Chapter 9

Piezoelectric effect and charge amplifiers

TEC / NOT / 012

This paper introduces force and pressure measurement using piezoelectric devices. In particular the piezoelectric effect is discussed along with circuits used to measure this effect (charge amplifiers).

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9.1 Overview

In 1880 the Curie brothers discovered the piezoelectric effect as illustrated in the following figure. Piezo comes from the ancient Greek verb Piezein - to press.

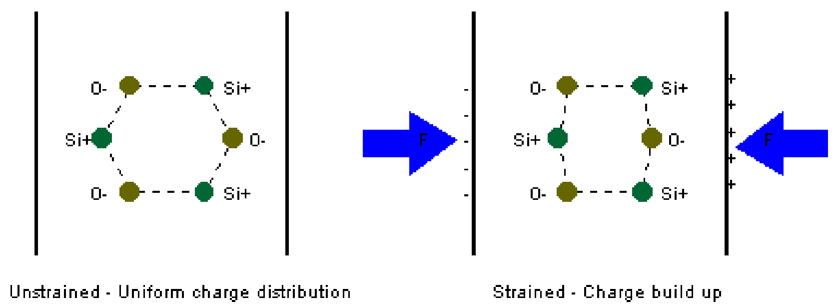

Figure 9-1: Illustration of piezoelectric effect

In crystals, such as quartz or tourmaline, all the molecules are arranged, and thus become deformed under pressure, in the same way.

These crystals are highly directional (no *Poisson type* effects), thermally stable, produce highly repeatable results and have a very large dynamic range.

However, the signal produced requires a charge amplifier (compared to the voltage output of a strain gage or thermocouple for example). This paper is concerned with the considerations and design aspects of charge amplifiers. In particular, unless the device has very high input impedance, the charge will *leak-away* and the device will have limited applications for dc signals.

Walter Kistler (founder of Kistler AG) patented the charge amplifier, as it is known to the industry today.

9.2 In-line charge converters

Because piezoelectric devices are charge-based, they are more susceptible to cabling and moisture variations. Often, the sensor can have the charge-to-voltage signal conditioning built in. Also some manufacturers supply in-line charge amplifiers that can be placed near the sensor. Both these methods are illustrated in the following figure along with a popular method of supplying power to these devices (constant current) and decoupling the signal returned.

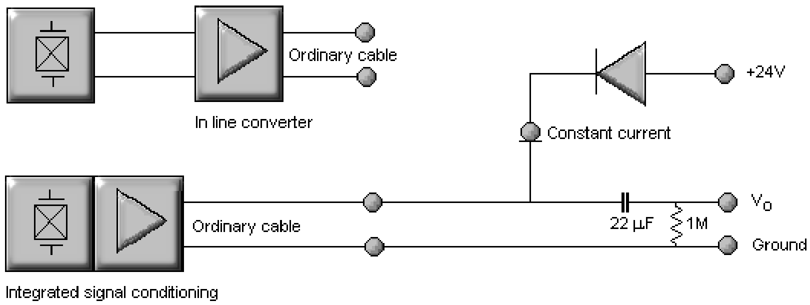

Figure 9-2: Integrated and in-line signal conditioning techniques

In-line charge amplifiers are available from Kistler, Endevco, PCB Piezotronics and others. The KAD/ADC/006 from Curtiss-Wright can be connected to six such devices.

9.3 Voltage mode charge conversion

The sensor can be modeled as a charge source in parallel with a capacitance as shown in the following figure. The charge is a function of the force or pressure being measured.

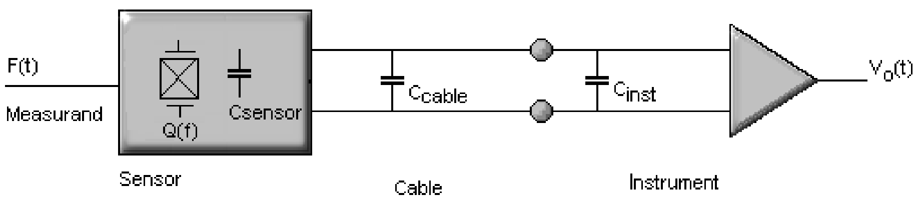

Figure 9-3: Voltage mode charge conversion

The transfer function for such a circuit is:

$$V_0(t) \propto \frac{Q(t)}{C_{sensor} + C_{cable} + C_{inst}}$$

To minimize the effects of variations of the sensor cable and stray capacitance within the instrument, C_{inst} must be made as large as possible, which in turn requires greater amplification. This circuit is rarely used and is shown here for completeness only.

9.4 Charge mode charge conversion

An alternative is the circuit shown in the following figure.

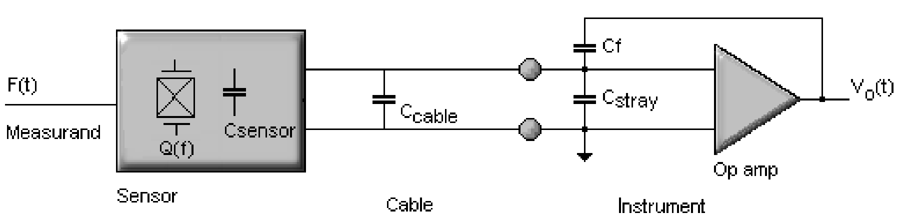

Figure 9-4: Charge mode charge conversion

The transfer function for such a circuit is:

$$V_0(t) \propto \frac{Q(t)}{C_f} \cdot \frac{1}{1 + \frac{1}{G_{op-amp}}\left(\frac{C_{sensor} + C_{cable} + C_{stray}}{C_f}\right)} \approx \frac{Q(t)}{C_f}$$

In other words, if the operational amplifier has a high negative open-loop gain ($G_{\text{op-amp}}$), variations in cable, sensor and stray capacitance have a negligible effect. However, great care must still be taken with connectors and the shielding of tracks.

A variation of this circuit (including high resistance returns for op-amp bias currents) is used on the KAM/CDC/001.

9.5 Conclusion

Piezoelectric sensors were introduced along with various methods of interfacing to them. In particular in-line charge converters (as used on the KAD/ADC/006) or charge mode amplifiers (as used on the KAM/CDC/001).

9.6 References

Applied Measurement Engineering

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Prentice Hall

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