Advances in Engineering: an International Journal (ADEIJ), Vol.1, No.1

MODELLING, ANALYSIS AND SIMULATION OF THE PIEZOELECTRIC MICRO PUMP

Samia Latreche and Mabrouk Khemliche

Department of Electrical Engineering, Setif 1 University, Setif, Algeria

ABSTRACT

The piezoelectricity is a reversible phenomenon, which corresponds to the direct piezoelectric effect. So that, the battery loads arrive at the pump, an electronic module must be established in the circuit. A flow pump must be used and its effectiveness must be evaluated according to the desired need. The system is conceived around 24 hour old clock which can be programmed to provide fluid in variable quantity on a regular basis. The piezo-hydraulic pump presented in this work is composed mainly of shareholder piezoelectric with two valves and a diaphragm of the room reinforced by a hard disk. This one is used to improve the performance of the micro-pump in forecast of pump realization. Modeling, analysis and simulation are carried out under SYMBOLS software.

KEYWORDS

Analysis, Simulation, Bond Graph Modeling Tool, Actuator, Piezoelectric, Micro-pump.

1. INTRODUCTION

The piezoelectric materials have enjoyed great level of study in the last ten years. They can generate force and displacement under electrical excitation. Because their bandwidth of operation is higher than traditional servo-motors, higher power can be achieved when operating in high frequencies. The high energy density of the piezoelectric materials can potentially lead to a higher energy density of the actuator than traditional servo-motor technology. However, the small achievable strain of piezoelectric materials keeps this technology from being adopted in many industry applications.

The research on micro-pumps initially emerged in 1980 at Stanford University [1]. Since then micro-pumps have received a lot of attention and have played an important role in the development of micro fluidics systems. The applications of micro-pumps include chemical analysis systems, micro dosage systems, ink jet printers, and other micro electromechanical systems (MEMS) that require micro liquid handling.

Micro-pumps can be classified as dynamic pumps and displacement pumps. Dynamic pumps are based on the principle that force due to electrostatic and magnetic fields can be used to displace the fluid such as electro hydrodynamic [2] and magneto hydrodynamic pumps [3]. The displacements of the micro-pumps on the other hand have diaphragms which are actuated by piezoelectricity. Several actuating principles have been used to develop micro-pumps, they are electromagnetic [4], [5], piezoelectric [6]-[8], shape memory alloy [9], electrostatic [10], and thermo pneumatic [11] devices.

In this work the bond graph model for piezoelectric micro-pump is developed and combined to that of connection multi-chamber piezoelectric micro-pumps (SCMCP). SYMBOLS (System Modeling by Bond graph Language Simulation) software is used with the goal of making simple model that runs on a personal computer.

2. DESCRIPTION OF THE PIEZOELECTRIC MICRO-PUMP

Piezoelectric micro-pump consists of piezoelectric disc attached on the diaphragm "Fig.1-a" pumping chamber and valves. Piezoelectric micro-pumps are actuated by the deformation of piezoelectric materials. Put in piezoelectric action "Fig.1-b" involves the stress induced by an electric field applied to a piezoelectric crystal. Typical characteristics of piezoelectric actuators include a large actuation force, fast response time and simple structure. However, manufacturing is complex as piezoelectric materials are not easily treated. The actuating voltage is comparatively high.

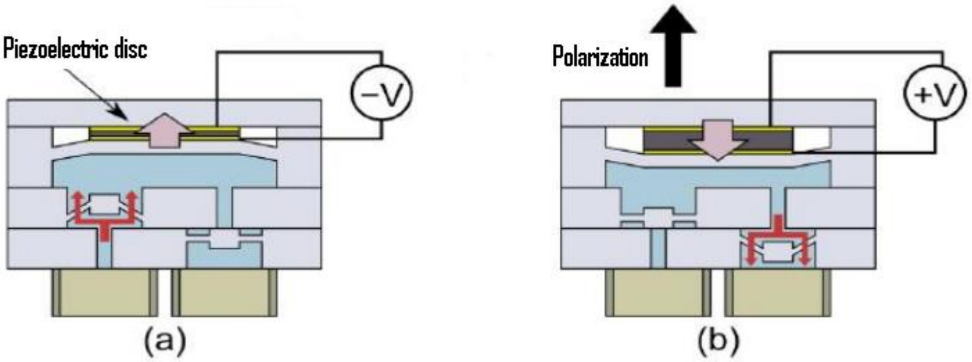

Figure 1. Operating of micro-pump with piezoelectric actuator in axial stresses (a) the section (b) to the pressure

The application of an electric field "Fig.2-a" causes a deflection of the diaphragm upward the aspiration of the liquid, "Fig.2-b". In "Fig.2-c" and "Fig.2-d", the voltage was eliminated because a deflection of the membrane was down (pumping).

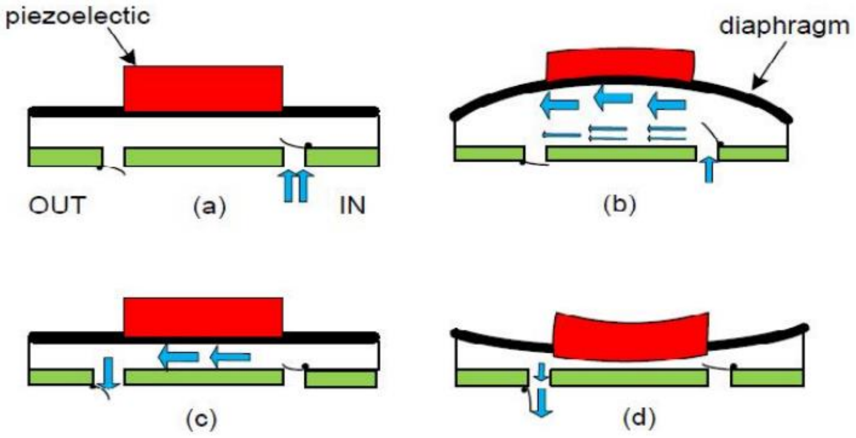

Figure 2. From micro-pump to the piezoelectric actuator

In this section we develop a complete model of the pump "Fig.3". This model has a single valve by adding a model of the pressure in the chamber. We give a general description of the model and subsequently, we describe more specifically the components.

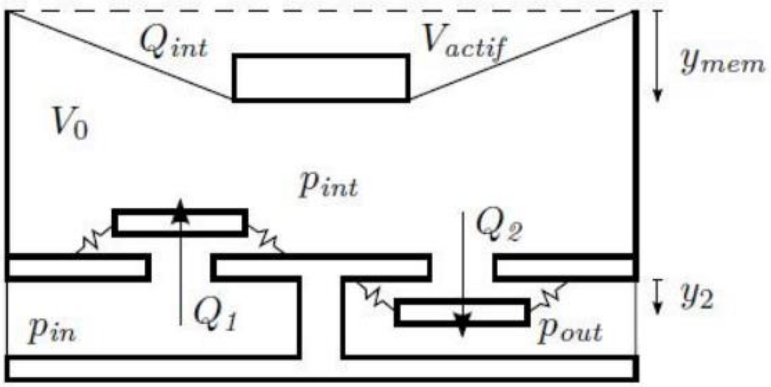

Figure 3. Schematic representation of the micro-pump

For each valve, we write the equations of motion and the expression of flow. For the equation of motion, we have:

$$my'' = \sum F = F_{fluid} + F_{Recall} + F_{damping} \tag{1}$$

Indeed, as we force components on the valve disc : F_{fluid} is the force exerted by the fluid due to pressure, F_{recall} is the restoring force of the planar spring and $F_{damping}$ is the force due to the damping of the fluid.

3. DESCRIPTION OF THE PIEZOELECTRIC MICRO-PUMP

3.1. Bond Graph Approach

Bond graph is an explicit graphical tool for capturing the structures among the physical systems and representing the mass an energy network based on the exchange of power [12]. Others [13], [14] have extended the bond graph concept to represent phenomena such as chemical kinetics and to extract causal models and control structures from the bond graph networks. One of the advantages of bond graph method is that models of various systems belonging to different engineering domains can be expressed using a set of only nine elements: inertial elements (I), capacitive elements (C), resistive elements (R), effort sources (Se) and flow sources (Sf), transformer elements (TF), gyrator elements (GY), 0–junctions and 1– junctions. I, C, and R elements are passive elements because they convert the supplied energy into stored or dissipated energy. Se and Sf elements are active elements because they supply power to the system and TF, GY, 0 and 1junctions are junction elements that serve to connect I, C, R, Se and Sf and constitute the junction structure of the bond graph model [15], [16].

3.2. Model of the Piezoelectric Pump

In the previous section we studied the valve only in static mode, but now we have to consider its behavior dynamically and therefore add a term of force from the damping fluid. "Fig.4" describes the graphical dynamic of the pump using bond graph tool and SYMBOLS software.

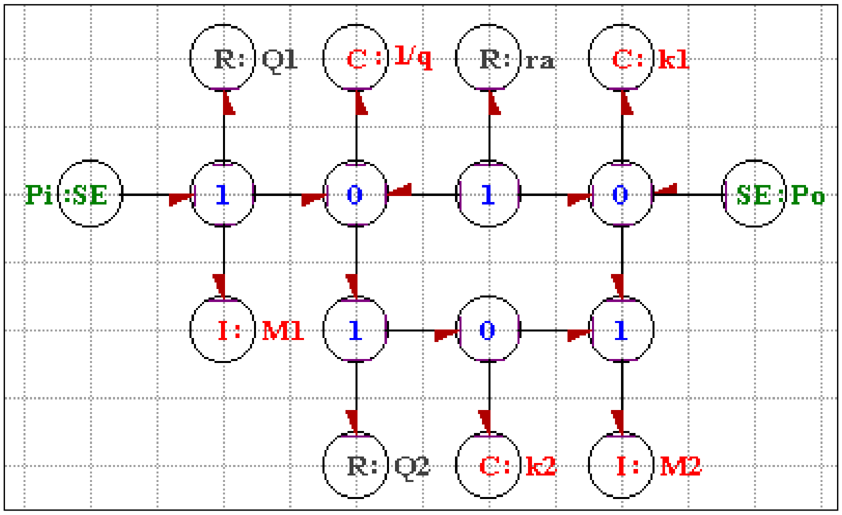

Figure 4. Bond graph model of the piezoelectric pump

3.3. Model of the Chamber Diaphragm

Here we propose a variant on the relation defining the pressure in the pumping chamber. Previously, we considered that the room was completely filled with liquid (no air in the pump). In what follows, we present the case where there is a certain amount of air (gas) trapped in the pumping chamber. The situation is shown in "Fig.5".

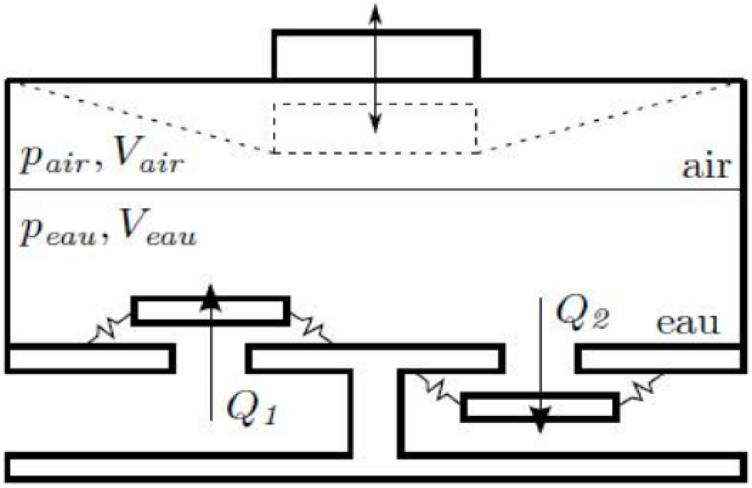

Figure 5. Composition of the fluid in the pumping chamber

There is not an available analytical equation to calculate directly the stiffness of a diaphragm. The authors [17] have treat the chamber diaphragm as an annulus plate inner edge clamed on rigid disc and outer edge on pump body and then establish its deflection function using the summation method presented in [18]. Analytical model of the chamber diaphragm is presented in "Fig.6".

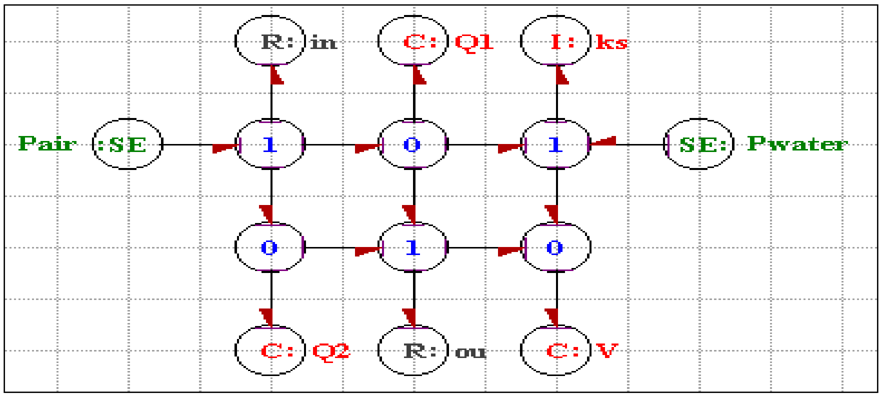

Figure 6. Bond graph model of chamber diaphragm

4. SIMULATION AND ANALYSIS

4.1. Simulation and Flow Rate Test of the Micro Pump

Theses simulations of flow rate of the diffuser and nozzle during a cycle are shown in "Fig.7". The angle of the diffuser and nozzle is 7°. The difference between them is the net flow rate of the micro-pump as curve C shows. The area under this curve is the flow in the cycle and its mean flow rate is 0.02µl/s.

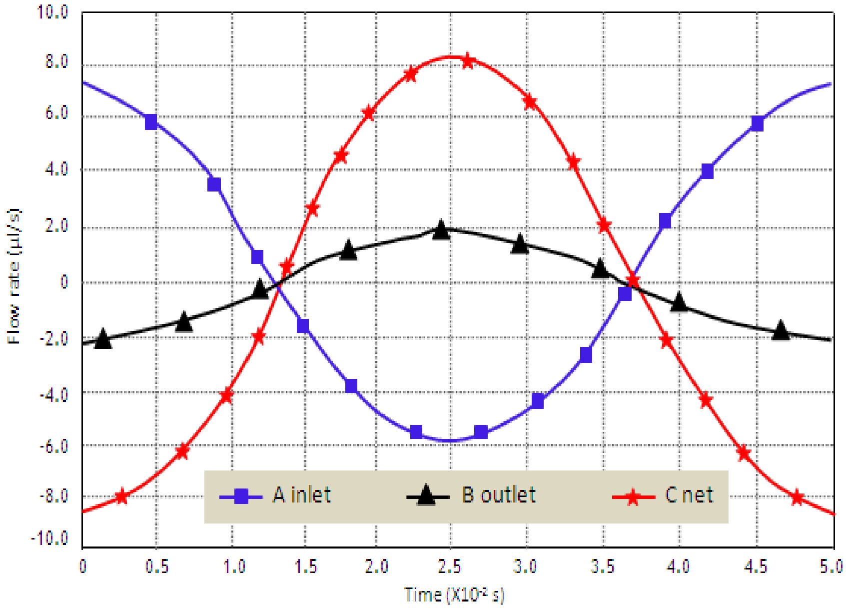

Figure 7. Simulation results of the flow rate of the cycle

The maximum flow rate of experimentation on a prototype micro-pump is 0.0189µl/s. This result illustrates that the simulation and modeling are approximately agree with the reality.

4.2. Damping on the Valve

In terms of depreciation of the fluid on the valve, we do not have tabulated values or specific information in the literature. That is why we consider it as constant. The effect of the fluid on the central disc of the valve damps the movement thereof "Fig.8". There is no problem to consider a constant damping in the valve opening phase.

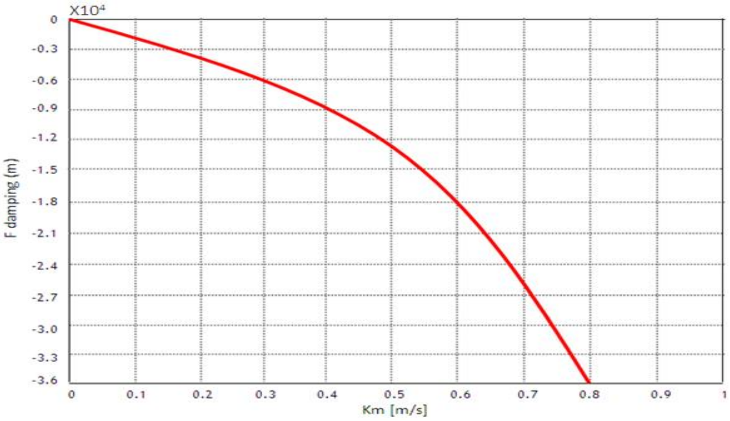

Figure 8. Damping force according to the variation of the stiffness Km

4.3. Mechanical Stop

It is to express the term F reminder of (1). The valve seat acts as a stop for the disc "Fig.9".

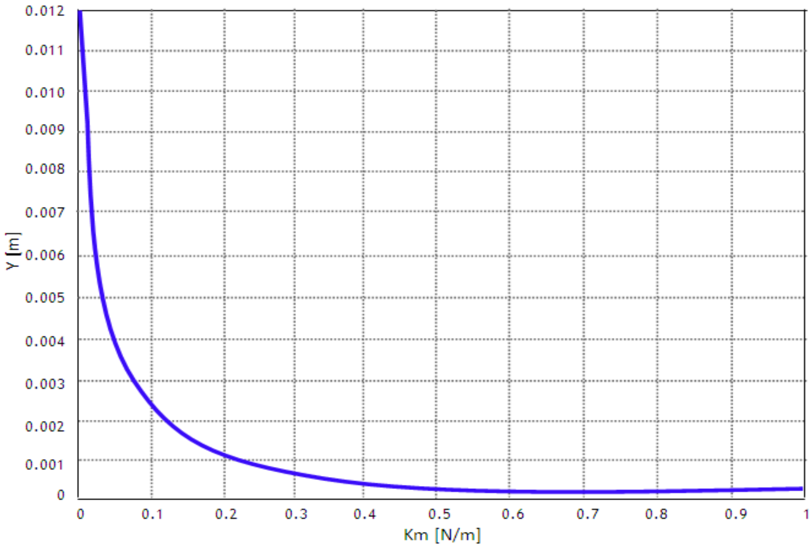

Figure 9. The Y displacement in function of the variation of the stiffness of the spring Km

The movement thereof is therefore permitted in the direction away from the seat, which introduces a discontinuity in the expression of the restoring force. This can cause problems to the digital level. Any negative movement then induce a very high spring force and will tend to spring to its neutral position, which is the desired effect.

4.4. Valve Pressing Force

The force exerted on the valve is obtained by integration of the pressure on the surface of the wall. The pressing force is depending of the channel height "Fig.10" and the speed pressure "Fig.11".

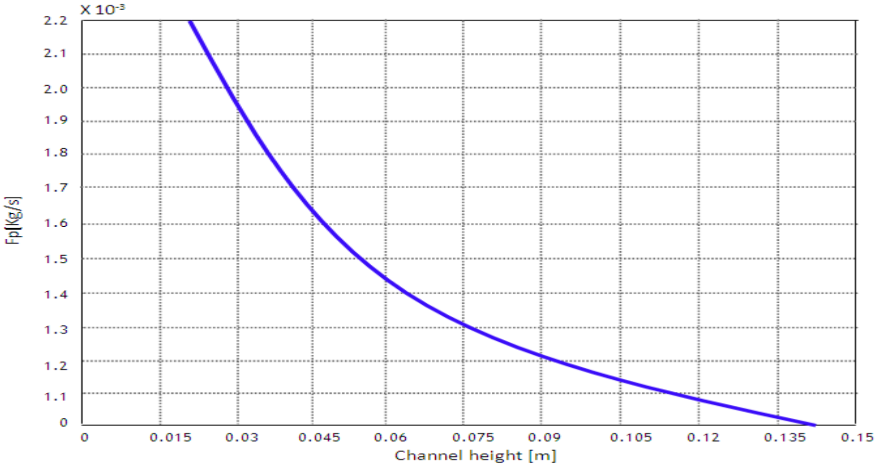

Figure 10. The Fp force as a function of channel height

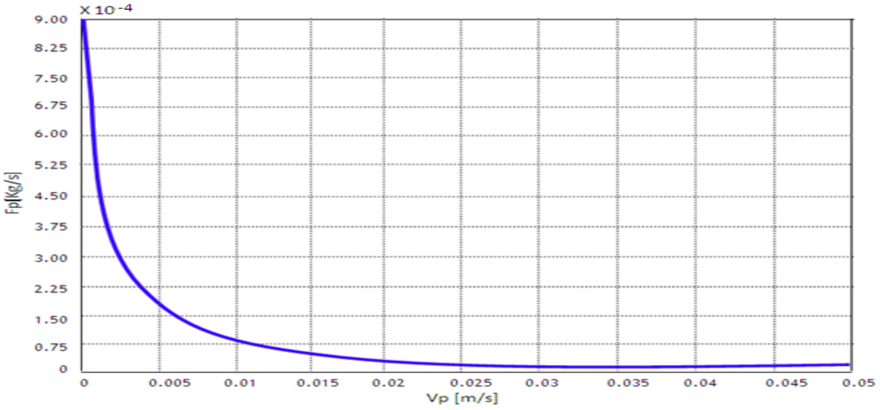

Figure 11. The Fp force versus the variation of the pressure speed Vp

5. CONCLUSIONS

In this work, we presented the graphical modeling of our pumping system. It is a model based on the representation of the valves of disk movement with one of the elements expressing the evolution of pressure in the pumping chamber under SYMBOLS software.

We leave course of the flow pattern in the valve established previously. This model was used to study and understand how developed pump diaphragm is. We finished with a study to determine the influence of the various parameters on the flow.

Bond graph model was developed for the optimization of parameters of the micro-pump based on its mathematical model.

The model is able to predict the performance of the micro-pump for the various geometries and actuating parameters.

REFERENCES

[1] W.F. Luo & H.K. Ma, (2014) “Development of a Piezoelectric Micropump with Novel Separable Design”, *Appl. Mech. Mater.* Vol. 670–671, pp. 1426–1429

[2] H. Moritz, M. Stubbe & J. Gimsa, (2009) “AC field induced fluid pumping in microsystems with symmetric temperature gradients”, *Physical Review*, Vol. 79, No. 2, pp.1-10.

[3] E. G. Kim, J. Oh & B. Choi, (2006) “A study on the development of a continuous peristaltic micro pump using magnetic fluids”, *Sensors and Actuators - Part A*, Vol. 128, pp. 43-51.

[4] S. Böhm, W. Olthuis & P. Bergveld, (1999) “A plastic micro pump constructed with conventional techniques and materials”, *Sensors and Actuators - Part A*, Vol. 7, pp. 223-228.

[5] C. Yamahata, F. Lacharme, Y. Burri & M. A.M. Gijs, (2005) “A ball valve micro pump in glass fabricated by powder blasting”, *Sensors and Actuators - Part B*, Vol. 110, pp. 1- 7.

[6] E. Stemme & G. Stemme, (1993) ”A valveless diffuser /nozzle based fluid pump”, *Sensors and Actuators - Part A*, Vol. 39, pp. 159-167.

[7] R. Ardito, E. Bertarelli, A. Corigliano & G. Gafforelli, (2013) “On the application of piezolaminated composites to diaphragm micropumps”, *Compos. Struct.*, Vol. 99, pp. 231–240.

[8] H. Suzuki & R. Yoneyama, (2003) “Integrated microfluidic system with electrochemically actuated on-chip pumps and valves”, *Sensors and Actuators - Part B*, Vol. 6, pp. 38-45.

[9] W. L. Benard, H. Kahn, A. H. Heuer & M. A. Huff, (1998) “Thin film shape-memory alloy actuated micro pumps”, *Journal of Micro Electromechanical Systems*, Vol. 7, pp. 245-251.

[10] O. Francais, I. Dufour & E. Sarraute, (1997) “Analytical static modeling and optimization of electrostatic micro pumps”, *Journal of Micromechanics and Micro-engineering*, Vol. 7, pp. 183-185.

[11] A. Wego, H. Glock, L. Pagel & S. Richter, (2001) “Investigations on thermo-pneumatic volume actuators based on PCB technology”, *Sensors and Actuators - Part A*, Vol. 93, pp. 95-102.

[13] C. Lin, Y.H. Ren, J.X. Ji, L.Z. Cai & J.M. Shao, (2016) “The bond graph method for analysis of the micro-motion characteristics of a micro gripper”, *J. Mech. Eng.*, Vol. 62, pp. 494–503.

[14] N. Zitouni, B. Khiari, R. Andoulsi, A. Sellami, A. Mami & A. Hassen, (2011) “Modeling and nonlinear control of a photovoltaic system with storage batteries: A bond graph approach”, *IJCSNS International Journal of Computer Science and Network Security,* Vol. 11, No. 6, pp. 105-114.

[15] A. Corigliano, R. Ardito, C. Comi, A. Frangi & A. Ghisi, S. (2018) “Mariani, Mechanics of Microsystems” *John Wiley & Sons: Hoboken, NJ, USA*, Vol. 7646.

[16] C. Lin, Z. Shen, J. Yu, P. Li, & D. Huo, (2018) “Modelling and analysis of characteristics of a piezoelectric-actuated micro-/nano compliant platform using bond graph approach”, Journal of Micromachines, Vol. 9, No. 10, pp. 498-514.

[17] K. Junwu, T. Kehong, R. Yu, Z. Guoren & L. Peng, (2008) “Study on a piezohydraulic pump for linear actuators”, *Sensors and Actuators A*, Vol. 149, pp. 331-338.

[19] K. L. Wong & J. Y. Wu, (1997) “Single-Feed Small Circularly Polarized Square Microstrip Antenna”, *Electronics Letters*, Vol. 33, No. 2, pp. 1833-1834.