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Magnetostrictive Versus Piezoelectric Transducers For Power Ultrasonic Applications

There are two fundamental transducer designs used for power ultrasonic applications today, magnetostrictive and piezoelectric. Piezoelectric transducers utilize the piezoelectric property of a material to convert electrical energy directly into mechanical energy. Magnetostrictive transducers utilize the magnetostrictive property of a material to convert the energy in a magnetic field into mechanical energy. The magnetic field is provided by a coil of wire which is wrapped around the magnetostrictive material. Both types of transducers have advantages and disadvantages. Blackstone~NEY Ultrasonics has weighed both technologies and chooses to provide piezoelectric transducers. The following will help the reader understand the rationale behind this choice.

Background

The very first ultrasonic devices were developed early in the 20th century when the piezoelectric effect was discovered by Jacques and Pierre Curie. These devices consisted of naturally occurring piezoelectric minerals such as quartz crystals attached by various means to surfaces to be vibrated. These early devices were inherently fragile due to the fragile nature of the piezoelectric materials used in their construction and rudimentary adhesive bonding technology. In the 1930's, as there was an effort to utilize ultrasonic energy more extensively, the piezoelectric technology then available fell short of the need for reliable, robust ultrasonic devices. It was at this time that magnetostrictive technology eclipsed piezoelectric technology as the "motor" for ultrasonic devices including early ultrasonic cleaning systems. Magnetostrictive devices of that era were unquestionably more reliable than their piezoelectric counterparts.

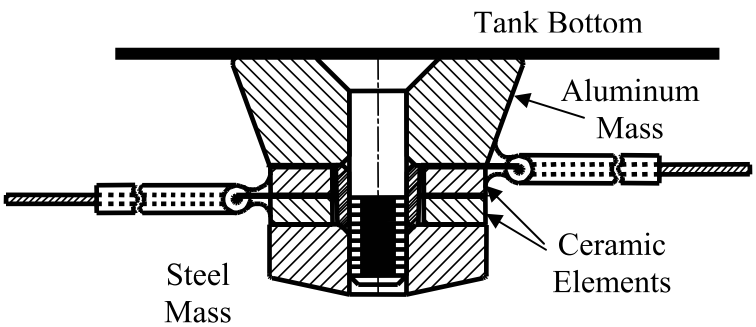
All of that began to change, however, with the development of new piezoelectric ceramics for use in SONAR applications during World War II. New, stronger, man-made ceramics replaced naturally occurring "crystals" as the source of vibration. In addition, ways were found to pre-stress the new piezoelectric materials (much like in the architectural use of pre-stressed concrete) to prevent failure due to their limited tensile strength. The remaining "weak link," the attachment of composite piezoelectric drivers to suitable vessels for ultrasonic cleaning use, was overcome with the development of advanced adhesive bonding methods necessitated by the aircraft industry during the 1950's. This technology continues to advance to this day.

So, although there was a period in time when magnetostrictive transducers ruled the world of ultrasonic cleaning, the pendulum has now swung back toward piezoelectricity as the preferred ultrasonic source. There is abundant support for this switch in preference for piezoelectricity.

The following brief description of both magnetostrictive and piezoelectric technology as it is utilized in ultrasonic transducers is provided to assist the reader in an understanding of the discussions that follow.

Transducer Technology

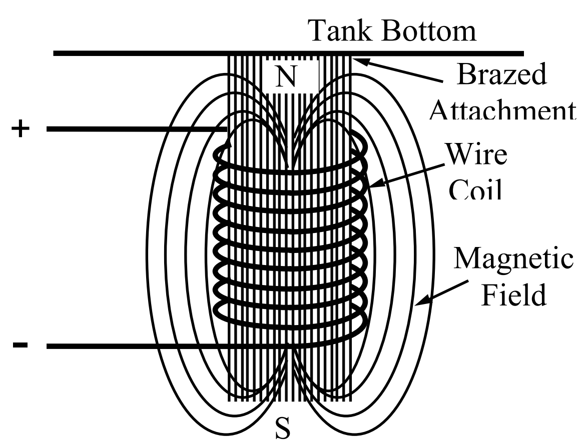
Piezoelectric Transducer

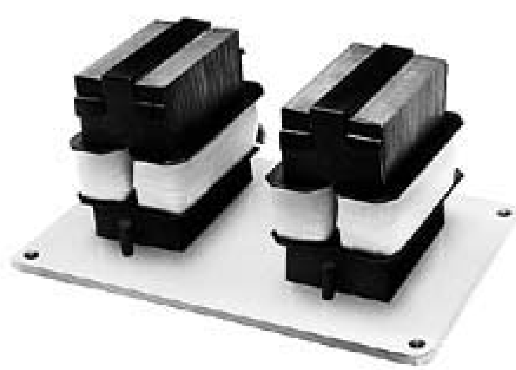


Theory of Operation

The heart of a piezoelectric transducer is a single or double thick disc of piezoelectric ceramic material, typically Lead Zirconate Titanate (PZT), sandwiched between electrodes which provide the attachment points for electrical contact. The ceramic assembly is compressed between metal blocks (one aluminum and one steel) to a known compression with a high strength, aircraft quality bolt. When a voltage is applied across the ceramic through the electrodes, the ceramic expands or contracts (depending on polarity) due to changes in its lattice structure. This physical displacement causes a sound wave to propagate into the cleaning solution. An interesting note - - piezoelectric ceramics used in load cells work in exactly the opposite way (supply a load, create a voltage).

Magnetostrictive Transducer





Theory of Operation

Magnetostrictive transducers consist of a large number of nickel (or other magnetostrictive material) plates or laminations arranged in parallel with one edge of each laminate attached to the bottom of a process tank or other surface to be vibrated. A coil of wire is placed around the magnetostrictive material. When a flow of electrical current is supplied through the coil of wire, a magnetic field is created (just like high power lines). This magnetic field causes the magnetostrictive material to contract or elongate, thereby introducing a sound wave into the cleaning fluid.

Comparisons

As was stated at the outset, there are relative advantages and disadvantages to the two technologies presented above. Some of these are not immediately obvious and are, therefore, discussed below in some detail.

Frequency Range

Typical ultrasonic frequencies range from 20 to 200 kHz. Due to physical size limitations of the magnetostrictive transducer (frequency is dependent on the length of the transducer with higher frequency requiring a shorter and shorter length) it is inherently limited to operate at frequencies below approximately 30 kHz. Piezoelectric transducers are not frequency limited within this range. The manufacturer can choose the proper piezoelectric design and drive it at a selected output frequency over the entire ultrasonic range by utilizing harmonic multiples of the primary resonant frequency. This makes piezoelectric transducers a more versatile choice from the standpoint of frequencies available.

Audible Noise

The typical adult human can hear sounds up to approximately 18 kHz. As magnetostrictive systems are limited to operate at from 18 to approximately 30 kHz, their first sub-harmonic (1/2 the operating frequency) is always within the human audible range. This means that magnetostrictive systems may often seem extremely loud to the human ear because of the high energy present at the first sub-harmonic of the ultrasonic frequency.

The 40 kHz energy that is typically used with piezoelectric transducers has its first sub-harmonic at 20 kHz which is above the normal adult hearing limit. The second harmonic is in the audible range (at 10 kHz), but the energy in this harmonic is very low compared to that at the first so the sound level is not as high. In short, this means that it may not economical to bring a magnetostrictive system under the 85 db level above which hearing protection is required according to OSHA standards. Higher frequency piezoelectric equipment can easily be brought under OSHA limits by appropriate design and acoustic shielding.

Transducer Reliability

Magnetostrictive sales pitches focus on the reliability of the transducer and the metallurgical bond to the tank bottom. It is thereby insinuated that piezoelectric transducers are less than reliable. The alleged historical support for these mis-statements can be seen in the

"Background" section above. In fact, both types of transducers are reliable with today's technology. Both are mature, highly reliable, engineered devices. This argument defending magnetostrictive technology is reminiscent of that advanced in defense of the continued use of "tube" type technology for electronics at the beginning of the semiconductor era.

Generator Reliability

The generators used to drive modern piezoelectric ultrasonic generators have a 2 year warranty which is made possible by the advanced semiconductors used in their fabrication. Magnetostrictive generator designs commonly utilize older SCR technology which, due to high amperage and switching frequency, is historically more prone to failure under load. Typical magnetostrictive generator warranties are limited to 1 year because of this.

Sweep Frequency

Sweeping frequency is critical to uniform cleaning results. Most major ultrasonic suppliers providing piezoelectric transducers now have some version of sweeping frequency due to the market demand for this highly effective feature. Magnetostrictive systems have not moved to a sweep frequency system. The reason is that the magnetostrictive transducer has such a large inertial mass that it is impossible to shift the frequency as rapidly as is required to get good sweep frequency. It is possible to slowly sweep the frequency, but this has been demonstrated to have limited benefits.

Effect of Aging

The electrical activity of piezoelectric materials slowly degrades as a half-life function from the time they are "poled" (the process of initially aligning the electrical domains of the piezoelectric material during its manufacture). However, since this effect is well-known and predictable, it is possible to take measures to counter-act its effect on transducer performance. One way is by "aging" piezoelectric elements prior to use.

One of the characteristics of a half-life function is that it proceeds more and more slowly with time. In the case of piezoelectric materials, the reduction in activity after 100 days has brought the activity level to within 1% of the ultimate level it will achieve over the next 17 YEARS of aging. This means that there is only a 1% additional decrease in activity in 17 years. To utilize this effect, ultrasonic manufacturers typically age piezoelectric ceramics for 100+ days prior to building them into transducer assemblies.

In addition to the stabilization achieved by aging ceramics – today's digital ultrasonic generators can easily sense and accommodate for any change in the electrical properties of the transducer over time. Aging of piezoelectric materials, therefore, is not an issue in today's ultrasonic systems.

Energy Efficiency

Piezoelectric transducers are extremely efficient due to the direct conversion of electrical to mechanical energy in a single step. Direct application of the power to the piezoelectrically active ceramic causes it to change shape and create the sound wave. Energy losses in the ceramic due to internal friction and heat are typically less than 5%. This means that up to 95% of the power delivered to the transducer is used to do cleaning. Modern ultrasonic generators used to drive piezoelectric transducers are generally over 75% efficient making the overall system efficiency 70% or higher.

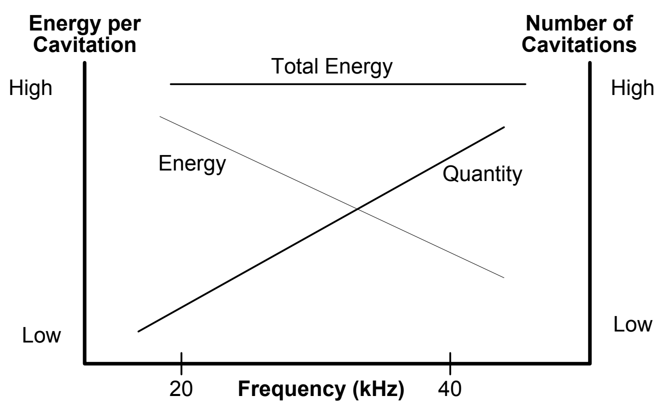
Magnetostrictive systems on the other hand rely on the double conversion of electrical to magnetic energy and then from magnetic to mechanical to produce the sound wave. Magnetic systems are usually less than 50% efficient due to the energy lost in heating of the coils and the effects of magnetic hysteresis. Additionally, the generators, even if well tuned, are generally no more than 70% efficient. This means that the overall delivery of cleaning power is between 35 and 40% efficient. In these days of increasing energy costs, the impact on operational costs of a large magnetostrictive system cannot be underestimated.

Typical 10 Gallon system:

System Type	Power Draw	Power from Generator	Power from Transducer	Power in Tank
Piezoelectric	1050 Watts	750 Watts	710 Watts	710 Watts
Magnetostrictive	2000 Watts	1300 Watts	650 Watts	650 Watts

Frequency Versus Application

Frequency impacts the diameter of the cavitation event. Low frequencies result in large diameter cavitations and higher frequencies result in small diameter cavitations. The energy per cavitation follows the same trend. However, the number of cavitations per unit volume is high with high frequency systems and low with low frequency systems. The combination of energy per cavitation and number of cavitations is total energy and this is equal for both frequencies.



Because of this relationship, 40 kHz is generally considered the precision cleaning frequency, dominating most cleaning applications. Low frequency systems have done well in high mass applications where the soil to be removed is extremely difficult, but complete removal is not required, such as removal of sand after aluminum casting in sand forms.

Summary

Today’s piezoelectric ultrasonic transducers are reliable, efficient devices which can be used with confidence in all power ultrasonic applications. Arguments against the reliability of piezoelectric transducers and in favor of transducers utilizing magnetostrictive technology are based on historical information which is now dated and largely inaccurate. The fact is that piezoelectric transducers are capable of providing a wider range of frequency and waveform characteristics and higher electrical conversion efficiency than their magnetostrictive counterparts. Piezoelectric transducers are a good choice given today’s advanced technology.