FLOW CHARACTERISTIC OF AN ELLIPTICALLY SHAPED PIEZOACTUATED MICROPUMP

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I certify that the project entitled "*Flow Characteristic of an Elliptically Shaped Piezoactuated Micropump* "is written by *Muhammad Zaim Bin Hassan*. I have examined the final copy of this project and in my opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering

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I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRACT

This project is an outcome of the work carried out in doing and completing final year project, design and analysis flow characteristic of an elliptically shaped piezoactuated micropump. This project is about the investigation of micropump system due to the flowrate of elliptical piezoactuated micro pump. It was started with an introduction in micropump design and structure. This method considers problem regarding valve and valveless types of micropump. After gathering all the relevant information, the project undergoes design process. The design was developed using SOLIDWORK 2010™ software based on the collected data. Several sketches have been made and only one was selected based on the suitability of the micropump and dimension of the nozzle and diffuser and the geometry of the elliptical micropump. The selected sketch was drawn in CAD software and simulates using CFD software. The result from simulation shows the design of micropump is fulfilled. After simulation, the micropump is fabricated. The fabrication is fully follows the specification of the elliptical micropump according to the design of micropump. The purpose of this fabrication is to develop an actual experiment to get the value of volume flowrate of an elliptically shaped of piezoactuated micropump. The result from the experiment shows with the increase of frequency, the volume flowrate also increase. Later on, flow characteristic of an elliptically shaped piezoactuated micropump can be determined. The design of micropump is successful as the investigation of the flow characteristic of an elliptically shaped piezoactuated micropump provides 0.5169μL/s for actuation frequency 25kHz, 0.4898μL/s for actuation frequency 15kHz and 0.4489μL/s for 5kHz actuation frequency. Throughout the investigation, the elliptical micropump is compared to another shape which are circular and square, the velocity through the gap for fluid to flow between membrane of piezoelectric and the body of micropump are be at variance. The micropump considered serves it purpose as it is successfully designed and fabricate.

ABSTRAK

Projek ini merupakan penghasilan kertas kerja tahun akhir yang melibatkan kerja-kerja reka bentuk dan analisis ciri-ciri aliran dari pam mikro bergetar berbentuk bujur. Secara menyeluruhnya, projek ini adalah berkenaan dengan penyiasatan system terhadap pam mikro berbentuk bujur. Proses projek bermula dengan penghasilan rekabentuk struktur pam mikro. Kaedah ini mempertimbangkan mengenai masalah injap dan jenis injap terhadap pam mikro. Setelah mengumpul semua maklumat yang relevan, projek ini diteruskan dengan melakar struktur dan rekabentuk pam mikro. Rekabentuk pam mikro ini dihasilkan menggunakan SOLIDWORK 2010^{TM} berdasarkan data yang telah dikumpul. Beberapa lakaran telah dibuat dan hanya satu yang dipilih berdasarkan kesesuaian pam mikro dan dimensi nosel dan difuser dan geometri pam mikro berbentk bujur. Lakaran yang dipilih diadaptasikan ke dalam perisian CAD dan disimulasikan menggunakan CFD. Hasil dari simulasi menunjukkan syarat-syarat rekabentuk pam mikro telah menepati cirri-ciri seperti mana hasil kajian yang telah dibuat. Setelah proses simulasi dilakukan, pam mikro ini seterusnya telah di fabrikasikan. Fabrikasi ini dihasilkan sepenuhnya mengikuti spesifikasi pam mikro berbentuk bujur yang sesuai dengan rekabentuk dan ciri-ciri pam mikro. Tujuan fabrikasi ini adalah untuk mengenalpasti dan menganalisa kelantangan kelajuan aliran cecair yang melalui pam mikro berbentuk bujur hasil daripada getaran piezo terhadap pam mikro. Hasil dari kajian menunjukkan dengan peningkatan frekuensi, kelantangan laju aliran cecair juga meningkat. Kemudian, ciri-ciri aliran dari pam mikro berbentuk bujur dapat ditentukan. Penghasilan pam mikro berbentuk bujur ini adalah berjaya sebagaimana penyelidikan ciri-ciri aliran menunjukkan penghasilan kadar kelantangan aliran 0.5169µL / s untuk 25kHz frekuensi aktuasi, 0.4898µL / s untuk aktuasi frekuensi 15kHz dan 0,4489 uL / s untuk aktuasi frekuensi 5kHz. Projek ini juga melibatkan proses menganalisa perbezaan kadar kelajuan aliran cecair yang melalui pam mikro yang mempunyai pelbagai bentuk seperti bentuk bulat dan segi empat tepat. Projek Pam mikro bergetar berbentuk bujur ini dianggap berfungsi tujuannya seperti yang berjaya direkabentuk dan difabrikasi.

TABLE OF CONTENTS

CHAPTER 4 RESULTS AND DISCUSSION

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

$\dot{V}$	Volume flowrate
v	Velocity
A	Cross sectional area
ΔP	Pressure drop along nozzle/diffuser
ρ	Fluid density
$\mathcal{E}$	Resistance coefficient
ε_{fr}	Friction resistance coefficient
ε_{exp}	Expansion resistance coefficient
α	Conical angles

LIST OF ABBREVIATIONS

CAD	Computational Aided Design
CFD	Computational Fluid Dynamic
EHD	Electrohydrodynamic
MHD	Magnetohydrodynamic
PZT	Piezoelectric

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Micropump can be defined as a pump which functioned as a fluidic transporter from one place to another. Micropump have characteristic of handling small and accurate volumes of liquid and gas makes them able to serve chemical, medical, and biomedical applications with great scientific and commercial potential. Micropumps usually have a simple structure. Y.L.Cheng et al. (2007) were investigated the sizing and criteria of pump that had been set based on fluid equations of several uncertainties such as mass, momentum and energy.

Nowadays micropump is something that is essential in the microfuidic systems which provide momentum to cause fluid flow. Microfluidic systems are of interest in medical testing, drug delivery, chemical analysis, chip cooling, and many more. L.S. Pan (2001) had declared that microsystems have the advantages of small volume, cheap cost, and fast reaction time. Historically, it is generally agreed that the first micropump was introduced in 1980s based on microvalves can be attributed to Smits. Based on these ideas, micromembrane pumps were further developed by other researchers. There are basically two types of micromembrane pumps which are one with the output and input check valves and the other without these check valves (or valveless).

Y.C.Wang et al. (2008) had deeply studied on structure of micropump. They noted that, in valve-based pumps, mechanical check valves known as flaps are used. Wear, fatigue and valve blocking are common issues and limit the applications. Valveless micropumps, first introduced by Stemme and Stemme. the equipment consist of diffuser and nozzle elements to perform as a check valve. The construction of valveless micropump is relatively simple compared to check valves and it can avoid the problems mentioned above. Most common actuation methods in micropumps include electromagnetic, electrostatic, shape memory alloy, thermopneumatic, and piezoelectric. Y.L.Cheng (2007) once again gave an idea that piezoactuation can provide relatively a high actuation force and a fast mechanical response, therefore, is widely used in micropump development.

Most of the micropumps today are based on the valveless systems which there are applying the concept of diffuser and nozzle as the check valve. For correctly designed diffuser elements the flow resistance in the positive diffuser direction is lower than in the negative nozzle direction. The principle has been shown to work for several pumps of different sizes. However there is a lack of relevant experimental data and analytical expressions for diffusers in microfluidic systems. Flow-directing properties are also shown for very low flow velocities where laminar flow can be expected in the diffuser neck. The results are compared with an attempt to calculate the diffuser-element performance using very simple analytical expression A. Olsson (1996)

Additional benefits of nozzle-diffuser elements include the ease of manufacture using conventional silicon micromachining technique, and the much higher flow rates achievable properties of such valves, stem from the possibility of using valveless micropumps at higher frequencies as compared to micropump with passive check valves. This is because check valves have a large response time, and pumps employing such valves cannot to frequencies greater than a few hundred hertz. On the other hand, valveless micropumps can be excited to much higher frequencies (~10 kHz) and hence can achieve flow rates which are several orders of magnitude higher when compared to conventional passive check valve micropumps V.Singhal et al. (2004)

1.2 PROBLEM STATEMENT

Among the large number of microfluidic components realized up to now, micropumps clearly represent the case of a “long runner” in science. An increasing number of researches are found from that time on representing widespread study activities, and there seems to be no change of this trend.

An amazing variety of micropump concepts and devices has emerged until today, reaching from peristaltic micropumps to a large number of micro diaphragm pumps to recent high-pressure devices without any moving parts. H.M Carlos (2001) had stated that there are almost every mesoscopic actuation principle has been combined with micropumps. An outstanding diversity is also found in the fabrication technology and the width reaches from silicon-based devices over accuracy machining to injection molding. This altogether makes it worth to summarize and also take a look into the future of micropumps

There are several common issues that appear which are related to the performance of micropump. One of the issues is about the shape of the piezoactuated micropump. We can see that there are many design of circularly shaped of piezoactuated micropump which currently widely used in industries. Hence, in this project, there are needs to study the performance of the elliptically shaped of piezoactuated micropump since this is the new area to be explore. Flow characteristic of elliptically shaped of piezoactuated micropump is to be analyzed by using experimental method and attempt to improve and achieve the maximum performance. In order to provide more accurate results for analyzing the performance of this micropump, the suitable locations of diffuser is to be recognized by determining the focus of an ellipse. These all can be done by using suitable software to analyze the performances of the micropump.

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1.3 OBJECTIVES

The main objectives of this study are:

- To design and fabricate an elliptically shaped piezoactuated micropump.
- To investigate the flow characteristic of an elliptically shaped piezoactuated micropump through the volume flowrate of water that flow in micropump.

1.4 SCOPES

- Use the software (CAD and SOLIDWORK) to design an elliptically shaped of piezoactuated micropump.
- Analyze the design using CFD method.
- Find the volume flow rate of water through micropump
- To relate the volume flow rate with the flow characteristic of on an elliptically shaped piezoactuated micropump.

CHAPTER 2

LITERATURE REVIEW

2.1 MICROPUMPS

There are two groups of micropumps that can be found nowadays which are reciprocating micropumps and continuous flow micropumps. The reciprocating micropump uses the oscillatory or rotational movement of mechanical parts to displace fluid. The development of micropump has started with “piston type” reciprocating micropumps like micro Diaphragram pumps and peristaltic micropump (P. Woias, 2005).

The common principle of diaphragm pumps it employs a pump chamber which is closed with a flexible diaphragram on at least one side as shown in Figure 2.1. Oscillatory movement of the diaphragram generates a two-phase pump cycle with periodic volume changes and, hence, under and overpressure transients (differential pressure) in the pump chamber. During the “supply phase” the underpressure in the pump chamber will suck fluid through the inlet into the pump chamber (P. Woias, 2005)

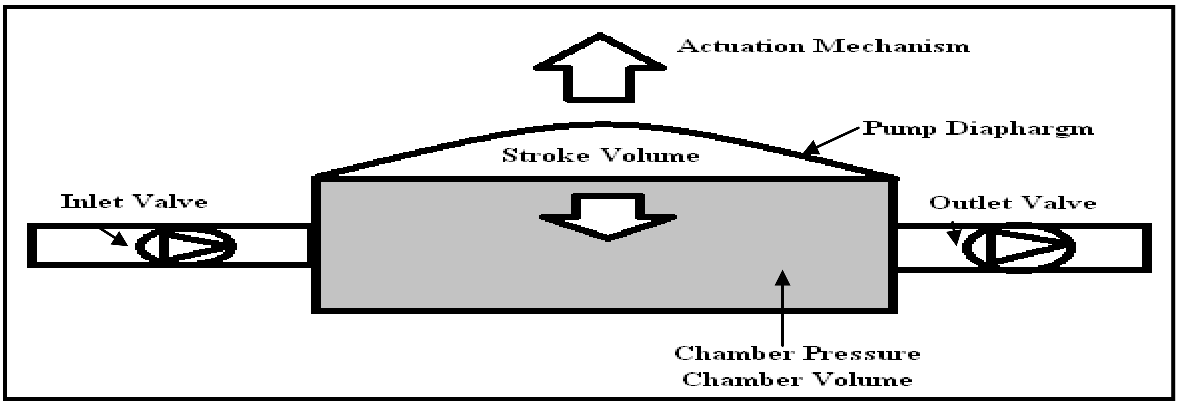

Figure 2.1: Principle set-up of a “piston type” micropump

During the following pump phase overpressure in the pump chamber transfers liquid into the outlet. The valveless at the inlet and outlet will block unwanted reverse flow in the respective pump phase. They therefore act as “fluidic rectifiers” that direct the bidirectional fluid movement which generated inside the pump chamber into a desired unidirectional flow. The medium such as liquid or gas is obviously delivered in a series of a discrete fluid volume whose magnitude depends from the actuator stroke volume ΔV which is the net volumetric displacement during one cycle (P. Woias, 2005)

The other group of micropump is “continuous flow of micropump”. The micropumps are based on a direct transformation of nonmechanical or mechanical energy into a continuous fluid movement. Devices with ultrasonic, magneto hydrodynamic (MHD), electrohydrodynamic (EHD), electroosmotic or electrochemical actuation mechanisms have been developed up to know. As the design principles are quite different depending on the respective physical or chemical principle this project will only give a brief overview for this type of micropump.

2.2 NOZZLE/ DIFFUSER FLOW

The general task of nozzle and diffuser is to increase or decrease velocity and pressure of fluid by changing its cross-sectional area along the flow axis (T.Gerlach, 1998). A nozzle has such complicated explanations on flow of fluid mechanism. Generally, the flow resistance coefficient ε of the nozzle/diffuser flow shown in Figure 2.2 can be written as:

$$\boldsymbol{\varepsilon} = \frac{\Delta \boldsymbol{P}}{(\boldsymbol{\rho}\upsilon^2)/2} \tag{2.1}$$

Where ΔP the pressure drop along nozzle/diffuser, ρ is is the fluid density; υ is the mean flow velocity at the narrowest part of nozzle/diffuser. It should be mentioned that $\mathcal{E}$ is not only depend only to the geometric characteristic such as diameter ratio, conical angle and the transient shape of inlet/outlet, but we must also concerned on its Reynolds number, Re of the flow (X.N.Jiang et al., 1998).

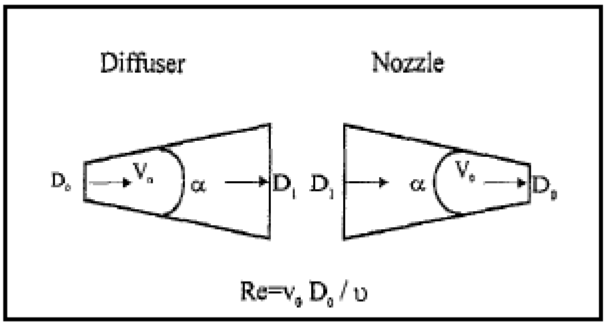

Figure 2.2: nozzle diffuser flow

Source: X.N.Jiang (1998)

2.2.1 Diffuser Flow

In most of the cases, nozzle/diffuser flow cannot be analytically described. Normally, the analysis on the nozzle/diffuser flow is based on the empirical results. The total flow resistance coefficient of the diffuser ε_d, is considered composed of the friction resistance coefficient ε_{fr} and the expansion resistance coefficient ε_{exp} as follows:

$$\varepsilon_d = \varepsilon_{fr} + \varepsilon_{exp} \tag{2.2}$$

Conventional nozzle/diffuser flow happens mostly at very low range of Reynold number (~50) and large Reynolds numbers (>10^5). For the conical diffuser, the uniform