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RELIABILITY STUDY OF A CONCEIVED WORKBENCH TO PERFORM FRICTION TESTS UNDER CONTROLLED CONDICTIONS

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Abstract. *A Test Workbench (TW) was designed and built at the Bioengineering Laboratory of the Federal Institute of Technology in Sao Paulo (IFSP) to make the selection of materials used in a Implantable Centrifugal Blood Pump (ICBP). The ICPB is a blood pump for long term ventricular assist in patients with advanced stages of cardiac insufficiency, maintaining blood flow and supporting life. The ICPB can be classified as a Ventricular Assist Device (VAD) of third generation with ceramic-polymeric pivot bearings. The tests are performed in TW evaluating ICBP bearings and the rotor shaft, which are subject to friction. ICBP actuator is composed by Brushless Direct Current Motor BLCDM that is magnetically coupled to the pump impeller. The impeller is supported by the pivot bearings. Various bearings and rotor shafts with predefined dimensions were developed and tested. The methodology used to assess the efficiency of TW was based on functionality and capability to simulate ICPB wear "in loco". The calibration was performed by standard weights on a precision balance. During the tests, the TW provided precise control of the contact pressure between the bearings and the rotor shaft for applying a constant force. A load cell sends an analog signal to an electronic circuit that converts this signal strength and shows it in a liquid crystal display. The speed control is made by an electronic converter, called a frequency inverter. The results of tribological testing of pivot bearing pairs serve for the selection of materials seeking greater mechanical durability of the ICPB. In this study, vibration in ceramic-polymeric pivot bearings was not evaluated although there is a study in parallel for this purpose. The TW was considered a reliable tool to perform the friction test (under controlled conditions). TW is been used to evaluate the wear materials of ICPB pivot bearings. In future, tests conjugating vibration and wear will be performed for a more accurate assessment of the friction inside the pump and its relation with possible deleterious vibrations.*

Keywords: *Tribology, Test Workbench, Blood Pumps, Biomaterials.*

1. INTRODUCTION

Cardiac Insufficiency (CI) is a disease characterized by the inability of the heart to pump blood in appropriate physiological conditions to meet the requirements of the tissues at rest or during exercise (Woods *et al*., 2000). It is estimated that about 23 million people worldwide have CI and the indexes have increased every year are about two million new cases each year (Nogueira *et al.*, 2010).

According to data from DATASUS *apud* Nogueira *et al*. (2010), in Brazil there are about two million patients with CI, with 240.000 cases diagnosed per year, thus bringing high hospital costs of treatment and hospitalization. Table 1 shows the costs of hospitalizations due to CI.

Table 1. Total costs of hospitalizations for all causes, cardiovascular disease (CVD) and cardiac Insufficiency (CI), comparing the years 2000, 2004 and 2007. Source SBC

	Year	***TOTAL***	***CVD***	***CI***
Hospitalizations (#)	2000	11,937,323.00	1,134,385.00	398,489.00
Total Cost (R$)		4,886,848,236.08	821,460,375.47	204,666,458.17
Unit Cost (R$)		409.38	724.15	513.61
Hospitalizations (#)	2004	11,492,883.00	1,205,067.00	339,770.00
Total Cost (R$)		658,121,333.54	1,247,888,762.41	226,842,857.98
Unit Cost (R$)		572.63	1,035.53	667.64
Hospitalizations (#)	2007	11,309,325.00	1,156,136.00	293,473.00
Total Cost (R$)		7,607,591,178.43	1,467,395,208.68	232,776,739.30
Unit Cost (R$)		672.68	1,269.22	793.44

Figure 1 shows an increase trending in hospitalizations costs by CI from year 2000 to 2007. Also, the future estimative may reach 280 million (in Brazilian reais, R$) by the year of 2016.

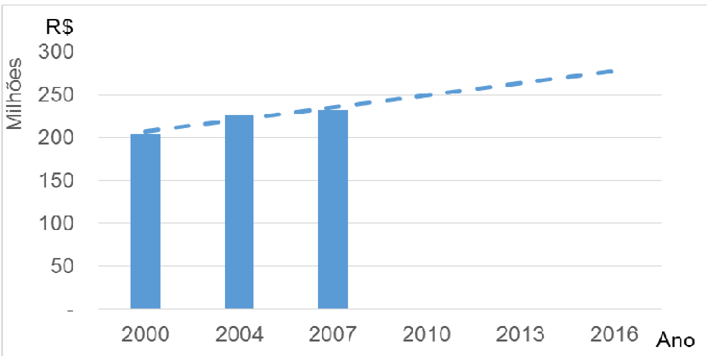

Figure 1. Evolution trend of hospitalizations costs by IC.
Adapted from: SBC de 2000 até 2007.

It is possible to observe in Fig. 2 that this problem can get worse if we consider that the Brazilian population is aging.

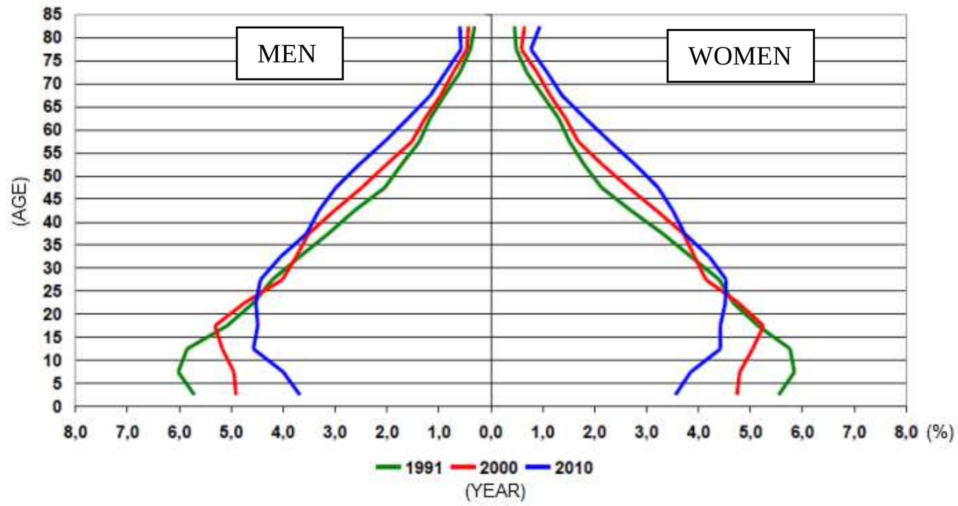

Figure 2. Composition of total resident population by sex and age groups - Brazil - 1991/2010. Source: IBGE

Every effort to develop new technologies, that prolongs the life of a person and avoid possible hospitalizations, will benefit our entire society. Among some of the technologies developed, there is the Implantable Centrifugal Pump Blood (ICPB), which already has an advanced development by several researchers where some of them are listed in Chapter 2.

The main objective of this study is to develop an automated worbench to test the wear resistance of biomaterials in the ICPB.

The topic 2 shows the development of some Ventricular Assist Devices (VAD), some functions and the importance of the pursuit of excellence of a project of little maintenance and low cost, justifying the need to develop devices for testing of VAD.

The topic 3 shows the development of a test Workbench for testing various types of biomaterials that can be used in bearings and rotor shaft of an ICPB.

The topic 4 shows the workbench validation TW test.

2. VENTRICULAR ASSIST DEVICES (VAD)

The ventricular assist devices (VAD) are intended to maintain hemodynamic conditions for a long period and replace partially or fully, temporarily or permanently the heart pump function (FIORELLI *et al.*, 2008). Among VAD groups, blood pumps are the most prescribed devices and it will be the focus of our VAD review.

Figure 3 shows a schematic of the types of circulatory assistance may be right, left, or both. Devices are called LVAD (Left Ventricular Assist Device), RVAD (Right Ventricular assist Device) and BVAD (Biventricular Assist Device).

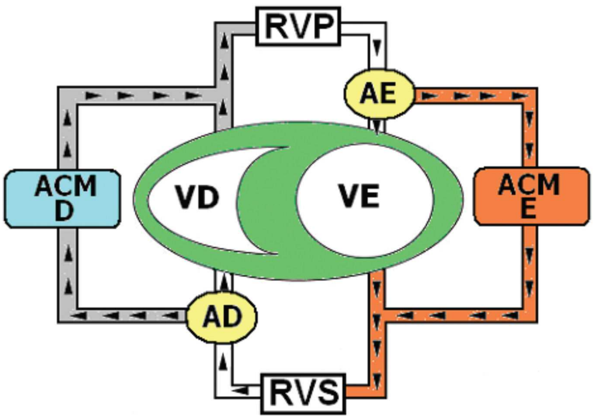

Figure 3. Scheme of the relation between the right ventricle (RV) and left (LV) and the different modes of right circulatory support (ACM-D) and left (ACM-E).
Source: Fiorelli 2008.

The Centrifugal Blood Pump Gyro® has been in development since 1995 presenting excellent result as LVAD and in 2001, Nonaka and his team went on to develop a BVAD, which requires two pumps simultaneously (Nonaka *et al*., 2001).

The design of the pump NEDO® "New Energy and Industrial Technology Development Organization" (NEDO, Houston, USA) was started in 1995 with an evolution of Gyro® pump. The NEDO® is a fully implantable centrifugal blood pump for BVAD (Nose *et al*., 2004). Bock *et al.* (2005) developed a new concept using a pump system with ceramic pivot bearings. Pump impeller consisted of a conical spiral associated with parallel vanes that proved to be a safe and reliable option.

Kosaka *et al*. (2007) developed a Centrifugal Blood Pump with hydrodynamic bearings and semi-open impeller levitation evaluated the performance test and hemolysis test, with the index of hemolysis (NIH) was reduced from 0.72 g / 100 l to 0.024 g / 100 l, this was due to the improved balance between the dynamic force of fluids and magnetic force. Hemolysis is the destruction of red blood cells (RBCs) which may be caused by mechanical trauma, and therefore there is a concern for minimizing the friction between the components to be developed with magnetic levitation devices or materials and geometries of components that reduce the most of these traumas.

Bock *et al*. (2008) developed an implantable centrifugal blood pump with double impeller rotor and two bearings originally developed by Dr. Yukihiko Nosé and held various friction tests, hemolysis and the pump showed great performance results.

Asama *et al*. (2009) developed a motor with a disc without the support of a magnetic bearing suspension for application in artificial hearts, constructively possible to decrease the size being 10 mm high and 70 mm in diameter and after prototype testing the economic viability has been validated.

Greatrex *et al*. (2010) developed and tested a Suspension System Biventricular Assist Device, consists of two semi-open centrifugal turbines mounted on a common axis and axially controlled by a magnetic suspension system.

Cheng *et al*. (2011) had some optimizations in their magnetic bearing 3D FEA via a Centrifugal Pump with Magnetic Levitation achieved by improvements in rotation and increasing of 6000 rpm to 9000 rpm, thereby improving blood flow.

Nan *et al*. (2011) developed an implantable Centrifugal Blood Pump with two degrees of freedom radially controlled by means of magnetic bearings to assist the pumping function of the weakened heart, the strategy was used to add redundant information to maintain the function of the centrifugal pump.

Kosaka *et al*. (2011) conducted a study to investigate the geometric configuration of the hydrodynamic step. They proposed hydrodynamic bearings with semi-open impeller. In order to minimize hemolysis, their work focused in the gap of a centrifugal blood pump. The results showed that the step of 67% was the most appropriate configuration to minimize hemolysis.

Bock (2011) developed the design and built an Implantable Centrifugal Blood Pump (ICPB) where a ceramic rotor has its shaft supported by upper and lower bearings constructed with polymers and are of different materials produces a damping effect by reducing vibration. Because there is a friction contact is be a natural wear which has to be as little as possible so it was tested several materials to choose the material that has the lowest wear increasing pump life.

3. TESTING WORKBENCH (TW) FOR FRICTION AND WEAR

3.1 Materials used

For construction of the Test Workbench (TW) (Fig. 4) the following components were used.

3.1.1 Structure

The structure is a SAE 1020 steel sheet 5 *mm* allowing bent tabs to be fixed on a workbench to provide greater stability by avoiding problems with vibrations.

3.1.2 Lever

The lever is made of rectangular tube perforated SAE 1020 steel with regular distances for plugins balances that determine the friction load to be applied between the samples.

3.1.3 Load Cell

The load cell is a rectangular bar of aluminum which has on one of its faces a variable resistor combined with other resistors to form a circuit known as Wheatstone bridge. The load cell is fixed at one end and the other applies a force which flexes the aluminum bar and thereby varies the electrical resistance can thus create a relationship between the applied force and an electric signal which is amplified and converted into an electronic circuit.

3.1.4 Microcontroller

The chosen microcontroller was the Arduino, an electronic device with ATmega328 microcontroller, support input and output of digital and analog electrical signals and programming language C. Used to receive the analog electrical signal of the load cell and convert to a power unit which will be presented in a connected liquid crystal display with Arduino.

3.1.5 Motor

Motor three-phase induction power of 1 CV. Used to rotate one of the test samples simulating the rotor shaft of implantable centrifugal blood pump.

3.1.6 Frequency inverter

Frequency inverter power 1CV, input voltage 220 V single phase, and output voltage three phase 220 V. An inverter used to control motor speed meeting the requirements of requested tests.

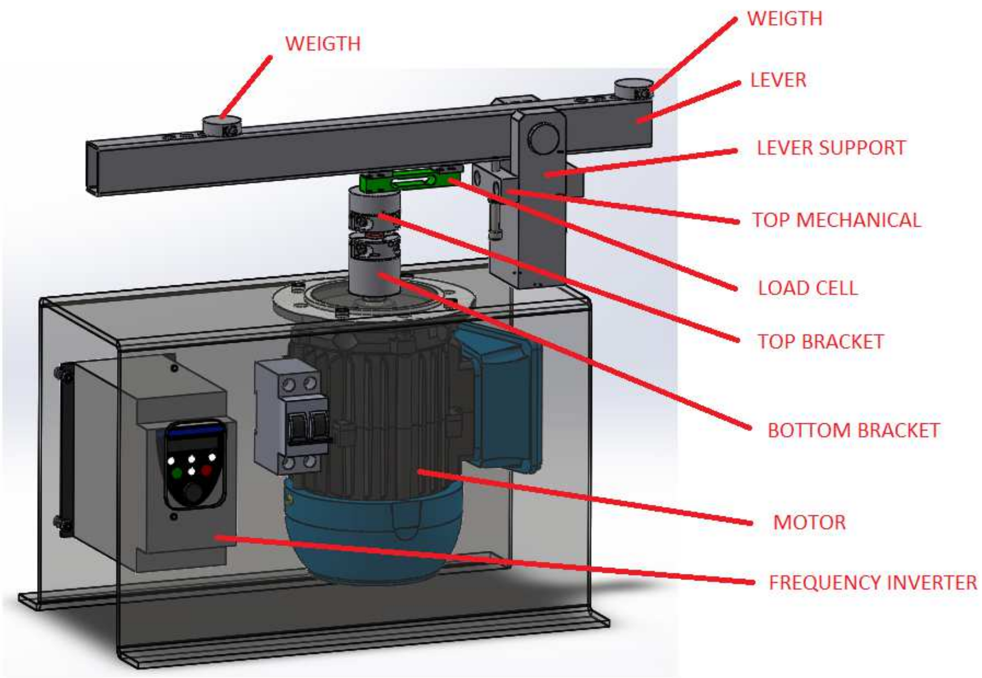

Figure 4. General Assembly TW

3.2 Developments in the 3D model and principle of operation

The development of the project through 3D modeling makes it possible to create a virtual prototype which can be analyzed and tested even before its construction, so we used the 3D modeling software SolidWorks (SolidWorks 2012, Dassault Systèmes, Concord, USA). Multiple virtual prototypes were developed until the final version of the design is shown in Figure 4.

This prototype (Fig. 4 and 5) comprises a motor which is coupled a lower support for fixing one of the specimens and a load cell which is fixed the upper support of the test piece. The samples have the same dimensions of the rotor and bearing the Blood Centrifuge Implantable Pump. The load cell has been set at a lever that gives us several settings in order to get the ideal weight for friction testing of the samples for more accurate load cell will send an analog signal to an electronic circuit which will amplify the signal and converts it to a digital signal that will be displayed in grams unit in a liquid crystal display. The motor has a rated speed of 3600 RPM which is controlled by an inverter frequency can be adjusted its rotation in accordance with the specifications of Implantable Centrifugal Blood Pump (Bock, 2011).

In Fig. 5, it has highlighted two mechanical tops that serve to prevent damage to a component by means of undue shocks. These tops are fitted with clearance between the lever and the screw to not interfere with the contact pressure between the samples, this gap will be determined during testing.

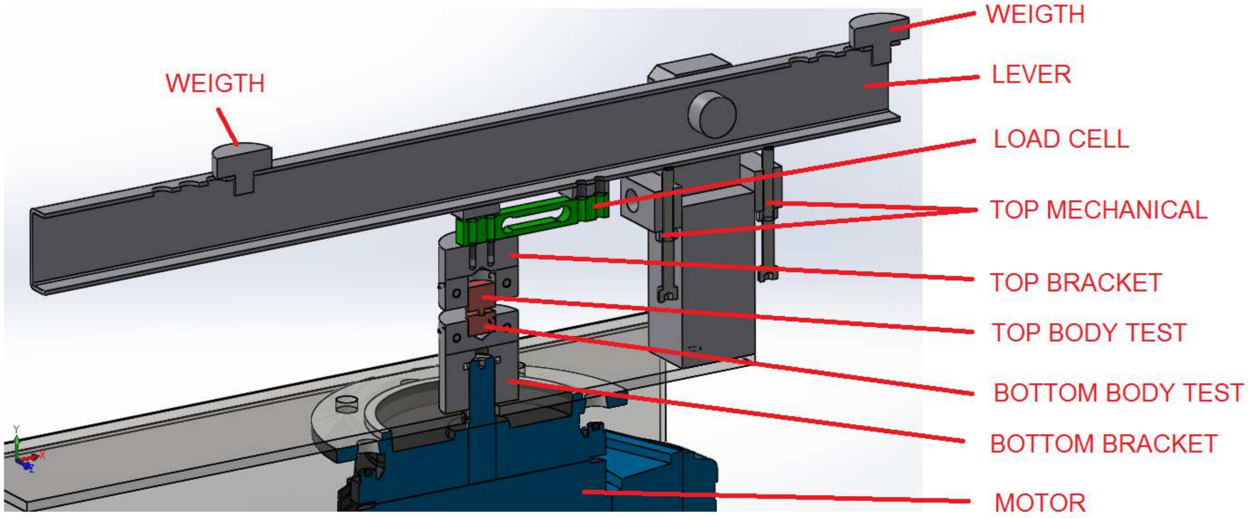

Figure 5. Assembling section with details of Lever, Weight, Motor and Load Cell locations.

4. TW PERFORMANCE

The automated testing for material selection has variables such, samples material; the rotor shaft rotation (one of the samples); contact force; time in minutes; and wear in grams (difference of mass before and after testing).

To validate the effectiveness of TW, trials with calibrated weights were performed on an analytical scale of Shimadzu AY220 model manufacturer with the precision of 0.0001 *g*. See Table 2 comparison of the value found in the analytical balance with the one presented in TW.

Table 2. Comparison of calibration weights

Calibrate Weight	Scale Shimadzu AY220 (g)	TW (g)
Weight 1	28.89	28.87
Weight 2	53.46	53.42
Weight 3	62.79	62.78
Weight 4	67.98	67.97
Weight 5	121.44	121.24
Weight 6	198.89	198.72

The scale used for calibration TW supports a maximum of 200 *g*. It was necessary to add the values of calibrated weights to verify the accuracy of the TW values for over 200 *g*. See Table 3 the comparison of the value found in the analytical balance with that disclosed in TW.

Table 3. Comparison of calibration weights

Calibrate Weight	Scale Shimadzu AY220 (g)	TW (g)
Weight 2 + Weight 6	53.46 + 198.89 = 252.35	251.97
Weight 5 + Weight 6	121.44 + 198.89 = 320.33	319.97
Weight 3 + Weight 4 + Weight 5 + Weight 6	62.79 + 67.98 + 121.44 + 198.89 = 470.73	450.7

5. CONCLUSIONS

The results of performance tests have shown the reliability of the TW, which will enable testing on new tribological pairs and will serve for the selection of materials bearing seeking greater mechanical durability of the ICPB. This work did not evaluated vibration on bearings. However, TW become possible to perform the friction test under controlled conditions and wear rate of a given material. The next step will be to test various materials, determining what the best material to be used in the ICPB.

TW is considered a tool of considerable importance for the development of VAD support bearings with ceramic or ceramic-polymer. The performance of TW was considered satisfactory for the isolated assessment of the wear in the bearings of the ICPB.

In future, materials selection testing based on wearing will be held in conjunction with vibration tests for a more accurate assessment of the friction inside the pump. Authors expect that the relation between vibration and wearing can lead to map deleterious vibrations, understand them and avoid their frequencies in ICBP and other VAD.

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7. RESPONSIBILITY NOTICE

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