TDK

Magnetostriction Vibrators
V2X Series

Conformity to RoHS Directive

Magnetostriction refers to changes in the dimension of a ferromagnetic material that occur in the direction of the magnetic field when it is magnetized. This phenomenon can be utilized to generate intense ultrasonic waves by giving a ferromagnetic material the appropriate shape and dimension.
TDK ferrite magnetostrictive vibrators, which are applications of this magnetostrictive phenomena and are based on ferrite material technologies, as well as machining technologies which TDK has accumulated over the years, deliver characteristics not found in metal magnetostrictive vibrators and have applications in a wide range of ultrasonic instruments.

FEATURES

- Due to high specific resistance, eddy current loss is very small.
- Electro-mechanical energy conversion efficiency is high(85 to 90%).
- As ferrite magnet is used, there is not necessary for DC bias.
- The magnet has excellent anticorrosive characteristics that permits to use in solvent such as acid, alkaline and others.

APPLICATIONS

Ultrasonic cleaning, sonar, ultrasonic machining.

PRODUCT IDENTIFICATION

V2	X	π	28	(A)
(1)	(2)	(3)	(4)	(5)

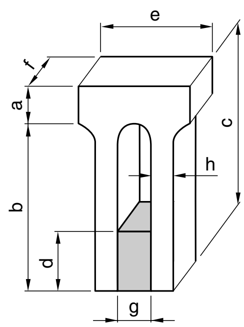
(1) Material name
(2) Ferrite magnetostrication vibrator
(3) Type
(4) Resonant frequency(kHz)
(5) Shape's classified code

MATERIAL CHARACTERISTICS

Temperature dependence of resonant frequency*1	T_K(1/°C)	17×10^{-5}
Motional impedance*1	Zm_{00}(Ω)	180
Quality factor Q*1	Qm	350
Electro-acoustic efficiency*1	η_0(%)	90
Electro-mechanical coupling factor*1	K(%)	18
Maximum input power(water load)*1	W/cm^2	10
Continuous input power(water load)*1	W/cm^2	3 to 5
Electrical resistivity*2	ρ(Ω• cm)	1×10^3 min.
Density*2	d(g/m^3)	5.1
Bending strength*2	σ_{d3}(kg/mm^2)	11 to 13
Thermal expansion coefficient*2	α	8×10^{-6}/°C
Curie temperature*3	Tc(°C)	450

*1 With 28kHz π type at 4AT
*2 With square pole specimen
*3 With toroidal specimen

SHAPES AND DIMENSIONS



Part No.	Resonant frequency(kHz)	Dimensions(mm) a	b	c	d	e	f	g	h	Weight (g)
V2Xπ20	19.5±0.4	18	114	132±3	26	51±1	25±0.5	14	13	555
V2Xπ28(A)*	28.5±0.4	14	74	88±3	18	40±1	20±0.5	11	9	240
V2Xπ40(A)	40.5±0.8	12	50	62±2	18	40±1	20±0.5	11	9	179
V2Xπ50	50.5±0.8	12	37	49±2	18	40±1	20±0.5	11	9	146
V2Xπ75(A)	75±1.6	6.5	26	32.5±2	12	27±1	13±0.5	7.7	6	40
V2Xπ100	100±1.6	5	20	25±2	9	21±1	10±0.5	5.5	4.5	17

* Appended to the product number is our control code.

▭ denotes the ferrite magnet for DC bias.
Designed to be used by inserting the ferrite magnet between legs.

RESONANT FREQUENCY DEVIATIONS

Unit:kHz

Frequency rank	Nominal resonant frequency 20kHz	28kHz	40kHz	50kHz	75kHz	100kHz
1	19.10 to 19.20	28.10 to 28.20	39.70 to 39.90	49.70 to 49.90	73.40 to 73.80	98.40 to 98.80
2	19.20 to 19.30	28.20 to 28.30	39.90 to 40.10	49.90 to 50.10	73.80 to 74.20	98.80 to 99.20
3	19.30 to 19.40	28.30 to 28.40	40.10 to 40.30	50.10 to 50.30	74.20 to 74.60	99.20 to 99.60
4	19.40 to 19.50	28.40 to 28.50	40.30 to 40.50	50.30 to 50.50	74.60 to 75.00	99.60 to 100.00
5	19.50 to 19.60	28.50 to 28.60	40.50 to 40.70	50.50 to 50.70	75.00 to 75.40	100.00 to 100.40
6	19.60 to 19.70	28.60 to 28.70	40.70 to 40.90	50.70 to 50.90	75.40 to 75.80	100.40 to 100.80
7	19.70 to 19.80	28.70 to 28.80	40.90 to 41.10	50.90 to 51.10	75.80 to 76.20	100.80 to 101.20
8	19.80 to 19.90	28.80 to 28.90	41.10 to 41.30	51.10 to 51.30	76.20 to 76.60	101.20 to 101.60

- The resonant frequency deviation is color coded. When two or more units are used as a set, those having the same color should be combined.
- Please note that, unless stated otherwise, frequency ranks are subject to change depending on production circumstances.

- Conformity to RoHS Directive: This means that, in conformity with EU Directive 2002/95/EC, lead, cadmium, mercury, hexavalent chromium, and specific bromine-based flame retardants, PBB and PBDE, have not been used, except for exempted applications.

TDK's TYPICAL APPLICATION EXAMPLES

The following is a description of wide spheres applications for TDK's ferrite magnetostrictive vibrators designed to give users a full understanding of their characteristics and effects so that users can design their apparatuses for maximum effectiveness.

GENERAL CHARACTERISTICS OF THE VIBRATORS

(1) Excitation and Driving

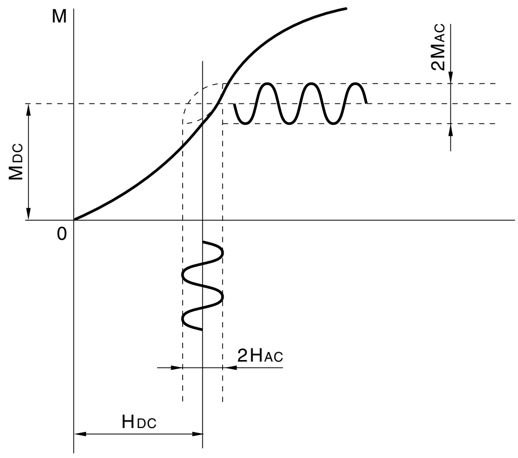
Ferromagnetic materials exhibit a characteristic called the Joule effect or magnetostriction, which is the change in the length of a ferromagnetic material in the direction of magnetization when magnetization is varied.

We take for example an annealed Ni propagated or ferrite vibrator fitted with a coil to which a direct current Idc is applied, thereby creating a longitudinally polarizing magnetic field (bias magnetization). When alternating current Iac is superimposed, the rod's magnetization fluctuates with the bias magnetization Mdc as the central value and magnetostriction causes the rod to vibrate. This in turn generates acoustic waves from the end surface of the rod. The nearer the alternating current's frequency is to the rod's resonant frequency for longitudinal vibration, the greater the amplitude of expansion and contraction, with maximum amplitude achieved when the current's frequency coincides with the rod's resonant frequency (Fig.1).

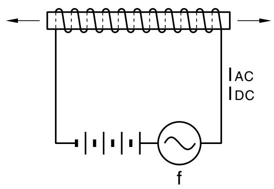
This is the basic principle by which such vibrators are driven. Commercially available ferrite vibrators are pre-shaped in the shape of the character "π" and utilize permanent magnets instead of a direct current to create the bias magnetic field. When using multiple magnets together, always make sure to align the magnets in the same polarity direction.

Fig.1 Bias magnetization

(a) Effects of bias magnetization



(b) Vibrator circuit



(2) Vibrator Life

Ferrite vibrators have a virtually permanent life when used under appropriate conditions.

The example shows the results of a life test for a 28kHz π-shaped vibrator (Fig.2).

Please remember that in applications such as Fig.3, improper bonding will lead to an uneven distribution of vibrating forces and will shorten the life of the vibrator. Also, when choosing a vibrating plate to bond the vibrator, select one that is made of material with a thermal expansion coefficient that approximates as much as possible that of the vibrator. Temperature increases of the vibrator is another important factor that affects its life. As a guideline, use the vibrator at 80°C max.

Fig.2 Life test of 28kHz π-shaped vibrator

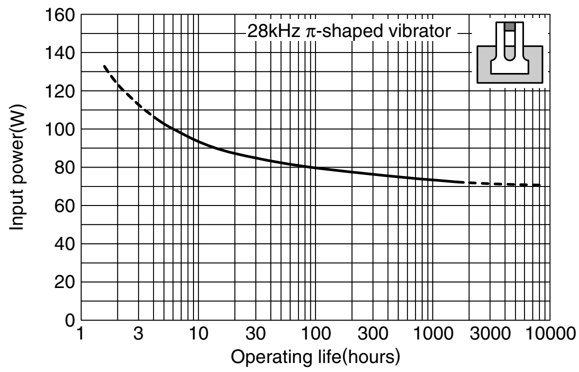
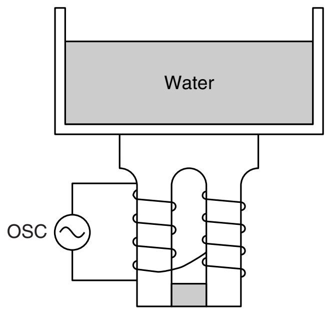


Fig.3 Vibrator bonded to container



(3) Corrosion Resistance

Because - in applications such as ultrasonic cleaners, sonars and ultrasonic humidifiers - magnetostrictive vibrators are used in various liquids including water, corrosion resistance becomes an issue. Ferrite vibrators excel in this respect because they cannot be corroded by water. They also exhibit good corrosion resistance against solvents including trichlene, thinners and alcohol. However, corrosion resistance of elements used for coils and magnets remains an issue. For example, vinyl covered wires cannot be left in thinner for extended periods of time because the coating may become friable and eventually dissolve.

And although a ferrite vibrator is able to resist corrosion in concentrated acid or alkali at high temperatures, caution is advised as magnets will corrode under such conditions.

(4) Shapes and Features

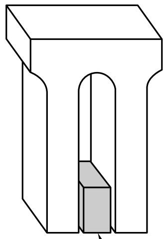
Ferrite magnets that give ferrite magnetostrictive vibrators their bias magnetic field are typically called bias magnets. These magnets are used to maintain static bias magnetization.

Fig.4 illustrates how a bias magnet and vibrator are combined.

Ferrite vibrators are manufactured by powdered, compressed, and sintered.. Since a bias magnet is not bonded to the π-shaped vibrator, the coil is removable.

Fig.4 Shape of the bias magnet and the vibrator

π-shaped vibrator



TYPICAL APPLICATIONS FOR FERRITE MAGNETOSTRICTIVE VIBRATORS

APPLICATIONS IN ULTRASONIC CLEANERS

When ultrasonic waves are propagated in a cleaning liquid, the cavitation effect creates acoustic pressure shocks within the liquid which remove dirt from the object to be cleaned. Applications for such cleaners include the cleaning of industrial products, surgical instruments, table ware, watch components and rings. There are many points to remember when designing an ultrasonic cleaner.

(1) Selecting a Vibrator

There are many types of ultrasonic vibrators available including ferrite magnetostrictive, piezoelectric, electrostriction, and Ni magnetostrictive vibrators. Ferrite vibrators are typically used in cleaners for their stability and cost.

The following table is a comparison of different types of vibrators

Vibrator type	Ferrite magnetostrictive	Piezoelectric	Electrostriction	Ni magnetostrictive
Material	TDK V2 material	Quartz	Barium titanate	Nickel
Electroacoustic transduction efficiency	80% min.	80% min.	80% min.	30 to 40%
Operating frequency	100kHz max.	1MHz min.	200kHz to 2MHz	50kHz max.
Operating input power (in water)	3 to 6W/cm^2	—	3 to 6W/cm^2	6 to 10W/cm^2
Impedance	Small	Large	Medium	Small
Size of device	Small	Small	Small	Large

(2) Selecting Vibration Frequencies

The operating frequency range of magnetostrictive vibrators is between 15 and 100kHz with the most typically used frequency being 28kHz. When cavitation of water and water soluble detergents is used to clean an object, the frequency that yields the largest amplitude is the most effective. For this reason, large-scale cleaners typically use vibrators that at 20 to 28kHz and smaller cleaners use those that vibrate at 40 to 50kHz.

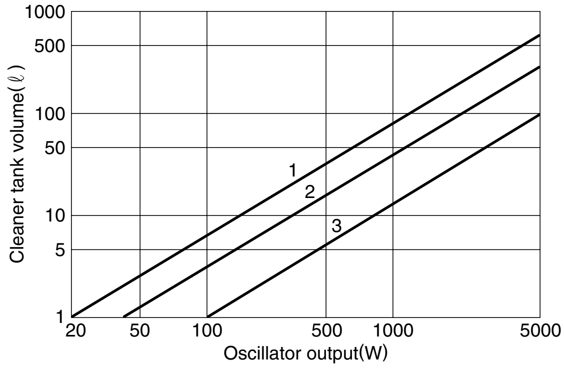
Vibrators at high frequencies such as 75kHz may not yield the best results because the shorter wavelengths reduce the effect of standing waves within the liquid and factors such as changes in resonant frequency that are introduced when the vibrator is mounted can cause unevenness in vibrations.

(3) Selecting Cleaner Power

Fig.5 shows an example of the relation between cleaner tank volume and oscillator output.

1: Normal cleaning (When cleaning can be achieved with relatively small output)
2: Large-scale cleaners (The average most typically used type)
3: Hand washing (When an intense acoustic field is required)

Fig.5 Cleaner tank volume and oscillator output



(4) Input Power

The following describes settings for the number of vibrators used.

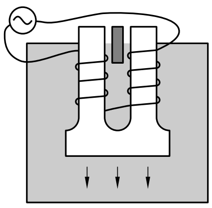
Input power for a single vibrator can be calculated simply based on Fig.6, but this creates the issue of loads.

Example (a) illustrates a case in which the vibrator is subjected to a heavy load. This occurs when the vibrator is thrown in the liquid or when the liquid depth is 200mm or greater in use.

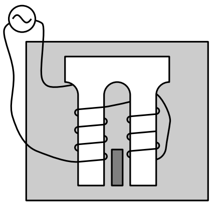
Examples (b) and (c) illustrate cases in which the load to the vibrators are small. These include cases where the liquid is shallow or the load impedance is small.

Fig.6 Examples of loads

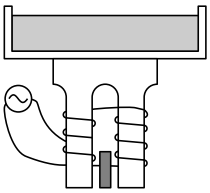
(a) Heavy load



(b) Light load (deep liquid)



(c) Light load (shallow liquid)



(5) Maximum Allowable Amplitude

Load fluctuations during ultrasonic cleaning or machining processes cannot be avoided. For your information, we have included the maximum allowable amplitudes and allowable input powers below. Please note that these merely serve as guidelines and that greater amplitudes are possible in the absence of sudden load fluctuations.

Vibrator	Radiating surface area (cm^2)	Maximum allowable input power with water load		Maximum allowable amplitude	Maximum allowable stress
		Light loads (W)	Heavy loads (W)	(μm)p-p	(kg/cm^2)
20kHz π type	13	40	80	7	150
28kHz π type	8	25	50	5	
40kHz π type	8	25	50	4	
50kHz π type	8	25	50	3	
75kHz π type	3.5	10	20	2	
100kHz π type	2.1	5	12	1.5	

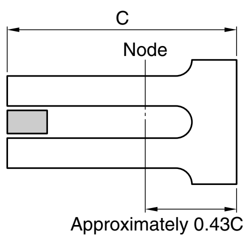
(6) Maximum Allowable Stress

During operation, stress is concentrated on the vibrator node. As a guideline, we have set a stress limit of $150kg/cm^2$. Apparatuses must be designed so that the vibrator is not subjected to stresses exceeding this limit. When calculating stress, we must first check the condition of the load and whether or not cavitation will be generated.

However, because calculations can become complex in situations where cavitation is present, we recommend that you determine the limit based on maximum allowable amplitude.

Fig.7 illustrates the node position of a π-shaped vibrator. Vibrator breakage near the node position is an indication that the maximum allowable amplitude may have been exceeded. In such cases, reduce the power and carefully check the amplitude before using.

Fig.7 Node position of π-shaped vibrator



(7) Radiating Surface Area

The radiating surface refers to the surface from which ultrasonic waves are generated (Fig.8).
The radiating surface can be expressed as “$e \times f$”.
For example, if a single 28kHz vibrator is used as illustrated in Fig.11, its radiating surface area is 4(cm)×2(cm) = $8cm^2$.
Its maximum allowable input power would therefore be $8(cm^2) \times 3(W/cm^2)$ = 24W.
However in this case, because the ultrasonic waves are generated from the vibrating plate, the radiating surface area will not be greater.
If at least half of the vibrator is to be submerged in water as shown in Figs.9, 10 or 12, please attach closed cell sponges to areas other than the radiating surface that generates ultrasonic waves as shown in Fig.13. This is to prevent unnecessary ultrasonic waves from being generated.

Fig.8

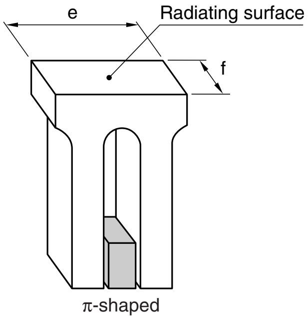


Fig.9

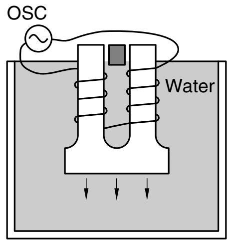


Fig.10

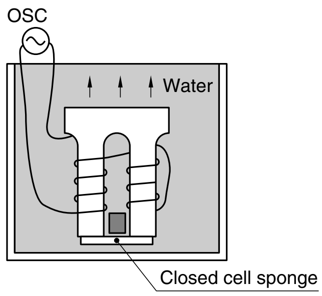


Fig.11

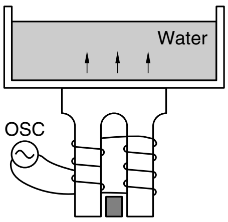


Fig.12

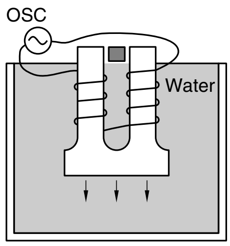
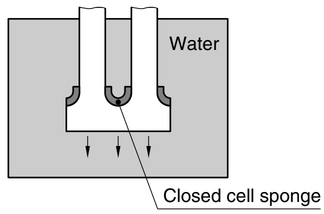


Fig.13



(8) Vibrator Arrangement

In a typical application, a vibrator is bonded to a thin vibrating plate.
Keep the following in mind when arranging the vibrator and vibrating plate.

- Arrange the vibrator only to portions of the vibrating plate that can considered to be free walls.
  Using the vibrator on frames or areas near the frames of a vibrating plate will impede vibration.
- An issue for vibrating plates, in large-volume cleaners in particular, is the concentration of power to only some of the vibrators. To prevent this, arrange the vibrators in equal intervals to achieve uniformity in load impedance.
- A resonance will occur when acoustic standing waves coincide with liquid depth.
  This is the condition at which the strongest vibration is effectively achieved. On the other hand, non-uniform liquid depths will cause partial resonance and may cause power to become concentrated to a particular area. Therefore, the tank must be designed in such a way that uniform liquid depth is achieved.
- Optimum effectiveness is achieved by concentrating the vibrators in their arrangement to make the radiated ultrasonic waves converge.

(9) Impedance Matching

The vibrators will not vibrate if their impedance is not matched.

If they are not matched, the vibrator's Q - which constitute loads in an output matching circuit's design - would be high, preventing the impedance to vary significantly near the resonant frequency and cause the Q to be different from the resistance load because the vibrator has the impedance.

Such problems can be resolved by adjusting the vibrator's impedance using coils and matching it with the oscillator's output impedance.

The following table shows actual examples.

Examples of applications	One 28kHz π-shaped vibrator	Eight 20kHz π-shaped vibrators
Coil	20 core 3mm diameter, heat resistant vinyl covered line, 15 turns/leg	20 core 3mm diameter, heat resistant vinyl covered line, 20 turns/leg
Efficiency	87% (micro amplitudes)	69% (micro amplitudes)
Input power	64W V=30V I=2.5A	800W V=270V I=3.7A
Load	Water (heavy load)	Water (heavy load)
Parallel capacitance	0.5μF	0.1μF
Impedance	8Ω	50Ω
Power factor	COSø=0.85	COSø=0.8

Actual impedance measurements must be made as these will vary depending on load conditions.

The following must be taken into consideration to determine the correct impedance for a vibrator:

(a) Type of medium generating the ultrasonic waves
(b) Radiating surface of the ultrasonic waves
(c) How the vibrator is supported
(d) Temperature of vibrator and medium
(e) Amplitude of vibrator
(f) Whether or not cavitation will be generated

There are three basic methods for exciting vibrators and each method will have a different affect on the matching impedance.

(1) Excitation applied at f_a (parallel resonance)

In the case of Fig.14, the impedance with load is $1/Y_{m0}$.

When the vibrator is excited at point f_a in Fig.14, the equivalent circuit Fig.15 (a) will be as shown in (b) of the same figure. And when a capacitor C_0 that resonates with damping inductance L_{d0} and frequency f_a is added, only the resistance component remains and can be expressed as in (c) of the same figure.

Therefore, the load impedance can be derived from Fig.14, where Z_{d0} is the damping impedance, Z_{m0} is the diameter of the motional impedance, f_r is the resonant frequency, f_a is the antiresonant frequency and Y is the admittance.

(2) Excitation applied at f_r (series resonance)

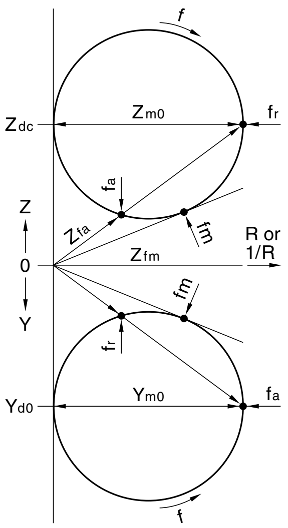
When the vibrator is excited at point f_r of Fig.14, series capacitance C_0 is added to the vibrator as shown in Fig.16(a) to cause a resonance with the vibrator's damping inductance L_{d0}. In this case, the equivalent circuit will be as shown in (b) of the same figure, where load impedance Z_1 is equal to Z_{m0} at f_r.

(3) Excitation applied at fm

The output terminal is connected to the vibrator as shown in Fig.17 to apply excitation at fm in Fig.14. When doing so, a parallel or series capacitance may be added to improve the power factor. This excitation method is very convenient from a practical perspective because Zfm remains constant even if the load fluctuates.

Although the best way to determine the frequency would be to measure the motional impedance under load, a typically used method is to match it with the frequency that generates the most intense cavitation under load. This is practical for measurement purposes because it represents fm excitation.

Fig.14 Impedance for parallel resonance



$Y_{d0} \fallingdotseq 1/Z_{d0}$ $\frac{Y_{m0}}{Y_{d0}} \fallingdotseq \frac{Z_{m0}}{Z_{d0}}$

Load imp. $Z_l = 1/Y_{m0} \fallingdotseq \frac{Z_{d0}^2}{Z_{m0}}$

Fig.15 Parallel resonance equivalence circuit

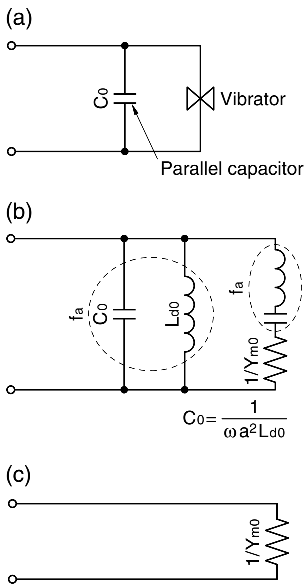


Fig.16 Series resonance equivalence circuit

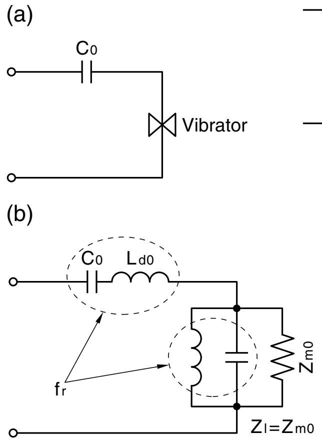
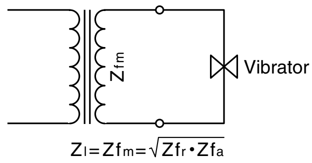


Fig.17 fm excitation circuit



(10) Securing the Bias Magnet

Typically, a closed cell sponge is bonded using rubber-based adhesive as shown in Fig.18.

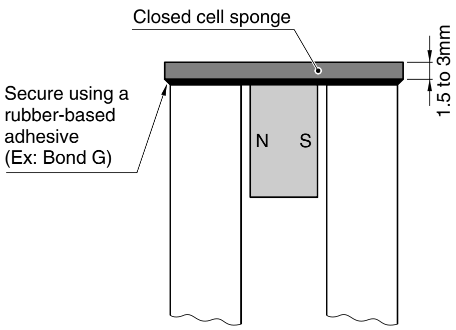
If this method is used, care must be taken to prevent the magnet from making contact with the vibrator.

Another completely different method is to bond the magnet with the vibrator. However, this compromises precision as the resonant frequency is reduced and the rate of such decrease is irregular and dependent on bonding conditions.

The following table shows examples.

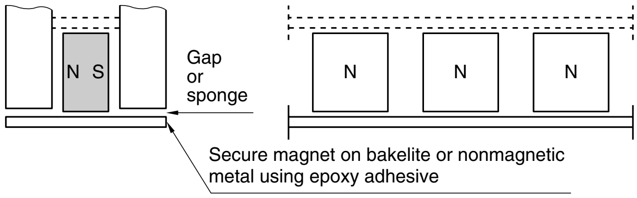
Vibrators type	Resonant frequency fr	
	Before bonding (kHz)	After bonding (kHz)
20kHz π-shaped	19.45	19.36
	19.50	19.37
28kHz π-shaped	28.68	28.34
	28.59	28.33
40kHz π-shaped	40.55	40.25
	40.51	40.21

Fig.18 Securing the magnet using a rubber-based adhesive



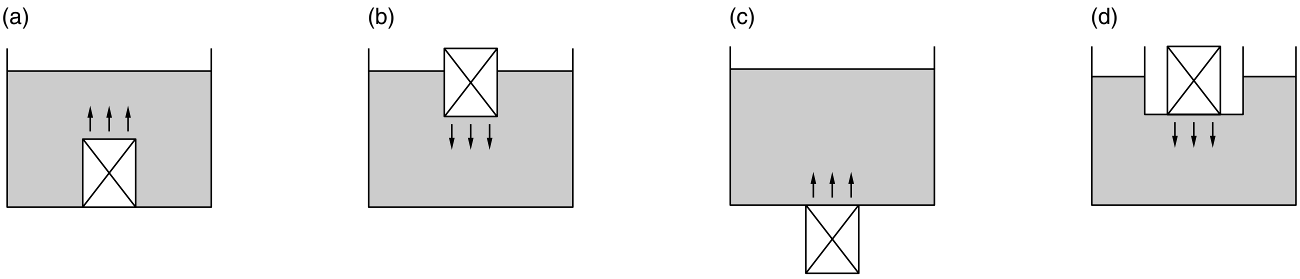
Another method is to secure the magnet onto bakelite or nonmagnetic metal using epoxy adhesive as shown in Fig.19. Rubber-based adhesives are not suited for this purpose.
Another point to remember is that a plate must be inserted on the upper side (as shown in broken lines in the figures) in situations where mechanical strength is required. When doing so, a gap must be created or a sponge must be inserted so that the plate does not directly contact the vibrator.

Fig.19 Securing the magnet using an epoxy adhesive



(11) Ultrasonic Cleaning in Practice
Ultrasonic cleaners are available in different types, including belt conveyor, batch and portable. Industrial cleaners are typically either belt conveyor or batch types and 28kHz π-shaped vibrators are suited for these purposes.
Vibrators with lower frequencies such as the 20kHz π-shaped vibrators are more effective for large objects with hard-to-remove dirt.
Water is the most economical and easy-to-handle cleaning liquid. Detergents and the like may be added to improve cleaning performance.
Methods for using vibrators basically include schemes illustrated in Figs.10, 11 and 12 mentioned earlier.
Fig.20 shows approximated illustrations of these schemes.

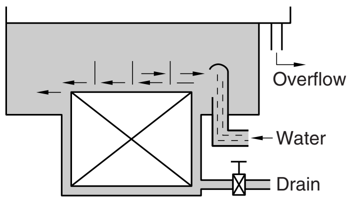
Fig.20



Other applications include schemes where ultrasonic waves are delivered simultaneously from above and below, or from the sides.
Combination-type vibrators are suited for situations such as (a) and (b) shown in Fig.20.

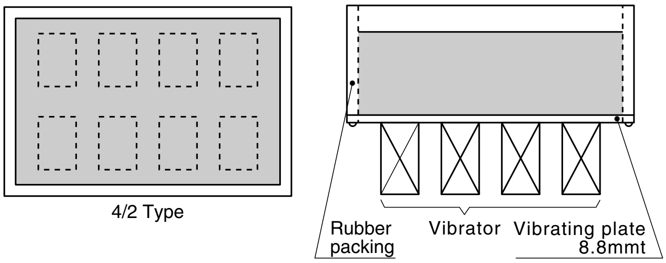
Fig.21 is an actual example of Fig.20 (a).
In Fig.21, ultrasonic waves will remove dirt momentarily, but as soon as the vibrator is stopped, the suspended dirt will precipitate and re-attach to the object to be cleaned. Therefore, a shower-like lateral flow of water must be created to constantly maintain a clean radiating surface and discharge the dirt from the object via an overflow. The radiating surface of the vibrator must be slightly higher than the bottom of the tank and make sure that the radiating surface does not become dirty even if large pieces of dirt is removed from the object (Fig.21).
When metal net conveyors or containers are used, use the largest possible mesh to reduce the attenuation of ultrasonic waves.
Small meshes considerably decrease the propagation of ultrasonic waves and can have extremely detrimental effects on cleaning efficiency.

Fig.21



The next part describes Fig.20 (c).
Fig.20 (d) can be considered to be a part of (c) as it is only an inverted version of (c).
Fig.22 is an actual example with eight vibrators bonded to a vibrating plate.
A vibrating plate thickness of 0.5 to 1mm is suited for such applications.
Vibrating plates that are too thick reduce efficiency, and those that are too thin cannot withstand the vibrator's weight, furthermore it compromises their erosion durability.
In the example illustrated in Fig.22, a rubber packing must be inserted between the vibrating plate and frames (Vibrators bonded directly to a container's bottom without the use of rubber packing will cause the entire container to become acoustically active, which is not undesirable).
Attaching a non-vibrating element too close to the container's perimeter can lead to adhesive separation or irregular frequencies. This is because the vibrating plate may become deformed by the tightening of screws when attaching it to the container.

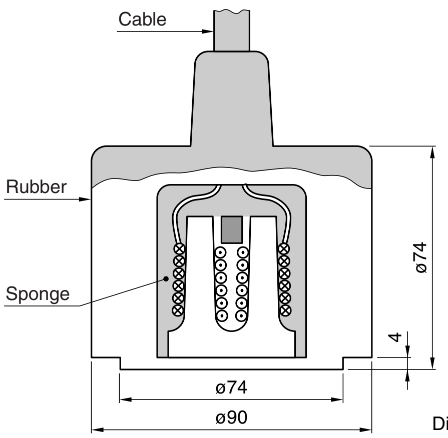
Fig.22



OTHER REMINDERS

In the preceding sections we have described ways in which the vibrators can be used primarily in ultrasonic cleaners. These vibrators have other applications including fish detectors and ultrasonic machining tools.
For your information, we have included an example of how a fish detector is configured in Fig.23. The design must be such that the unit is able to withstand water pressure and mechanical shocks.
Ultrasonic machining requires that a horn be used in conjunction with a vibrator. An important point in this application is the selection of horn material and adhesives suited for ferrite cores.

Fig.23 Example of fish detector configuration



Dimensions in mm

PRECAUTIONS IN HANDLING

- The vibrators are made of ceramic. Please do not hit or drop them. Broken vibrators are irreparable.
- Do not apply intense excitation in open air (i.e. without load). This includes removing an operating vibrator of a cleaner from the water and into open air with the power still on, and tuning vibrators in open air. In such situations, even a small output can amplify very quickly and lead to damage. This is also true for tuning vibrators without placing them in water.
- If sponges are required, only use closed cell sponges. Because all of the cells in these sponges are independent of each other, they do not soak water and therefore do not transmit acoustic waves from the vibrator to the water. This creates a nearly loadless condition for the vibrator. Sponges that simulate natural sponges are not suited for this purpose.
- Always make sure that the excitation magnets are used in their proper polarity.