BLOOD PUMP PERFORMANCE EVALUATION FOR CARDIOPULMONARY BYPASS

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Abstract. *A new model of blood pump design for cardiopulmonary bypass (CPB) application has been developed and evaluated in our laboratories. Inside the pump housing is a spiral impeller which is a conically shaped structure with double entrance threads on its surface. The worm gears provide an axial motion of the blood column through the threads of the impeller. The rotational motion of the conical shape generates the centrifugal pumping effect and improves the effeciency of the pump without increasing hemolysis. An annular magnet with six poles is used in the impeller base to provide magnetic coupling to a motor, transmitting rotational movement. When combined, axial and centrifugal pumping principles produce a better hydrodynamic performance and improve the pumping effect. In order to study the pumping performance, a mock loop composed by Tygon® tubes, oxygenator, digital flowmeter, pressure monitor, electronic driver module and a tourniquet to control the flow intensity was assembled. The whole experiment was made with six prototypes, with modifications at threads, at conically structure and at the magnets. Each prototype was tested separately and flow and pressure data were obtained for frequencies of 1000, 1500, 2000, 2500 and 3000 rpm. Pressures versus flow curves were obtained, for each prototype, to analyze the pumping efficiency. The results from six prototypes were considered satisfactory, comparing to results from literature. However, the prototype #6 showed best results. Next step is to perform blood in vitro tests to obtain the normalized index of hemolysis (NIH) which represents the main value to measure the blood damage. The NIH is calculated from Plasma Free Hemoglobyn (PFH) as described by ASTM F1841 and ASTM F1830 standards.*

Keywords*: Blood Pump, Hemolysis, In Vitro Tests, Cardipulmonary Bypass*

1. INTRODUCTION

The use of centrifugal blood pumps in various applications have increased rapidly. This fact became obvious when the advantages of centrifugal pumps were studied and compared to other devices, pulsatile pumps or roller pumps (Andrade, 1996).

The centrifugal pump and roller pump are both commonly used to pump blood in extracorporeal circuits. Centrifugal pump are safe for patients and atraumatic to the blood for cardiopulmonary bypass (CPB), because they cannot pump large amounts of air or create a considerable amount of low pressure in the inlet section or high pressure in the outlet (Lynch, 1978 and Nosé, 1997).

A new model of blood pump design for cardiopulmonary bypass (CPB) application has been developed and evaluated in our laboratories. This new type of blood pump uses both centrifugal and axial pumping principles simultaneously, and thus improves pump efficiency without increasing hemolysis. To generate both pumping actions, inside the pump is a spiral impeller that is conically shaped and has threads on its surface (Andrade, 1996), see Fig. 1. An annular magnet with six poles is used at the impeller base to provide the rotational movement. Because of the double entrance threads, the axial effect is produced. In the other hand, the centrifugal effect occurs because of impeller conicity.

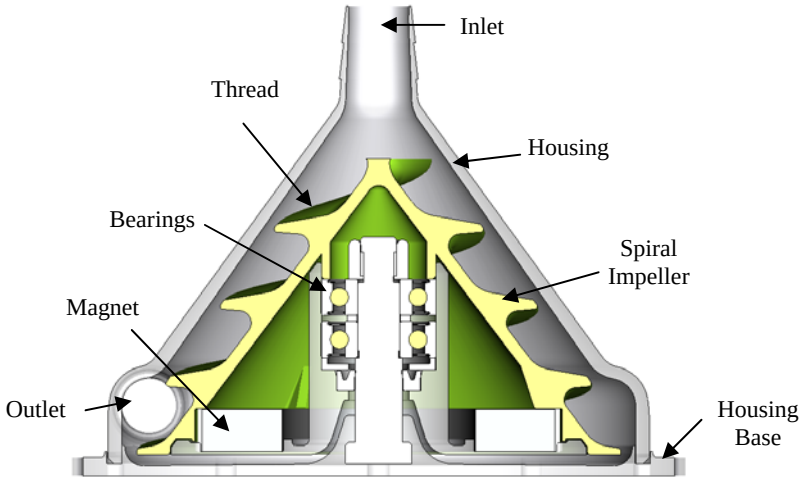

Figure 1. Schematic drawing of the new pump.

At the top of the housing, is the inlet port and, at the bottom, is the outlet port, both with 3/8-inch connections. The base is attached under the housing and consists of a disc with a stainless steel shaft that holds all internal components of the pump. The housing base provides total isolation between inside and outside of the pump.

The torque is transmitted from the motor to the spiral impeller by magnetic coupling, using 2 magnets: 1 inside the impeller and other fixed to the motor in the electronic driver (Andrade, 1996).

Modifications in details of the pump design can induce great modifications in the device performance. Six prototypes were studied.

2. MATERIALS AND METHODS

2.1. Blood Pump

These prototypes are a conversion of the original Spiral Pump, from one entrance threads to double entrance threads. Six prototypes with modifications at threads, at conically structure and at the magnets were constructed, see Table 1.

Table 1. Prototype modifications.

Prototype	Modifications
#1	Original project without modifications: normal screw at impeller, and housing base with normal height of the outlet.
#2	Changes at internal components to facilitate the assembly: different position of magnet and bearings, normal screw at impeller and housing base with normal outlet.
#3	Changes at the housing: lower height of the outlet, decreasing the area of low pressure.
#4	Changes at the impeller: removing the cylindric base, leaving the thread up to the end, and lower outlet;
#5	Changes at the impeller: without cylindric base, lower outlet and increasing 0,7 mm at the thread deep.
#6	Changes at the impeller: replacing the cylindric base, lower outlet, increasing 1,2 mm at the thread deep and increasing the magnet diameter.

The principal modifications are shown at Fig. 2, 3 and 4.

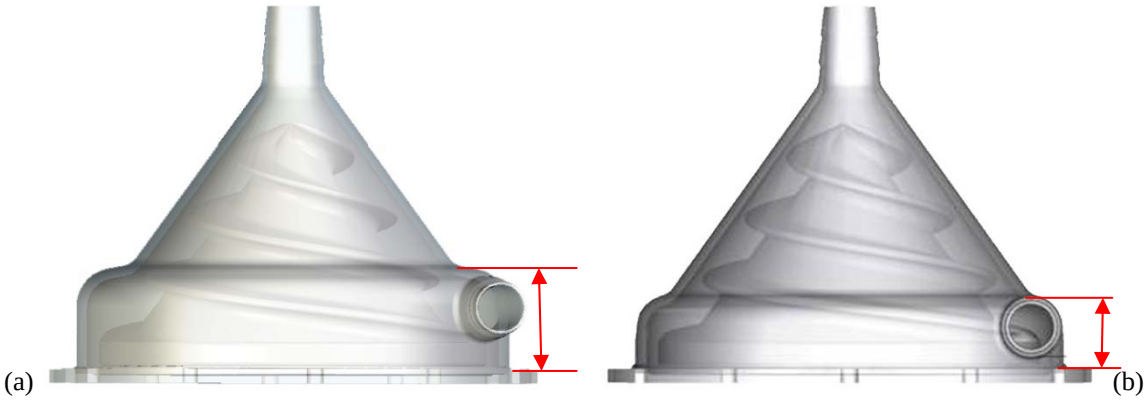

Figure 2. (a) Original project and (b) lower height of the outlet at Prototype #3.

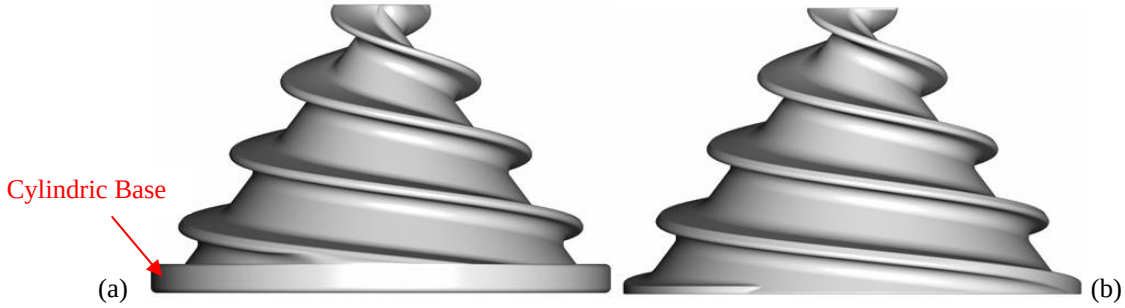

Figure 3. (a) Prototype #3 with cylindric base and (b) Prototype #4 without cylindric base.

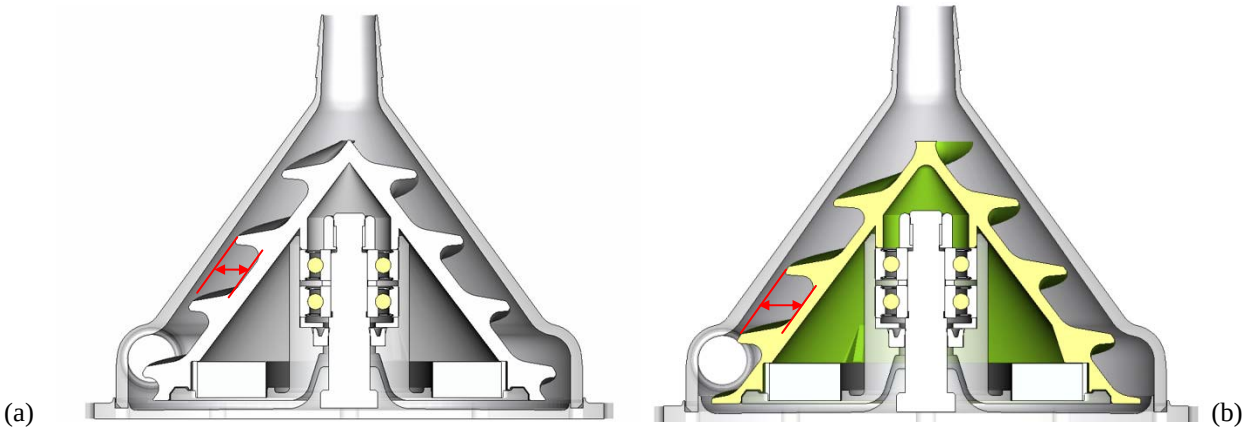

Figure 4. (a) Prototype #5 without cylindric base and increasing 0,7 mm at the thread deep and (b) Prototype #6 with cylindric base and increasing 1,2 mm at the thread deep.

2.2. Hydrodinamic performance tests

The hydrodynamic performance was studied from six prototypes.

A closed loop circuit filled with a solution (1/3 glycerin, 1/3 water and 1/3 alcohol 99%, at 25ºC), simulating the density and viscosity of blood, was used in these tests (Legendre, 2009).

The circuit consists of a polycarbonate reservoir normally used for CPB with polyvinyl chloride 3/8-inch tubes (Nipro, Brasil), see Fig. 5. An adjustable clamp was used to control the flow at pump outlet. Pressure monitor (Dixtal DX2020, Brasil) was connected at the pump inlet and outlet (Bock, 2005). A flow meter (Transonic Systems, USA) was used to measure the flow at the pump outlet, during these tests. The pumping rotations were fixed at 1000 rpm, 1500 rpm, 2000 rpm, 2500 rpm and 3000 rpm. Using and adjustable clamp, the flow varied between zero and the maximum flow possible for that pumping rotation (Andrade, 1996).

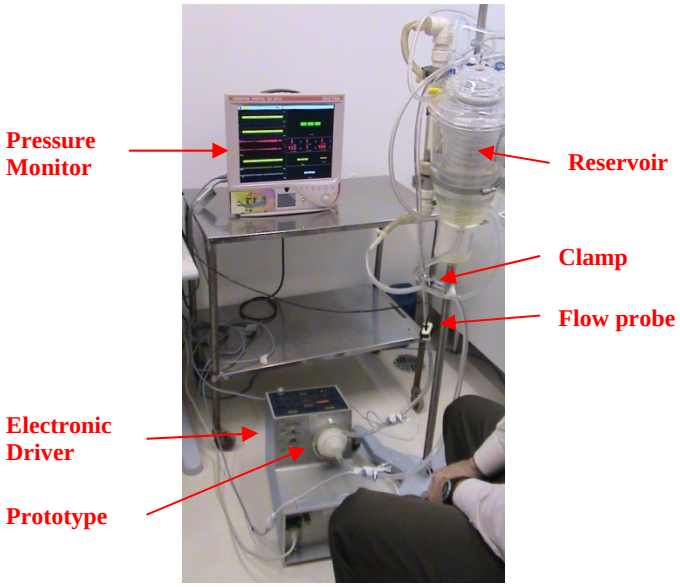

Figure 5. Closed loop circuit for hydrodynamic performance tests.

3. RESULTS

The results of each pumping rotation are shown as relationship between the total pressure head and flow, see Fig. 6. The pressures (at inlet and outlet) were calculated as ΔP and flow was varied by the clamp.

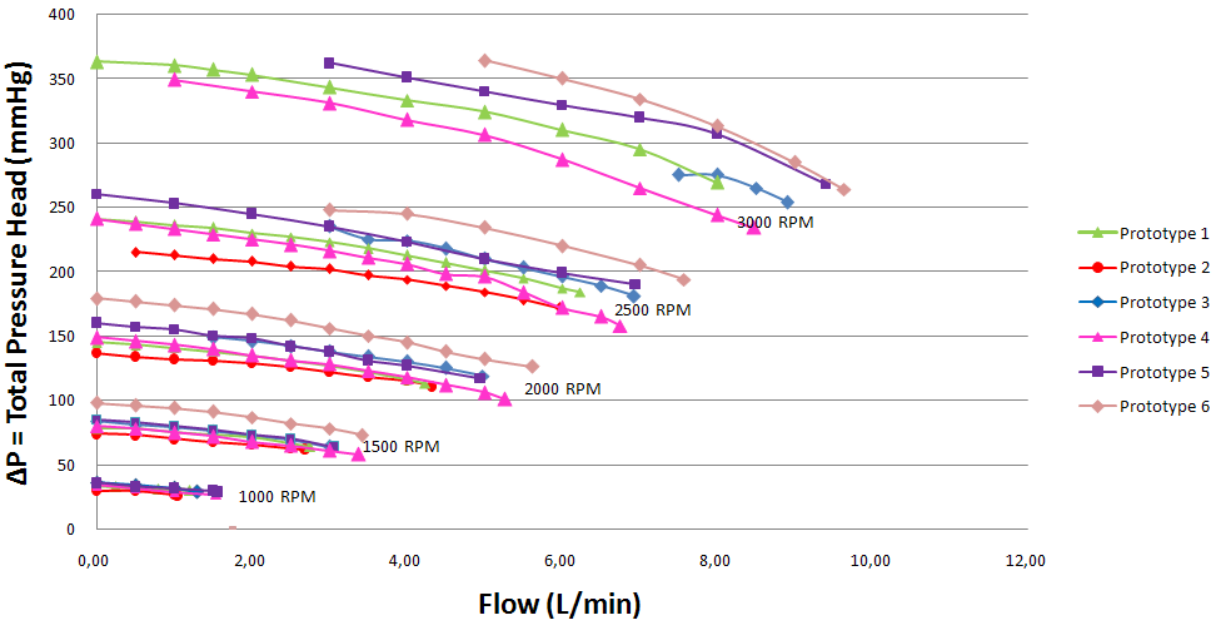

Figure 6. Hydrodynamic performance from the 6 prototypes.

Hydrodynamic performance of Prototype #1 was considered satisfactory. However, small modifications were made and new hydrodynamic performance tests were conducted. Comparing the six prototypes, the Total Pressure Head (ΔP) x Flow curves demonstrated that:

1. Comparing prototypes #1 and #2, there is not performance difference;
2. Comparing prototypes #2 and #3, there is an increasing pressure and flow, occurred by change at the housing;
3. Comparing prototypes #3 and #4, there is a decreasing pressure and flow, occurred by removing the cylindric base;
4. Comparing prototypes #4 and #5, there is an increasing pressure and flow, occurred by increasing 0,7 mm at the thread deep;

5. Comparing prototypes #5 and #6, there is an increasing pressure and flow, occurred by increasing 1,2 mm at the thread deep with cylindric base;

4. CONCLUSIONS

This blood pump is a new concept that uses both centrifugal and axial pumping principles. When both of these principles work simultaneously, there is an improvement in the hydrodynamic performance. The hydrodynamic performance of the pump is an important characteristic, and this blood pump has demonstrated satisfactory pumping performance in all tested design.

Hydrodynamic performance curves were obtained from data generated in vitro tests. The curves show that the prototype #6 is superior to the other prototypes. At low speed all prototypes have similar performance, differences occur at high speed, where prototype #6 over the others.

Now, next step is to perform blood in vitro tests to obtain normalized index of hemolysis (NIH) which represents the main value to measure the blood damage, calculated from Plasma Free Hemoglobyn (PFH), as described by ASTM F1841 and ASTM F1830 standards.

5. REFERENCES

Andrade, A., et al., 1996, “Characteristics of a Blood Pump Combinig the Centrifugal and Axial Pumping Principles: The Spiral Pump”, Artificial Organs, 20(6):605-612.

Bock, E., et al., 2007, “A new concept of centrifugal blood pump using pivot bearing system: the conversion of the Spiral Pump inlet port”, ABCM Symposium Series in Bioengeneering, Vol. 1, Rio de Janeiro.

Legendre, D.F., 2009, “Estudo de Comportamento de fluxo através de modelo físico e computacional de aneurisma de aorta infra-renal obtido por tomografia, Tese de Doutorado, Escola Politécnica da Universidade de São Paulo.

Lynch, M.F., et al. 1978, “Centrifugal Blood Pumping for Open Heart Surgery”, Minn Med, 536-7.

Nosé, Y., Kawahito, K., 1997, “Hemolysis in Different Centrifugal Pumps”, Artificial Organs, 21(4):323-326.

6. RESPONSIBILITY NOTICE

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