Experimental Investigation on the Effect of Stimulating Frequency on the Reciprocating Motion of Mercury in a Micro Cavity

Saeed Kazemi Abnavi, Shahab Haghaeygh, Mohsen Karmozdi, Mohammad Behshad Shafii and Alinaghi Salari

Abstract— The increasing need for small-scale devices for use in areas of chemical, biological and environmental viewing systems has caused a large amount of researches in this area. Part of these researches is devoted to the micro-pumps. Mercury electromagnetically stimulated micro-pump is a new type of micropumps. These are based on a reciprocating motion using electromagnetic force. The present work examines the effect of stimulation frequency on the amount of mercury coming from the micro cavity. Since it has a great impact on the performance of these pumps, in this work by taking pictures of the micro cavity and analyzing the results, the best frequencies was determined empirically.

Keywords— Electromagnetic force, Frequency, Mercury, Micro cavity

I. INTRODUCTION

The use of micro-pumps has a great vogue in handling biological samples in laboratory equipments [1], micro total analytical systems or lab on a chip integrated microprocessor, spatial researches and pumping refrigerant fluid into micro heat exchanger channels [2], in recent years.

Micro-pumps can be divided into two categories: sweep and dynamic.

Driving factors in the diaphragm micro pumps are very diverse. Among them may be stimulated by piezoelectric [3] and electrostatic [4] cited. The micro-pump with the help of thermal [5] and thermal - Pneumatic [6] stimulation has also been developed. Limitations of diaphragm micro pumps are pulsed flow and air bubbles. Piezoelectric and electrostatic excitation requires high voltages. Thermal stimulation may cause biological decomposition of fluid by changing the structure of proteins. Also in the diaphragm type, valves are needed for directing the flow. The probability that particles get trapped in the valves with moving components is very high.

In dynamic micro-pumps, the energy is continuously transferred to the fluid. In these micro-pumps, the pressure difference causing force which causes flow is created by various methods. In this category, there are three types of more applicable micro-pumps which are MHD\(^1\), EHD\(^2\) [7] and EOP\(^3\) [8]. The driving factors in these three types are respectively magneto dynamic force, electrostatic force and the force which is applied to the ions near the surface.

In general, dynamic micro-pumps have lower pressure difference in comparison with reciprocating micro-pumps. Also the working fluid can set constraints in dynamic micro-pumps. For example in EOP and EHD types the working fluid should be electrically non-conductive. The performance of these two categories is dependant to the basicity or acidity of the fluid.

Among these different types mentioned those which use magnetic field force, have unique advantages. As an example, it is possible to control the particles in the micro tube without any direct contact. Also, unlike to electrical systems, these devices are not sensitive to surface charges, pH, ionic concentration and temperature [9]. Combinational using of flexible and magnetic plates [10], Ferro fluid plugs for pumping fluid [11], micro-pump and hydromagnetic flow controllers [12] are examples of these category.

Another type of micro-pump which uses the advantages of magnetic systems is MHD micro-pump. The advantages of this type of micro-pump which are the absence of any moving part, ease of construction and continuous-flow pump, has led it to extensive researches in the field of MHD micro-pumps. But the samples made are not without problem.

The use of Lorentz force which is the basic theory of magneto dynamic for pumping liquid metals or ionized gasses goes back to much earlier [13], [14]. But it is nearly a decade since the first MHD micro-pump has been made. This MHD micro-pump which is attributed to Jang and Lee was

1 Magneto Hydro Dynamic
2 Electro Hydro Dynamic
3 Electro Osmotic Pump
introduced in 2000 [15]. This micro-pump in which direct flow and sea water was used as the working fluid, had reached a 180 Pa pressure difference and a flow rate of 63 µL per minute. However, due to the hydrolysis of electrodes and producing large amount of bubbles in the micro channel, the performance of this micro-pump was faced with serious obstacles. The bubble production is a common problem in MHD micro-pumps.

In 2009, Shafii and Emaieli Moghadam, at Sharif University of Technology, invented an exquisite micro-pump in which some of the problems of MHD micro-pumps including low pressure difference were solved [16]. In the proposed micro-pump, the Lorentz force was used for moving the mass of mercury and pumping fluid. The advantages of this design are the ability to make high flow rate and pressure and ease of construction. However, it has some disadvantages such as large size and inability to pump water.

The problems mentioned for existing micro-pumps was the main motivating factor for making an electromagnetically stimulated mercury micro-pump. In fact this type of micro-pump was made by using the advantages of reciprocating micro-pumps and MHD micro-pumps and eliminating their defects.

The first type of this micro-pump was made and examined by Shafii and Karmozdi at Sharif University of Technology [17]. This micro-pump has many features such as high performance, the absence of any moving mechanical part, easy and low-cost construction, the absence of any valve, no need for high voltage or high temperature, not sensitive to pH, environmental temperature and surface charges, and finally high flow rates.

The way it works is that in this micro-pump, the mass of mercury in the micro cavity which is connected to the micro channel is stimulated by electromagnetic force with a particular frequency. This movement causes the fluid to be pumped.

In this study, the effect of stimulating frequency of the mass of mercury in the micro cavity on the performance of this type of micro-pump is examined experimentally.

II. DESIGN OF EXPERIMENT

Given that the purpose was investigating the effect of stimulating frequency on the performance of micro-pump, in all cases the amount of mercury in the micro cavity, the applied electrical power and magnetic field and also the shape of micro cavity were considered identical. Therefore, for measuring the effect of this parameter, the electrical current with a frequency from 1 to 20 Hz was applied. Then photographing was performed to measure the amount of mercury entering the micro channel and also to see how it crosses through the channel.

It is expected that by an increase in the stimulating frequency to a certain extent, the amount of mercury entering into the micro channel increases in each movement of the mass of mercury. However, by excessive increase in mercury stimulation frequency, a decrease in the amount of mercury entering into the micro channel is not unexpected.

In order to use the output of data generating device, an industrial wiring terminal board with CJC\textsuperscript{5} circuit is used. This board should be appropriate for the selected data generating device; so the PCLD-8710 model - a production of Advan Tech Company - was selected. This board is connected to the main board using a PCL-10168 with a length of one meter. The electrical pulse coming from the data generating card should be sent to the micro-pump in the form of electrical current. So the board was used to perform such work for four independent channels. In this project it was desired to produce positive and negative currents when receiving electrical pulse. In fact, by receiving the electrical pulse, the desired board

![Fig. 1 Schematic view of the mercury entering into the channel](image)

III. INSTRUMENTATION

A. Electronic Instruments

In order to declare the mass of the mercury to stimulate, it is required to design a system which is able to create the desired pattern and deliver it to the mass of mercury in the form of an electrical current. This system has two parts: a computer program and an electrical board which converts the computer output to electrical current. The computer program was developed using Lab VIEW\textsuperscript{4}. In the final design of the electrical board, PCI-1711L-BE data card - a production of Advan Tech Company - was used. Since this card is installed on the computer motherboard, it is necessary to have an extension cable and an electrical board to get the desired output. PCI-1711 series are one of the multifunction cards for PCI Bus. Their advanced circuit design offers high quality and performance. Specifications related to digital output device which is used in this project, can be seen in Table I.

<table>
<thead>
<tr>
<th>Number of Input Ports</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Voltage</td>
<td>Minimum: 0.8 V, Maximum: 2.0 V</td>
</tr>
<tr>
<td>Number of Output Ports</td>
<td>16</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>Minimum: 0.8 V at 8.0 mA (sink), Maximum: 2.0 V at -4.0 mA (source)</td>
</tr>
</tbody>
</table>

\textsuperscript{4} Laboratory Virtual Instrument Engineering Workbench  
\textsuperscript{5} Cold Junction Compensation

![Table I DIGITAL OUTPUT OF THE DATA GENERATING CARD](image)
should be able to reverse the direction of electric current. This board can handle a maximum of 5mA for all channels. The delay in production of current is less than 1ms for this board.

B. Design and fabrication of micro cavity

In this project, an innovative method was used to create the micro channel and micro cavity. Initially the micro channel was created by this method and then a new innovative approach has been suggested to solve the problem of sealing the channel which more will be explained.

A 3mm thick sheet of Plexiglas was used for the body of micro cavity and a 1mm thick sheet was used for the cover of micro channel and micro cavity. Plexiglas is actually a type of transparent thermoplastic which is known with the scientific name PMMA. General characteristics of this material are given in Table II.

<table>
<thead>
<tr>
<th>Chemical Formula</th>
<th>Density</th>
<th>Melting Point</th>
<th>Boiling Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>(C,H,O),</td>
<td>1.18 g.cm³</td>
<td>160 °C</td>
<td>200 °C</td>
</tr>
</tbody>
</table>

For cutting and engraving desired designs on sheets of Plexiglas, laser cutting machine with the characteristics shown in Table III was used. While engraving on Plexiglas Sheets, the engraving depth and elegance of design depends on three parameters:

1) The power of Laser
2) The speed of moving element on workpiece (Laser speed)
3) The displacing accuracy of the moving element (The time interval between each cycle, The gap)

TABLE III
CHARACTERISTICS OF THE LASER CUTTING MACHINE

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>The power of Laser</td>
<td>80-90</td>
</tr>
<tr>
<td>Working table area</td>
<td>160×100 cm</td>
</tr>
<tr>
<td>Type of Laser</td>
<td>tube CO₂</td>
</tr>
<tr>
<td>Engraving speed</td>
<td>0-50 m/min</td>
</tr>
<tr>
<td>Cutting speed</td>
<td>0-20 m/min</td>
</tr>
<tr>
<td>Supported software</td>
<td>AutoCAD – Corel Draw</td>
</tr>
</tbody>
</table>

After creating the desired depth and width for the desired channel, putting a cap on channel and micro cavity and sealing them has a great importance. Since the material which is used for the cap on channel and micro cavity is the same as one in the body, the first and easiest way forward is using the chloroform solution which is a suitable solvent for Plexiglas sheets. This solution is used in most industrial applications in which two sheets of Plexiglas should be firmly and permanently attached to each other. It is commonly named as Plexiglas glue. In this project, for attaching the cap to micro cavity body, a chloroform solution was used. This must be done with very high accuracy. Since the channel is narrow and shallow, if the adhesive which is injected into the space between two Plexiglas sheets is a little too much, the glue will get into the channel and cause it to be stuffy. On the other hand, excessive caution and inadequate injection of glue may cause the fluid to penetrate to the space between two Plexiglas sheets and interfere with the experiment when it is flowing through the channel.

IV. RESULT AND DISCUSSION

Fortunately, the results of photography from the mercury inside the channel with different frequencies were completely consistent to what was anticipated. As in Table IV, with increasing frequency from 1 Hz to 10 Hz, the amount of mercury entering the micro channel at the end of its way, increases. Thus, the mercury can pump more fluid in each entry to the micro channel, which will improve the performance of micro-pump; But with increasing frequency from 10 Hz to 20 Hz, the amount of mercury entering into the micro channel, decreases. The cause of this phenomenon due to the short time of excreting force can be explained by linear momentum. The linear momentum is proportional to force and time as Eq. 1:

\[ P = \frac{dF}{dt} \]

Since the intensity of electrical and magnetic field is constant in this experiment, the force which is applied to the mercury will be constant and equal in all frequencies. Therefore, with increasing frequency, Lorentz force is applied to the mass of mercury in a shorter period which causes an increase in momentum. In other words, the mercury is hit more severe toward the micro-channel and it will reach more into it. However, due to the mass inertia of the mercury, with excessive increase in frequency, mercury does not have enough time to enter the micro channel. Because at the time that mercury starts moving toward the micro channel, the change in the direction of the electrical field will reverse the Lorentz force and subsequently this force brings the mass of mercury back to the micro cavity.

It should be noticed that the number of entrance of mercury into the micro channel at high frequencies, will be more. Therefore, selecting the best frequency range needs more caution.

CONCLUSION

The amount of mercury entering into the micro channel increases by raising the frequency to 10 Hz, but decreases with further increase in frequency. So the optimal frequency is 10 Hz for this arrangement of micro cavity. Therefore, considering the increasing number of entrance of mercury at higher frequencies, the frequency range of 10 to 12 Hz is recommended.
APPENDIX

TABLE IV. Pictures which were taken from the mass of mercury at the end of its way crossing the micro-channel for all frequencies

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Picture</th>
<th>Frequency (Hz)</th>
<th>Picture</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><img src="image1.png" alt="Picture 1" /></td>
<td>11</td>
<td><img src="image11.png" alt="Picture 11" /></td>
</tr>
<tr>
<td>2</td>
<td><img src="image2.png" alt="Picture 2" /></td>
<td>12</td>
<td><img src="image12.png" alt="Picture 12" /></td>
</tr>
<tr>
<td>3</td>
<td><img src="image3.png" alt="Picture 3" /></td>
<td>13</td>
<td><img src="image13.png" alt="Picture 13" /></td>
</tr>
<tr>
<td>4</td>
<td><img src="image4.png" alt="Picture 4" /></td>
<td>14</td>
<td><img src="image14.png" alt="Picture 14" /></td>
</tr>
<tr>
<td>5</td>
<td><img src="image5.png" alt="Picture 5" /></td>
<td>15</td>
<td><img src="image15.png" alt="Picture 15" /></td>
</tr>
<tr>
<td>6</td>
<td><img src="image6.png" alt="Picture 6" /></td>
<td>16</td>
<td><img src="image16.png" alt="Picture 16" /></td>
</tr>
<tr>
<td>7</td>
<td><img src="image7.png" alt="Picture 7" /></td>
<td>17</td>
<td><img src="image17.png" alt="Picture 17" /></td>
</tr>
<tr>
<td>8</td>
<td><img src="image8.png" alt="Picture 8" /></td>
<td>18</td>
<td><img src="image18.png" alt="Picture 18" /></td>
</tr>
<tr>
<td>9</td>
<td><img src="image9.png" alt="Picture 9" /></td>
<td>19</td>
<td><img src="image19.png" alt="Picture 19" /></td>
</tr>
<tr>
<td>10</td>
<td><img src="image10.png" alt="Picture 10" /></td>
<td>20</td>
<td><img src="image20.png" alt="Picture 20" /></td>
</tr>
</tbody>
</table>
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REFERENCES