FABRICATION OF CROSS-FLOW BIO-MICRO-TURBINE

Henry Cabra, Doctoral Student and Sylvia W. Thomas, PhD
Electrical Engineering Department, University of South Florida
Presenting Author: hcabra@mail.usf.edu

Abstract: This paper presents the design and simulation of an impulse micro-turbine using a modified cross-flow of the Michell Banki turbine model. An action or impulse micro-turbine, which can be integrated onto smaller devices, is presented. The power characteristics of the turbine were evaluated using macro models and hydrodynamic similarity laws in implemented designs [1]. Theoretical calculations show that the micro-turbine provides a high number of revolutions making them particularly valuable for energy transformation, for instance, in micro surgery tools that require reasonably high forces or high speed [2]. According to the calculation, and the simulation, it is reasonable to classify the turbine behavior as an action turbine, where the speed generated on the blades is produced by the transformation of kinetic energy to mechanical energy. In other words, the fluid pressure in motion moves the blades. The design has been optimized to reduce the friction between the rotor and the case in order to avoid the loss of rotational speed. To examine the flow behavior inside of the turbine, and to determine if all the conditions are given for the turbine to rotate, a succession of simulations using ANSYS FLUENT Flow Modeling Software were performed.

Keywords: micro-turbine, cross-flow turbine, Banki turbine, Euler's equation.

INTRODUCTION

One of the most basic features of the cross-flow turbine is the simplicity of its construction. The turbine is based on concepts from both impulse and reaction turbine designs, but in general it uses impulse behavior. This feature allows adaptability and flexibility to a variety of liquid, places, applications and power needs. The simplicity in the design reduces cost and makes it very suitable for small power development.

An impulse micro-turbine can be implanted into physiological systems, such as the respiratory, urinary, and blood systems. Also, it can be integrated onto multiple applications, such as the delivery of medicines, energy generation (micro-generator systems), sensing or the control of particle and liquid filtration. Furthermore, there are medical conditions that require the replacement of some living parts, such as pumps and valves to regulate fluids in the human body.

Micro-turbines have been designed primarily adapting the concepts from actual jet turbines using common fuels and compression. In this scenario, this paper presents the design of a micro-turbine that can be a component used in a physiological system, where flux or motion and pressure are the principal parameters of the model. It also contributes to the academic and practical discussion about the development and harnessing of alternative energy sources for bio, micro, and nano technologies altogether.

Living organisms have numerous micro-systems, such as respiratory, urinary, and blood systems, that are potential spaces for research in areas such as micro-mechanic, biomedical, bio-energy, etc. Currently there are some research projects studying the possibility to produce energy using physiologicalsystems such as the respiratory system, urinary system, blood system or the motion system [3] in animals or humans [4]. Some research groups are developing micro and nano-turbines used in small aero-engines, pacemakers and pumps as an application of Micro-Electro-Mechanical-Systems (MEMS). The objective of this paper is to design a bio-turbine with multiple 'in-vitro' and 'in-vivo' applications. However, it is important to differentiate between our research (design of a micro-turbine), which has physiological driving mechanisms, applications, and special characteristics, such as size and shape, from the approaches reported by others [6-8].

This paper shows a modified Banki model according to the specific environmental conditions and application where the final micro-system that includes the micro-turbine will be implanted. The turbine consists of two main parts: the runner or wheel, and the enclosing. The runner has a circular solid center where curved vertical blades are fixed. The top and bottom of the blades are supported in circular disc to assure rigid blades and stability, the geometry is shown in Fig 1. Approximately 50% of the liquid passes directly from the inlet nozzle to the runners before it is discharged, and the other part runs free in direction of the outlet nozzle through the enclosing. The rotor design takes advantage of systems, reaction and impulse turbines, resulting in an accelerated flow using a widely known Venturi principle and obtaining torque in the reaction rotors.

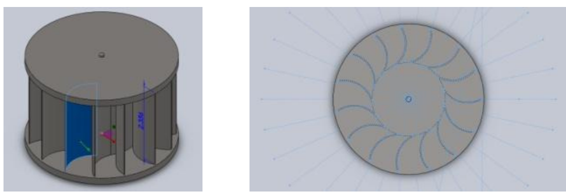

Fig. 1 Rotor isometric and top view

To produce an elevated torque and to make sure compatibility and applicability can be achieved; the turbine design is developed and calculated with water parameters. The dimensions are on the range of 0.001 to 6.2 millimeters, which make the turbine viable for micro surgery tools. The blades have curved form to improve the capabilities of the design. The turbine is designed as a constant pressure turbine that requires a low head and a constant flow to work.

MICROTURBINES DESIGN

The design is supported in the previous macro models developed and reported by others [9] [10][11].

Blade design geometry

Using the parameters that are shown in Fig. 2 and modeling across a range of 7-15 blades according to the turbine dimensions [12], it is possible to calculate all angles and a good blade arc to design the rotor. Using the sine theorem and parameter values specified in the modeling equations, we found the design parameters for the arc and each blade, resulting in a radius, R_a, given by

$$Ra = R\frac{sin\hat{Z}}{sind} * \frac{sint}{sina} = 0.90566mm \qquad (1)$$

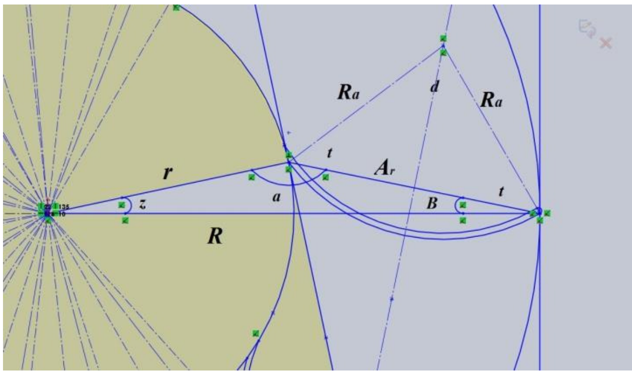

Fig. 2 Blade design

Velocity and power characteristics

The velocities were calculated using the geometry shown in Fig. 3, and the theoretical model supporting such design is drawn from several references included [1], [2], [9-11]. In order to find numerical values and run the simulation, different parameters such as velocity inlet and volume flow rate were set according to a regular water distribution system of a house in the US, where water at 20°C has an 8m/s inlet velocity and is referenced at atmosphere pressure[12]. Those conditions were set as the input parameters of the simulation in an attempt to produce the following output parameters: velocity vectors, pressure contours and fluid path lines. The design used the following values: Inlet velocity c_1 =8m/s, Inlet area, water density (1000 kg/m^3) [11].

$$A = \frac{\pi\emptyset^2}{4} = 3 \text{ x } 2.356 \text{ mm}^2 = 7.068 \times mm^2 \qquad (2)$$

Using the Euler equation for turbo-machinery, the result in Eq. (3), and the velocity triangle relation shown in Fig 3, it is possible to find the values for rotor relative input, and tangential and radial velocities, just as is reported by others [1],[2],[9],[10],[13].

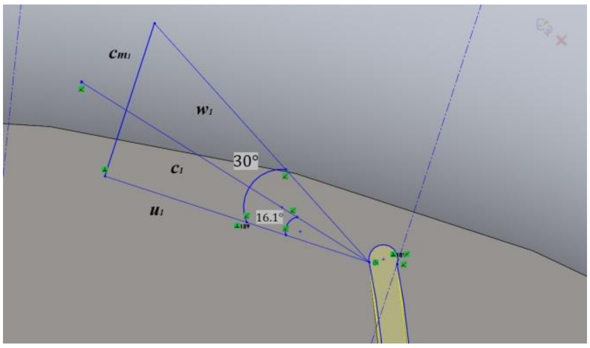

Fig. 3 Velocity triangles

Inlet velocity, $c_1 = \frac{8m}{s} = k_c\sqrt{2gh}$, (3)

where $0.95 \leq k_c \leq 0.98$, is the velocity coefficient that is assumed as 0.96.. Tangential velocity, u_1, is,

$u_1 = 2.127k_c\sqrt{h} = 4.05\ m/s.$ (4)

The hydrostatic pressure in the turbine is given by Pascal's Law [2]:

$P_1 + \rho gh_1 = P_2 + \rho gh_2$ = constant, (5)

ρ = fluid density (kg/m^3);
g = acceleration due to gravity on Earth (m/s^2);
h = height of a point in the direction of gravity (m).
P = pressure (N/m^2, Pa).

In this case the pressure value, P, in the Inlet is found to be

$P = h\rho g = 38518.9$ Pa (6)

Using the continuity equation and Euler's equation, the volume flow rate, Q, and Power are calculated to be:

$Q = 3392.64$ cm^3/min (7)

$Power = 2.1891$ Watt (8)

Under these conditions, the rotor will reach a frequency of rotation of 19337.32 revolutions per minute (RPM).

CAD DESIGN

Micro-turbines have been designed in the past, but presented restrictions in fabrication processes and design geometries [14]. Researchers at MIT developed a planar model in order to be more compatible with existing fabrication capabilities and to ensure viability [15].

Rotor design

The rotor was designed using the model reported by [1],[2],[13]

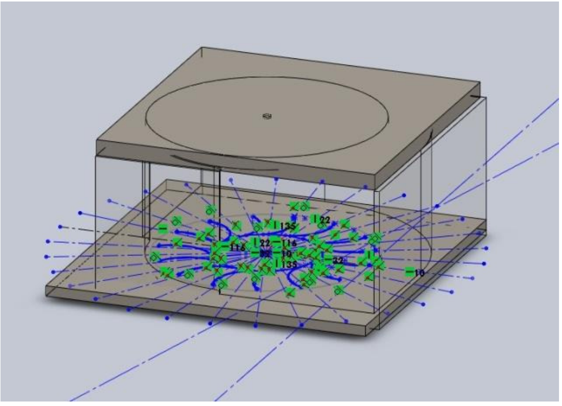

Fig. 4 Rotor design

Holder design

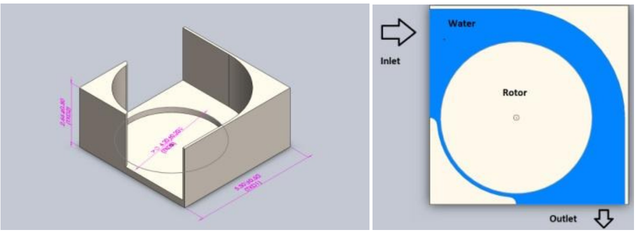

Fig. 5 Holder: isometric and top view

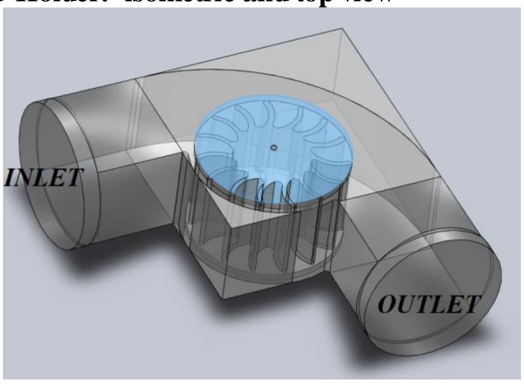

Fig. 6 Turbine assembled

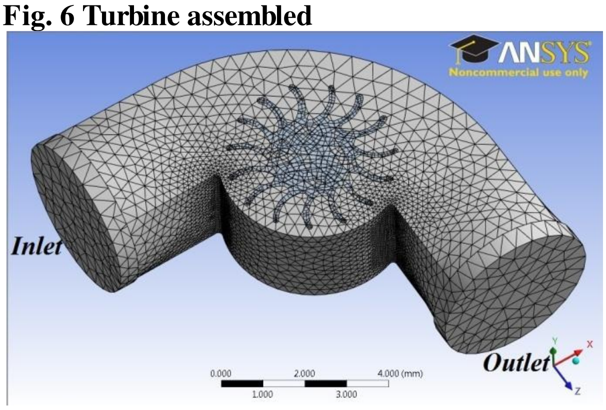

Fig. 7 Turbine Mesh Result

TURBINE SIMULATIONS

The simulation was developed in two different moments. The first moment was using a CAD model with a rotor fixed and in the second moment the rotor has free rotation, where the angular velocity depends on inlet volume flow rate. The CAD tool used to build the model was SolidWorks and the simulation tool used was ANSYS 12.1.

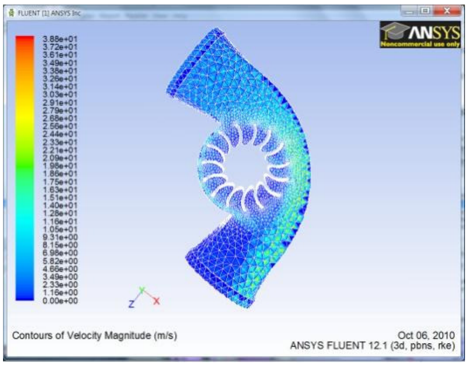

Fig. 8 Contours of Velocity

The contour of velocity, when the rotor is fixed, shows an increase in the velocity when the liquid enters the rotor zone, but the flow is kept consistent through the turbine.

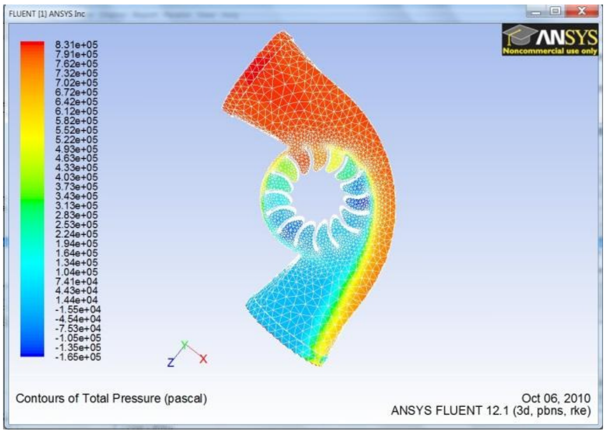

Fig. 9 Contours of pressure

The contour of total pressure shows that the three blades in the inlet zone are influenced by the inlet pressure. This indicates that these blades act as a reference. When the rotor is free to spin, we can inference that only these blades would exert moment to induce the desired movement in the rotor.

CONCLUSION

New practical efficiency must be found because the changes developed in the original Banki turbine design could modify the efficiency of the turbine[16][17] (the Michell turbines have efficiency between 55 and 65 percent[18]).

Physic laws that govern the macro world could be applied in this kind of micro design scale.

This work should be regarded as a contribution in the current develops of micro and nano devices that could be used in medical, in environmental and energy application.

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