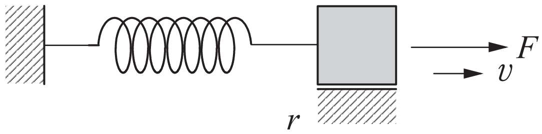
Guide for Using a Piezoelectric Elements

■The electrical system and the mechanical system



Connect the object m to the coil spring s as shown in the FIG. And then gives the vibration force F. Then the object will vibrate. The relationship between this vibration force F and velocity v is shown in the following formula.

$$f = Z_{\mathrm{m}} \cdot v$$

This Z_m is the mechanical impedance of the vibration system. It mass m of the object, and compliance s (reciprocal of the stiffness c) indicating the strength of the coil spring, and consists of the frictional resistance r. These relationships are all the same relationship with the voltage V, current I, resistance R, reactance L and capacitance C in an electrical circuit. The corresponding electrical circuit and mechanical circuits is shown in the FIG below.

(a) Electrical circuit

(b) Mechanical circuit

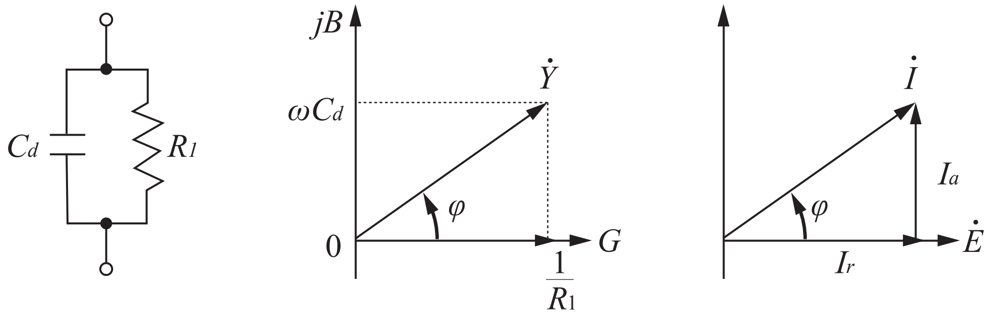
In addition, the elements of the electrical circuit can be treated the same as the elements of the machine vibration system. Their relationships are shown in the following table.

Electrical system	Voltage	Current	Charge	Electrical resistance	Inductance	Capacitance	Impedance	Admittance
	V	I	Q	R	L	C	Z	Y
Mechanical system	Force	Velocity	Displacement	Mechanical resistance	Mass	Compliance	Mechanical impedance	Mechanical admittance
	F	v	u	r	m	s	Z_m	Y_m

Mass m and compliance s is the same as that of the electrical circuit L and C, is the element to store energy as kinetic energy or potential energy.

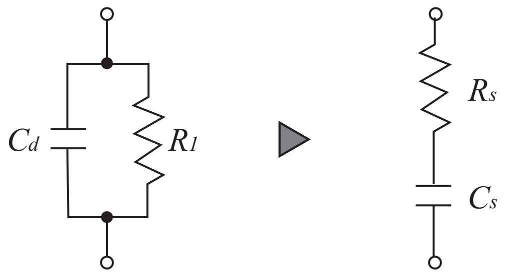
■Impedance matching

The ceramic vibrator has capacitive impedance at the resonance point. For this reason, an efficient drive cannot be performed even if it inputs electric power from an oscillator. The following is guidance for supplying electric power effectively. Please check the absolute value of the capacitive reactance of a vibrator. Please prepare inductive reactance (chalk coil) equal to this absolute value. Please connect this to a vibrator and parallel (or series), and cancel reactance.



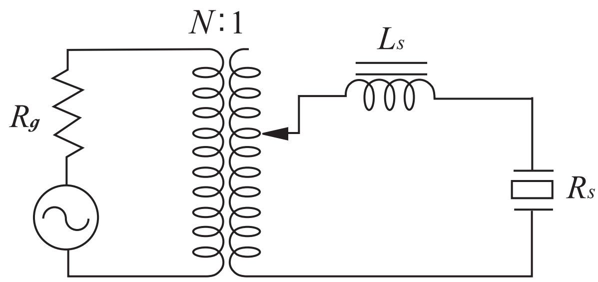
Vector chart at the time of the vibrator resonance

Equivalent circuit of the vicinity of the resonance point of the vibrator is constructed of the L_1, C_1, R_1 and C_d. For C_1 and C_d is canceled, it will be parallel circuit of C_d and R_1. And impedance Z of the vibrator will be $1/\omega C_d$. The equal ωL_p to the absolute value of Z are connected in parallel. Since the Z is canceled, the impedance of the vibrator will be only R_1. And, become $R_g = R_1$ if the output resistance of the oscillator is the R_g. In this way you can most efficient drive. The following is easy way. Adjust the output transformer of N:1 winding ratio. To adjust to the winding ratio of $R_g = N^2 R_1$.



$$R_s = \frac{R_1}{1+(\omega C_d R_1)^2} \qquad C_s = \frac{1+(\omega C_d R_1)^2}{(\omega C_d R_1)^2}$$

Series equivalent transformation of the vibrator



Impedance matching circuit example of the vibrator

R_1 is correspondence with the mechanical load of the vibrator. It will also change the value of R_1 by the largeness of the load. For example, in the water load, it will change significantly over the depth and cavitation existence. It must be measured on actual use conditions. In addition, parallel equivalent circuit can also be changed to a series circuit of the $R_s - C_s$. Also in this case, a choke coil L_s with an absolute value equal to $1/\omega C_s$ is connects in series. And can cancel the C_s by doing this.

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■Calculation of output with respect to the force F

Impressing a force F, there is application to generate the charge Q or voltage V. This is the applications of the machine-electrical transduction. Piezoceramics will generate a charge Q. The total charge Q is corresponding to the applied force F through the factor of proportionality of size, piezoelectric constant d_{33}, capacitance C_d and others.

$$Q = C_d \cdot V = F \cdot d_{33}$$

This output voltage V is the relationship formula of following due to the piezoelectric constants g_{33} and the piezoceramics element thickness t and cross-section A.

$$V = \frac{F \cdot d_{33}}{C_d} = \frac{F \cdot g_{33} \cdot t}{A}$$

Charge Q generated in the piezoelectric element corresponds to the magnitude of the force F. If the force F is constant, the charge Q is also constant. Insulation resistance value of the piezo elements, which is also regarded as a kind of condenser (capacitor) is finite. For that reason, the charge Q generated will get discharged in accordance with the time constant $C_d R$ in the following formula.

$$q = Q\mathrm{e}^{-t/C_d R}$$

q: Actual apparent charge

For example, in the case of applying the piezo elements to the pressure sensor, it does not have a static sensitivity.

Force F, can be expansion as the AC, by the relationship between mass m, acceleration α, displacement u, the angular frequency ω. Refer to the following formula.

$$F = m \cdot \alpha = m \cdot u \cdot \omega^2 = m \cdot u \cdot (2\pi f)^2$$

Calculation of displacement with respect to the input voltage V

Impressing a voltage V, there is application to produce the strain. It will be applied to obtain a mechanical output from the electrical input. And that is driven by AC as of ultrasonic equipments, there is a thing to be driven by an AC of the DC or low frequency. The displacement u of the no-load, and the generative force F is calculated by the following formula.

$$u = V \cdot d_{33}$$ V: Input voltage、d_{33}: Piezoelectric constant

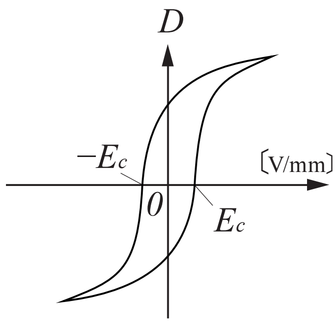
$$F = \frac{u}{s_n}$$ s_n、s_{33}^E: Compliance

$$s_n = s_{33}^E \cdot \frac{t}{A}$$ t、A: Thickness、Area

If want to drive in the load and AC, consider those conditions.

Anti-electric power (Anti-electric field & Anti-voltage)

Piezo element does the polarization process in the DC high voltage. This aligns the spontaneous polarization of the inside of the piezo element in a certain direction. And by giving the residual polarization, have gained a piezoelectricity. On the other hand, to applied, the direction of polarization and a voltage of inversely direction. The electric field the residual dielectric polarization will be a zero is called the anti- electric power E_c.



Anti-electric power of the piezo ceramics

The value of the anti-electric power E_c will vary depending on the material of the piezo elements. If want to apply the high voltage of an inverse to the direction of polarization electric field be careful. The depolarization characteristics of the residual polarization is, becomes a functions of voltage, time, temperature and others. Accordingly it will vary depending on the conditions at that time. With respect to the between electrode thickness of the piezo elements, the electric field of several tens to several hundred volts will be the limit.

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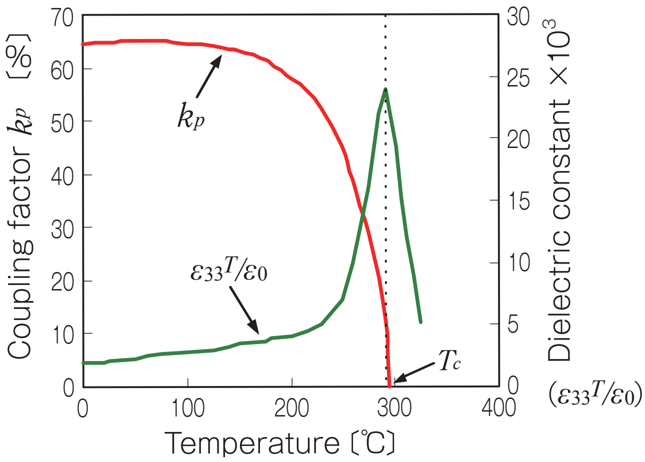
■Maximum use temperature

Characteristics of polarization treated piezo elements, has been stable in the low-temperature area. In the high-temperature area, the Curie point T_c has. For that purpose, there is a limit to the use temperature range. In the Curie point T_c, the dielectric constant is increased to infinity. In the result, the crystal becomes unstable, the crystal structure will transition phase. As a result, the spontaneous polarization and the residual polarization are lost. And the piezoelectric properties are lost.



High-temperature characteristics of piezo ceramics (PZT)

When cooled below the Curie point, spontaneous polarization will be restored. Residual polarization will remain lost. And, remains also piezoelectricity is lost. Lost of the residual polarization depends on the temperature and time or material. Problem-free use temperature is temperature, 1/3 to 1/2 of the Curie point.

■Physical constants in normal temperature

Density (ρ)	7.3～7.7×10^3〔kg/m^2〕
Linear expansivity (α)	5～10×10^{-6}〔1/℃〕
Specific heat (C)	500～700〔J/kg·℃〕
Thermal conductivity (k)	1～1.5〔W/m·℃〕
Electrical resistivity	10^{10}～10^{11}〔Ω·m〕
Compressive strength	5～7×10^8〔N/m^2〕
Tension strength	0.6～1×10^8〔N/m^2〕
Transverse strength	0.6～1×10^8〔N/m^2〕
Vickers hardness (HV)	350～450
Sound velocity of longitudinal wave (v)	2800～3600〔m/s〕

Physical constants in normal temperature of the PZT〔Pb(Zr·Ti)O_3〕

Table is typical physical constants in the normal temperature of the piezoceramics PZT.
These values will vary depending on the temperature and shapes.
For detailed data, please refer to other documents and the like.

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■Implementation note

Considerations for implementing a piezo elements, is the handling of the electrode. Many of the electrode, is the silver electrode of the high-temperature firing, and the nickel electrode on the chemical plating.
Electrode, it may cause the surface alteration and intensity degradation. Soldering or adhesive bonding method or chemical condition is caution needed.

●Soldering method to the electrodes

It is an example： The solder is using Alumit LFM48 solder. Temperature of the soldering tip is a maximum 270 ℃. The size of the solder points is to minimize. It is recommended that work in a short time of less than 3 seconds.

●Aadhesive bonding method

Do the degreasing treatment of the adhesive surface. Apply appropriate amount using an epoxy-based adhesive. Hold in the condition of being crimped an adhesive surface. And cure at a temperature of 80℃ about in this condition.
Piezo elements, and charged by the heating and cooling. Piezo elements of large size, it is desirable to short circuit between advance electrodes.

●Chemical resistance & environmental resistance to the electrode

Silver and nickel is brought into combinable with acid and sulfides or halides. Therefore, to the chemical condition is caution needed.

Conditions	Silver electrodes	Nickel electrodes
In airs	Not oxidized even when heated in oxygen. Within the ozone, it becomes black silver peroxide Ag_2O_2.	Difficult to oxidation in air and moisture.
Acid solutions	Dissolved in sulfuric acid and hot concentrated sulfuric acid, it will be $AgNO_3$, Ag_2SO_4.	Dissolved in sulfuric acid and nitric acid, it will be $NiSO_4$, $Ni(NO_3)\cdot 6H_2O$.
Alkali solutions	Silver is insoluble. Dissolving the glassy contained in the electrode, silver film peeling will arisen.	There is no impact..
Sulfides	Reacts with the sulfur and hydrogen sulfide, it will be silver sulfide of black.	Combine with sulfide, it will be NiS.
Halides	Combine with halide, it will be AgCl, and AgBr or AgI, etc.	Combine with halide, it will be $NiCl_2$, etc.
Others	In the high humidity, please avoid applied of a DC electric field of long times. It will cause the silver migration.Moisture-proofing treatment recommended.	For use in high humidity, moisture-proofing treatment recommended.
Storages	To avoid the heat and humidity, the sealing state is desired. Don't packing with rubber bands or urethane foams.	To avoid the heat and humidity, the sealing state is desired.

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■Information for use

- Products and specifications, for the purpose of improvement, might want to stop change or manufacturing without notice. In use, with the request of the specification, please check its contents.

- Described matters of products and specifications, guarantee the characteristics and quality of the product itself. In use, in the state that mounted to be application products, please evaluate it and check it.

- In the following cases, please the pre-consult. If require a very high reliability. Or for the product deficiency, when reviewing the use of the equipment and devices, such as it would directly endanger human life.

- If the problem related to the intellectual property rights of third parties using our product has occurred, in other than those directly involved in the structure and process of our products, our does not assume the responsibility.

- Our has taken all possible measures against the quality and reliability of the product. By improper use, there is risk that result in bodily injury, fire or social loss. If you have any questions about how to use, please contact us.

- For products that fall into regulation cargos in accordance with the provisions of the Foreign Exchange and Foreign Trade Law, if you want to export, it requires an export license or other official approval under the law.

- If there is no documents consent, prohibits the unauthorized reprint and duplication.

- In our manufacturing process, does not use ozone-depleting substances (ODS).