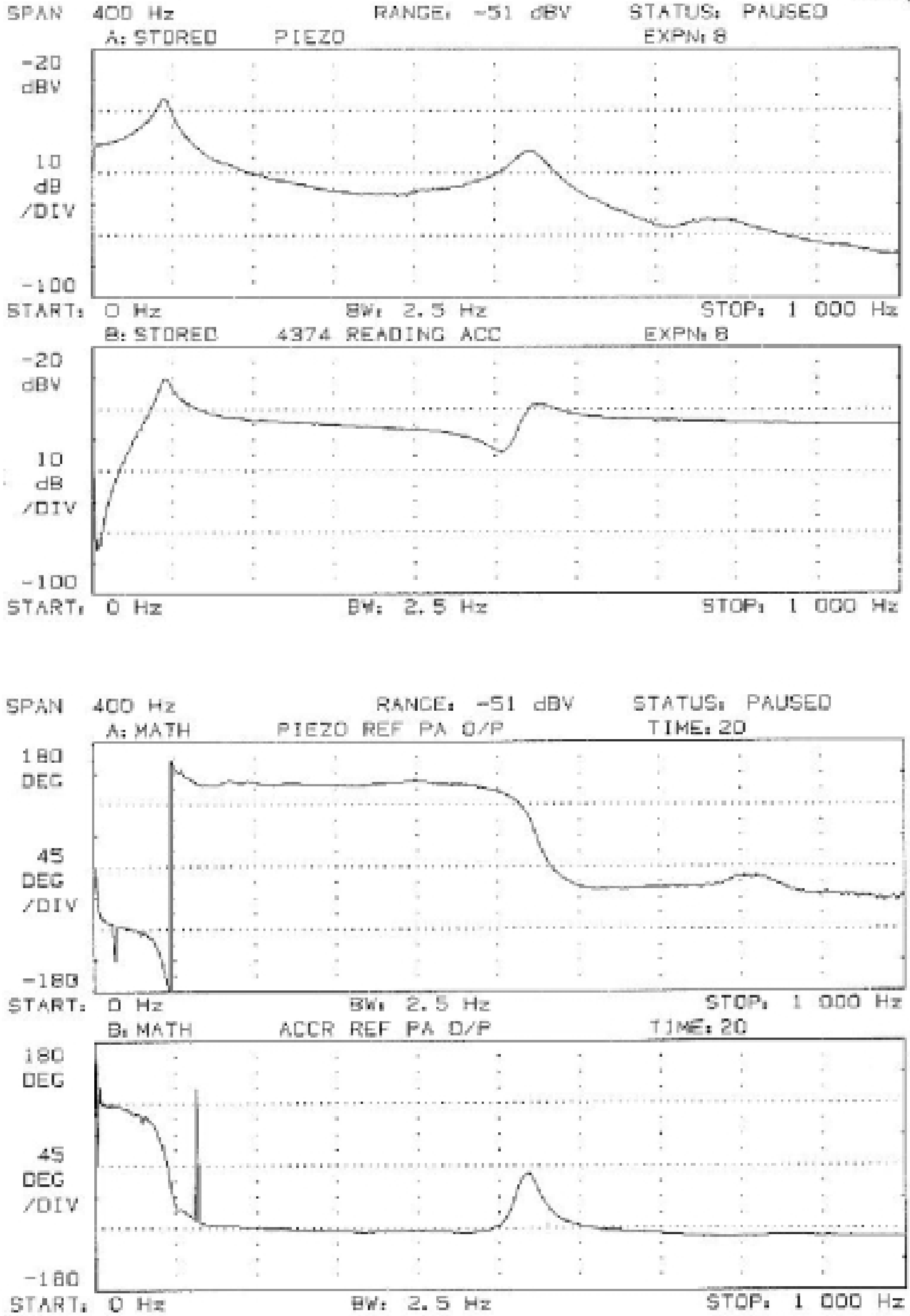

SPAN 400 Hz
RANGE: -51 dBV
STATUS: PAUSED
B: MATH
STRAIN GAUGE
TIME: 100
OVLD
-20
dB(V)
6
dB
/DIV
-68
START: 1 Hz
BW: 1 Hz
STOP: 400 Hz
Xr: 17 Hz
Yr: -3.05 dB

FIG 3


SPAN 400 Hz
RANGE: -51 dBV
STATUS: PAUSED
A: STORED PIEZO
EXPN: 8
-20 dBV
10 dB /DIV
-100
START: 0 Hz
BW: 2.5 Hz
STOP: 1 000 Hz
B: STORED 4374 READING ACC
EXPN: 8
-20 dBV
10 dB /DIV
-100
START: 0 Hz
BW: 2.5 Hz
STOP: 1 000 Hz
SPAN 400 Hz
RANGE: -51 dBV
STATUS: PAUSED
A: MATH PIEZO REF PA O/P
TIME: 20
180 DEG
45 DEG /DIV
-180
START: 0 Hz
BW: 2.5 Hz
STOP: 1 000 Hz
B: MATH ACCR REF PA O/P
TIME: 20
180 DEG
45 DEG /DIV
-180
START: 0 Hz
BW: 2.5 Hz
STOP: 1 000 Hz

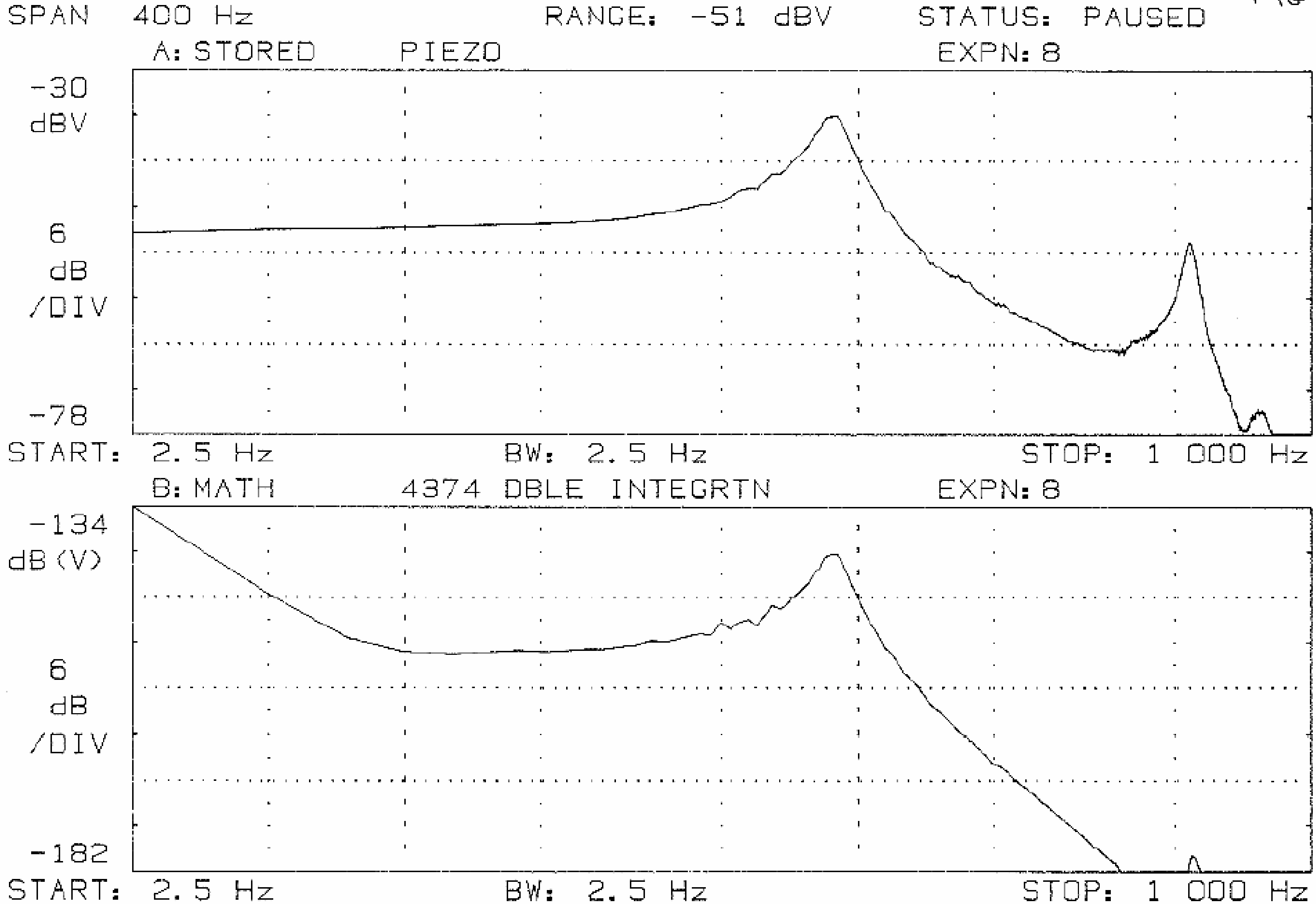
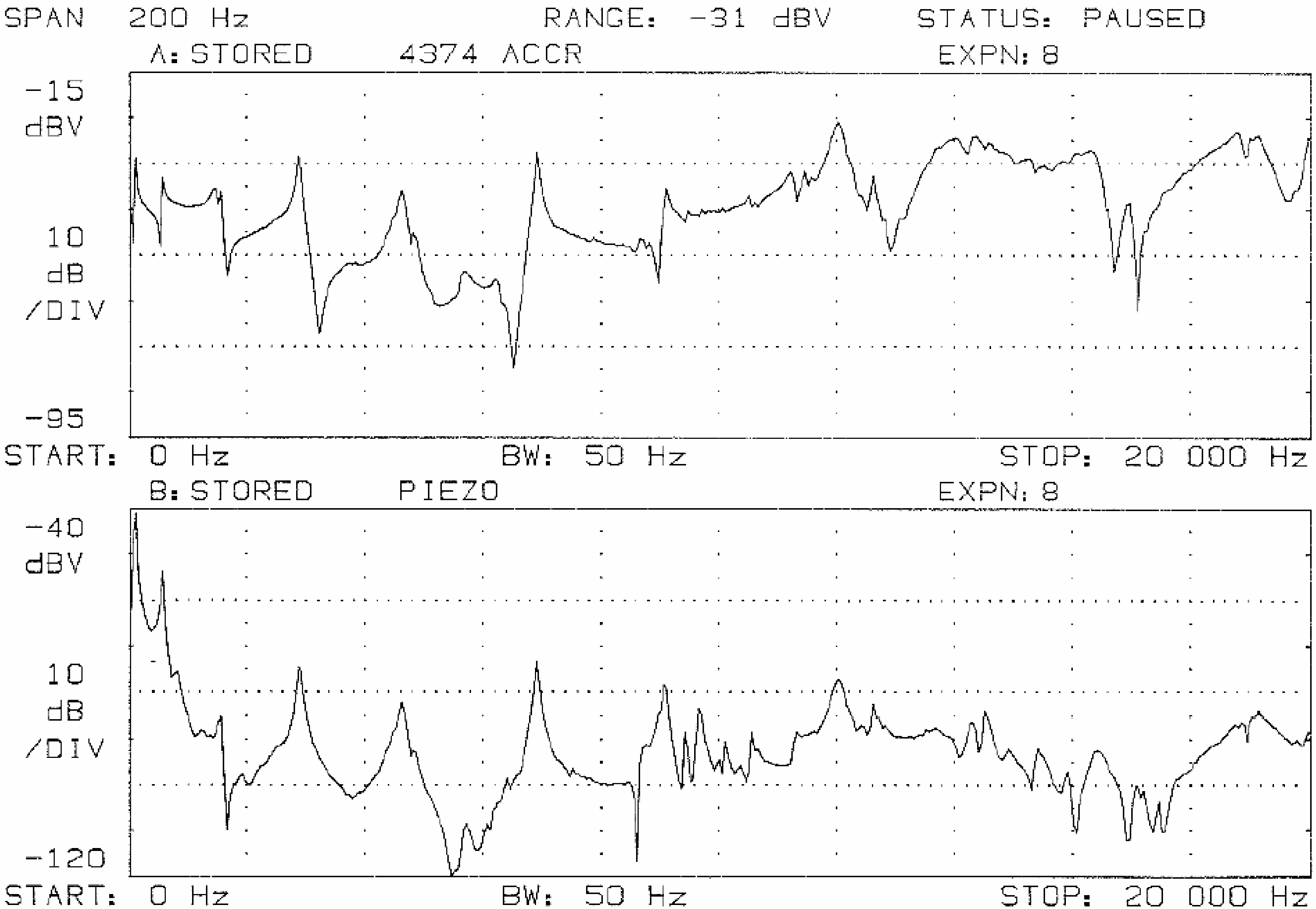

SPAN 400 Hz
RANGE: -51 dBV
STATUS: PAUSED
A: STORED
PIEZO
EXPN: 8
-30
dBV
6
dB
/DIV
-78
START: 2.5 Hz
BW: 2.5 Hz
STOP: 1 000 Hz
B: MATH
4374 DBLE INTEGRTN
EXPN: 8
-134
dB(V)
6
dB
/DIV
-182
START: 2.5 Hz
BW: 2.5 Hz
STOP: 1 000 Hz

FIG 4

FIG 5


SPAN 200 Hz
RANGE: -31 dBV
STATUS: PAUSED
A: STORED
4374 ACCR
EXPN: 8
-15
dBV
10
dB
/DIV
-95
START: 0 Hz
BW: 50 Hz
STOP: 20 000 Hz
B: STORED
PIEZO
EXPN: 8
-40
dBV
10
dB
/DIV
-120
START: 0 Hz
BW: 50 Hz
STOP: 20 000 Hz

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