Piezo Film Glass-Break Sensors

(adapted from an original article by R H Brown, Pennwalt Piezo Film Ltd, Nov 89)

Introduction

Piezo Film may be used to detect damage to glass in three ways:

1) impact detection - a simple element bonded to glass may be used as a strain gauge. Impacts to the glass (with or without fracture occurring) generate much energy, mostly low frequency. A limit can be set so that impacts above a certain energy level trigger an alarm.

2) fracture detection - when breakage occurs, there is a release of very broadband mechanical noise. The high bandwidth and sensitivity of piezo film can easily detect this event. The low-frequency signals must be filtered out, and the high frequencies amplified and threshholded.

3) controlled bandwidth sensors - using the principle of fracture detection as above, an element of film may be patterned so that a certain band of frequencies is given preferential "amplification", thus making the subsequent signal processing easier.

Common to all types is the convenience of the thin-film format, allowing low mass, unobtrusive sensors and ease of attachment to glass. The piezo film may be fashioned so that an extended strip carries the signals a short distance to "remote" electronics mounted on or within the frame.

Spectra of signals

The different frequency bands of interest may be called "push", "bang" and "hiss".

"push": DC to 100 Hz, shows the force involved in the event

"bang": 100 Hz to 50 kHz, corresponds to the acoustic noise of a hard impact

"hiss": 200 kHz to 1 MHz, uniquely generated by fracture of glass

Different forms of attack will generated different levels of each band, as will different potential false triggers. In general terms, the "push" and "hiss" bands are the most useful.

Class (1) sensors

Impact detection may be a very simple and effective solution. The drawbacks are that breakage itself is not discriminated as such (although repeated high-energy impacts may well constitute an attempt to break), and that the trigger level must be optimised according to the thickness and area of glass to be monitored.

The film element may be almost any size or shape, with large areas making the detection of the force information at low frequencies easier by virtue of large capacitance.

If the impact detector is small in size, it may also respond to the higher frequency fracture emission, and so the borderline between Classes (1) and (2) is not well defined.

Class (2) sensors

The response bandwidth of a piezo film element is governed by its physical geometry and the speed of sound in glass. Small elements (0.25 inch or less in diameter) will respond equally well from almost DC up to many hundreds of kilohertz. The spectra from break events are seen to show very high amplitudes in the audio band (like non-break events) which must be removed if the lower-amplitude HF energy is to be examined. Small elements make this easy by their low capacitance.

One disadvantage of examining only the "hiss" band is that low energy, high frequency impacts (such as caused by throwing a handful of gravel at glass) may generate spurious signals, possibly because of localised damage (chipping).

Class (3) sensors

Suitable patterning of piezo film creates a type of surface acoustic wave (SAW) filter, where the shape of the pass-band may be controlled. In addition, different wiring or connection may allow either low-pass or band-pass characteristics to be acheived. Thus a single sensor can yield the vital "push" and "hiss" signals and thereby discriminate to a high degree of accuracy whether a valid alarm condition exists.

It should be noted that, for all types of sensor, most development effort has been devoted to the examination of signals and that the trigger and associated circuitry has been considered in terms of functional blocks rather than in component detail.

The variety of possible modes of attack, and different types of glass to be protected, means that a single generic sensor is unlikely to satisfy all needs. The sensor styles mentioned above are capable of detecting most forms of attack (with Class (1) and (3) types also allowing detection of thermal assault if very low frequency signals are examined) and all have the capability of being highly tamper-proof (e.g. by using redundant tracks carrying DC to detect cutting of connectors). The high frequency sensitivity of Class (3) sensors makes them suitable for use even on laminated glass, which shows much greater attenuation of HF signals over distance.

Glass-Break Sensor Type GB-01

(Development Data Sheet November 1989)

Description

The device consists of a 3 mm diameter active area patterned on a sheet of 110 µm piezoelectric film. Passive (non-overlapping) tracks lead to contact pads, suitable for small eyelets and solder lugs.

The capacitance of the sensor is very low (about 20pF), and thus is ideal for rejecting low-frequency vibration which may emanate from any impact, whether or not glass is fractured. The small physical geometry permits good sensitivity to very high-frequency vibration.

Interface Electronics

The circuitry suggested in Glass-Break Sensor Type GB-02 Development Data Sheet (Nov 89) should be referred to.

Although the device capacitance is low, it is found that the sensor may be connected to either the HF or LF circuit described in the above, with very similar function (although the signal amplitude using GB-01 will be lower and thus threshholds in subsequent circuitry would require adjustment).

It is possible that use of a single high-speed, high-impedance buffer would allow parallel and independent operation of the high-pass and low-pass filters.

Installation

The sensor may be attached to glass using a good quality double-coated adhesive tape. Experimental results have shown very little degradation even of very high frequency information using d/c tape when compared with epoxies or cyanoacylates. Similar tests using absorbent material applied to the entire glass surface revealed that only partial VHF attenuation was possible, so that "quiet" fracture was virtually impossible.

Leads to the interface electronics should be kept as short as possible to minimise RF interference.

Glass-Break Sensor Type GB-02

Development Data Sheet November 1989

Description

The device consists of eight pairs of interdigitated electrodes patterned on the front side of a 110 µm piezoelectric film, and a rectangular common rear electrode. Active areas are brought out via passive (non-overlapping) tracks to contact pads, suitable for small eyelets and solder lugs.

The interdigital electrodes allow cancellation of low-frequency signals which occur during both "break" and "no-break" events, and offer signal gain at frequencies around 200 kHz.

Signals from one side of the upper pattern relative to the rear plane, however, will contain much low-frequency energy, and may be used to discriminate between minor chipping of glass and major fracture.

Interface Electronics

Although much signal processing is performed by the patterned sensor, some additional circuitry is required for impedance matching and to bring the high-frequency signals up to a more useful level.

The dual-purpose nature of the transducer leads to separate considerations for LF and HF detection.

The low-frequency side should buffer signals down to less than 1 Hz, and attenuate signals above 100 Hz. Since the capacitance of one side of the interdigital pattern relative to the rear plane is about 880 pF, an input resistance of about 200 Megohm is suggested, with unity gain in the "pass-band". A second-order low-pass filter with a cut-off frequency of about 50 Hz will prevent low energy (force) impacts from causing an alarm condition. Charge amplifier circuits, which present virtually zero impedance to the input, are not permitted; the interdigital electrodes must see the rear plane to be floating, and a charge amplifier would tie one side of the pattern and the rear plane together. The ground connection must be made to one nominated side of the upper pattern.

High-frequency signals from the interdigital pattern need some amplification: 40 dB is found to be adequate under most circumstances. Since the fracture of glass causes emission of vibrations up to and beyond 1 MHz, ultra-high-speed op-amps have been used for development purposes, although bandwidth limitation to a few hundred kilohertz is almost certainly beneficial. Also, the low-frequency content may still require further attenuation, and excellent results have been achieved using a third-order high-pass filter using a single op-amp (with the breakpoint set at around 200 kHz) as a further processing stage.

With the above circuitry, the low-frequency threshhold may be set at around 1 volt, and the high-frequency threshhold at about 0.5 to 1.0 volt. A final point to notice is that the LF and HF triggers may not be exactly coincident in time, and some "hold" facility may be required before "AND-ing" the results.

Installation

The sensor may be attached to glass using a good quality double-coated adhesive tape. Experimental results have shown very little degradation even of very high frequency information using d/c tape when compared with epoxies or cyanoacylates. Similar tests using absorbent material applied to the entire glass surface revealed that only partial VHF attenuation was possible, so that "quiet" fracture was virtually impossible.

Ideally, the sensor should be affixed half-way up one edge of the glass, with the "fingers" oriented vertically (major axis horizontal). "Off-axis" response is still very good, and the complex reflections of signals ensure very high probability of detection.

Leads to the interface electronics should be kept as short as possible to minimise RF interference. [Note that the differential nature of the pattern serves to eliminate much RFI, while the suggested low frequency processing may be modified if necessary to provide more rejection of 60 Hz also.]

Appendix: FFT Analysis

Signals recorded on a digital storage oscilloscope sampling at up to 20 MHz have been post-processed to reveal the energy distribution over frequency. The filter characteristic of the interdigital device may be seen when selected portions of the time record of a "break" event are windowed and passed through an FFT algorithm. FFT processing of the entire event, however, shows much blurring of the filter shape, and a much more "noisy" (random) response. Since vibrations of different frequency travel at different velocities, the centre frequency of the filter will appear to vary throughout the event. Convolution (echoes) of signals, and varying angles of incidence, add to the blurring effect. In general, though, the energy density is much more concentrated around 200 kHz using this style of device than a single-element sensor. The inter-digital device may be regarded, at worst, as an ensemble of smaller elements, but the whole is normally greater than the sum of the parts.

Postscript

The Glass Break Sensors GB-01 and GB-02 did not go into volume production, and samples are no longer available. The original drawings are missing, presumed lost. But much raw waveform data, from early trials leading to the design of these sensors, remains archived. For illustration purposes, a brief snapshot is presented here, based on trials of a 3 mm circular PVDF element of 110 µm thickness. Interface electronics of two types were tested: a hybrid high-bandwidth linear amplifier, and an active 3rd order high-pass filter circuit (f_c approx 200 kHz). The linear amplifier "RIFA" had relatively low input resistance and therefore formed a single-order high-pass filter when driven by the small piezo film element (exact characteristic unknown). All traces were obtained using piezo film bonded to 3.8 mm glass sheet using double-coated adhesive tape.

Key to attached figures:

"F5 3mmKH, HARD TAP, RIFA AMP"

Using the linear amplifier, glass impacted sharply but without any crack occurring

"F6 3mmKH, HARD TAP, HPF O/P"

Using the 3rd order high-pass filter, similar event to above

"F7 3mmKH, EDGE CHIP, RIFA AMP"

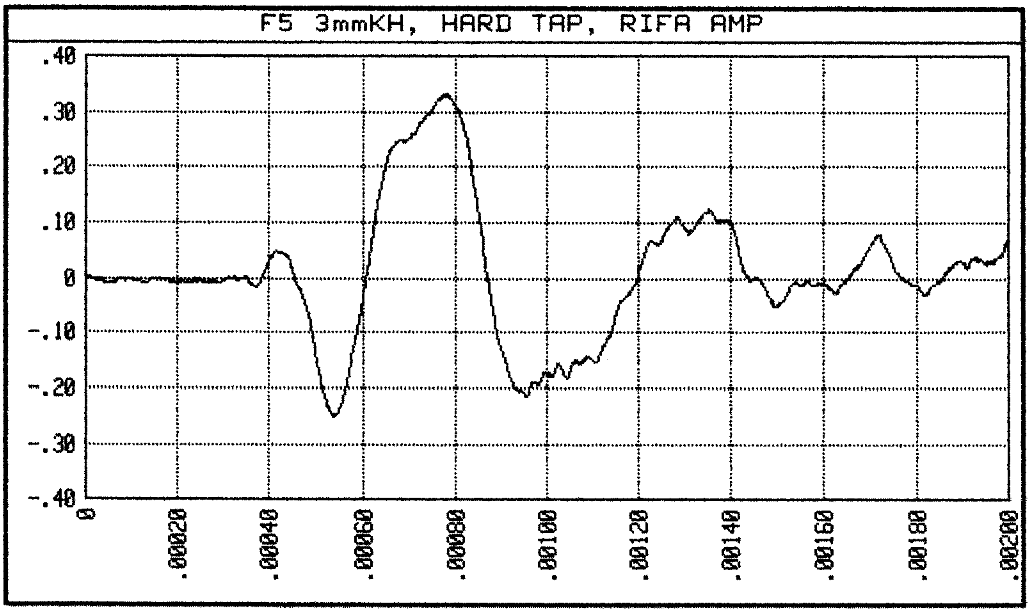
Using the linear amplifier, edge of glass impacted causing chip to break off

"F8 3mmKH, EDGE CHIP, HPF O/P"

Using the 3rd order high-pass filter, similar event to above

(Unlabelled trace)

FFT (Fast Fourier Transform) of waveforms F5 (solid) and F7 (dotted) overlaid, logarithmic Y-axis (20 dB per division), linear X-axis from 0 to 250 kHz, 50 kHz per division. The "with fracture" event shows significantly higher energy at all frequencies above about 20 kHz. A band energy measurement (from 50 kHz to 150 kHz) showed almost 20 dB higher energy with fracture.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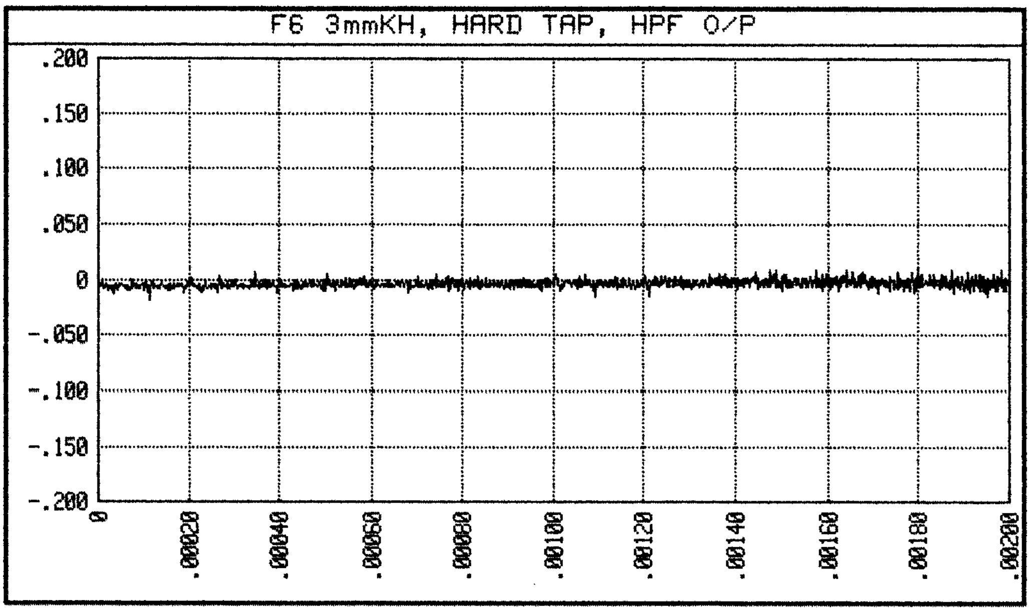
F6 3mmKH, HARD TAP, HPF O/P
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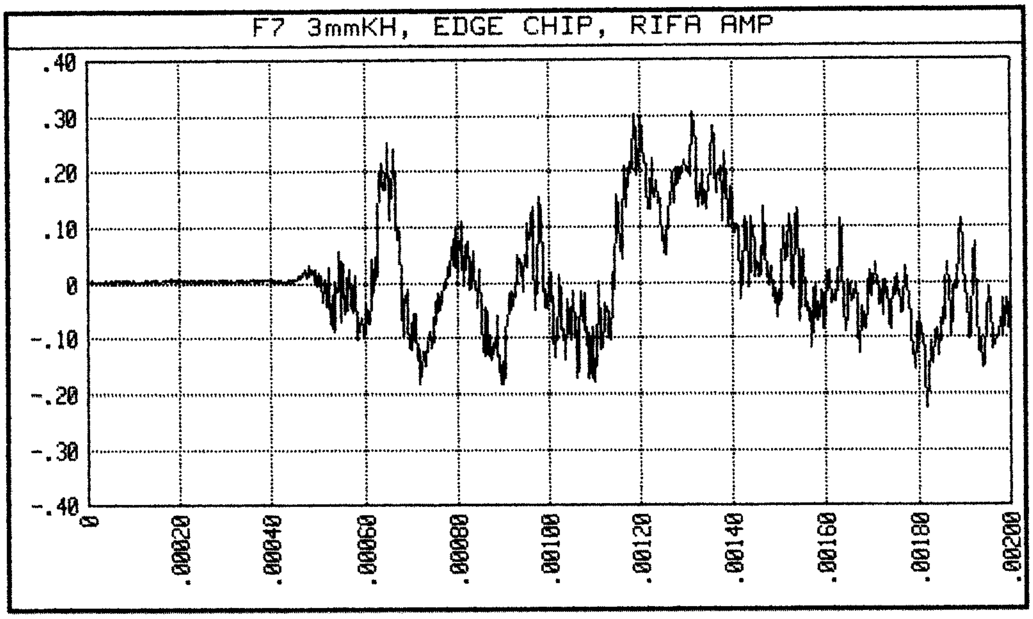
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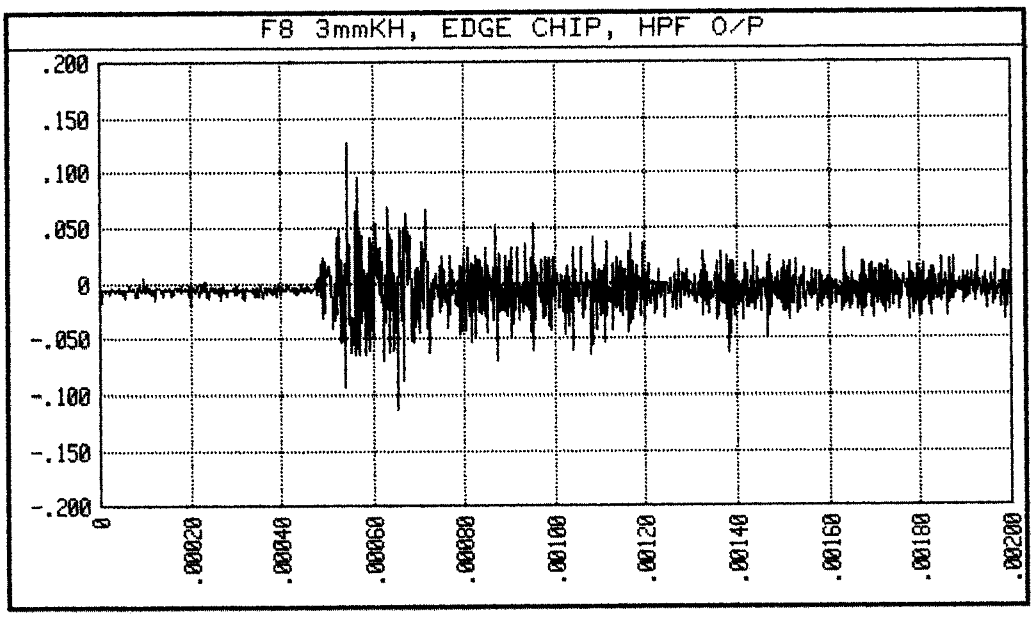
F8 3mmKH, EDGE CHIP, HPF O/P
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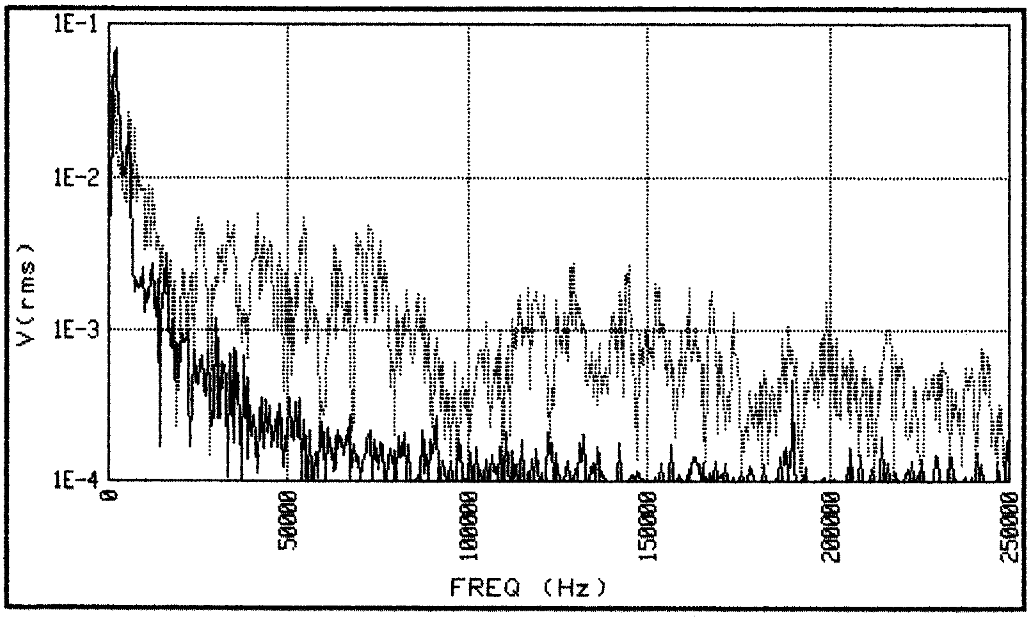

1E-1
1E-2
1E-3
1E-4
V(rms)
0
50000
100000
150000
200000
250000
FREQ (Hz)

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