# MODELS FOR COMPUTATIONAL SIMULATIONS OF AN IMPLANTABLE CENTRIFUGAL BLOOD PUMP WITH CERAMICAL PIVOT BEARINGS

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***Resumo.*** *The Implantable Centrifugal Blood Pump (ICBP) is a Left Ventricular Assistance Device (LVAD) that can promote long term circulatory support in cardiac patients. Its design was focused, since the beginning, in models for computational simulations in parallel with the empiric development that is historically common in artificial organs field of study. Computational simulations avoid unnecessary costs and promote deeper knowledge of involved phenomena. However, different situations had been studied and simulated with isolated dynamic models making difficult to couple solutions. This work analyses several simulations performed in order to compare results and propose a unified platform to simulate the whole system. Computational Fluid Dynamics (CFD) analysis was performed in Fluent, Ansys, comparing laminar and turbulent models. ICBP actuator, a Brushless Direct Current Motor (BLDC) and local controller was simulated with MATLAB/SIMULINK and Sim Power Systems toolbox, block of Permanent Magnet Synchronous Machine (PMSM). A supervisory controller based on Petri Nets (PN) and Bayesian Networks (BN) will fit those parameters and include Safety Instrumented System (SIS) based algorithms. As results, models are been validated with experimental data obtained in a mock loop circuit with LabVIEW virtual instrument. In conclusion, three different platforms could export results to MATLAB but it would be a time costing challenge to include one more model, for instance PN or BN based software. Since Ansys, MATLAB, and LabVIEW softwares run in Microsoft Windows, a new computer program is been implemented in C#, designed to manage simulations in Microsoft .Net environment. In future, our results from different simulations could be compatible and ICBP operation could be even more predictable.*

***Palavras chave****: left ventricular assistance device, implantable centrifugal blood pump, computational simulations.*

## 1. INTRODUCTION

The Implantable Centrifugal Blood Pump (ICBP) is a Left Ventricular Assistance Device (LVAD) that can promote long term circulatory support in cardiac patients, Fig. (1). Our group started this project in 2006 and now it is part of a multicenter study with associated researchers in more than 6 laboratories.

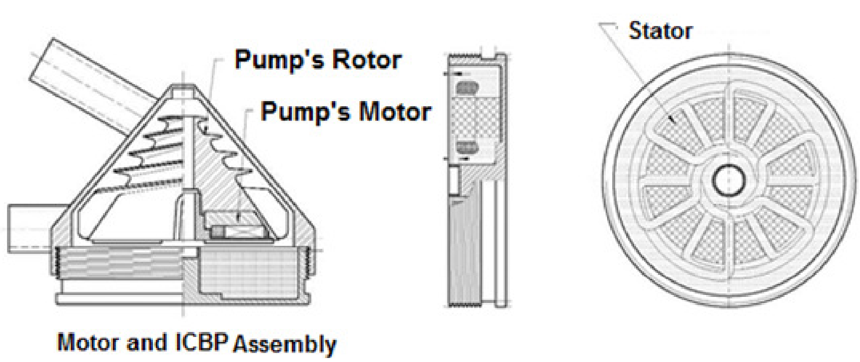


Figure 1. Schematics of ICBP assembled (at left), BLDC actuator (in center) and coils distribution (at right).

ICBP is a dual impeller pump with original features like ceramic (Al2O3) and polymeric (PEUHMW) pivot bearings that reduce wear and avoid mechanical trauma imposed to red blood cells. The benefits of this approach, instead of magnetic levitation pumps, are simplicity, low consumption of energy and reliability. ICBP design effectiveness was possible to be measured in Normalized Index of Hemolysis (NIH), previously studied by Bock *et al.,* (2008).

As described by Wood *et at.* (2005), the design of a blood pump has to satisfy several engineering requirements like atraumatic behaviour, affordability, control flexibility, reliability, implantability, and applicability for different physiological demands varying from patient to patient.

Design was focused, since the beginning of this project, in models for computational simulations (Legendre *et al.,* 2008) in parallel with the empiric development that is historically common in artificial organs field of study (Nosé, 1998).

Computational simulations avoid unnecessary costs and promote deeper knowledge of involved phenomena (Zhang *et al.,* 2013). However, with a large research group, different situations had been studied and simulated with isolated dynamic models making it difficult to couple solutions.

## 2. METHODOLOGY

This work analyses several simulations performed in order to compare results and propose a unified platform to simulate the whole system. Simulations were divided in blood pump flow, actuator local control, Neural Network based control, and supervisory control.

After simulations, results obtained with the proposed models were compared with previous experimental data obtained in a mock loop circuit (Uebelhart *et al.,* 2013). Data were acquired using LabVIEW (National Instruments, Austin, TX, USA) virtual instrument and apparatus assembled by Fonseca *et al.* (2011).

### 2.1. Blood pump flow

Previous Computational Fluid Dynamics (CFD) analysis was performed by Legendre et al. (2008) in order to analyze blood pump flow. Since new prototypes were assembled with dual impeller and new features in geometry after that Fig. (2), it was mandatory a new exploratory CFD analysis.

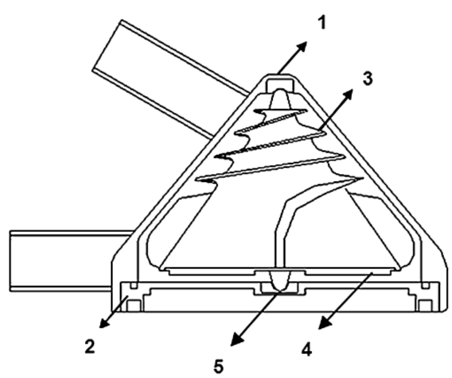


Figure 2. ICBP parts: 1. housing; 2. external base for actuator; 3. dual impeller with spiral and centrifugal vanes; 4. impeller base; 5. ceramical pivot bearing

In this paper, CFD simulations were performed in Fluent, Ansys, in order to compare laminar and turbulent models with our previous experimental data (Uebelhart *et al.,* 2013).

### 2.2. Pump controller

ICBP actuator, a Brushless Direct Current Motor (BLDC) and local controller was simulated with MATLAB/SIMULINK and Sim Power Systems toolbox, block of Permanent Magnet Synchronous Machine (PMSM). In a previous paper, Leao *et al.* (2014) show how to model aortic valve stenosis with this model, Fig. (3).

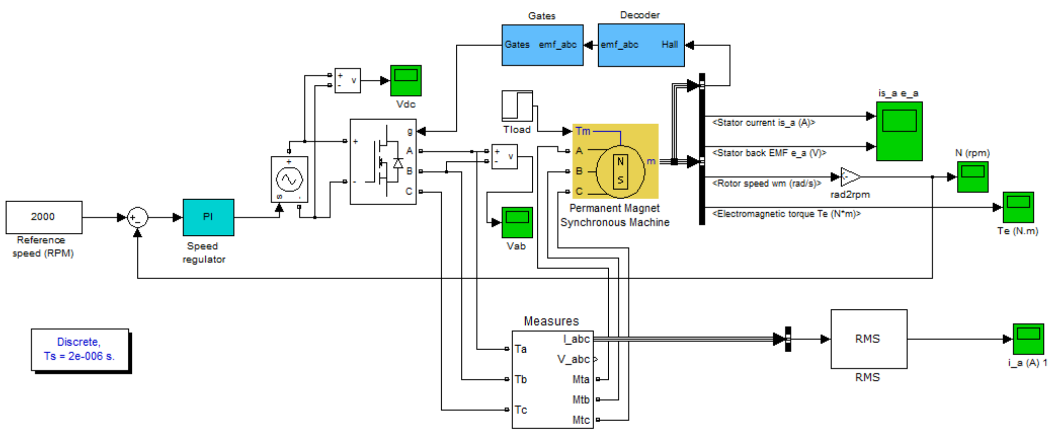


Figure 3. Block Diagram implemented in Simulink representing BLDC control system.

A supervisory controller is been developed by Cavalheiro *et al.* (2011) based on Petri Nets (PN) and Bayesian Networks (BN) will fit those parameters and include Safety Instrumented System (SIS) based algorithms. This development is important to our group because the modeling approach can achieve an automatic and dynamic control system possible to adjust with patient needs and therefore provide higher quality of life.

Another approach is focused in control ICBP through an Artificial Neural Network (ANN) operating similar to heart's natural control. Simulations were also performed in MATLAB using ECG from Physionet MIT data bank. Two ANN were applied to identify QRS and calculate motor speed.

## 3. RESULTS

As results, models are been validated with experimental data obtained in a mock loop circuit with LabVIEW virtual instrument. In conclusion, three different platforms could export results to MATLAB but it would be a time costing challenge to include one more model, for instance PN or BN based software.

CFD simulations showed the turbulence models presented more accuracy in pressure differences and velocity fields than laminar model even with low Reynolds numbers.

The created ANN, after trained, steadily controls the motor speed with considered small error and provided a good signal of QRS waves, Fig. (4).

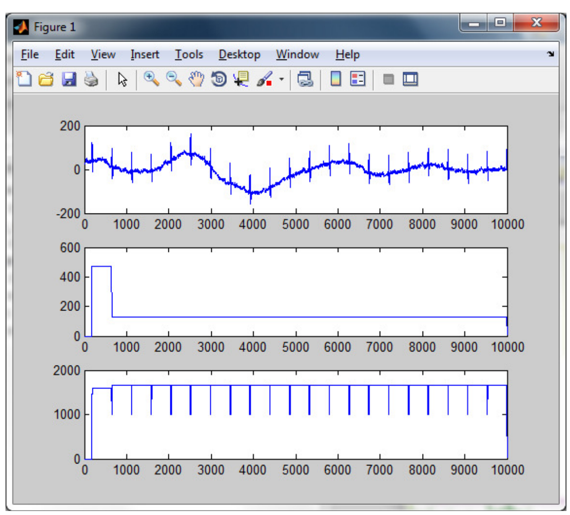


Figure 4. Main ANN software output: ECG, heart rate (BMP) and motor speed (RPM).

## 4. CONCLUSIONS

Interactions between many researchers could be more effective with a singular platform capable of simulate different phenomena and work with coupled solutions. Our group tried to substitute the described programs without success. The reason for that could be the convenience for each researcher or even the time would be spent to replace them.

Since Ansys, MATLAB, and LabVIEW programs run in Microsoft Windows environment, a new computer program is been implemented in language C#, designed to manage simulations and its interactions in Microsoft .Net (dotnet) environment, Fig. (5).

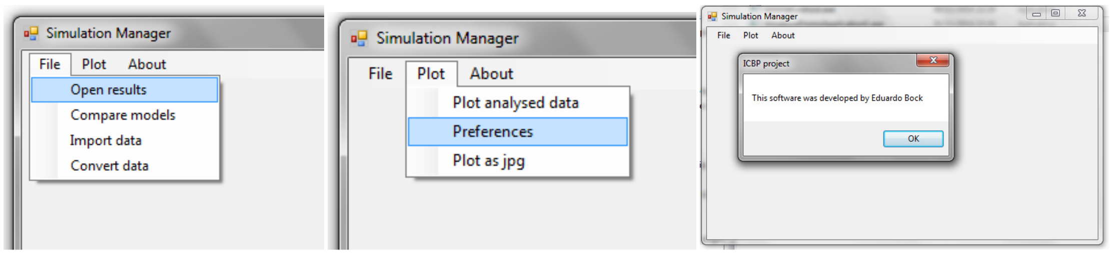


Figure 5. Simulation Manager Program created in C# .NET.

The Simulation Manager is still been coded and results from this implementation could help to better understand situations where computational modeling diverge from experimental data. Other possible study could be a Hardware-in-the-loop (HIL) simulation. In future, our results from different simulations (actuator, pump, controllers, and circulatory system) could be compatible and ICBP operation could be even more predictable.

## 5. REFERÊNCIAS

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## 6. ACKNOWLEDGMENTS

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## 7. RESPONSABILITY

Authors are the only responsible for information included in this work.