

Hold the Anchovies!

Or

No small silvery fish on my “Piezo” (Clyde Hancock & John Folsom, MicroMo)



What’s a piezomotor? We’ve heard about it and we know that it’s not some kind of a new engine for an Italian sports car. Piezo- (pī ē’zō’, pē ā’zō’-) kind of sounds like Pisano the Italian sculptor (also a brand of wine), but it’s not even Italian. Piezo is derived from the Greek word “piezein” which means to squeeze or press. And no, we’re not going to make wine. Around 1880 the Curie brothers (Jacques & Pierre) demonstrated that if you applied enough pressure to some crystals you could generate electricity. Further study has revealed more materials with crystalline structure that maximize the Piezo effect. This has a lot of interesting possibilities. I’m sure you’ve seen shoes that light up as you walk or the igniters used to light gas grills. And you’ve got to hate those irritating beepers. So here’s where it gets interesting. This effect is reversible. If you apply a voltage to the same crystal it will change shape. This change in shape is very, very small. There’s just a few percent of a change from the original shape, at most. But if you control the way you change the shape, you can use the change to make things move. The earliest piezomotor of record was built by Alfred Williams and Walter Brown of Brush Development Company in 1942. They received a patent for this “Piezoelectric Motor” in 1948. There have been quite a few developments related to piezoelectric motors since then.

What took so long John?



Can you keep a secret? Material Science had to catch up. During World War II researchers in several countries developed much easier to manufacture materials with improved performance characteristics. The biggest problem was that the new development started during the war in an environment of secrecy which continued after the war due to the desire to keep technology and process secret to maximize market potential. The first applications for these materials were really in the realm of acoustics. These new materials led to more sensitive sonar transducers, microphones, phonograph cartridges, audio sound transducers, and ignition systems.

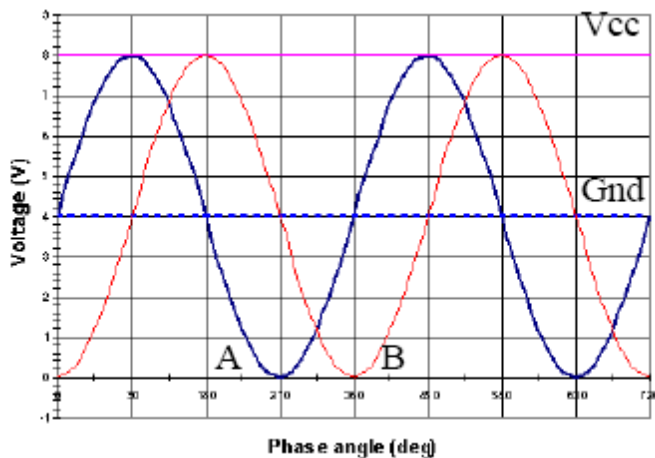
Early motors developed for commercial applications used high voltage drives. Years ago, when Clack still had hair, a marketing manager handed me a piezoelectric motor and a driver with an instruction sheet in Japanese and said “see how this runs”. Being the typical male of the species I ignored the instructions (who needs instructions, it’s just a motor) but was curious about what the 警告300V label on the driver was all about. Although Google language wasn’t around then the manufacturer had a website and I found out the little label was basically telling me I should be careful because the driver output 300Vpp!!! Things have improved since then. These days I have Techs I can hand 300V stuff like that to hook up and further improvements in materials have led to motors like the Piezomotor Legs and Wave motor (shameless plug) that operate off much lower drive voltages.



It's a good thing that a method of electronically controlling these materials was developed. Just applying a voltage to the Piezo material to change the shape will not make it a motor. It has to be applied in the right direction and repeatedly. This means the voltage will have to be applied in the proper direction(s) and have some frequency associated with it. The movement that can be achieved is on the nanometer scale. This of course means that the number of moves per second will have to be very high to realize any speed from the motor (linear or rotary), generally above 20,000 Hz (cycles per second). This is why these devices are sometimes referred to as "Ultrasonic Motors".



Remember how I joked about the 警告300V label and handing it to a tech to hook up. Well the PiezoMotor AB Piezo Wave motor will operate at phase voltages less than 9V which is much more conducive to making it home every night and also makes it useful in battery powered devices. In addition the drive is relatively simple to implement. The two phases are driven with sine waves 90 degrees apart.



However there is no need to create sine-cosine tables within a microprocessor to drive the motor. A simple digital pulse train with a 90 degree phase shift between the two elements is all you need. Because the motor is driven at its resonant frequency of 91-93kHz a simple inductor in series with the piezo elements will be enough. The inherent capacity of the Piezo Wave motor and the inductor will create a filter that will smooth out the signal.



OK, so how does the motor actually work? Well, there's several ways to achieve motion using the reverse piezoelectric effect. The ideas we are talking about apply to both rotary motion and linear motion. Generally speaking, it involves the stationary part pushing the moving part in very small increments. At the same time you are pushing the moving part, you have to insure that it moves in the direction you want it to and that it doesn't move when you don't want it to. If you do this fast enough, you get usable speeds with a fairly large force, and because the incremental

moves are so small you can control position very accurately. Another interesting point, these piezoceramic materials have the most change in shape if they are excited at their resonant frequency. Since there are so many methods of achieving this motion, we'll just stick to the two types used by the Faulhaber Group to make a piezomotor; Piezo Legs and Piezo Wave motors. Both of these are manufactured by PiezoMotor AB, located in Uppsala, Sweden.

How about the Piezo Legs for instance? If you look at the figure below you see four possibilities for controlling a "leg". If no voltage is applied you have the basic shape (fig. A). When you apply voltage to the right side you extend the right side (fig. B) which bends the leg to the left. Applying voltage to both the left and the right side (fig. c) the leg is straight and fully extended. So removing the voltage from the right side (fig. d) causes the leg to bend to the right. If you do this in the right sequence and there is a moveable object at the end of the leg, you will get motion. Although you can accomplish this with just one leg, Piezomotor AB uses multiple legs. Think about a juggler laying on his back and spinning a ball with his feet.



And the Piezo Wave, how does that work? Is it like surfing? John, help us out here, how do you control these motors? What's a traveling wave or standing wave? I understand that a traveling wave can be demonstrated by tossing a pebble in a pond and observing the motion of the ripples (traveling waves) as they move outward from the point of impact. And a standing wave can be demonstrated by observing a guitar string after you pluck it. So how's this going to make a motor? Help me out. Toss me a pebble or better yet, you play guitar, so play a something (no singing please).



Figure 1 Traveling Wave



Figure 2 Standing Wave

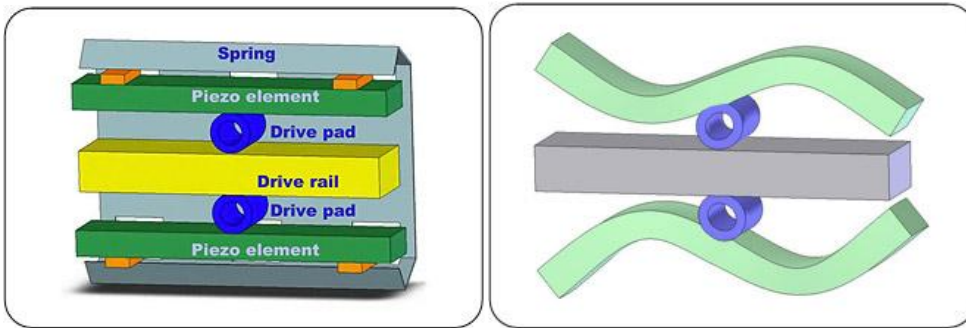


Um, those aren't really good examples of standing or traveling waves. Does our Sales Manager know you used his company photo for figure 2?

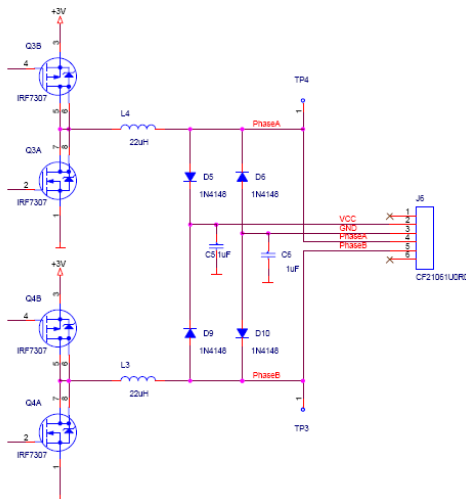
A traveling wave is somewhat akin to the motion of the ocean or the action created by throwing a pebble into a pond. The "wave" at the football game (minus of course, the drunk who is a section or two early or late) is another example of a traveling wave.

A standing wave is more like a rubber band stretched between two thumbtacks (nodes is the technical term) set to oscillating by an external impulse, like pulling it with your finger and letting it go. Guitar strings are another good example, tied to nodes at the bridge and frets and then set in motion by plucking the string with a pick or your fingers. The peak displacement will be between the two nodes and no motion will occur at the nodes. Now if you catch the signal with a pickup, drive it through some 12AX7A's, EL34's, four 12" speakers and stand in the right spot, the standing wave will stand there until the Police show up. But that's a subject for an episode of a TV reality show.

In our case of a piezo electric element the motion is induced in what amounts to a pedigreed piece of rock, not a football stadium. Piezo Wave motors utilize two piezo elements being driven by sine waves 90 degrees out of phase with each other to drive a rail along a linear path. As the wave travels the length of the piezo element it causes the piezo element to flex. Drive pads attached to the piezo elements move in a tight elliptical pattern due to the elements flexing like waves in the ocean. The drive pads anchored to the piezo element squeeze the drive rail between them and, as they move with the piezo elements in an elliptical motion, push the rail along. As the elliptical motion of the drive pad continues the pads release the drive rail and cycle back around to grab the rail again. You can see this animated here. <http://www.piezomotor.se/pages/waveanim.html#>



To reverse the direction of the drive rail you simply reverse the lead lag relationships of the driving signals to the phases. Pretty simple? The drive circuitry for the Piezo Wave elements is even simpler, basically just a digital pulse train fed through an inductor. It is the combination of the inductance and the inherent capacity of the piezo elements that act as a filter to smooth the square wave into a sine wave.



Now that all seems very simple and, compared to the piezo legs drive, it is. In the Piezo Legs motors we need the phase shifted signals like the ones used in the Wave motor but because we have two sets of legs, we need another set of signals phase shifted 180 degrees from the first set. Like this:

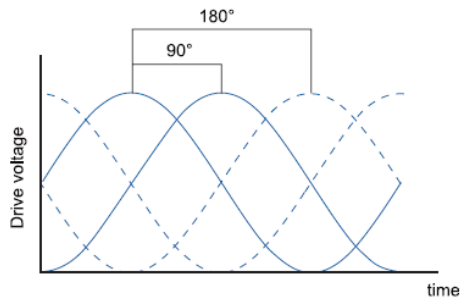
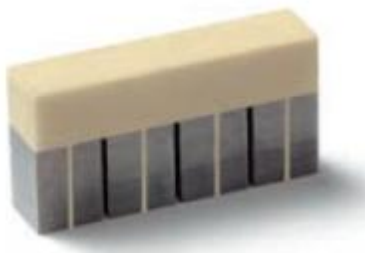


Fig. 5. Normal phase shifts between drive voltage signals.

The solid blue lines would drive one set of legs while the dashed blue line would drive the other set. In the picture below we can see each leg has two parts.



One part of the leg would be driven by the first wave and the other side would be driven by the wave shifted by 90 degrees. Let's say the first leg would be driven by the solid blue waveforms. The third leg would then also be driven by the same set, making these legs, 1 and 3, move in unison. At the same time the dashed waveforms would be driving the 2nd and 4th legs, making them move in unison.



Well, I guess that about sums it up. While we have traditionally had the interaction of electromagnets and permanent magnets to turn electric power into mechanical power, Piezomotors are a non-electromagnetic method of doing the same thing. This technology expands the range of products available to make getting the right component for the right application possible. The potential for greater torque in a smaller package with nanometer move capability is something worth getting excited about.

More about waves:

<http://www.phys.unsw.edu.au/jw/strings.html>

More about PiezoMotor (Legs and Wave)

<http://machinedesign.com/ContentItem/72955/TinyMotorsMakeBigMove.aspx>