Novel Actuation Method For Electro-Magnetic Micro Relays

Mazran Esro and Thurai Vinay

***Abstract*—The design of a Micro Electro Mechanical System (MEMS) relay system is facing so many challenges due to the relay's small micro size. Numerous methods have been invented in latching the relay with the most efficient way possible. The small micro relay requires larger contact separation to create isolation between the two contacts to avoid accidental short circuit. This could not be achieved by having a conventional relay system which requires high power to turn on the magnetic coil. This high current could destroy any other circuit in MEMS system due to its tiny track width that could burn easily like a fuse. A project on novel actuation method for electro-magnetic micro relays is carried out to search for an alternative solution to the problem. The method used in this project is by applying pulse trigger to encourage oscillations of the relay cantilever from its natural frequency until the relay latches. A model of such system has been designed to demonstrate how this technique is being implemented.**

Index Terms— Actuation method, MEMS, Micro relays, latch.

I. INTRODUCTION

There are several reasons that contributed to the idea of inventing a new method to latch the relay in MEMS system. MEMS relay must provide high isolation and low insertion loss when closed. This restriction makes the design of the system is difficult especially when the relay size is concerned. High isolation would require large separation between the relay contacts. However, the problem is that the larger the separation, the higher voltage and currents required to latch the relay. Therefore, a MEMS relay should be designed with low voltage and current in order to match the power supply for an integrated circuit. A power hungry conventional relay switch would not be a wise choice for an integrated circuit.

The objective of this project is to develop a new method of actuation for electromagnetic micro relays. The method suggests that applying repetitive pulse at the relay's cantilever natural frequency which energizes the electromagnetic coil to pull down the cantilever and make it oscillate would reduce the power consumption. This method will be demonstrated by simulation using Matlab and verification of the design by building a large scale model of the system hardware. The simulation is carried out with several assumptions to reduce the system's complexity in terms of calculation. Among the assumption that has been made is that the damping factor (Q factor), friction and gravitational force are very small and negligible.

The design of a large scale model includes the design and fabrication of the relay cantilever, magnetic coil, magnetic core, model base and the sensor placement.

II. METHODOLOGY

A. Simulation

Simulation is carried out using Matlab Simulink software. The first step to do the simulation is to create the free body diagram of the relay system.

To build a free body diagram of the system, there are a few assumptions has to be made:

1. Assuming the damping factor (Q factor) and friction is very small and negligible
2. Assuming the Gravitational force is small and negligible.

With the above assumptions, the following is the free body diagram of the system.

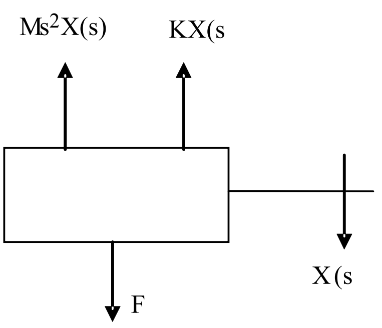

Figure 1: System's Free Body Diagram.

Note:

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X= distance traveled downward
K= spring constant
F_v=Friction / damping factor
Fm= force acting downward due to magnetic field. (see equation (2) below)

Summation of forces = 0

$$F_m = Ms^2X(s) + KX(s)$$

Or equivalently, $F_m = M\ddot{x} + kx$

Rearranging the equation,

$$M\ddot{x} = F_m - kx$$

$$\ddot{x} = \frac{1}{M}F_m - kx \qquad (1)$$

The magnetic force Fm is a product of two force:

$$F_m = F_{m1} \times \Delta F_{m2} \qquad (2)$$

Where the Fm_1 is the magnetic force due to permanent magnet embedded under the cylinder core and ΔFm_2 is magnetic force due to changes in energized coil.

The magnetic force F_m for a cantilever is inversely proportional to the air gap, g_o, represented by the following equation:

$$F_{m1} = \frac{F_{mo}}{1+\lambda(g_o - x)^2} \qquad (3)$$

Where the term F_{mo} represents the initial force exerted on the cantilever. The λ term from denominator is the magnetic coefficient from the system.

Substituting equation (2) and (3) into (1) will result the following equation:

$$\ddot{x} = \frac{1}{M}\left(-kx + \frac{F_{mo}}{1+\lambda(g_o - x)^2} \times \Delta F_{m2}\right) \qquad (4)$$

With the above formula, the simulation is carried out using Matlab Simulink program.

The simulation is expected to produce a continuously growing oscillation with the applied stimulus. The stimulus in this case would be the pulse triggered at the right frequency window. The following graph shows how the pulse is expected to be triggered.

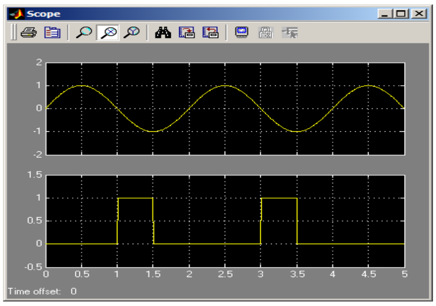

Figure 2: Time duration where the pulse should trigger.

B. *Hardware design.*

Hardware design include the Mechanical part & electronic part. For the mechanical part, a cantilever made of mild steel is chosen based on its elasticity and thickness. This cantilever is attached on wooden base at one end and left hanging at the other end.

A mild steel core wrapped with insulated copper wire is placed below the hanging end of the cantilever to create electromagnetic induction when the current pass through the wire. Permanent magnet is placed below the core to hold the cantilever when the relay latches. The figure below shows the mechanical part of the system.

Figure 3: Mechanical part.

The electronic part includes the sensor placed on the cantilever, signal conditioning circuit, pulse controller and pulse actuator. The sensor chosen for this project is the strain gauge sensor arranged in Wheatstone Bridge. There are 4 strain gauges is used.

The signal from the sensor is passed through signal conditioning circuit where the signal is processed electronically to produce desired signal for the pulse controller.

The controller will then analyze the signal and produce pulses at the right time that match the cantilever's frequency. These pulses will make the cantilever to oscillate starting from its natural frequency until the relay latch. The pulse is amplified by a high power transistor which allow current to pass through the electromagnetic coil in the mechanical part.

III. SIMULATION RESULT

The output signal shows that the pulse triggering increases the signal amplitude over time. The signal oscillates starts at small amplitude at its natural frequency and it kept growing. The simulation output is as shown in the following figure:

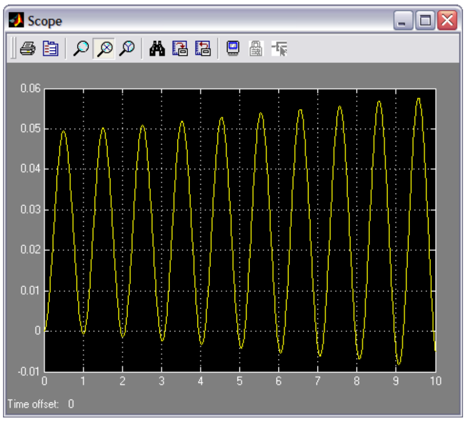

Figure 4: Simulation Output signal

Through this simulation, it is proven that by sending repetitive pulses to the system based on the output feedback frequency will produce bigger oscillation. This is in line with the objective of the project to make oscillation growing bigger over time.

IV. HARDWARE TEST RESULT

The diagram below shows the output captured from oscilloscope.

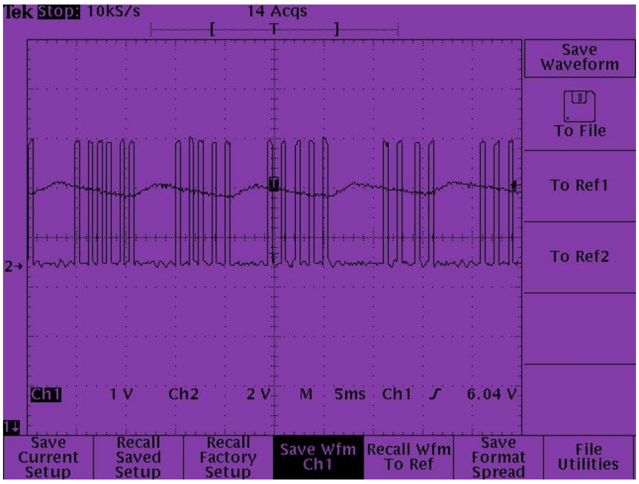

Figure 5: Output signal captured from oscilloscope.

From the oscilloscope output above shows that the pulse triggered from the controller occurred several times in each frequency window. This is not the expected pulse waveform as designed in simulation. The pulse was supposed to be longer and turned high (ON) all along when the signal from the sensor decreases from center point to the minimum point. This type of pulsing however is way much better than what it was planned because this will reduce the total power consumption and also proves that the cantilever could be pulled down with much smaller magnetic force.

The sensor output from signal conditioning circuit itself is a bit noisy where small fluctuations can be seen through the oscilloscope output. This is because that the signal is tapped before the signal is fed into the filter and voltage divider. The reason this is done is because the signal from voltage divider is too small to notice through the oscilloscope. The oscilloscope can be set to have smaller voltage per division on the screen but it is not possible to view the signal because it will cut off by the digital oscilloscope and shifting the reference ground voltage only allowed up to the lowest grid on the scope screen. This is the limitation with digital oscilloscope whereas the analog scope can do the same job better. The output signal however does not affect the output pulse too much because the signal to noise ratio is just enough for controller's analog to digital converter input.

V. CONCLUSION

The system simulation has shown that the oscillation of the relay's cantilever will grow bigger as the force that helped to increase oscillation is triggered at the right frequency window.

The hardware implementation works as what has been predicted from the simulation results. Despite all the problems and challenges in building the system, continuous effort and hard work helped very much in troubleshooting the hardware. The amount of power required to attract the cantilever down touching the contact is reduced by 50 percent using this technique. This is achieved by sending repetitive pulse to energize the magnetic coil by matching the cantilever's oscillation frequency. Pulsing the magnetic core at half of the cantilever's oscillation cycle has proved that it will increase oscillation which subsequently reduces half of the amount of power used in conventional relay. This project can be implemented in a system which requires least amount of power to excite the relay contact or a solenoid valve provided that the response time is not a critical factor in such application.

Besides the positive aspects of this project, there are some drawbacks too. According to the simulation result, the pulse to trigger and energize the magnetic coil should start from the point which the oscillating sinusoidal wave intercepts the midpoint when the sinusoidal signal is in the negative slope moving downward up to the point that it reaches the minimum level. This will create one pulse within the frequency window. However, in actual implementation, the pulse triggered several times within the frequency window which is not what has been expected in the output. Further troubleshooting could be done to correct this problem. On the other hand, several pulse triggering at the specified time would further reduce the power consumption in latching the relay even though it is not how the way it was designed in simulation.

In order to implement this actuation method in MEMS relay, there are several factors that require attention because it contributes to the complexity of the design of the system in the micro electro mechanical system. The factors involved would be the placement of the sensor onto the relay's cantilever. The size of the strain gauge sensor is really small to be incorporated in MEMS system. Therefore to have the ratio of strain gauge's size to the size of the cantilever built in a very tiny size in a micro level in MEMS system would be a very difficult task. Besides the sensor, the design of the controller in this model could be replaced with an analog controller to reduce the design complexity. It could be wasteful to have a digital controller to handle a task which is not fully utilizing its capability in MEMS system. Furthermore, the use of analog controller which has a dedicated task to trigger the pulse in the relay system would reduce the number of components and thus reduces the system complexity.

In terms of implementation of this relay in MEMS system, fabrication techniques such as deposition, lithography and etching process would also need to be modified to place certain parts or devices onto the relay. There are three basic building blocks in MEMS technology, which are the ability to deposit thin films of material on a substrate, to apply a patterned mask on top of the films by photolithograpic imaging and to etch the films selectively to the mask. A MEMS process is usually a structured sequence of these operations to form actual devices. All these techniques require a lot of research and manpower to be developed. Therefore, there are many factors must be considered before proceeding with the implementation of this project in MEMS system.

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