8 TESTING PZT DISCS AND PLATES

8.1 General

This chapter describes methods to check the piezoelectric charge- and voltage-constants, polarity and coupling factors of PZT products.

The measuring methods are based on following formulas:

$$E= -g_{33}\, T \qquad (8.1)$$

$$Q = -d_{33}\, F \qquad (8.2)$$

The charge constant d_{33} and the voltage constant g_{33} are related via the dielectric constant of the ceramic bv:

$$d_{33} - g_{33}\, \varepsilon_{33}^{T} \qquad (8.3)$$

These formulas are valid for PZT -elements stressed in the same direction as their polarization and with the electrodes on the end faces perpendicular to this direction.

For most measurements, only compressive forces are used, which, by definition, have a negative sign. So the electrode that was positive during the polarization will have a positive charge induced on it. Normally this electrode is marked. Upon relaxation of the force, the charge is re-absorbed by the piezoelectric material. A tensile force would induce a negative charge on the marked electrode.

Several methods of measuring charge constant, voltage constant and polarity will be described. The effective coupling coefficient (k_{eff}) will be derived from the resonance behaviour.

8.2 Dynamical methods

With the so-called *Berlincourt* tester, an alternating (e.g. 50 Hz) force is applied to the unknown PZT -element and to a calibrated PZT -cylinder (Fig.8.1) by means of a loudspeaker coil for example. The amplitudes and phases of the voltages from both PZT -elements are compared.

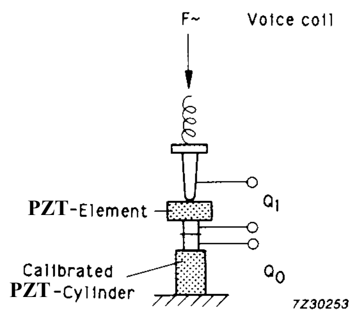


Fig.8.1 Dynamic measurement principle as used in the Berlincourt tester.
(type CPOT 3300, Channel Products Inc. Chagain Falls, Ohio 44022, USA)

This method is used by many manufacturers to measure polarity and charge constants of piezoelectric products.

A drawback of this method is that the forces are rather low. So the values measured give low-signal properties of the material. Often this is not enough information to predict the actual performance of a piezo device operating at high force levels.

8.3 Quasi static method

If only polarity needs to be checked, this is a popular method with the advantage that it can be carved out using standard laboratory equipment.

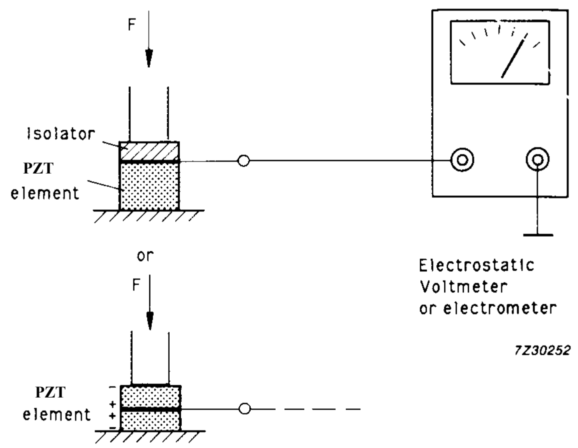


Fig.8.2 Static test method using an electrometer.
(GOSSEN GMBH, Erlangen, Germany)

A difficulty might be the low capacitance of the PZT element, which means that the voltage must be measured with equipment having a very high input impedance to give a long enough RC-time (Fig.8.2).

An isolated contact pin is placed on the surface of the product to be tested and then tapped manually (Fig.8.3). The manual tapping should be done via some isolating material with high mechanical damping (e.g. rubber or soft PVC). Because of the mechanical damping, the force will be mainly compressive, no ringing occurs. Since the tapping force is somewhat variable, only polarity can be checked in this way.

The output can be measured on a standard oscilloscope. The high input impedance of this instrument together with the lag introduced by the screen phosphors and the eye's persistence of vision make it possible to observe the positive or negative excursions on the screen.

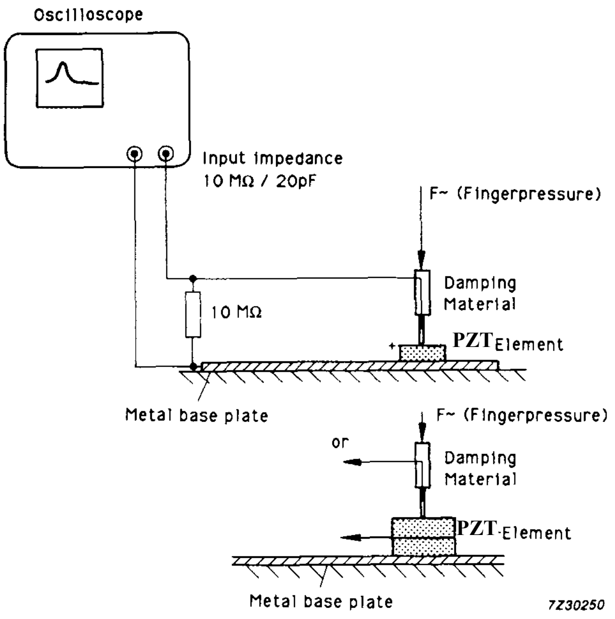


Fig.8.3 Test method using an oscilloscope

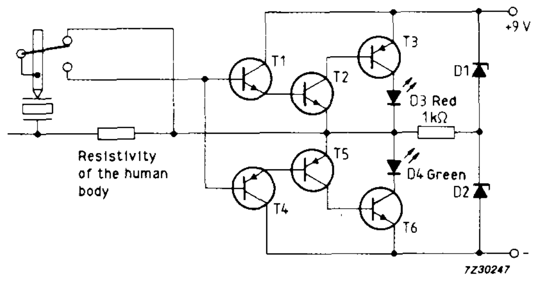
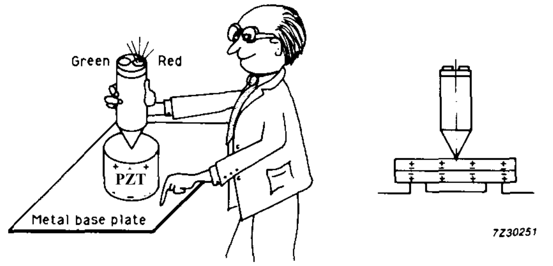


Fig.8.4 Test method using a multimeter
with peak-value indication.

The sensitivity of PZT is very high. A compressive stress of 1 MPa (10^6 N/m^2) generates a field of about 20 V/mm in PZT5A. For a product of 010 x 3 mm this means that 80 N of force will give rise to a voltage of about 60 V. Forces in this range can easily be applied by hand without any special equipment.

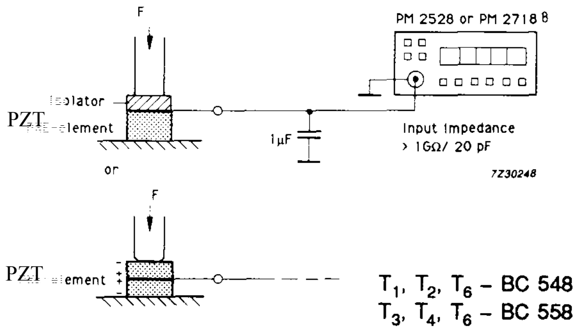
Another way would be to use a modern multimeter (e.g. PM2528). In peak detection mode, the maximum signal observed within a given time frame will be displayed. Input impedances are often so high that RC-times as long as 10 seconds can be attained. With "reproducible" tapping, not only the polarity but also the voltage constant can be estimated with some accuracy.



(a) disc

(b) bimorph element

Fig.8.5 Polarity check with Morgan polarity tester



T_1, T_2, T_6 - BC 548 B
T_3, T_4, T_6 - BC 558 B
D_1, D_2 - BZX 79/C6V2
D_3 - CQY 24B
D_4 - CQY 94B

Fig.8.6 Circuitry of polarity tester

Morgan's polarity tester

This simple hand-operated instrument is useful for checking the polarity of a PZT element.

The device under test should be placed on a conductive surface. The operator touches this surface with one hand and positions the tester on top of the PZT element (Fig.8.5). The resistance of the human body is used to close the electrical circuit (no danger!). Then the tester should be pressed down slowly but positively. The switch closes and the charge on the PZT element activates either transistor T_1 or T_4 and the red or green LED lights up. Red means that the electrode on top is the positive one. The RC-time of the circuit is about 0.5 sec. During the period the force is applied, certain variations are unavoidable (the human influence). As the force is released, a negative charge is induced on the positive electrode causing the green LED to flicker. Since this could be misleading, only the indication as the force is being applied should be taken into account.

8.4 The effective coupling factor (k_{eff}) derived from resonance behaviour

The effective coupling factor, keff is a measure of the piezoelectric quality of a PZT body.

The piezoelectric element is clamped gently between two contacts, preferably in its centre, so that it can vibrate freely (Fig.8.7). An alternating voltage is then applied, for instance by means of an impedance analyser (HP 4192A or 4194A for example), and the frequency is swept through a range around the expected resonant frequency of the element.

Figure 2.12(b) shows the resulting impedance variation. This can be described as follows:

- a steady decrease according to $1/\omega,C$
- a sharp decrease to a minimum Z value,
- followed by a sharp increase towards a maximum in the impedance curve,
- levelling off to a slope of $1/\omega C$ again.

This impedance curve comes from the mechanical behaviour of the piezoelectric element.

At low frequencies the element vibrates in phase with the applied voltage. Since electrically the element acts as a capacitor, the impedance decreases linearly with $1/\omega C$.

At a specific frequency (f_m), a mechanical resonance occurs. Here the alternating voltage is exactly in phase with the vibration of the PZT body. The amplitude is multiplied by a factor Q_m (mechanical quality factor). The high strain levels in the PZT cause large charge displacements and thus high current levels. The impedance decreases to a low level.

The minimum level is governed by internal losses and the resistance of leads and electrodes. In the equivalent circuit (Fig.2.11) this is represented by a series resonance (f_s) of L_1 and C_1, which occurs at practically the same frequency as f_m.

When the frequency is increased still further, the difference in phase between the applied voltage and the mechanical vibration grows. The impedance reaches a maximum for a phase shift of 180° (at f_n). The vibration is then almost entirely suppressed, the voltage generated by the PZT element is in anti-phase with the applied voltage and almost prevents the current from flowing.

In the equivalent circuit, this phenomenon is represented by the parallel resonance of C_O, C_1 and L_1 (frequency fp.

Modern impedance analyzers (e.g. HP 4192A) can be combined with a computer and programmed to find f_s, f_P, Z_{min} and $Z_{\max}$ The effective coupling factor k_{eff} then follows from the formula:

$$k_{\text{eff}} = \sqrt{\frac{f_p^2 - f_s^2}{f_p^2}}$$

It's also possible to determine k_{eff} of more complicated devices like bimorphs or PZT discs or plates glued on some substrate.

Depending on the construction different values of k_{eff} will be found. The translation to the *absolute* quality level is often very complicated or impossible. However k_{eff} is always a useful *relative* measure for the effectiveness of a device.

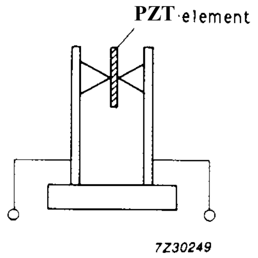


Fig.8.7 Test jig for dynamic measurement of PZT elements