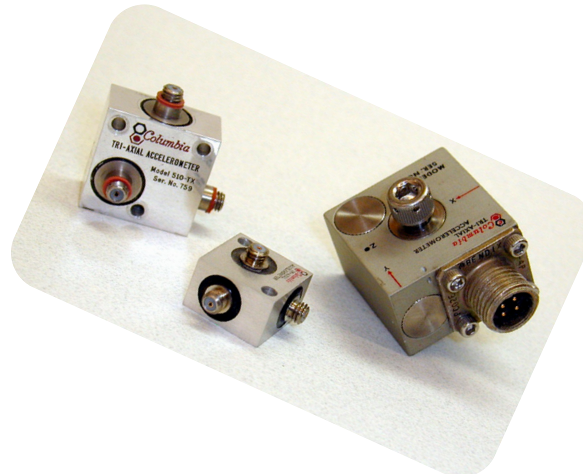

Piezoelectric Sensor Technology

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Shock and Vibration Information

Introduction

Shock and vibration can be expressed in terms of variations in displacement, velocity or acceleration with time. Acceleration is the most frequently used since the inertial load or destructive force is equal to mass times acceleration,

$$F = Ma \qquad \text{(Eq.1)}$$

The maximum destructive force (Fm) is obtained from

$$Fm = WG \qquad \text{(Eq.2)}$$

Where ,

W = weight of the specimen

G = the maximum acceleration in gravity units

Acceleration, velocity and displacement measurements can only be easily correlated when the vibration being measured is a simple sinusoidal motion containing one frequency. However, the vibratory motions measured in practice almost always contain some harmonic distortion even with sinusoidal laboratory shakers. Thus, if acceleration data is needed, a transducer that senses acceleration should be used. Correlations should not be attempted with velocity and displacement data without careful consideration of the calculations that are necessary for complex wave motion.

Application Information

Accurate measurement of shock and vibration phenomena requires an understanding of the transducer and its associated electronic equipment in terms of the dynamic response as a system. Very often records from the past show serious errors (in some cases by a factor as much as 100 times) have been introduced in test work by the spurious output of the measuring instrumentation.

The wide dynamic responses of the Columbia Accelerometer and Instrumentation design are capable of handling almost any problem occurring today with accelerations ranges from .001 to 40,000 g at frequencies from 1 to 15,000 cps, thereby, greatly reducing the possibility of errors resulting in failure of the measuring system.

Accelerometer Equivalent Circuits

A knowledge of the equivalent circuits for a piezoelectric transducer is very helpful to understand the problems associated with their use. The accelerometer may be considered either a charge generator or a voltage generator. Both circuits in the actual and simple form as shown below.

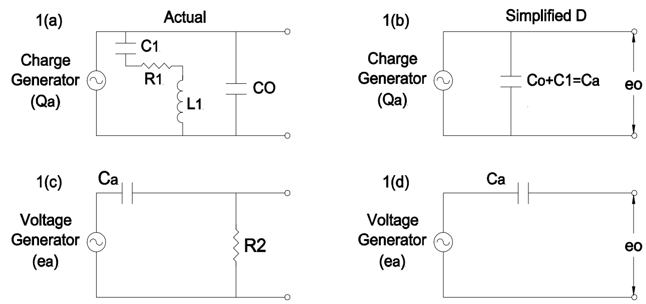

Fig. 1 Two Equivalent Circuit-Forms for Piezoelectric Transducers

Since the operating frequencies of the accelerometer are relatively low, only the capacitive reactance is appreciable compared to the inductive reactance and resistance.

In 1(b) a charge q_a is generated across the crystal faces for any given acceleration measurement. The voltage e_o out of the accelerometer is

$$eo = q_a / C_a \qquad \text{(Eq.3)}$$

where C_a is the capacitance of the accelerometer. The charge q_a generated per unit of acceleration is independent of any shunting capacity.

In 1(d) a voltage e_a is generated across the crystal faces for any given acceleration measurement. Here it is evident the voltage e_o out will vary with the external shunting capacity.

Coulomb or Charge Sensitivity

Each Columbia accelerometer is provided with a calibration card stating the sensitivity in pCMB/G. The charge sensitivity S_q can be obtained from Eq. (3) if the total shunting capacity C_s is known. The expression is as follows:

$$S_q = S(C_a + C_s) \times 10^{-3} \text{(coulombs)/(peak g)} \qquad \text{(Eq. 4)}$$

where,

S = the peak voltage output e_o (peak) divided by the peak acceleration g in gravity units, that is,

S is the factory supplied sensitivity in peak millivolts per peak g calibrated with 100pF total external shunting capacitance.

C_s is the total external shunting capacitance of 100pF

C_a is the crystal capacitance in pF

Substituting for C_s in Eq.(4) the relation becomes

$$S_q = S(C_a + 100) \times 10^{-3} \text{(coulombs)/(peak g)} \qquad \text{(Eq. 5)}$$

Voltage Sensitivity

The voltage sensitivity vrs frequency also appears on every calibration card. This calibration S is made with exactly 100pF of total external shunting capacitance across the accelerometer output. The sensitivities are given in peak millivolts per single peak g. The root mean square sensitivity $S_{(RMS)}$ is S/1.41. When measuring the accelerometer output on an RMS VTVM use $S_{(RMS)}$ for the calibration value. When measurements of single peak voltage on meters or oscillographic records are more convenient, use S for the accelerometer sensitivity. If measuring peak to peak voltages, use 2 x S for the calibration sensitivity. The open circuit sensitivity So can be determined from the sensitivity S from the following equation:

$$S_o = S\,(C_a = 100) \,/\, C_a \qquad \text{(Eq. 6)}$$

Effect of Cables and Capacity on Accelerometer Sensitivity

A correction must be made when any capacity in the form of cables, connectors and input capacitance of the matching amplifier or cathode follower is put on the output of the accelerometer other than the 100pF used in the factory calibration to determine the sensitivity S. The new sensitivity S_1 may be obtained from the relation,

$$S_1 = S\,(C_a + 100)/(C_a + C_s) \text{ (peak mv)/(peak g)} \qquad \text{(Eq. 7)}$$

Where,

S is the factory supplied voltage sensitivity in peak mv/peak g with 100pF total external shunting capacitance.

C_a is the crystal capacitance in pF

C_s is the total external capacitance including the cable in pF

S_1 is the new sensitivity for any total shunting capacitance C_s

Normalization of Accelerometer Sensitivity

The COLUMBIA Amplifiers are equipped with input shunt capacitors and variable gain controls that allow standardization of accelerometer sensitivities. The input shunt capacitors consist of a variable capacitor along with fixed capacitors. The variable trim capacitor allow standardization of many accelerometer sensitivities to a single value so that a convenient readout on VTVM scale can be made directly in g's. For example, if a 12 rms mv/peak g accelerometer is standardized to 10rms mv/peak g then a full scale setting of 0.1 rms volt will indicate 10g for full scale deflection. This normally permits reading from 0.1g to 10 g. The fixed capacitors allow reduction in sensitivities by as much as 10 and 100 times for higher g-level shock work in 1000 g range where the 10-20 overload voltage limit of the amplifiers may be exceeded. The capacity necessary for standardization to a specific value can be determined by solving for Cs in Eq. 8.

$$C_s = \frac{S}{S_1}(C_a + 100) - C_a \qquad \text{(Eq. 8)}$$

Charge Amplifier

The functional circuit of a transducer charge amplifier system is shown in Fig. 2. In this amplifier the capacitive component of the input impedance is very large differing from a cathode or emmiter follower where the resistive component is very high. The equivalent capacitance can be shown to behave in a manner somewhat similar to the well known Miller effect. The amplifier derives its high capacitive component by negative feedback and is proportional to the open loop gain of the amplifier. Hence, the effect input capacitance of the amplifier is:

$$C = C_{fb}\,(1 + A) \qquad \text{(Eq. 9)}$$

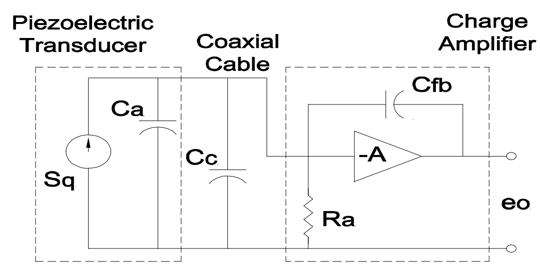

Fig. 2

Since the gain is generally very large, that is A>>1 the input capacitance is approximately equal to Cfb times A. The high input resistance Ra is developed by the use of field effect transistors in the input stage. The combination of high input capacitance and high input resistance results in the capability of a very low frequency response with small transducer capacitances. Thus,

$$F1 = \frac{1}{2\pi R_a C_{fb}\,(1+A)} \qquad \text{(Eq. 10)}$$

The overall charge gain of the amplifier is defined as,

$$A_q = \frac{-E_o}{E_t C_t} \qquad \text{(Eq. 11)}$$

and the charge gain of the amplifier in terms of volts output/pcmb input is

$$A_q = \frac{1}{C_{fb}}\left[\frac{1}{1 + \frac{1}{A} + \frac{C_c + C_t}{A\ C_{fb}}}\right] \qquad \text{(Eq. 12)}$$

normally,

$$AC_{fb} > C_C + C_t \text{ and } A >> 1$$

Therefore the equation above becomes approx.,

$$Aq = -\frac{1}{Cfb} \qquad \text{(Eq. 13)}$$

Indicating the charge gain is inversely proportional to minus the feedback capacitance.

Transducers

Transducers should ideally be isolated from ground by at least 10MΩ. Where a grounded transducer is employed, noise pick-up from ground currents in the structure under test may prevent accurately measuring low level signals. Where this occurs, it may be necessary to employ some sort of "insulating stud" or other method to isolate the transducer from structure ground.

Transducers used with the charge amplifiers must present a capacitive impedance to the input of the amplifier. Resistive shunting to ground will adversely affect amplifier operation. If the shunt resistance falls below approximately 50MΩ, the amplifier DC bias input will shift until at some value of shunt resistance the amplifier will become inoperative.

If it is necessary to use a device which will not maintain the minimum required shunt resistance, a scheme such as shown in Fig. 3 may be employed. The capacitor Cs must be a very low leakage type such as a film capacitor or high quality tantalum.

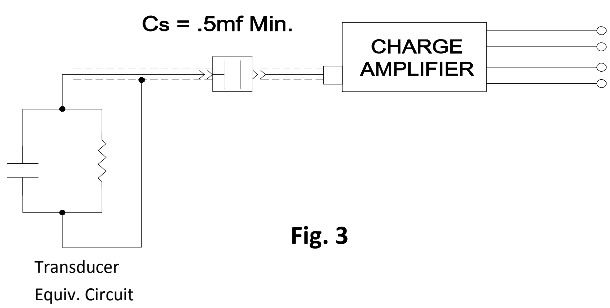

Fig. 3

An additional consideration when using a low shunt resistance capacitive device is the deterioration of the low frequency response due to the RC time constant formed. The –3db response point is given by the equation.

$$f\,(-3dB) = \frac{1}{2\pi RC} \quad \begin{array}{c}\text{(R in megohms)}\\ \text{(C in microfarads)}\end{array} \qquad \text{(Eq. 14)}$$

The –5% response point is approximately 3X the –3db frequency.

Frequency Response Characteristics of Crystal Accelerometers

The accuracy with which a piezoelectric pickup responds to a vibratory or shock motion is of considerable importance.

Usually, the lower frequency response is limited by electrical parameters and consequently is determined from electrical considerations. The upper frequency response is usually limited by the first mechanical resonance of the accelerometer system and is therefore determined from calculations based on mechanical characteristics.

Lower Half Power Cut-Off Frequency

The low frequency response of a crystal type accelerometer is related to the RC time constant of the accelerometer and the matching electronics. A typical pick-up with a crystal capacitance of 580pF must operate into a high input impedance of 100MΩ or more when used with VTVM in order to obtain satisfactory frequency response below 100 cps.