

Piezoelectric Measurement System Comparison: Charge Mode vs. Low Impedance Voltage Mode (LIVM)

Introduction

Piezoelectric sensors (Transducers) measure dynamic phenomena such as force, pressure and acceleration (including shock and vibration). Inside the sensor, piezoelectric materials such as quartz and man-made ceramics are stressed in a controlled fashion by the input measurand i.e., the specific phenomena to be measured. This stress “squeezes” a quantity of electrical charge from the piezoelectric material in direct proportion to the input, creating analogous electrical output signals. (“Piezo” is from the Greek word meaning to “squeeze.”) Because of the high stiffness of piezoelectric materials, it is possible to produce sensors with very high resonant frequencies making them well-suited for measurement of rapidly changing dynamic phenomena such as shock tube pressure wavefronts, high frequency hydraulic and pneumatic perturbations, impulse (impact) forces, vibrations in machinery and equipment, pyrotechnic shocks, etc. The task faced by the measurement system is to couple information, contained within the small amount of electrical charge generated by the crystals, to the outside world without dissipating it or otherwise changing it. (The quantity of charge generated by the piezo element is measured in units of picocoulombs, (pC) which is 1×10^{-12} Coulombs.) Throughout the evolutionary process of piezoelectric sensor development, two types of systems have emerged as the main choices for dynamic metrology. 1. The Charge Mode System 2. The Low Impedance Voltage Mode (LIVM) System. This section is intended to help make your choice between these systems a little easier by pointing out the advantage and limitation of each type.

The Charge Mode System

Dytran Charge Mode sensors are manufactured with both ceramic and crystalline quartz piezoelectric elements. Charge mode accelerometers used for vibration measurements utilize piezo-ceramic materials from the Lead Zirconium Titanate (PZT) family. These materials are characterized by high charge output, high internal capacitance, relatively low insulation resistance and good stability. Most charge mode pressure and force sensors use pure Alpha quartz in the sensing elements. These sensors are normally used with a Charge Amplifier, a special type of amplifier designed specifically to measure electrical charge. The charge mode system is thus composed of the charge mode sensor, the charge amplifier and the interconnecting cable. (see Figure 1).

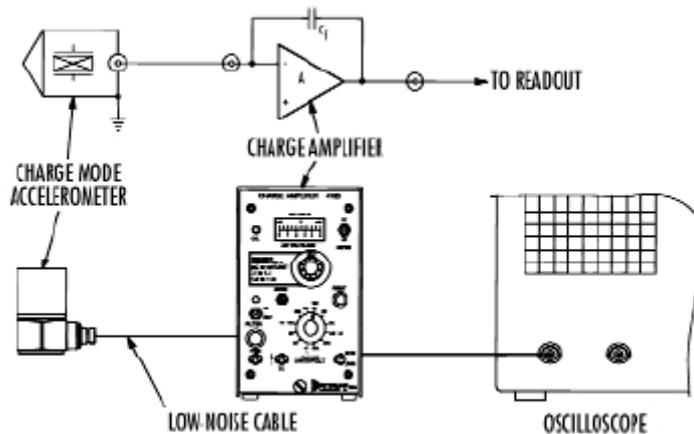


Figure 1 is a symbolic and graphic representation of a typical charge mode vibration measurement system. The input stage of the charge amplifier utilizes a capacitive feedback circuit to balance or “null” the effect of the applied input charge signal. (This action is explained in more detail in the section “Introduction to Charge Mode Accelerometers”.) The feedback signal is then a measure of input charge. This amplifier presents essentially infinite input impedance to the sensor and thus measures its output without changing it - the goal of all measurement processes. The gain (transfer function) of the basic charge amplifier is dependent only upon the value of the feedback capacitor C_f (See Figure 1) and is independent of input capacitance, an important feature of the charge amplifier. Following stages may add voltage gain and attenuation, filtering, and other functions to further process and refine the data before coupling it to the readout instrument.

A Word About Cables

Because of the very high input impedance of the charge amplifier, the sensor must be connected to the amplifier input with low-noise coaxial cable such as Dytran series 6013A. This cable is specially treated to minimize triboelectric noise, e.g., noise generated within the cable due to physical movement of the cable. Coaxial cable is necessary to effect an electrostatic shield around the high impedance input lead, precluding extraneous noise pickup.

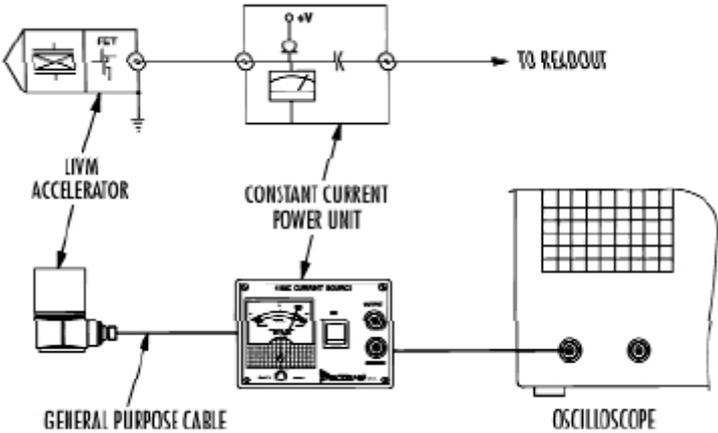
Charge Mode System Advantages

- Since there are no electronic components contained within the sensor housing, the upper temperature limit of charge mode sensors is much higher than the +250°F (121°C) limit imposed by the internal electronics of LIVM sensors. Rather, the high temperature limit is set by the Curie temperature of the piezoelectric material or by the properties of insulating materials employed in the specific design. Check the individual product data information for the operating temperature limits of Dytran charge mode sensors.
- Laboratory type charge amplifiers currently available offer a wide range of signal augmentation choices such as filtering, ranging, standardization, integrating for velocity and displacement, peak hold and more - all conveniently contained in one package.
- Charge amplifier gain is independent of input capacitance, therefore system sensitivity is unaffected by changes in input cable length or type, an important point when interchanging cables.
- A special type of charge amplifier, the very long time constant “Electrostatic” type, used in conjunction with certain quartz element charge mode force and pressure sensors can, with

certain precautions, be used to make near static (quasi-static) measurements of events lasting up to several minutes duration.

The LIVM System

Figure 2 contains a symbolic and a graphic representation of a typical LIVM system. We have chosen to illustrate an accelerometer system in Figure 2 so that direct comparisons can be made with the charge mode system illustrated in Figure 1. LIVM systems are available for pressure and force measurements as well. Piezoelectric Measurement System Comparison: Charge Mode vs. Low Impedance Voltage Mode (LIVM)



Referring to Figure 2, the LIVM accelerometer, although of similar basic construction as the charge mode unit, uses crystalline quartz as the signal generating element instead of piezoceramic. Unlike the charge mode accelerometer, the LIVM accelerometer utilizes the voltage signal generated by the quartz element rather than the charge signal. The voltage signal is related to the charge signal by the following relationship:

$$V=Q/C \quad \text{(Eq. 1)}$$

- Where:
- Q = charge (pC)
 - V = voltage (Volts)
 - C = crystal capacitance, including any shunt capacitance added (pF)

Although the charge sensitivity of quartz is very low when compared to ceramics, the self capacitance is also very low resulting in a high sensitivity voltage signal, higher in fact than that from an equivalently proportioned ceramic element. A miniature IC metal oxide silicon field effect transistor (MOSFET) amplifier built into the housing of the sensor, converts the high impedance voltage signal from the quartz element to a much lower output impedance level, so the readout instrument and long cable have little effect on the signal quality. Because the high impedance input to the IC amplifier is totally enclosed and thus shielded by the metal housing, the LIVM sensor is relatively impervious to external electrostatic interference and other disturbances. The sensor amplifier is a common drain, unity gain “source follower” circuit with the source terminal brought out through a coaxial connector on the sensor body.

The sensitivity of the LIVM sensor is fixed at time of manufacture by varying the total capacitance across the quartz crystal element (refer to Equation 1). The highest possible voltage sensitivity is obtained with no added capacitance across the element. To decrease sensitivity (increase range), capacitance is added to attenuate the voltage signal. Once the sensitivity is set in this manner, it cannot be changed by external means. External amplification performed in power units, or by other means can amplify or attenuate the signal but cannot change the fixed sensitivity (mV/g, psi or LbF) of the sensor.

The LIVM Power Unit

The LIVM sensor, unlike the charge mode sensor does not require a charge amplifier, but rather a much simpler Current Source Power Unit. The power unit contains a DC power source (batteries or a regulated DC power supply), a current source element (constant current diode or constant current circuit), and a means of blocking or otherwise eliminating the DC bias voltage that exists at the center terminal of the sensor connector, so the signal may be conveniently coupled to the readout instrument (oscilloscope, meter, recorder, analyzer, etc.)

Since the source load for the sensor IC (the constant current diode or circuit) is located in the power unit and not within the sensor housing, a single two-conductor cable is used to connect the sensor to the power unit. The low output impedance of the sensor makes it unnecessary to connect sensor to power unit with the more expensive low noise coaxial cable as with the charge mode system. Rather, we recommend the standard series 6010A coaxial cable. Twin lead cable with the 6115 solder connector adapter may also be used, a real cost-saving advantage for LIVM systems.

As with the charge amplifier, some dedicated signal augmentation can be accomplished within the LIVM power units such as gain, attenuation, filtering, etc., within the constraints of the fixed sensor sensitivity. With rare exceptions, full scale sensor output voltage is 5 Volts.

LIVM System Advantages

- Low output impedance (less than 100 ohms) makes the sensitivity of the LIVM sensor independent of cable length within the frequency response limits outlined in the chart (Figure 6) in the section "Introduction to Current Source Power Units". Basic system sensitivity does not change when cables are replaced or changed.
- The low output impedance precludes the use of expensive low noise cable allowing the use of inexpensive coaxial cable (or twin-lead ribbon cable) to connect sensor to power unit.
- Sensitivity and discharge time constant are fixed at time of assembly, setting full scale range and low frequency response. This makes LIVM sensors ideal for dedicated applications such as modal analysis and health monitoring.
- Sealed rugged construction, with high impedance connections contained within the sensor housing, makes LIVM sensors ideal for field use in dirty or moist environments.
- With proper considerations, very long cables (up to thousands of feet long) can be driven by LIVM sensors.
- LIVM power units are relatively simple and fractions of the cost of laboratory charge amplifiers. Multi-channel units with 3, 4, 6, 12 and 16 channels are available to greatly lower the per-channel cost of the system. Even the singlechannel cost is a fraction of that of the typical charge mode system.
- The tiny IC amplifier chip built into LIVM sensors is very rugged, able to withstand shocks over 100,000 g's. This makes LIVM accelerometers, such as the Dytran 3200B series, excellent choices for measurement of very high shocks (e.g., those encountered in pyrotechnic testing). Dytran can supply ruggedized coaxial cable (series 6034A) or 2-pin

solder connector adapters (model 6115 for use with very light 2-wire cable) to withstand the punishment of such severe applications.

Conclusion

We have attempted to help with your decision as to which type of system best suits your needs by pointing out the advantages and limitations of two types of dynamic measurement systems. We realize this decision is often determined or influenced by factors outside the control of the test engineer or technician. This may include having instruments already on hand which must be utilized for economic reasons, limited operating budgets, and personal preferences based upon years of familiarity with one type of instrumentation. All of these factors must be weighed.

Whatever your choice, we hope we have improved your ability to make an intelligent decision. We stand ready to offer technical assistance and to provide the best possible instrumentation at reasonable cost.