

Introduction to Piezoelectric Pressure Sensors

LIVM PRESSURE SENSORS

Dynamic pressure sensors are designed to measure pressure changes in liquids and gasses such as in shock tube studies, in-cylinder pressure measurements, field blast tests, pressure pump perturbations, and in other pneumatic and hydraulic processes. Their high rigidity and small size give them excellent high frequency response with accompanying rapid rise time capability. Acceleration compensation makes them virtually unresponsive to mechanical motion, i.e., shock and vibration.

Figures 1a and 1b are representative cross sections of Dytran Model Series 2300V LIVM (Low Impedance Voltage Mode) acceleration compensated pressure transducers. This series is characterized by very high frequency response and fast rise time. These instruments contain integral impedance converting IC amplifiers which reduce the output impedance by many orders of magnitude allowing the driving of long cables with negligible attenuation.

Series 2300V utilizes thin synthetic quartz crystals stacked together to produce an analogous voltage signal when stressed in compression by pressure acting on the diaphragm. This pressure, by virtue of diaphragm area, is converted to compressive force which strains the crystals linearly with applied pressure producing an analog voltage signal.

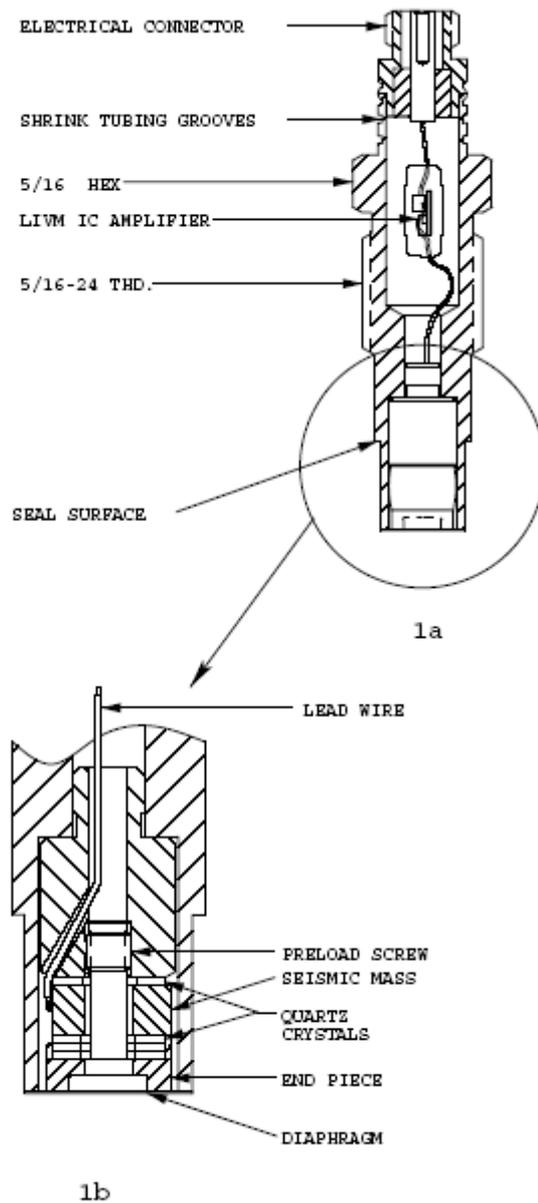


Figure 1: Low Impedance Voltage Mode (LIVM) pressure sensor.

As with all LIVM instruments, the voltage generated by the crystals is fed to the gate terminal of the FET input stage of an impedance converting IC amplifier which drops the impedance level 10 orders of magnitude. This allows these instruments to drive long cables with little effect on frequency response.

Referring to figure 1a and 1b, series 2300V contains an integral accelerometer built into the crystal stack. This accelerometer, consisting of one quartz crystal and a seismic mass, produces a signal of opposite polarity (to that produced by pressure on the diaphragm) when acted upon by vibration or shock. This signal cancels the signal produced by vibration or shock acting upon the diaphragm and end piece, negating the effects of mechanical motion on the output signal.

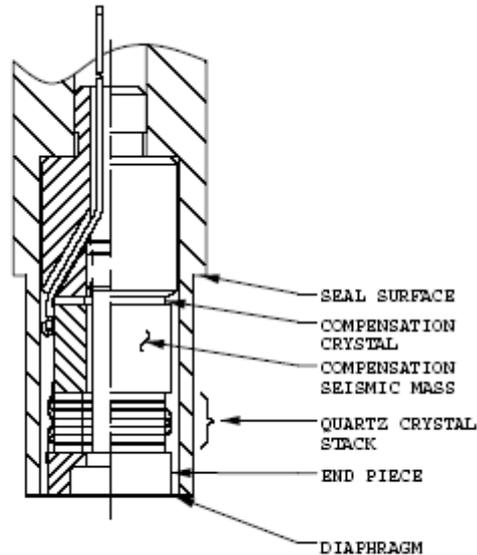


Figure 2: Model 2200V1 higher sensitivity pressure sensor.

Model 2200V1 (refer to figure 2) is constructed similar to series 2300V with the difference that model 2200V1 has several more quartz crystals in the stack to produce more voltage sensitivity for the lower pressure range sensor. The maximum sensitivity of series 2300V is 20 mV/psi whereas the sensitivity of model 2200V1 is 50 mV/psi. The resonant frequency is lower than that of Model series 2300V.

System Interconnection

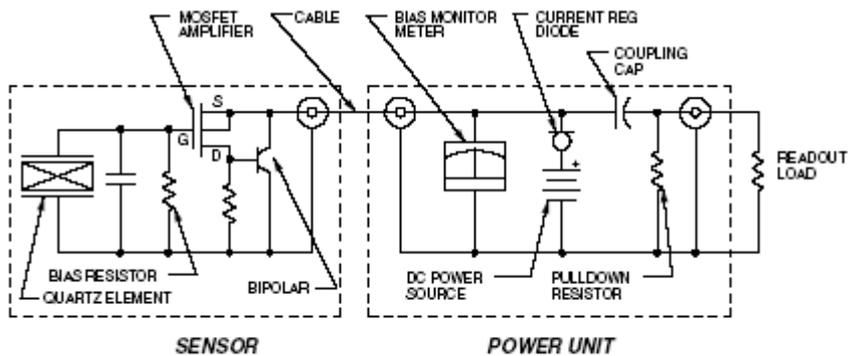


Figure 3: Schematic, typical system interconnect

Figure 3 is a schematic diagram of a typical LIVM system consisting of pressure sensor, cable and power unit. To complete the LIVM measurement system, choose the current source power unit needed to power the internal sensor amplifier and select the input and output cables.

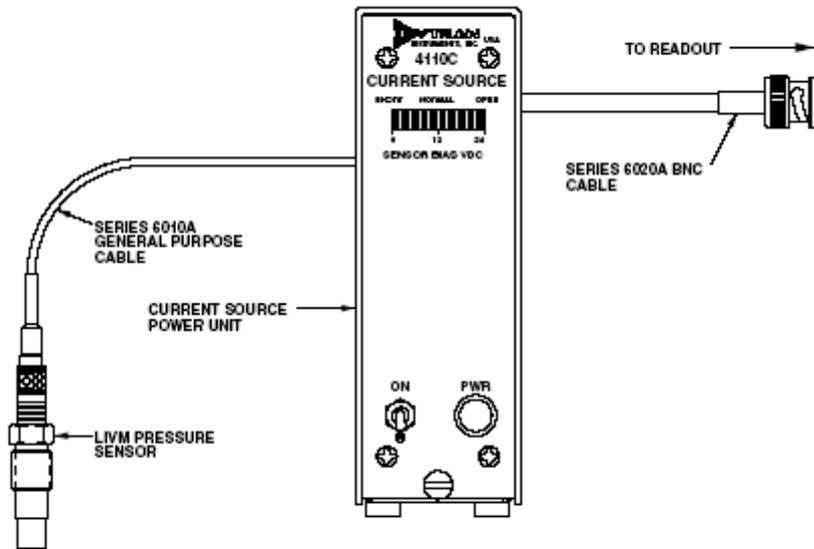


Figure 4: The complete measurement system

Figure 4 illustrates the components of a typical LVM pressure measurement system. Pressure sensors may be used with a variety of current source power units depending upon the specific application. Consult the section “Introduction to Current Source Power Units” and the specification charts in that section for help in selecting the best power unit for your needs.

Low Frequency Response

Refer to the section “Low Frequency Response and Quasi-Static Behavior of LVM Sensors” in this series for an explanation of these two parameters and how they relate to sensor discharge time constant (TC).

CHARGE MODE PRESSURE SENSORS

Dytran charge mode pressure sensors utilize pure synthetic quartz crystals to produce electrostatic charge signals analogous to pressure changes at the diaphragm. The very rigid structures of the charge mode quartz elements are similar to those of the LVM sensors, however, there are no amplifiers built into the charge mode sensors.

Advantages of Charge Mode

The absence of internal electronics allows the charge mode sensor to be used at temperatures well above the 250°F upper limit of most LVM sensors. Charge mode sensors must be used with charge amplifiers, special high input impedance amplifiers which have the ability to measure the very small charges (expressed in pC or 10-12 Coulombs) without modifying them.

Two distinctly different types of charge amplifiers for use with charge mode pressure sensors are available from Dytran:

1. The versatile laboratory type direct coupled electrostatic charge amplifier, Model 4165 which provides for easy standardization of system sensitivity and convenient range selection. Because of its long discharge time constant capability, Model 4165 is especially useful for calibration of sensors by quasi-static means (dead weight testers) and for very low frequency measurements. Model 4165 also features a reset (ground) button for returning the output to zero as well as interchangeable plug-in filters and variable discharge time constant settings for control of system "drift" in thermally active environments.

2. Series 4750A, 4750B and 4705A are miniature fixed range in-line type charge amplifiers designed for use in "Hybrid" systems. These amplifiers adapt charge mode sensors to LIVM power units and allow you to use these sensors in dirty and damp field environments, just like LIVM sensors, but at higher temperatures. These charge amplifiers are powered by standard LIVM current source power units and present a low cost field useable alternative to the expensive laboratory charge amplifier while providing the convenience of 2-wire LIVM operation.

When to Select Charge Mode

You will normally use charge mode pressure sensors in the following situations:

1. When making routine dynamic measurements above the +250°F limit of LIVM sensors.
2. When range switching capability and wide dynamic range of the laboratory charge amplifier are desired.
3. When calibrating charge mode pressure sensors by quasi-static methods such as a dead weight tester. The extremely long discharge TC obtainable with electrostatic charge amplifiers such as the Model 4165, make them ideal; for this purpose.

You would not choose charge mode pressure sensors in the following situations:

1. When operating in dirty or damp field environments driving very long cables from sensor to power unit or from power unit to readout with un-buffered power unit. (Buffered units are not affected by cable length from power unit to readout).
2. When you are making multi-channel measurements and cost is a factor.
3. When the fixed range simplicity of LIVM sensors is a positive factor such as when making multiple dedicated range measurements.

The Conventional Charge Mode System

In the charge mode system shown in Figure 5 below, the sensor is connected to the input of the electrostatic laboratory type charge amplifier using low-noise treated coaxial cable.

It is important to use coaxial cable for this purpose because the input to a charge amplifier is at a very high impedance level and as such, is susceptible to noise pickup if not continuously shielded.

The low noise treatment is also important because physical motion of untreated coaxial cable will generate electrostatic charges which will show up on the signal as spurious noise. This type of cable-generated noise is called triboelectric noise. Low noise cable is treated with a

special coating within the layers of the cable which minimize the generation of this type of noise.

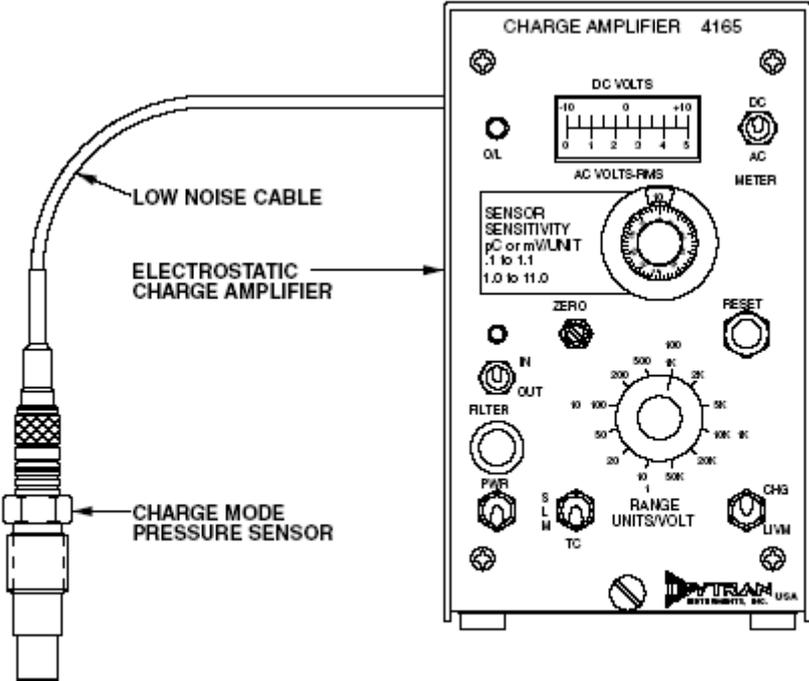


Figure 5: Conventional charge mode system.

In moist and dirty environments, it may be necessary to protect the high impedance cable connections at the sensor with shrink tubing over the cable connector. To facilitate this, most Dytran pressure sensors are designed with shrink tubing grooves just below the connector. It is recommended that you use about an inch of sealing type shrink tubing across the connection after the cable nut has been tightened securely by hand. This will seal the connection against moisture and other contaminants which can cause loss of insulation resistance at the input to the charge amplifier and which may cause annoying “drifting” of the charge amplifier output.

The Hybrid System

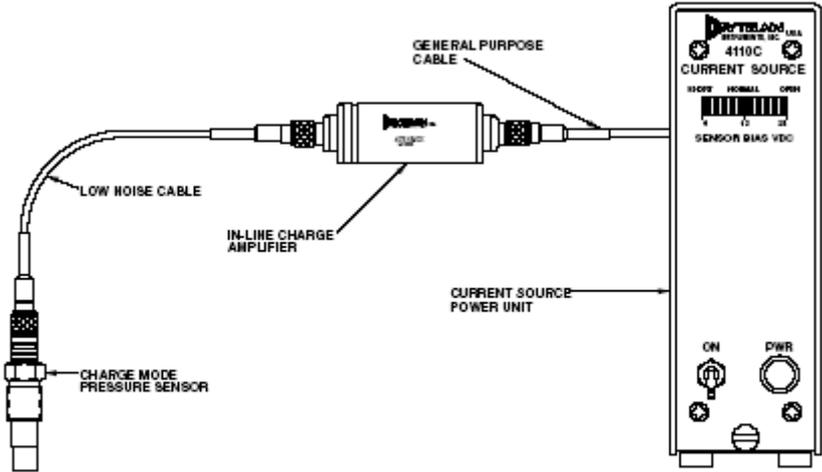


Figure 6: A hybrid pressure measurement system

The hybrid system combines charge mode and LIVM systems as shown in Figure 6. A charge mode sensor is connected to a miniature in-line charge amplifier which is driven by a conventional LIVM constant current power unit. The in-line charge amplifier (so called because it is inserted in the line between the sensor and the power unit) is powered by constant current power from the LIVM power unit. These charge amplifiers, operating over two wires like LIVM sensors, convert the charge signal from the charge mode sensor to a voltage signal which appears at the output jack of the power unit.

High Frequency Response

The high frequency behavior of piezoelectric pressure sensors approximates that of a second order spring-mass system with close to zero damping. (See Figure 7 below)

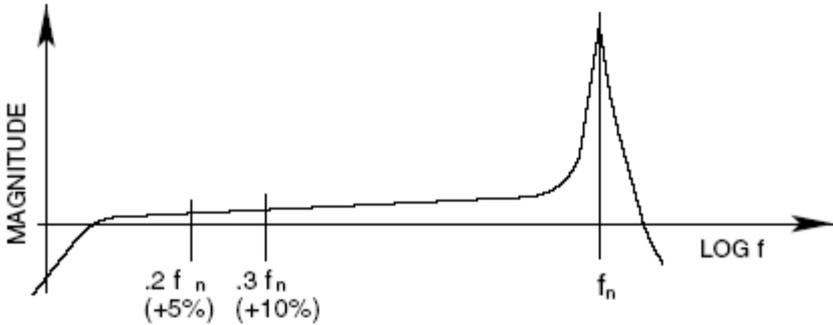


Figure 7: Frequency response of a piezoelectric pressure sensor.

Figure 7 is a graph of Magnification Factor vs. Log Frequency for a typical piezoelectric sensor. As shown by the graph, the sensitivity of the sensor will rise about .5db (5%) at 20% of the natural frequency f_n and will rise about 1db (10%) at 30% of f_n . The corresponding phase lag for these two points are one and two degrees respectively. These parameters will

define the useable frequency range of the sensor based upon its natural frequency. The natural frequency of each sensor is recorded on the calibration sheet supplied with each instrument.

Installation

Installation instructions, including port preparation details, are supplied with every Dytran pressure sensor. Follow these instructions carefully. These sensors are precision measuring instruments and it is important for optimum accuracy, that they be properly installed. Prepare mounting ports carefully, paying particular attention to the seal seat. It is important that the sealing surface be smooth and free from chatter marks and other machining imperfections.

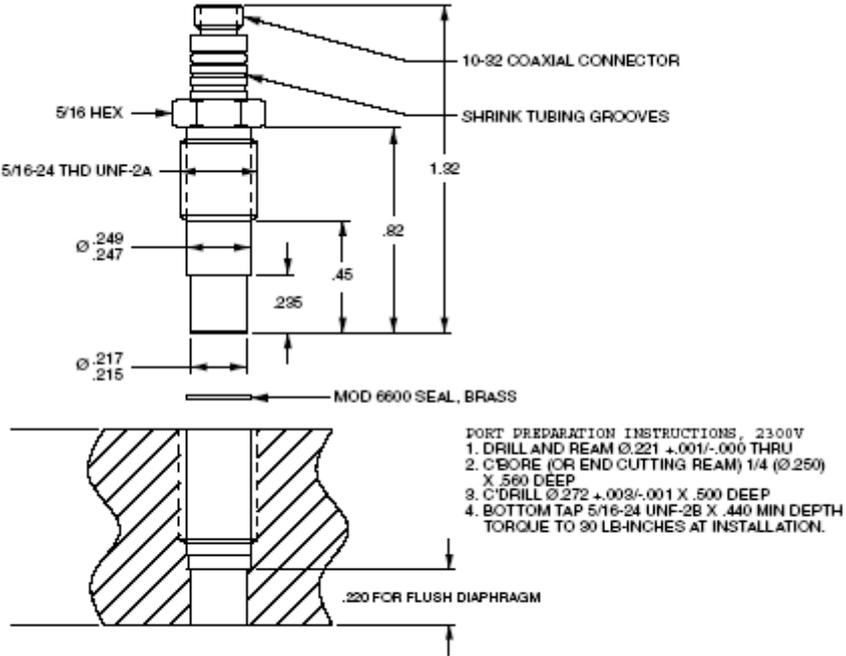


Figure 8: Typical flush diaphragm installation.

Use a torque wrench to monitor the mounting torque. All piezoelectric sensors are sensitive to mounting torque value to some degree so for highest accuracy, duplicate the torque value specified on the Outline/Installation drawing provided with the sensor. This is the torque value with which the sensor was calibrated at the factory. Always use the seal provided with the sensor to avoid damage to the mounting port or mounting adaptor from the hardened steel housing of the sensor.

Recessed Diaphragm Installation

A pressure sensor mounted with a passage in front of the diaphragm as shown in Figure 9 (recessed diaphragm mount) will exhibit impaired high frequency response and rise time characteristics when compared to the flush mount sensor characteristics. These limitations are due to the passage. The column of gas or liquid in the passage cavity ahead of the diaphragm is in itself a second order system with its own resonant frequency characteristic. Since we are using this column to couple the pressure event to the sensor diaphragm, its frequency characteristics are most important.

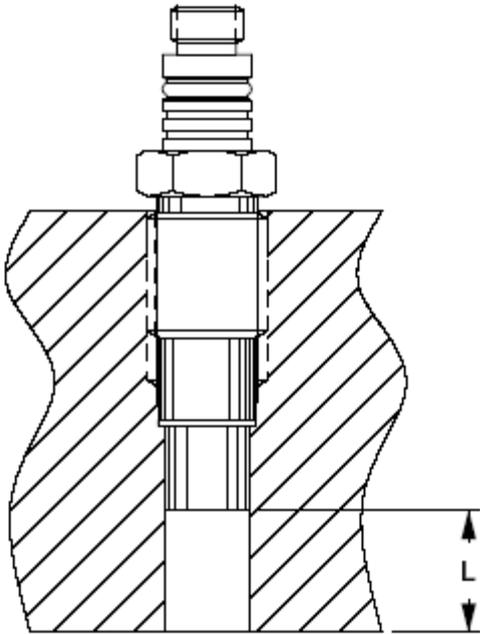


Figure 9: The recessed diaphragm installation.

The following chart (Figure 10) displays the theoretical effect of various length passages formed by the diaphragm recess. The formula used to calculate the chart value is the well-known pipe organ formula. The approximate fastest rise time that will pass through the passage is also related to the passage resonance.

$$f_n = \frac{v}{4L} \quad \text{where:} \quad (\text{Eq. 1})$$

- f_n = passage resonant frequency (Hz)
- v = velocity of sound in air (in./Sec)
- L = cavity length (in.)

Note: The value for sound in air at sea level, 20°C is 13,512 in./Sec.

As a general rule, the frequency response of a recessed diaphragm system will be useable to about 1/3 of the passage natural frequency. The fastest rise time that can be expected to be transmitted by the passage is roughly 1/3 of the period of this frequency. These are

general guide rules only and are not hard and fast rules. Remember that the chart values, (Figure 10), must be corrected for variations in media and temperature.

.001	3.3 mHz	.1 μ Sec
.002	1.6 mHz	.2 μ Sec
.003	1.1 mHz	.3 μ Sec
.005	660 kHz	.5 μ Sec
.010	330 kHz	1 μ Sec
.050	66 kHz	5 μ Sec
.100	33 kHz	10 μ Sec
.200	16.6 kHz	20 μ Sec
.500	6.6 kHz	50 μ Sec
1.00	3.3 kHz	.1 mSec
2.00	1.66 kHz	.2 mSec

Figure 10: Cavity length vs. resonant frequency and rise time

Mounting Adapters

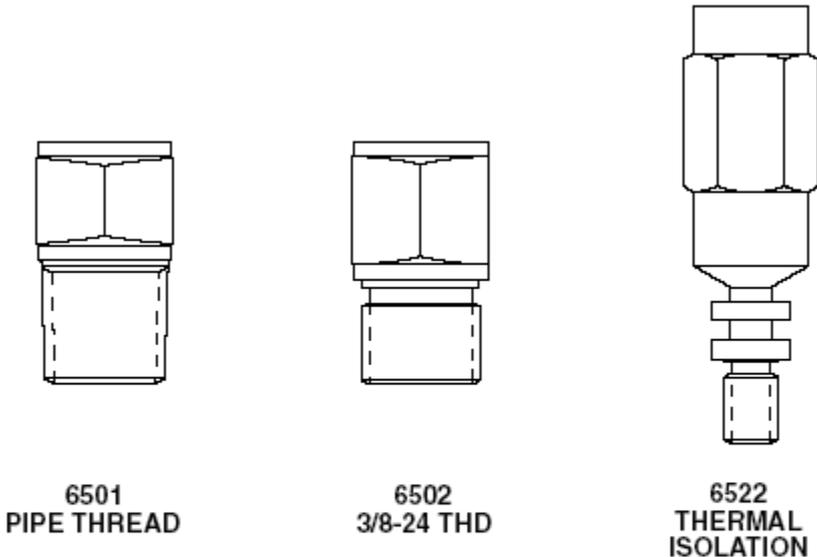


Figure 11: Various mounting adapters

Several mounting adapters are available which can simplify sensor installation. The critical internal seal seats in these adapters are precision machined to preclude leakage and the larger external threads provided by some of these adapters require less precision machining and skill in mounting. Mounting adapters can be used to adapt the installation to pipe threads or larger machine threads, to isolate the sensor diaphragm from high flash temperature (Model 6522) or from ground loop interference (Model 6520). Custom mounting adapters can

be designed and fabricated to suit most applications. Contact the factory for help in solving your special installation problem.