Design, Simulation, and Prototyping of an Impulse Turbine for Biomedical Applications

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ABSTRACT

An impulse bio turbine with circular inlet/outlet area which can be integrated into small devices, is presented. The system was designed using a scaled impulse macro turbine model, which was modified in size and shape to guarantee integration in implantable bio medical devices and physiological circulatory system. The simplicity in the design reduces cost and makes it very suitable for developing MEMS technology or for prototyping machine systems. Simulations and a scaled prototyping model were performed to examine the structure and the flow behavior inside of the turbine and to determine if all the conditions are given for the turbine to rotate. The Impulse turbine is designed with bio compatible materials and will be used as a component in a physiological system. Delivery of medicines, energy generation, sensing or the control of particle, the replacement of parts from systems that have limited lifetime and compatibility problems will be the final destination of the turbine.

Keywords: biomaterials, impulse turbine, motion, pressure, and physiological system.

1 INTRODUCTION

The project uses a cross flow turbine model modified, and all calculations are based on concepts from both impulse and reaction turbine designs. Using a different model, the project would need to prepare a wide variety of meticulous designs and stock a large number of parts and materials to cover the range of possible sizes and ratings required. Cross Flow modular construction significantly reduces this overhead and brings extra benefits through simplicity of fabrication, assembly and/or redesign. The simplicity in the design reduces cost and makes it very suitable for to be developed with MEMS technology or using prototyping machine system. The macro turbine model was modified in size and shape to guarantee integration in implantable devices and physiological systems. Also, bio compatible materials are used to sure in-vivo and in-vitro uses. The turbine has a diameter inlet/outlet measurement of 4 mm, and consists of two main parts: the holder or enclosing, and the runner or rotor. This paper is focused on design, simulation, and prototyping of a milimeter-scale turbine. The knowledge of this research might be applied in design of artificial organs, valves, sensors, micro motors, microgenerators, and micro robots.

2 TURBINE DESIGN

The turbine consists of two main parts: the holder or enclosing, and the runner or wheel. The runner has a circular solid center where 15 curved vertical blades are fixed. The solid center has a radio of 1 mm. Each blade has 2.3561945 mm of length, 1 mm of lateral side, and 0.2 mm of thickness. The top and bottom of the blades are supported in circular disc to assure rigid blades and stability, and have 0.2 mm of thickness; the turbine 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 because there is a free space of 1mm between the rotor, lateral side, and the holder wall. 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 rotor.

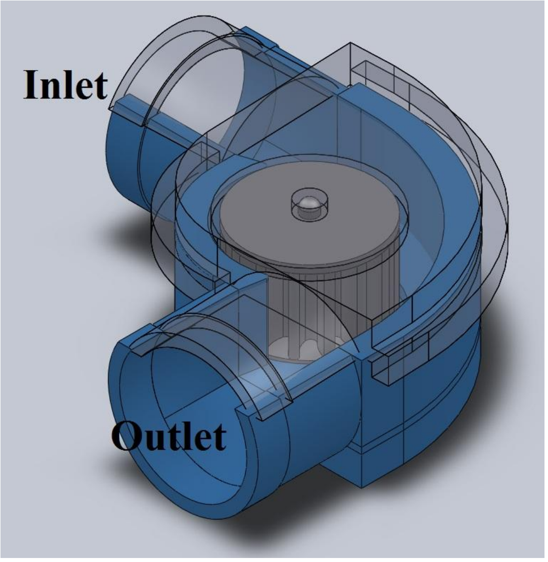

Figure 1: Turbine isometric view

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. The design has been optimized to reduce the friction between the rotor and the case in order to avoid the loss of rotational speed. The blades have curved form to improve the capabilities of the design.

2.1 Blade Design Geometry

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, Ra, given by

$$\mathrm{Ra} = \mathrm{R}\frac{\sin\hat{\mathrm{Z}}}{\sin\mathrm{d}} * \frac{\sin\mathrm{t}}{\sin\mathrm{a}} = 0.90566\mathrm{mm} \tag{1}$$

In order to find numerical values and run the simulations, different parameters such as velocity inlet and volume flow rate were set according to a healthy circulatory system of a adult human body, where blood at 37°C has a overall blood flow in the total circulatory system about of 5000 ml/min = 8.333 x10-5 m3/s, a viscosity of μ=4 mPa.S, and a density ρ=1063kg/m3.

2.2 Aerodynamic Turbine Design Description

To calculate all parameters, the design used the following values: Inlet area A2 (3mm x 2.356mm = 7.068 mm2), and pressure P=13333.33 Pa. The Fig. 2 show some parameters and Inlet dimensions used in the micro turbine design. The theoretical model supporting such design is drawn from several references included [1-5]. The rotor was designed using the models and data reported by Filho and Díez [1], [6]. The unit used in the turbine design is millimeter.

$$\mathrm{A}_1 = \frac{\pi\emptyset_1{}^2}{4} = 1.25664 \times 10^{-5}\mathrm{m}^2 \tag{2}$$

$$\mathrm{A}_2 = \mathrm{base} \times \mathrm{height} = 7.068610^{-6}\mathrm{m}^2 \tag{3}$$

$$\mathrm{V}_1 = \frac{\mathrm{Q}}{\mathrm{A}_1} = 6.6312\,\mathrm{m/s} \tag{4}$$

$$\mathrm{V}_2 = \frac{\mathrm{Q}}{\mathrm{A}_2} = 11.7888\,\mathrm{m/s} \tag{5}$$

To calculate the pressure P2 on the inlet rotor blades is used the Poiseuille's law[1]. In most arteries, blood behaves in a Newtonian fashion, and the viscosity can be taken as a constant.

$$\mathrm{Q} = \frac{\pi\mathrm{r}^4}{8\mu}\frac{\Delta\mathrm{P}}{\mathrm{L}} = \frac{\pi\mathrm{r}^4}{8\mu}(\mathrm{P}_1 - \mathrm{P}_2) \tag{6}$$

$$\text{Where, } \mathrm{P}_2 = \frac{8\mathrm{Q}\mu\mathrm{L}}{\pi\mathrm{r}^4} + \mathrm{P}_1 = 12830.0119\ \mathrm{Pa} \tag{7}$$

Using the Pascal's law [2] is calculated the height, h2, on the first rotor blades,

$$\mathrm{P}_1 + \rho\mathrm{gh}_1 = \mathrm{P}_2 + \rho\mathrm{gh}_2 = \mathrm{constant} \tag{8}$$

ρ = fluid density = 1063(kg/m3)
g = acceleration due to gravity on Earth=9.8 (m/s2)
h = height of a point in the direction of gravity (m)
P1 = Blood pressure average (N/m2, Pa)
P2 = pressure on the firsts blades (N/m2, Pa)

In this case the height value, h2, in the Inlet (first rotor blades) is found to be

$$\mathrm{h}_2 = \frac{\mathrm{P}_2}{\rho\mathrm{g}} = 1.23159\ \mathrm{m} \tag{9}$$

2.3 Velocity and power characteristics

Using the Euler equation for turbo-machinery, the result in Eq. (1) to (7), and the velocity triangle relation explained in detail by Filho and Díez [9], [10], it is possible to find the values for rotor relative input, and tangential and radial velocities.

$$\text{Inlet velocity, } \mathrm{c}_1 = \mathrm{k}_\mathrm{c}\sqrt{2\mathrm{gh}} = 4.7185\,\mathrm{m/s}, \tag{10}$$

where $0.95 \leq \mathrm{k}_\mathrm{c} \leq 0.98$, is the velocity coefficient that is assumed as 0.96.. Tangential velocity, u1, is,

$$\mathrm{u}_1 = 2.127\mathrm{k}_\mathrm{c}\sqrt{\mathrm{h}} = 2.2661\ \mathrm{m/s}. \tag{11}$$

Using the continuity equation and Euler's equation, Power is calculated to be:

$$\mathrm{Power} = \tau\mathrm{w} = \mathrm{h}\rho\mathrm{gQ} = 1.06912\ \mathrm{Watt} \tag{12}$$

Under these conditions, the rotor will reach a frequency of rotation of,

$$\eta = 40.62\mathrm{k}_\mathrm{c}\frac{\sqrt{\mathrm{h}_2}}{\mathrm{D}} \tag{13}$$

$$\eta = 10818.92\ \text{revolutions per minute (RPM).}$$

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[1] Poiseuille's law relates the blood flow Q [ml/min] through a blood vessel with the difference in blood pressure at the two ends of vessel segment ΔP created by the heartbeat, radius r, length L, and viscosity μ of the blood.

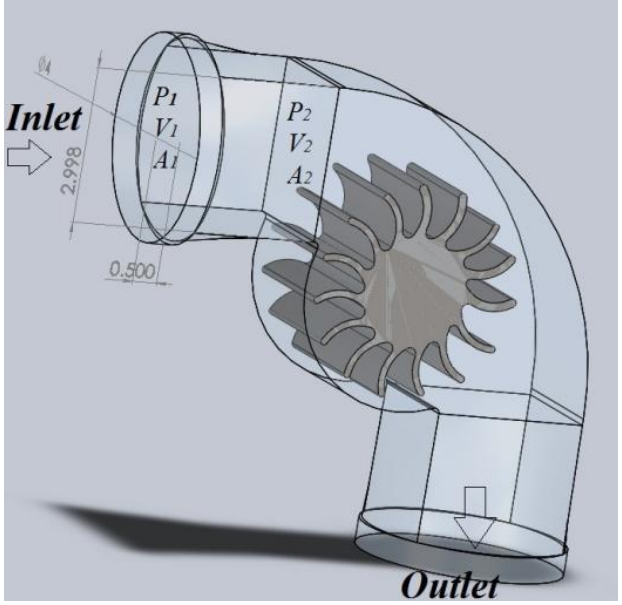

Figure 2: Micro Turbine: Inlet Parameter and dimensions

3 SIMULATIONS AND PROTOTYPING

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.

The contour of velocity, Figure 4, 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. The contour of pressure, Figure 6, 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.

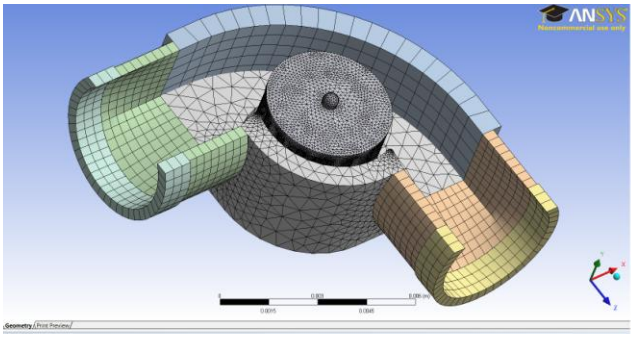

Figure 3. Turbine Mesh Result

The flow simulations in the assembled turbine show a good behaviour in velocity and pressure. Figures 5 and 6.

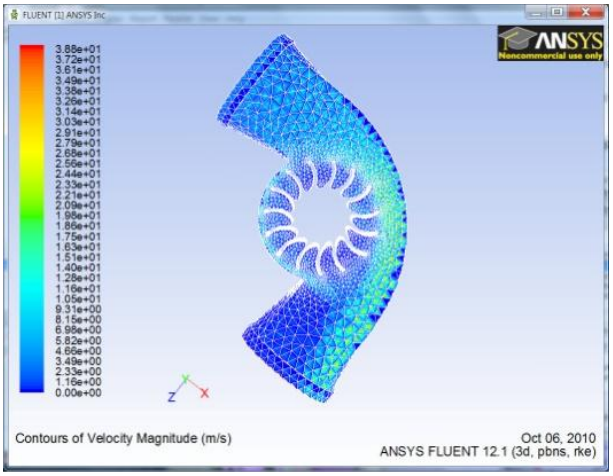

Figure 4: Contours of Velocity: rotor fixed

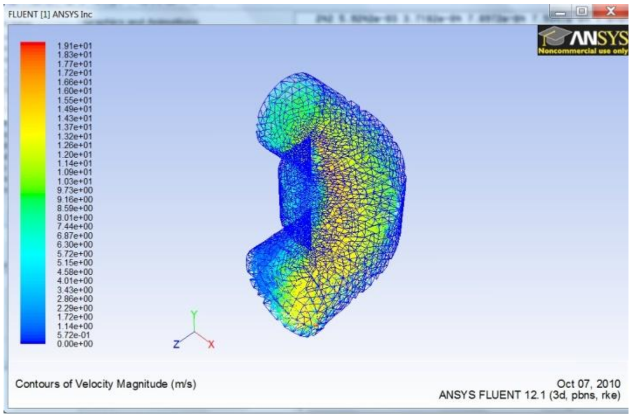

Figure 5: Contours of Velocity: rotor free

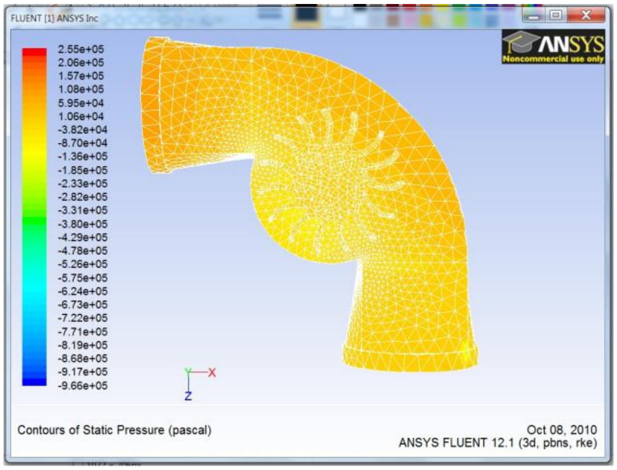

Figure 6: Contours of pressure: rotor free

The pressure simulation shown that the inlet pressure produces rotation about its axis and this movement increases the pressure in the outlet and reduces the velocity magnitude inside of the turbine, reaching stability wished in a system that is projected to work in physiological systems.

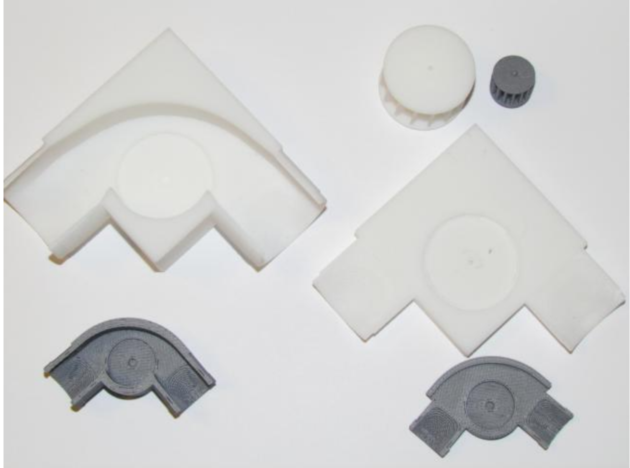

Figure 7: Turbine Prototype 4X and 8X

Simulations and a prototypes in scales 4X and 8X of the original design were performed to examine the structure and the flow behavior inside of the turbine and to determine if all the conditions are given for the turbine to rotate. A prototype in scale 4X (four times most of original size) is shown in Fig. 8.

Figure 8. Turbine Prototype 4X

The modular construction significantly reduces the number of parts and materials and brings extra benefits through simplicity of fabrication, assembly and/or redesign. The firsts prototyping were developed using plastic, but the current model are being prototype in alloys of Titanium. Anneal process and pressure applied will be used to join the holder and the cover of the turbine. Soft metal as main product cover with SiC will be a new technique to be proved.

Turbine parts have no microscale features, so micromachining is not necessary for them. Macro-scale machining techniques are used in this research to develop all prototypes.

4 CONCLUSION

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

The global application of this research will meet critical challenges for the healthcare, environmental, and military arenas, such as the delivery of medicines, energy generation, sensing or controlling nano-particles and liquid filtration.

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