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INERTIAL STEPPER

Group No. D15

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Abstract:

To design an inertial stepper. The idea is to make an object move some distance by causing it to make incremental steps when a small speaker used as transducer, with a microscope slide attached to the diaphragm of the speaker is fed a ramp a input, a slowly rising waveform with rapid fall. It is during this rapid fall that the object kept on the slide will this retain its original position due to inertia, and so the cycle can repeat. With each step the object can be made to move a known small distance.

1. Introduction:

In modern world, there are so many applications, where, we need high precision movements. We human beings can move small objects, but our sense of measurement is so course that we can hardly be assured about relative degrees of successive displacements, we have caused. Another issue is automation. We certainly don't want to do everything by hand.

For example, if we want to reach displacements of atomic order, we have to develop something different. That is why; we are trying to make an inertial stepper.

There is a transducer, either a piezo-electric material, or an electromagnet. As current or voltage, whatever appropriate, increase, the transducer gets elongated. When fed with a saw tooth waveform of a suitable magnitude, it elongates slowly and then compresses abruptly, or vice versa.

If a small platform is attached to the transducer, it will feel translational motion due to the elongation, and compression in the transducer.

When a small object is put on the above platform, it will move along with the platform during the slower motion, but it will stay at its place during the abrupt motion, thus creating a net displacement.

We are using this property to make an inertial stepper, as its name suggests, it steps due to inertia. And by selecting appropriate driving current and voltage, we can make it to shift in order of nanometres in one period of the saw tooth.

2. Design Approach:

Although an inertial stepper made using piezoelectric material can be used to get high precision, in this project we tried to make two simplistic versions.

1. Using Electromagnetic transducer
2. Using a small speaker as transducer

2.1. Block Diagram:

(Saw-tooth voltage generator-->Amplifier-->Transducer-->Mechanical System)

2.2. Using Electromagnetic transducer:

- ✓ The first stage is a microcontroller- DAC setup which will generate a saw tooth current waveform.
- ✓ The second stage is an amplifier setup which will now amplify the saw tooth current, while maintaining the waveform, as we have to get enough magnetic fields to deform our core.
  - ✓ The current will now be fed to a coil wound on some ferrite core. We have two

alternatives for this:

- We can have our coil to a horse shoe core. When we feed the current to it, it will deform as the two poles attract.

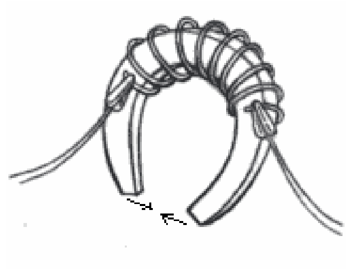

Figure 1.

Using a saw tooth voltage, thus we can make it oscillate in a manner that, in one direction, it goes slowly while in other direction, it goes abruptly, thus causing the motion in our subject.

- Alternatively, we can have a bobbin shaped core. It will deform as current passes through the coil.

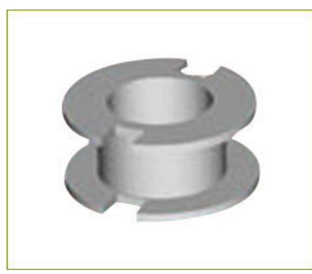

Figure 2.

Again using saw tooth voltage, it will work like the horse shoe core.

- ✓ In this case, we prefer bobbin shaped core, as it is more easily available. Also it causes less vibration than the horse shoe core.
- ✓ The mechanical system consists of a platform, which supports our material to be displaced. It will be attached to the core on one end and its motion will be attributed to the elongation and compression of the core. The object on top undergoes a displacement due to inertia. This displacement can be of order of microns or even nanometres.

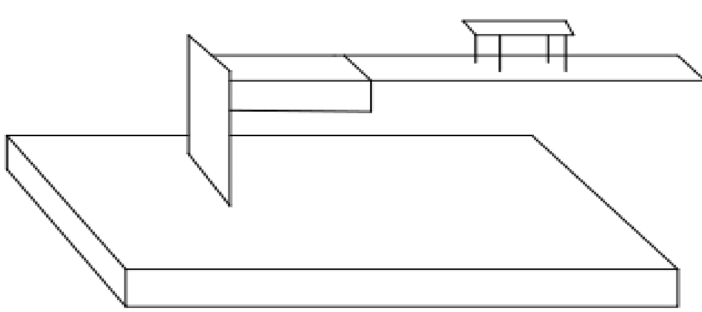

Figure 3.

2.3. Using small speaker (Tweeter) as transducer:

- ✓ We need a microcontroller-ADC-Amplifier setup to get a saw tooth voltage. Also, we need to drive a speaker, where power rating is known, so, we have to use a power amplifier, LM380.
- ✓ This output of the amplifier will be fed to the tweeter, leading its diaphragm to oscillate in the same manner, as in the previous case.
- ✓ After this, we need the mechanical setup as before.

3. Circuit Diagram:

Microcontroller schematic for generating the saw tooth voltage:

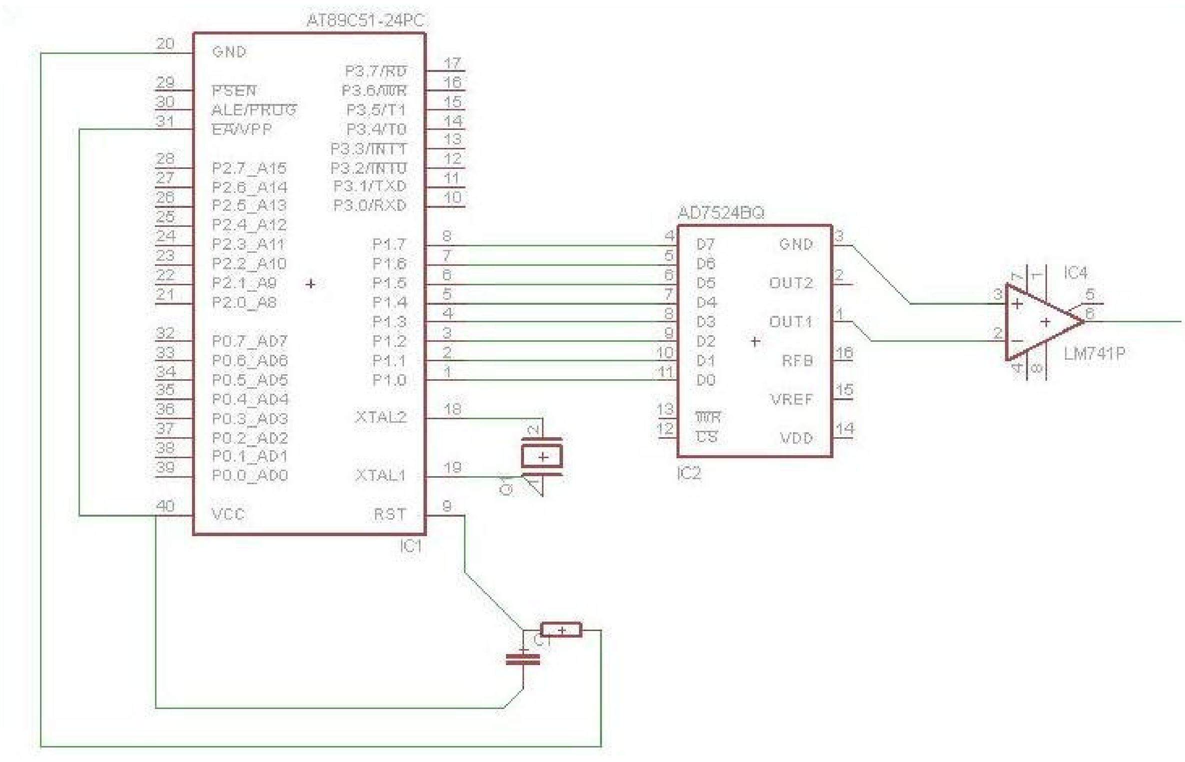

Figure 4.

The circuit schematic for the audio amplifier part:

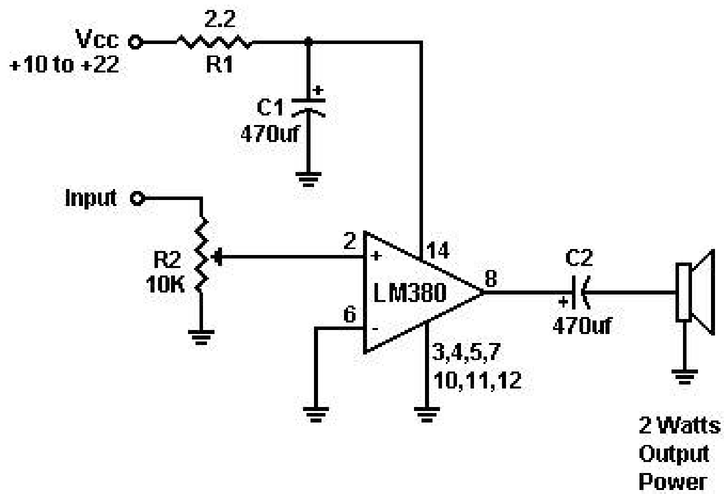

Figure 5.

3.1. Components:

Microcontroller:
The microcontroller used is AT89c51, which is a low power microcontroller which can operate on a supply of 5V.
The microcontroller is supposed to perform the following operations:

(1) Generate a saw tooth waveform using a DAC.
(2) To display operating frequency on the LCD.
(3) To interface with the keypad.

AT89c51 has been used due to its ease of use and familiarity (in baby EDL) and also low ROM requirement.

Digital to Analog Converter:
The DAC used is DAC0808, which is a 8-bit digital-to-analog converter. Its output voltage is between -0.55V to 0.4V which perfectly suited to the input restrictions of LM380.

Signal Amplifier:
For the setup involving speaker as the transducer, we have used LM380 as the voltage amplifier which is a low cost 2.5W audio power amplifier for any typical consumer application. As we have to take care of input power to the speaker, we have to use a power amplifier.

3.2. Program state diagrams / Algorithmic flow diagram:

We have written a program to generate a saw tooth wave of different frequencies.

Figure 6.

3.3. Work done so far:

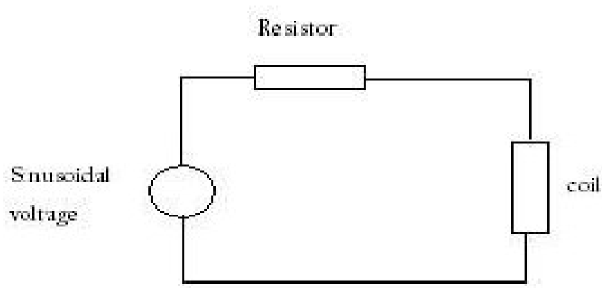

Figure 7.

- ✓ We estimated the inductance of our ferrite core coil using the above simple circuit.
- ✓ Then, we tried various circuits to work as a current amplifier.

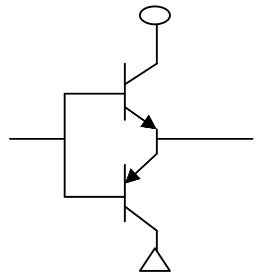

Figure 8.

We tried the above circuit and fed the output directly to the coil, but when the output was connected to the coil, the supply voltage was pulled down to zero. Also, the waveform was distorted into spikes.

Then we tried to connect the coil to the output as shown in the figure below.

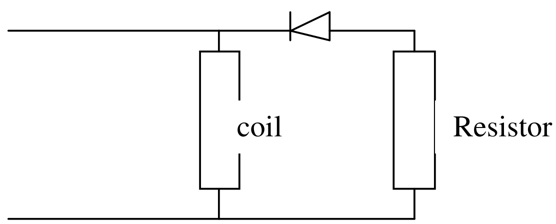

Figure 9.

But once again did not get the desired results.

- ✓ We generated the saw tooth voltage by using an AT89c51, a DAC0808, and an LM380 Op-Amp.
  We can get a voltage of 10-12 V peak using OPA741.

- ✓ We can also use it as a saw tooth current source, as the DAC is giving us the output as a current of around 0.4 mA peak value. We have to just amplify it.

- ✓ The mechanical setup consists of a small speaker as transducer, with a microscope slide attached to the diaphragm of the speaker. The object to be moved is to be put on the slide.

4. Test results:

We estimated the inductance of the coil. The data are given below for R = 50 Ohms:

Table 1

No. Of turns in the coil	Frequency for $R = \omega L$
5	>2 MHz
10	1226 KHz
20	307 KHz
40	77 KHz
80	19 KHz

The inductance can be estimated as:

$$L = \frac{50}{\omega} \quad (1)$$

And by calculations, we can see that:

$$L \propto N^2 \quad (2)$$

While working with the bobbin coil, we observed that overheating of the components occurred. That was because the inductor had a very low series resistance. And also, due to sudden decrease in the current, it produced large spikes of voltage.

While working with the speaker system, the LM380 needs an input very low, typically, 0.2 volts. When we gave a higher input, it completely distorted it into spikes.

There is a difficulty in keeping the slide perfectly horizontal. Otherwise, we saw, that the gravity comes into play and the object moves in the same direction for the waves of opposite symmetry. Also, the magnet of the speaker was contributing as a force, since we were using paper pins as legs to the object.

5. Discussion of Results:

The inductance of an 80 turns coil came out to be 0.42 mH. And also, the experiment followed equation (2), which is true.

While using circuit in figure 8, there was overheating. This was possibly due to a negligible series resistance in the coil. And also because for an inductor, current voltage relationship is given by:

$$V = L\frac{dI}{dt} \quad (3)$$

So, a sudden change in current, as is in a saw tooth current, produces a large voltage.

If the slide (the platform in our mechanical system) has even a little bit of vertical component, there is a contribution of gravity into it. But a diaphragm of a speaker being a soft material, we struggled to keep the platform absolutely horizontal.

6. Conclusion and suggestions for further improvement:

The inertial stepper is a machine that can be used to move up to an order of micrometers. It is controlled by a switch which turns it on or off.

1. It can be made to work for an order of nanometres, by using better transducers.
2. We can alter the speed by changing the frequency of the saw tooth wave. This can be implemented by putting some push buttons with the microcontroller unit.
3. We could connect an LCD which could show the speed at which the subject is moving.
4. We could attach a key pad such that we could enter some number, it could read it, and move to that distance by making some calculations internally.
5. We could use position sensors to determine if it has moved to the desired location.

7. References:

[1] www.national.com
[2] www.ti.com
[3] www.atmel.com
[4] www.8052.com
[5] The 8051 microcontroller architecture, programming and applications, by Kenneth J. Ayala.