TP 216

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Piezoelectric Transducer Calibration Simulation Method

by James E. Rhodes

It is often desirable to check a transducer system's calibration before, during, or after a test. A convenient method for doing so, now in wide use, involves insertion of a voltage source in series with an ungrounded transducer. The voltage simulates the self-generating output of the transducer.

The technique, useful in both laboratory and field tests, is applicable to practically every situation involving piezoelectric transducer.

Typical of the situations in which the technique is advantageous are:

1. Establishing the proper system gain calibrations when many elements are involved in a system. This applies, for example, to the adjustment of system gain in order to obtain the desired deflection of a recording galvanometer at a speciified input level.

2. Checking a system for gross malfunction, i.e., shorts, opens and unintentional maladjustment. This may apply to laboratory testing as well as to flight tests.

3. Evaluating the electrical characteristics of pream plifiers, signal conditioning equipment, readout and data storage devices under conditions which closely simulate the final measuring situations.

How to Do It

The test method requires insulating the transducer case from instrument ground. With an accelerometer, the best way is to insulate the accelerometer from electrical contact with mounting surfaces. This is quite simple if the accelerometer is lying open upon a bench; if the accelerometer is attached to a test specimen the use of insulating mounting studs is recommended. Endevco's Type 2980B is such a stud. Electrical insulation is also inherent in certain adhesive mounting techniques.

Next the ground side of the signal output is broken and measures are taken to insert a voltage in series with the transducer on the ground side (Fig. 1).

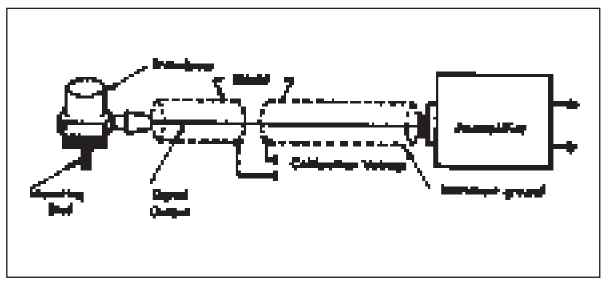


FIGURE 1
INSERTING VOLTAGE IN SERIES

The usual method assumes that there is no mechanical excitation of the transducer while the simulation of calibration is being performed. Techniques whereby the simulation voltage could be applied in the midst of measurements would require some means of separating the calibration signal from the transducer output.

There are several techniques based on the set-up as diagrammed in Figure 1. Some of them, with some of their advantages or limitations, are:

(1) Breaking the shield of the coaxial cable and connecting a voltage source to the two sections

of the shield. Satisfactory in the laboratory as an emergency measure, but reliable and workmanlike connections are difficult to make. A small portion of the signal lead may be left unshielded - a possible source of noise pickup.

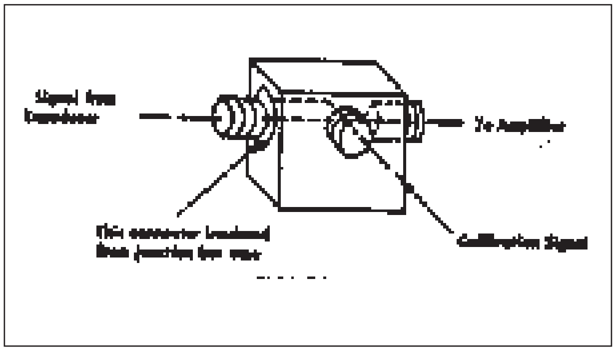
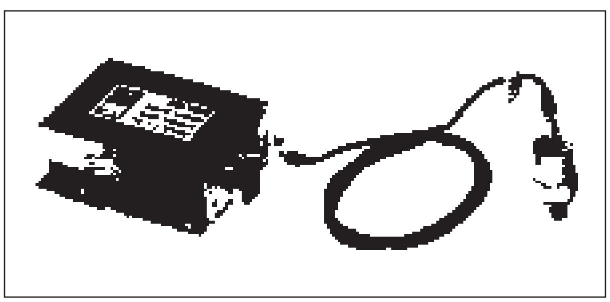


FIGURE 2
“T” JUNCTION BOX

(2) Incorporating a “T” junction, fitted with con nectors to match the associated cables, at which point a voltage source may be connected. With this configuration the ground circuit is open within the junction box and must be closed externally (measurements cannot be made when the calibration input connector is left open). A shorting plug on the calibration signal connector can be used to short the calibration input during actual measurements.

The junction box should be insulated so that it will not ground out to a mounting surface when it is installed, a precaution that will pre vent creation of a ground loop in the measuring system.



The ENDEVCO® 28319A System includes a Model 2642M58 Amplifier and a Model 2272M15 Accelerometer. Several amplifiers in this series incorporate a fixed resistor or a potentiometer as a ground-side calibration resistance.

(3) Incorporating a “T” junction or “cable insert,” similar to that outlined above, which contains, however, an internal resistor or potentiometer to close the ground circuit and permit measure ments with external calibration circuitry con nected or disconnected. In some cases, calibra tion simulation is based upon the current rather than the voltage from the calibration source. Current measurement is preferable if the lead resistance from the cable insert to the calibra tion source is appreciable in comparison with the internal resistor in the cable insert. When the basis of calibration simulation is the current through the calibration resistor, the simulation voltage is E - 1R, where I is the calibration current and R is the resistance of the calibration resistor.

A commercial part incorporating a 100-ohm resistor is Endevco Part No. 2944.1. Its connectors mate with the standard connectors on Endevco coaxial cables.

(4) Providing a calibration resistance in the associat ed amplifier. Calibration voltage depends on the length of coaxial cable between the transducer and the amplifier.

(5) Providing an internal calibration resistance within the transducer being used. Two connec tors and two coaxial cables are required - one for signal output and one for calibration input. has the advantage that the level of calibration voltage is independent of any external capaci tance in the system. With all techniques that use insertion of a calibration voltage at some point outside the transducer, the calibration voltage is dependent upon the external capaci tance (primarily cable capacitance) between the transducer and the point of voltage insertion.

Circuit Theory Background

The usual simplified transducer equivalent circuit consists of a charge generator in parallel with the transducer capacitance. The amount of charge generated is proportional to the input excitation, as per Figure 3.

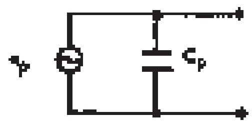


FIGURE 3

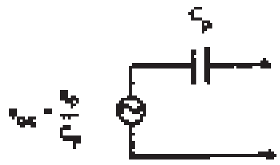


FIGURE 4

This transducer circuit is equivalent to a voltage generator and a series capacitance (Fig. 4):

$e_{oc} = \frac{q_p}{C_p} =$ open circuit voltage generated by the transducer.

An actual measuring circuit involves an external capacitance and a shunt resistance. The external capacitance C_1 is commonly cable capacitance plus input capacitance of the associated amplifier. The shunt resistance R_L is commonly the input resistance of the associated amplifier.

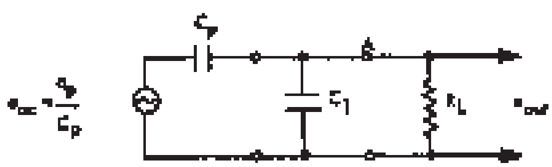


FIGURE 5

This circuit is, in turn, equivalent to:

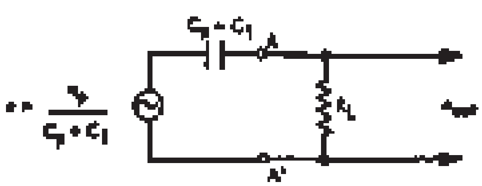


FIGURE 6

where

e=XX= open circuit voltage at A - A^1

The above system is subject to a low frequency rolloff which is dependent upon the time constant R_L (XXXXX) . In other words, for accurate measurements the resistance R_L should be large compared to the reactance of the capacitance XXXXX) at the lowest frequency of concern.

To obtain large values of the time constant R_L XXX , it is common practice to use an amplifier with a large input resistance (R_L =XXX ohms), to use a transducer with a large capacitance XXX, or to use a large external capacitance XXX.

When the time constant XXX is sufficiently large, the voltage XXX is dependent upon the charge at the transducer and the total system capacitance:

$$e_{out} = \frac{q_p}{C_p + C_1}$$

The addition of the external capacitance C_1 reduces the voltage at the amplifier input. When the source capacitance XXX is large, the decrease in output due to the addition of C_1 is minimized.

It should be noted that the presence of C_1 and R_L in the measuring circuit has no effect at any time on the high frequency response of the system, even though the low frequency response is determined by the time constant R_L XXX

Measuring Circuit Including Calibration Resistor

When a voltage insertion resistor is included in the system, the equivalent measuring circuit with a voltage amplifier is as follows:

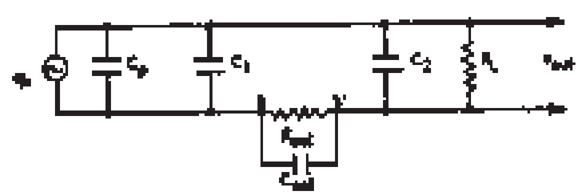


FIGURE 7

RXXX may be an actual series resistance inserted into the system, or may be the internal resistance of a voltage generating device connected to B-B' for calibration voltage insertion. C_1 is the external capacitance of the cable between the transducer and circuit point B where XXX is inserted into the system. C_2 is generally cable capacitance and/or amplifier input capacitance. XXX is the shunt capacitance of the calibration voltage source; in actual use RXX will be compared with XXX and the presence of XX can be ignored.

It is of interest to determine whether there are any limitations on the value of XX which can be used.

Ignoring XX the above circuit is equivalent to:

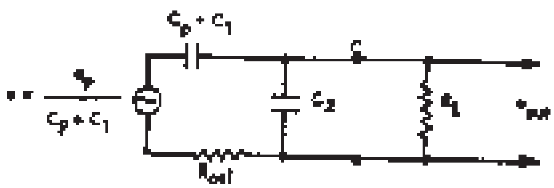


FIGURE 8

Consider the portion of the circuit excluding RL:

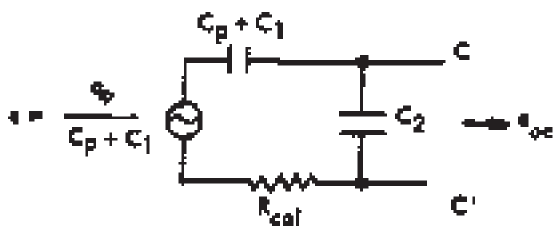


FIGURE 9

For this portion of the circuit, the open circuit output voltage at C - C' is:

and the equivalent circuit reduces to the normal

$$e_{oc} = \frac{q_p}{C_p + C_1}\left[\frac{1}{\frac{C_p + C_1 + C_2}{C_p + C_1} + j\, R_{cal} C_2}\right]$$

if $\omega R_{cal} C_2$ is small compared with $\frac{C_p + C_1 + C_2}{C_p + C_1}$, reduces to:

$$e_{oc} = \frac{q_p}{C_p + C_1 + C_2}$$

equivalent previously discussed:

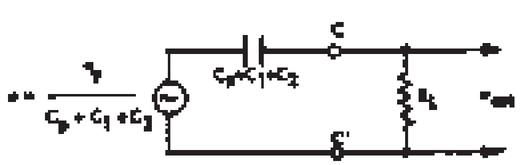


FIGURE 10

Therefore, in order for XXX not to affect the circuit performance during measurement, it is essen-

$$\omega R_{cal} C_2 << \frac{C_p + C_1 + C_2}{C_p + C_1}$$

tial that

at the highest frequency of interest.

In all practical situations encountered to date, a value of XXX of the order of 100 ohms has proven to be more than satisfactory when a high impedance voltage amplifier is used with the system.

When a charge amplifier is used rather than a voltage amplifier, the above requirement reduces to:

$$R_{cal} << \frac{1}{\omega (C_p + C_2)}$$

at the highest frequency of interest.

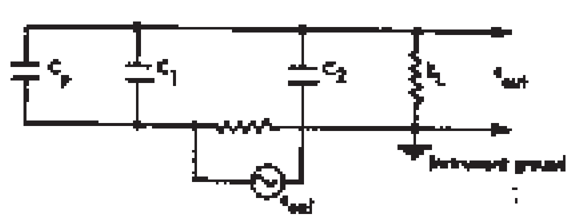
For XXX = 100 ohms and a maximum frequency of interest at 10 Kcps, it is satisfactory for XXX to be as large as ten thousand picofarads or more. With the charge amplifier, less than 1 per cent fall-off in high frequency response will be encountered if

$$10\, R_{cal} \leq \frac{1}{\omega (C_p + C_2)}$$

at the highest frequency of interest.

Calibration Voltage Level

It is of interest to determine the calibration voltage



that should be used. During calibration insertion the transducer acts as a passive capacitor. The equivalent circuit is:

FIGURE 11

or, rearranging and combining elements:

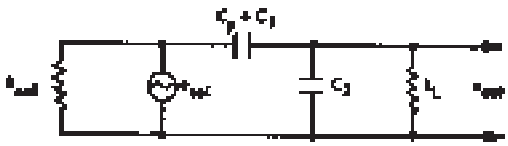


FIGURE 12

$$e_{cal} = \frac{q_T}{C_T + C_1}$$

In order to simulate the transducer properly, the calibration voltage sensitivity must be

For an accelerometer:

XX = calibration voltage sensitivity in peak volts/peak g
XX = transducer charge sensitivity in pk pcmb/peak g
XX = transducer capacitance in pf
XX = external capacitance in pf between the accelerometer and the point of calibration voltage insertion.

Laboratory calibrations of piezoelectric accelerometers are sometimes reported in terms of a known voltage sensitivity with a known external capacitance. In this case

XX = XXX where
XX = transducer charge sensitivity in pk pcmb/peak g
XX = known voltage sensitivity in pk volts/pk g with an external capacitance XXX
XX = transducer capacitance in pf

$$e_{cal} = e_E \left(\frac{C_T + C_E}{C_T + C_1} \right)$$

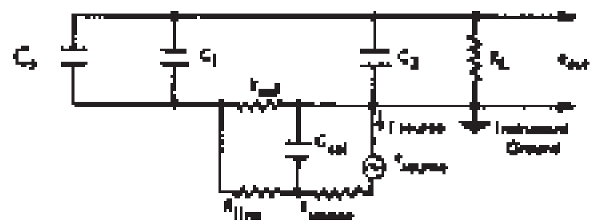
XX = external capacitance in pf for which e_g is known.

Calibration Simulation

Substituting in the previous relationship

In the above conclusion, eXXX and e_g can be either in volts/g or millivolts/g, as long as consistency is maintained. Voltages and g levels can likewise be peak, RMS, or peak-to-peak, as long as they are consistent.

The discussion concerning piezoelectric accelerometers is pertinent, too, to piezoelectric pressure pickups and force gages. Sensitivities are then



expressed in electrical output per psi or electrical output per pound rather than electrical output per g. Electrical insulation of a pressure pickup or force gage from instrument ground may be difficult if not impractical in some situations.

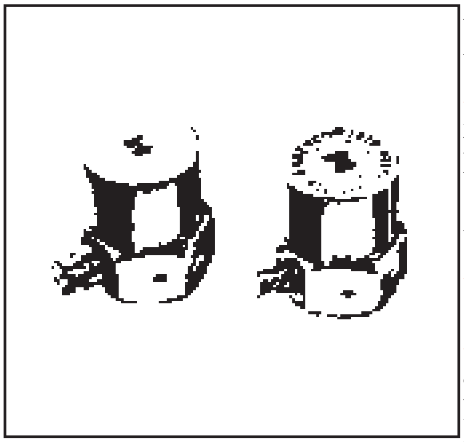
With respect to the calibration circuit itself, there are three items worth mentioning when considering the following circuit approximation:

FIGURE 12

XXX = Output resistance of the calibration voltage source.
XXX is primarily the cable capacitance of the cable from the insertion point to the cali bration voltage source.

(1) The calibration voltage may not be the same as the voltage at the source being used to generate the calibration signal; it is usually desirable that the resistance XXX be as small as is practical, and XXX plus XXX may then be appreciable in comparison with XXX.
(2) The capacitive reactance XXX will normally be very large compared with the resistances involved; however, it may be well to make cer-

ENDEVCO PRODUCTS RELATED TO THIS ARTICLE

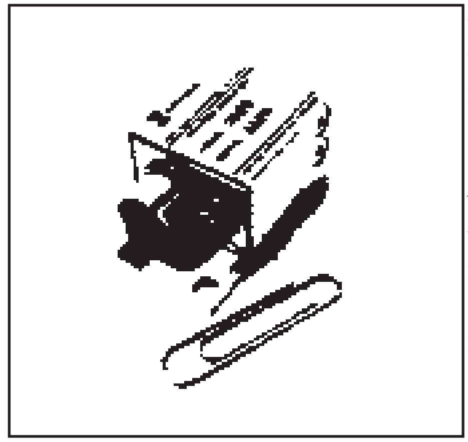


tain that XXX is at least 10 times XXX + XXX at the highest frequency to be used in the calibration simulation.

(3) It is desirable that the voltage XXX be isolated from any frame or power supply ground, such that the system instrument ground can be tied to earth ground at one point only. This may suggest transformer coupling of the voltage XXX into the calibration circuit.

Model 2271A and 2275 Precision Isobase® Accelerometers

The Models 2271A and 2275 piezoelectric accelerometers feature extremely low output sensitivity to strain or the bending of their mounting surface. Their wide and useful dynamic characteristics of 2 Hz to 5500 Hz and 0 to 10,000 g permit them



to be used for most shock and vibration measurements.

Transverse sensitivity is very low, 2% maximum. Flat charge-temperature response, XXX 3% nominal, over the range of -300⁰F. to -500⁰F., is achieved with Piezite® Type P-10 crystal material.