UNDERGRADUATE REPORT

Piezoelectric Motor

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Design and Construction of Piezoelectric Motor

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ABSTRACT

This report describes the technical aspects of a piezoelectric motor that was designed and successfully demonstrated at the Intelligent Servosystems Lab (ISL) of the University of Maryland at College Park. The motor was constructed with two piezoelectric benders and Lego blocks. It was driven by signals generated by the AC100 system and suitable voltage amplification. Using a similar procedure, one can make a smaller version that would be ideal for a small fan. Also described are the basic principles of the piezoelectric motor, an assessment of the motor, and ideas for improvement.

TABLE OF CONTENTS *Page*

BACKGROUND

Piezoelectrics

A piezoelectric element is a type of material, in this case ceramic, with the property of changing shape given an applied voltage[1]. When used in this way it is called an actuator. It also has the ability to do the reverse, that is to send out a voltage when deflected a certain amount. In this capacity it is called a sensor. It is possible to make a self-sensing piezoelectric actuator[2], but that is out of the scope of this report.

One feature that is very helpful for certain applications is that it only affects magnetic fields by an insignificant amount[1]. Because of this, piezoelectric fans could be used for cooling computers. Some other features of piezoelectric material are its large force and its brittleness. To take advantage of this force and minimize the breakage, piezoelectric benders were created.

A piezoelectric bender is a sheet of metal sandwiched by two piezoelectric elements. “The voltage across the bender element forces one layer to expand, while the other contracts... The application of voltage to the element is analogous to the application of heat to a bimetallic strip[1].” When looking at the bender as a two dimensional rectangle, the poling is parallel to the shorter of the two sides. Then, depending on the applied voltage, either the width contracts and the length expands, or vice versa. The elements can be set up in series or in parallel. The parallel set-up gives it a greater force with less voltage, but the maximum deflection of the two are the same.

Conceptual Theory

The idea of this motor is to have a piezoelectric bender hit a wheel in order to turn it.

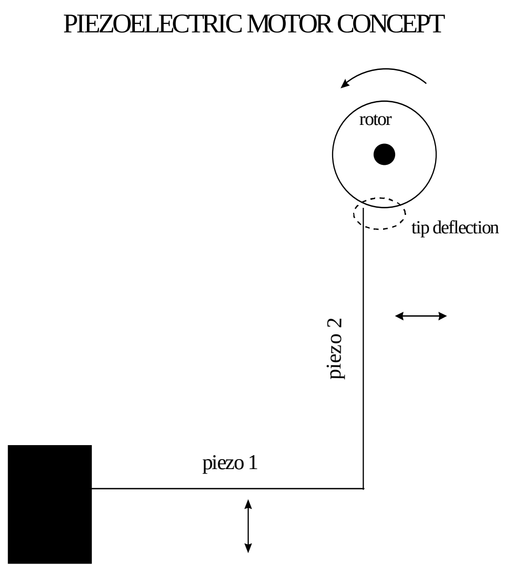


Figure 1

Since the bender cycles quickly with a small deflection, it can hit the rotor at a fairly high frequency to give the rotor a larger (but slower) deflection.

To get the rotor to move, there must be friction between it and the piezoelectric bender. However, if the tip of the bender only moved in a straight line, contact would always remain between the two, and the rotor would never turn. One way to get around this problem is to have the tip move in a circular or elliptical shape. This way, contact remains for forward motion, and not for backward motion. This process is called rectification. We can achieve this by adding two spatially perpendicular sine waves that are 90° or 270° out of phase. When the waves are 0° and 180° out of phase, they form a line with the slope of one and negative one. All other phase shifts form ellipses. Our goal then is to find the optimum phase angle and frequency to run the motor.

CONSTRUCTION

This motor was built in a limited time frame with somewhat limited materials. The legos were easy to work with, yet hard to adjust. This made it difficult to fine tune so as to find the ideal position for the greatest output.

Materials

-two piezoelectric benders (63mm x 38mm x 0.19mm)
-techno legos
-krazy glue
-two amplifiers (to amplify the AC100 system)
-AC100 System (for generating two sine wave signals)
-digital to analog converters (to interface the motor with the AC100)
-power source of 140 Volts (to amplify the AC100 signals)
-oscilliscope (to view the signals)

Piezoelectric Elements

There were no modifications necessary to the piezoelectric transducer that was poled for series operation. I simply had to solder two leads to it, one to each side, according to the instructions in the manual. For the piezoelectric bender that was poled for parallel operation, however, I first had to access the center shim. I did this by using a drummel tool, and sanding about one quater of an inch square on one side, until I reached the metal layer. Then I soldered two positive leads to the outside layers, and a negative lead to the inside layer. (There really is no difference between a positive lead and a negative lead. However, the convention is to make the positive leads red and the negative ones black).

Base

There are really two parts to the base. One part to support the piezoelectric elements, and one part to support the wheel, or rotor. These two parts are then attached to a large flat base in such a way that the rotor is suspended directly over the vertical piezoelectric element, almost touching it. However, the point of contact, i.e. the part of the rotor that is closest to the bender, is not the lowest part of the wheel. It is actually approximately 45° away from that point. In order for it to sit at the proper height one layer of legos supporting the rotor had to be shaved down about 10 thousandths of an inch. In this form, the axle attached to the wheel rotates as well, as opposed to the option that exists for some of the larger Lego wheels, which is to have only the wheel rotate. In the latter case, there would be less friction, but in our case there is more stability. However, the "give" or slippage is enough in our case to make quite a difference, as explained later.

The goal of the base for the piezoelectric elements was to have them stand at a right angle to each other without touching directly. If they were to touch, or be connected by a conductor, then the circuit would short out. Legos, as an insulator, serve us well in this situation. I mounted the piezoelectric bender poled for series operation horizontally, and the one poled for

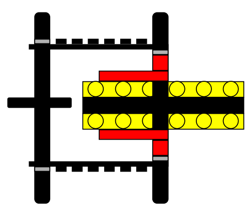


Figure 2

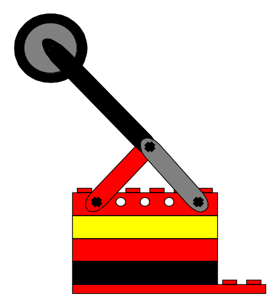


Figure 3

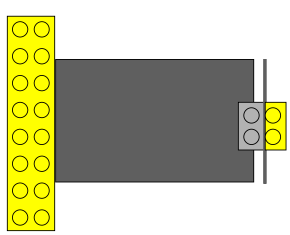


Figure 4

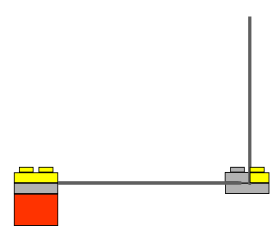


Figure 5

parallel operation vertically.

As seen in the diagram, the horizontal bender is clamped down between two legos. To get it to fit, five studs from one row were shaved off with a mill. No additional adhesive was necessary. To connect the two piezoelectric elements, one thin two-by-two and two thin one-by-twos were used. We shaved about two-thirds of the front two studs on the two-by-two, leaving behind two moon-shaped studs. The horizontal bender lies on the shaved part, and the vertical bender stands up between the studs, perpendicular to both the lego and the horizontal bender. The moon-shaped studs now separate the two piezoelectric elements. The two one-by-ones are placed on top of the two-by-two. However, in order for the vertical element to fit in between them, part of the one-by-one not touching the horizontal piece had to be shaved. Krazy glue was used to attach these pieces to the legos.

AC-100 System

The AC-100 system is a program which enables the user to create a "black box," or a block diagram of a system of inputs and outputs. I made a black box that outputs two sine waves, according to the specifications of the inputs; the inputs being the frequency, voltage, and phase angle of the waves. I built animation for the inputs, consisting of slide rules for the said inputs, so that they can be changed easily during operation. I made one icon that changes both the frequencies, one that changes the phase angle of one of the waves (the other wave has a set phase angle of zero), and two icons for the voltages, one for each wave.

I created the system according to figure two. Since the two amplifiers I am using have a gain of -35 and -58, I divided by these numbers in the program so that an input of X volts will be divided by 35 or 58, and then amplified back to X volts. The reason that amplifiers must be used is that the program can only generate a maximum voltage of five volts.

After the block diagram was written and saved, I followed the rest of the computer's flow chart necessary for the completion of my program. To connect to the AC-100 server, I typed ac100svr at its command prompt. This step is necessary for the auto code to be compiled and for the program to run.

Set Up

After all the pieces were constructed, I had to put them together. The digital signals generated from the AC100 program are outputted to two channels in the IP DAC module, where they are converted to usable analog signals. Connector wires attach these output channels to the amplifiers: the positive to the input, and the negative to the ground.

The next part of the circuit is the resistors. I calculated the necessary resistance according to the equation:

$$5\ R\ C \geq 4\ f$$

where R = resistance, C = capacitance, and f = resonance frequency. For the series bender the resistance came out to 194.4 KΩ (kilo-ohms), and for the parallel bender it came out to one-fourth of that. However, to be on the safe side, I used a 270 KΩ resistor for each circuit. I soldered these resistors directly to the output of the amplifiers.

To complete the circuits, I hooked up the piezoelectric elements. I attached them using wires with alligator clips on both ends. I grounded the negative leads, and connected the positive leads to the resisters on the amplifiers. The parallel piezoelectric bender has two positive leads, so I connected both of these together along with the resistor.

Running the Motor

To start the motor, I click on “download and run” on the AC-100 program, with the AC-100 server on, and it opens the program and its graphics. Then, using my mouse, I fix the settings on the graphics for the frequency, wavelength, and voltage. I usually set the voltage to 100 volts. Then I turn on the power to the amplifiers, making sure it’s above the said voltage, and click on the “start controller” button.

HYPOTHESIS

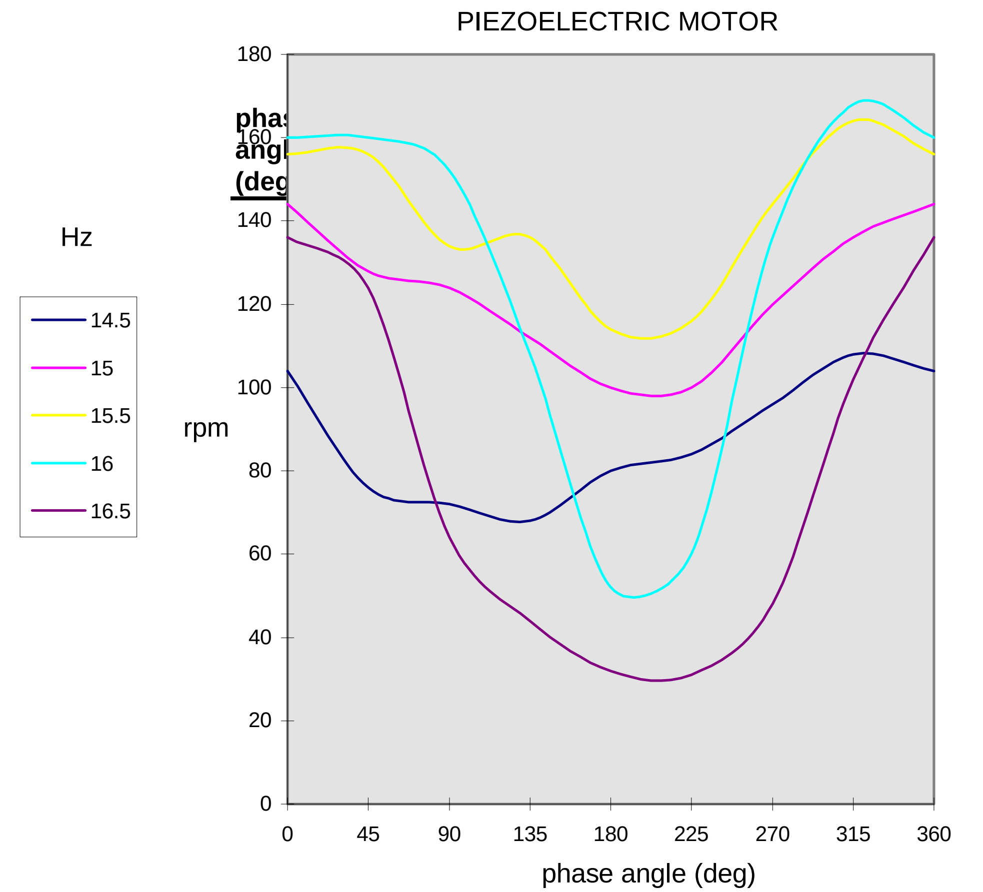
I expected the motor to generate the highest output with the phase angles (added to the vertical bender) of 90° and 270°, each turning the rotor in the opposite direction. I also expected that at 0° and 180° the rotor would move very slowly, if at all.

I conjectured that there would be an optimum frequency (the resonant frequency) at which the motor would run fastest and most efficiently.

TESTING

To test my hypothesis, I timed the revolutions per minute (rpm) of the rotor at various frequencies and phase angles. To do this, I put a strip of yellow tape on the radius of the rotor, counted how many revolutions it made in a 15 second time period, and multiplied this by four. I did this all in one sitting, since when the placement of the rotor is shifted even the smallest amount it favors different phase angles and frequencies. All testing was performed at 100 volts.

RESULTS:



Graph 1

In second test, I removed the rotor apparatus and taped a felt tip marker to the end of the piezoelectric bender. I taped a piece of paper to the wall, and had the motor trace out the shape of its motion onto the paper. I did this at a frequency of one Hertz, at intervals of 15°. I also tried it at 9 Hz.

The results to this test at one Hz are lines/ellipses ranging from two to seven millimeters, as described in the analysis section of this report. At 9 Hz the marker traced out a diagonal figure eight, about one cm long. The various phase angles were indistinguishable.

ANALYSIS

At low frequencies, around one Hz, the motor behaved close to expected. The tip rotated clockwise throughout half of the phase angles, and counter-clockwise throughout the other half. However, the "straight line" areas occurred at a phase angle of around 30° and 210°, as opposed to the expected 0° and 180°. Also, the lines themselves traced out to approximately 20° and 90° from the horizontal, as opposed to the expected 45° and 135°. A perfect circle was traced out at 190° and 230°, both equidistant from the vertical line (at 210°) and 40° apart. All of the ellipse shapes between the circle and the line were slanted within the boundary of 20°-90°.

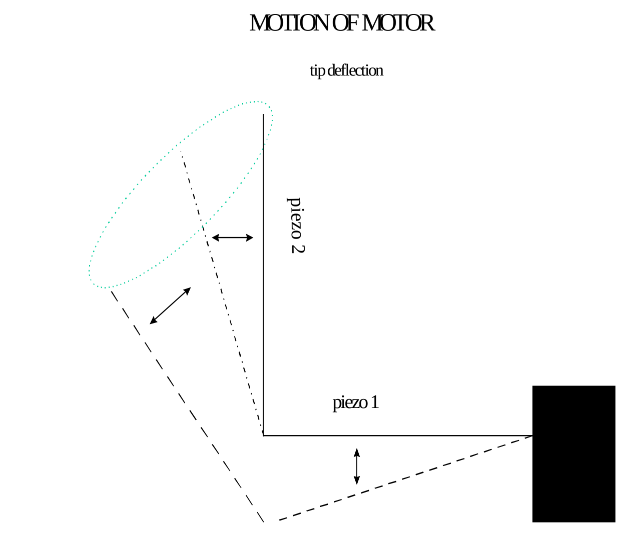
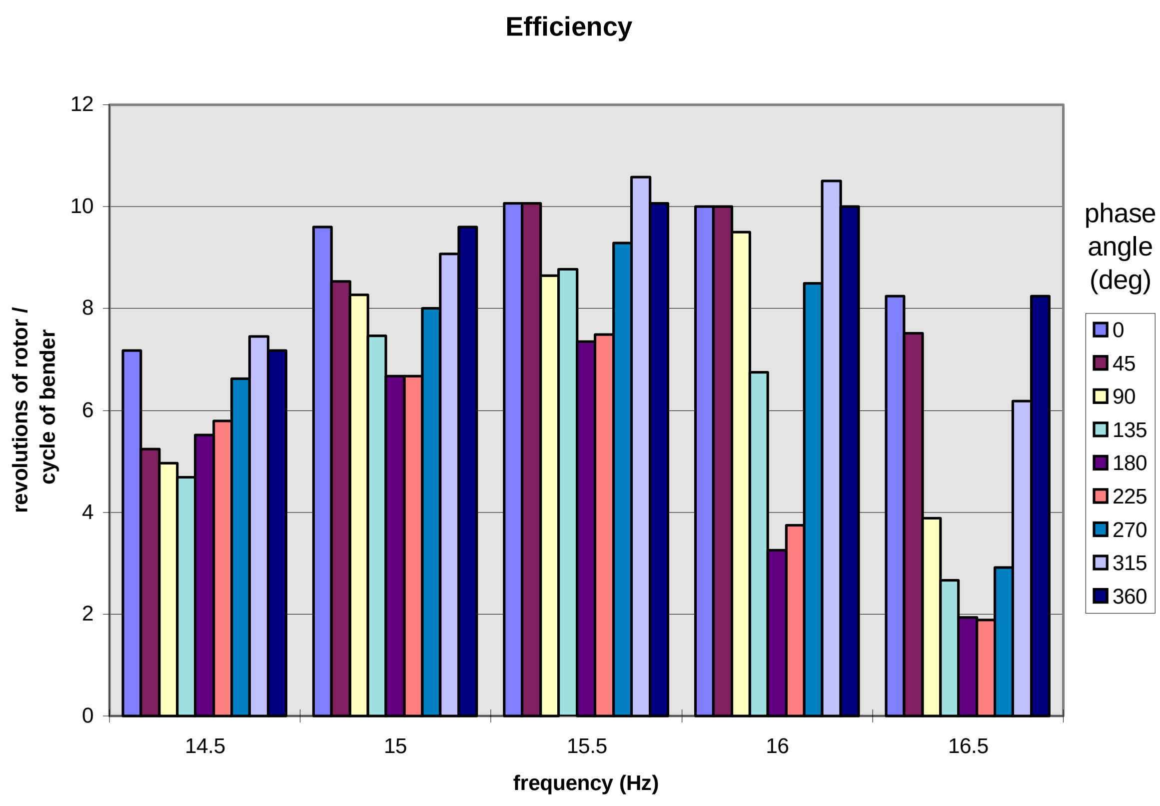


Figure 6

The reason the circle appeared at phase angles not 90° apart, and the reason the angle of the ellipses stayed within the said boundary conditions at low frequencies is because of the limited motion of the bender. It only bends in one direction from the resting position, as opposed to sweeping through like a pendulum. Because of this, the results of the low frequency testing are not symmetrical. Another factor contributing to the degree of the slant is the added weight of the marker.

At high frequencies, however, the story might be different. The graph of the results, though not perfectly smooth, is somewhat symmetric. This seems to show that at frequencies near resonance, more of a pendulum motion is taking place, and the piezoelectric bender is acting like a spring. This result is still not understood by the author. One thing I did notice is that when there is no voltage applied to the vertical bender, the rotor still turns at comparable speeds. This means that the motor would in fact work, near resonance frequencies, with only one bending element.

I determined the efficiency of the motor by dividing the number of revolutions the rotor made by the frequency of the benders. For example, if the rotor revolved twice per second at one Hertz, then the efficiency would be two. As seen in the chart, the efficiency was greatest near 315°-360°.



Graph 2

CONCLUSION

For this project I made a motor out of two piezoelectric benders and a rotor. I created two known AC signals to send both of the benders to control their motion. This, in turn, hit the rotor to make it spin. Observations showed that at low frequencies the tip of the piezoelectric bender moved in a simple elliptical motion. This was caused by the piezoelectric elements bending and unbending. However, at frequencies near resonance the tip moved like a figure eight, suggesting that the benders moved like a spring. I took most of my data at this frequency.

Future research with this motor should include how it behaves under a given load, comparing it to a similar motor with only one bender, and modeling its motion near resonant frequency. To improve the motor, it can be made smaller, and with more stable material than legos. Piezoelectric materials have the potential for many future applications.

ACKNOWLEDGMENTS

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