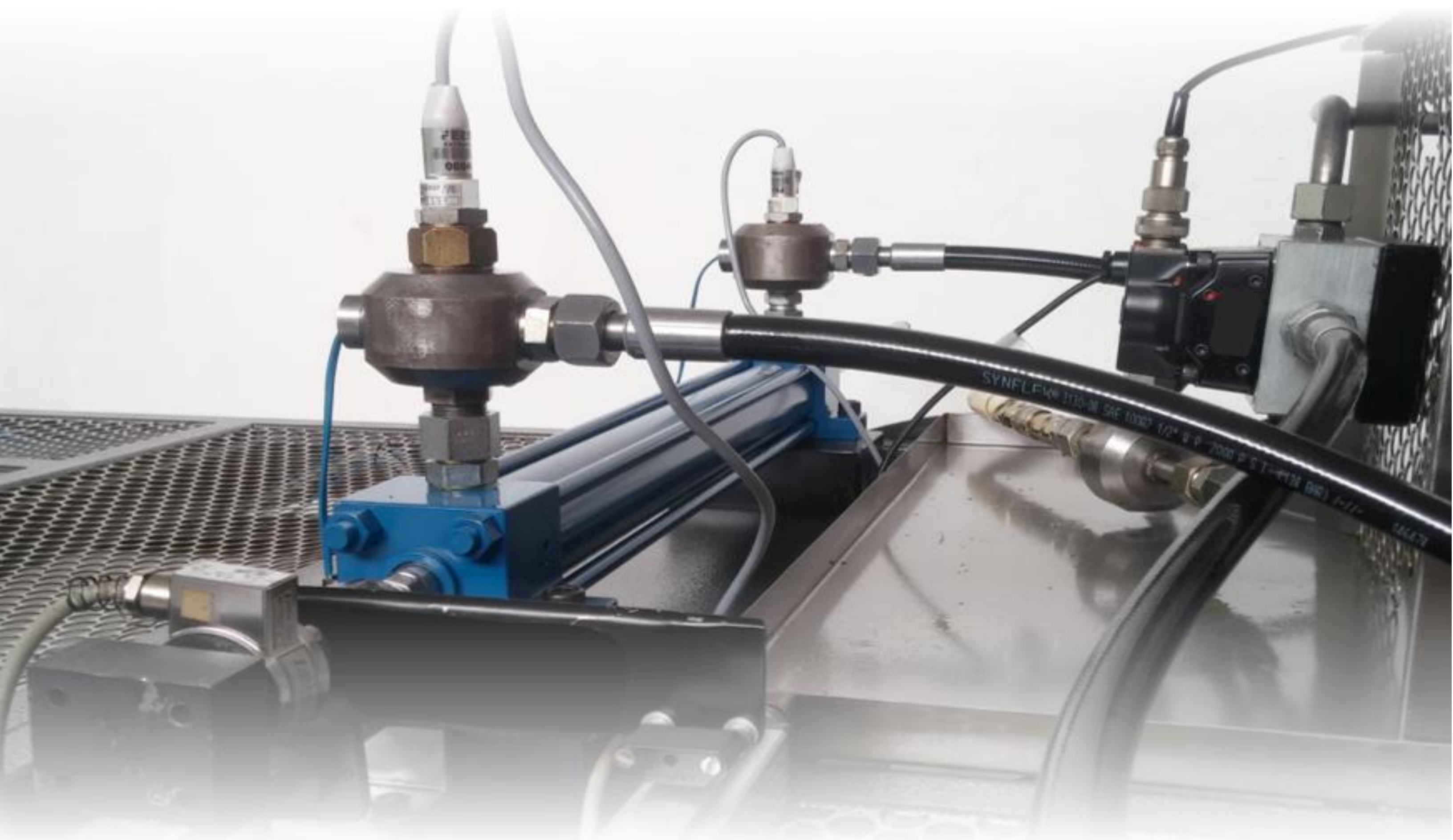
PROCEEDINGS OF

The 4th Workshop on Innovative Engineering for Fluid Power (WIEFP 2018)

28 – 30 November 2018

ABIMAQ, São Paulo, SP, Brazil



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Editors

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The 4th Workshop on Innovative Engineering for Fluid Power is a Swedish-Brazilian initiative started in 2012 focused on promoting the collaboration in the development of technologies, education, innovation management, methods and tools for hydraulic and pneumatic system development and design. The first two editions occurred in São Paulo, at the Brazilian Association of Machinery and Equipment (ABIMAQ) headquarters. The 3rd edition took place in Florianópolis along with the FPNI2016, at the Campus of the Federal University of Santa Catarina (UFSC), Brazil. In the 2018 edition, besides the presentations from invited speakers from industry and academia, the workshop selected extended abstracts submitted by industry engineers and master's and doctoral students.

The topics of the workshop are focused, but not limited to:

- Pneumatic & Hydraulic Systems
- Machine Automation & Control
- Hydraulic Systems & Applications
- Entrepreneurship
- Academia & Industry Collaboration
- Aircraft & Mobile Systems

PAPERS

PROPOSAL OF AN AUTONOMOUS SYSTEM FOR INSPECTION OF STRUCTURES

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ABSTRACT

Inspection of defects in civil infrastructure has been a constant field of research. The enlargement of a crack, along the time, can increase the deterioration of the structure, which can result in slight problems on the material's surface until, in the serious case, the rupture of the concrete structure. In the current operational paradigm, a technician is responsible to go physically to the field in order to measure cracks in the structures. However, in terms of efficiency, the manual inspection presents many problems, such as the low accuracy of measurements taken in the field and problems for accessing high-rises, narrows places, nuclear plants, among others. Hence, the current project developed at the Federal University of ABC aims to develop a fully autonomous system capable to automate the crack measurement detection and measurement process. The proposed system uses a set of robots capable to navigate and process data by itself, ground and aerial platforms, machine vision algorithms embedded into a processing device and a remote station in order to manage all the tasks to be done. In the current proposal, the ground platform adopted is the Turtlebot 2 ®, which uses an embedded computer to process the programs. The aerial platform to be adopted is an eight-engine drone - octocopter that will make use of the flight controller Pixhawk 2.1 ®. Both of them will be integrated and controlled from the network interconnection of several programs, such as mapping, navigation, and image processing programs. Thus, simulations will be performed by using the Gazebo ® program and the Robot Operating System ®, wherein the system will be exposed to the real situations to evaluate the system efficiency. As result, once the autonomous system detects cracks, the embedded vision system algorithm must be able to process the image and assess the type and the damage caused to the inspected structure.

Keywords: structure maintenance, crack inspection, control systems, robots and automation, autonomous system inspection.

INTRODUCTION

The increase in the demand of civil constructions for diverse purposes allowed the technological development in the area of structural engineering, making studies and development of tools of detection of anomalies, ampler. Among the possible anomalies in this area are the cracks, which are pathological evidence of damage to a structure. It can be of minor gravity as is the case of cracks, average (cracks), or of more critical degree with the deep and prominent opening, classified as cracks [1].

Because of their severity, cracks require immediate attention and to do so, they must be promptly detected and as efficiently as possible, since this type of damage directly affects the durability and structural safety of the building and can cause catastrophes, for example, the Minneapolis (USA) bridge collapse in 2007 and the collapse of the Savar building in Bangladesh 2013, noticing the importance of performing periodic inspection and maintenance.

For inspections to be performed with the highest level of reliability, the use of an autonomous robotic system and the development of embedded processing technologies enable such tasks to be performed without human interference. Thus, the purpose of this work is to briefly discuss the use of such systems, to propose their architecture in a completely autonomous way for inspection of structures (aerial platform, terrestrial platform and embedded vision system for detection and measurement of cracks) and validation of their technical feasibility by performing simulations. Such systems will be integrated through the Robot Operating System ®, whose function is to integrate such technologies for autonomous navigation and image processing.

SYSTEM ARCHITECTURE

Autonomous systems and inspection software integrate each other via ROS, which can be understood as a distributed system, where a certain number of nodes communicate through messages. Each node of the network can operate in the client/server mode, which allows direct interaction between the nodes, or by publishing/signing messages, which allows the use of sensors [2]. The use of the turtlebot for mapping and navigation based on the ROS is already widespread, which offers a lot of technical support, based on bibliography available on web, as an example of the proposed use of ROS in [3] where the autonomous robot was developed for navigation and the same deviates from persons and objects, according to their respective control algorithm, and navigation of structured and unstructured external environments [4]. Moreover, besides the aforementioned examples, a robotic system assistance has been proposed and deployed in [5] and an autonomous tunnel structural inspection and assessment has been evaluated in [6].

The terrestrial platform of the proposed system uses the TurtleBot 2 robot, where the ROS has been installed in a notebook with the Linux Operating System Ubuntu 16.04 LTS, simulated in Gazebo, that receives the signals coming from the camera (for the identification and measurement of the cracks) and of the use of sensors such as Microsoft Kinect, gyroscope, accelerometer, among others, for autonomous navigation. In the aerial platform, the ROS will exchange data with the Pixhawk flight controller, where the navigation route will be pre-established so the drone can perform the inspection and measurement of the structures that according to Anac's standard must be connected to a control with a pilot case the stand-alone system fails [3]. Both the terrestrial platform and the aerial platform are being developed and validated in the Gazebo simulation platform, and the navigation programs written in C ++ and Python. Fig. 1 shows schematically the proposed architecture.

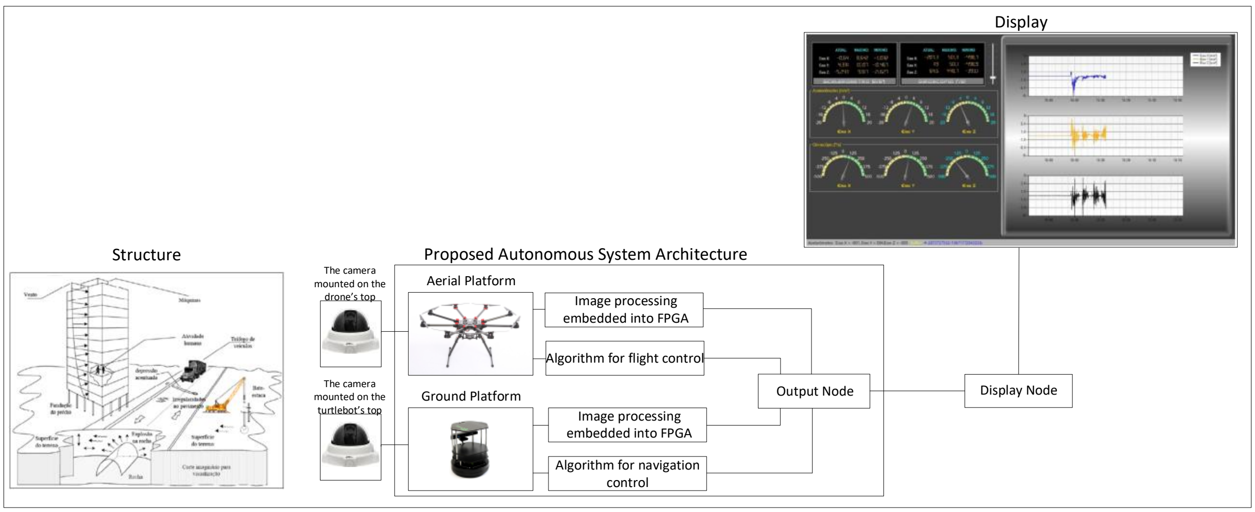
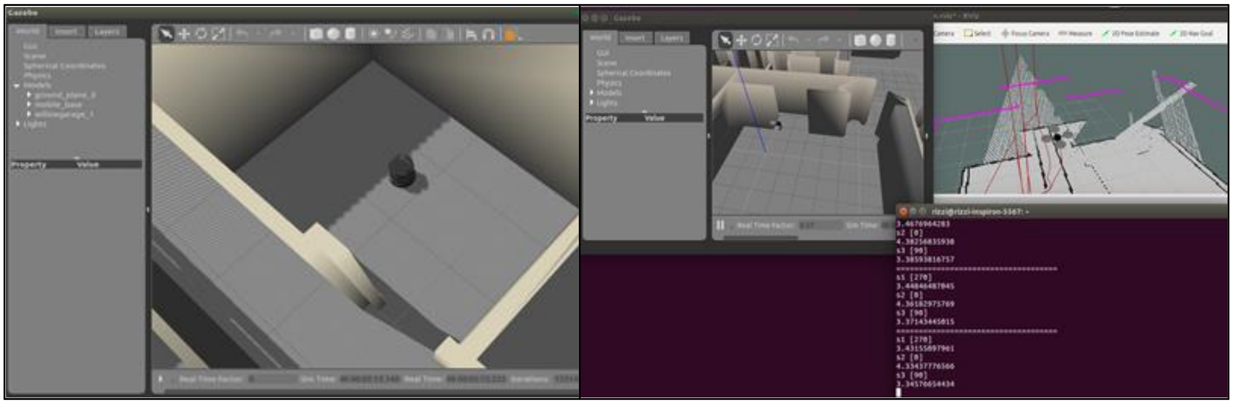


Figure 1 – Proposed Architecture of an autonomous system for inspection.

From the need to inspect a structure to be monitored, the turtlebot should be used to navigate the structure interior, such as corridors and rooms, as well as places where it can be accessed and the drone on the outside, where it is impossible to access the terrestrial platform, receiving information from their respective cameras, and both platforms will have their planning implemented by ROS. The turtlebot will have an algorithm for processing images embedded in a Field Programmable Gate Array (FPGA) board, and an algorithm of control and navigation embedded in its processing system. The drone follows the same principle of the terrestrial platform, that is, the processing of the images will be performed separately from the flight control system. The results of the image processing should be sent to the output display, as well as the flight data and trajectory data of the terrestrial platform.

PRELIMINARY TESTS FOR VALIDATION

In order to test and validate the proposed architecture, initially the platforms will be programmed and tested using a virtual environment whose the goal is to reproduce, as accurate as possible, the real environment to be inspected. Thus, the terrestrial platform is inserted into gazebo simulator, where the parameters for the simulation should be inserted and their descriptions are available in [7]. With the initial setup performed, the control algorithms are written in Python, the robot performs the autonomous navigation in the environment that simulates the floor of a building. Autonomous navigation is accomplished through the acquisition of the signals coming from the various sensors installed in the robot, such as laser scan, gyroscope, and accelerometer, among others. These signals are transformed into a point cloud, which allows the robot to identify objects, measure distance and deflect autonomously, when necessary. Fig. 2 (a) shows autonomous robot navigation through the environment.



(A) (B)

Figure 2 - Simulation of turtlebot navigating in a floor (a). Autonomous drone flight using ROS (b).

While Fig.3 illustrates the nodes and algorithms embedded in the robot's controller for ensuring the proper navigation in the internal environment.

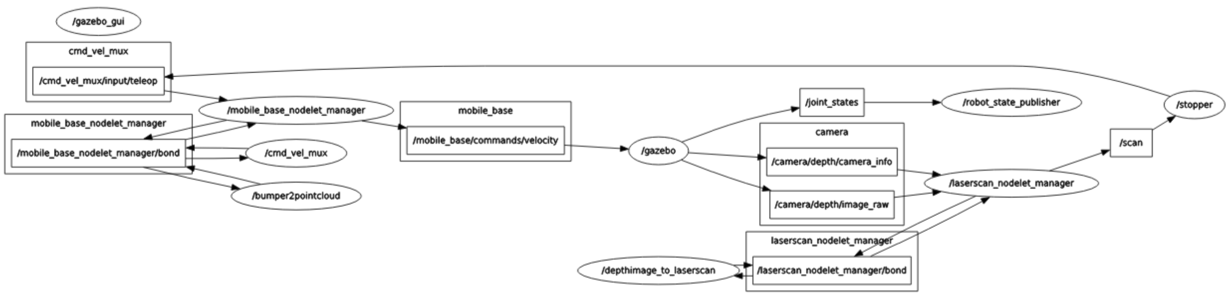


Figure 3 – ROS nodes that are currently running, as well as the ROS topics connections.

Likewise, for the ground platform, the drone has a set of sensors that allow it to fly autonomously. The hector quadrotor simulator has been used as simulator programming. First, a drone is positioned in an external environment for the initial simulations, whose the goal is to test the many functions of ROS, as well as to test the drone's mission planner. By initializing the mission, the drone starts the mission and its flight controller uses the sensors signals as inputs and updates the motors in order to accomplish the path previously established. Hence, the drone is able to navigate through the proposed environment while the camera mounted on its top takes pictures in a certain frequency. It must be noticed that the ground platform has a similar camera taking images in order to detect and measure possible cracks on surfaces. Fig. 2 (b) shows the drone flying autonomously as established previously on the mission planner.

Finally, the last element that composes the proposed architecture is the vision system for detection and measuring the cracks. According to the proposed methodology to do so, a sequence of images is processed by the crack detection algorithm in order to detect the cracks. The algorithm receives images as inputs and outputs a new image with red particles along the detected crack. The pixel positions of the particles are stored in a vector that is passed along to the crack measurement algorithm. With these pixel positions, the algorithm estimates the number of pixels in a cross section and outputs the crack dimension. It must be noticed that the aforementioned algorithm has been proposed and developed by the paper author and it is already published in [8], where accordingly to the deployed methodology, the crack detection algorithm processes a sequence of images, process all of them and outputs the pixel positions of each crack recognized. From these pixel positions, the algorithm estimates the number of pixels in each cross section and estimates the crack dimension. The statistical analysis demonstrates that the error is small on average permitting the accurate measurement of structures.

CONCLUSION

Failures in concrete structures occur at various levels of gravity and are caused by several factors. Because they are very common and due to their potential consequences, it is evident the need for new technologies that can perform inspections in the buildings in an autonomous way and in order to guarantee a result with greater fiduciary, these being the basis of a planning of interventions and maintenance. By using an embedded computer vision system performing autonomous inspection in such structures to detect cracks, both on a land platform and on an aerial platform, is an important technology to be developed that will have a positive impact on the area as it provides greater security to all who may make use of constructions such as bridges, buildings, or any structure which has concrete in its main component and is therefore subject to deterioration.

The tests and simulations already carried out demonstrate the understanding of the operating system that makes the interconnection of the proposed architecture and the first results about the development of the autonomous navigation indicate the current degree of autonomy of the drone and Turtlebot in the accomplishment of inspection missions.

ACKNOWLEDGEMENTS

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HYDRAULIC PRESSURE FED SYSTEM USING HELIUM GAS AND FAST ELECTRO-HYDRAULIC ACTUATOR APPLIED TO BRAZILIAN SOUNDING ROCKETS AND MICROSATELLITE LAUNCHERS

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ABSTRACT

This work presents the research and technological development of a hydraulic high Pressure Fed System (named PFS) using Nitrogen/Helium gas and a fast electro-hydraulic actuator (FEHA) applied to movable nozzles for Brazilian sounding rockets and microsatellite launchers. The preliminary control capability analysis to sounding rockets design requires a high performance FEHA, e. g. the bandwidth, to perform the attitude control using the Thrust Vector Control (TVC) strategy. The Thrust Vector Assembly (TVA) consist of the PFS mounted on the EHA that controls the nozzle angular movement, in closed-loop operation. Modeling and simulation results using AMEsim environment show the PFS performance compared to step-unit response obtained from experimental tests. Frequency Response Functions (FRF) are obtained from experimental data using sinusoidal signals of excitation with frequency from 1 to 10 Hz, and the bandwidth B_w is accessed. Equipment to the PFS includes a pressure regulator to the helium gas in order to pressurize the hydraulic fluid with a constant pressure of 200 bar. A high performance electro-valve controls the oil flow in the hydraulic cylinder and a real-time digital controller is implemented to stabilize the closed loop. The results are of very interest if compared to the European actuator flight model of the Brazilian satellite launcher vehicle VLS-1. Details and improvements are discussed in order to obtain best bandwidth in the next FEHA engineering model, e.g. the digital flow control technique to the servo-valve.

Keywords: pressure system, electro-hydraulic actuator, control system

INTRODUCTION

The VLM-1 is a Microsatellite Vehicle Launcher being developed at the Brazilian Institute of Aeronautics and Space (DCTA/IAE) presented in the Figure 1 and discussed in Ettl [1]. It is designed to launch small satellites (Mini-, Micro- and Nano-Satellites) with mass less than 150 kg, to equatorial and polar orbits. Its basic configuration consists of two stages with S50 propellant solid motors with about 10 tons of propellant and a S44 motor. The attitude of the vehicle during its flight is controlled by a Thrust Vector Assembly, shown in the Figure 1, maintaining the nominal attitude of reference, according to [2, 9]. The TVA system consists of a movable nozzle (angular displacement) controlled by a hydraulic actuator (linear displacement) in closed-loop operation (real time system) and must offer a minimum 3 Hz bandwidth for control capability requirements, discussed in [6, 7]. The hydraulic energy to the actuator is provided by a Pressure Fed System, shown in the Figure 3, and actually is considered an engineering model (Figure 4). The basic equipment to the PFS are: accumulators filled with Nitrogen/Helium gas, pressure regulator, solenoid valve 2 ways/2 ports, gas/liquid cylinder to provide a 210 bar of pressure to the hydraulic actuator (Figure 2, right), pressure and temperature sensors. Dynamic and static tests are performed using the actuator work bench shown in the Figure 4, in which a well-known mass-spring is attached to the hydraulic actuator, the PFS is fixed to the servovalve and a closed-loop is implemented for the actuator rod linear displacement. The hydraulic cylinder, named MAQDRAU, shown in the Figure 2 (right), was manufactured by Brazilian industries and assembled to a high dynamic servo-valve. Actually some improvements to the mechanical design are in course: mass optimization, compacted size, embedded LVDT linear sensor, stress and temperature analysis, steel/aluminum material definition, and digital control system.

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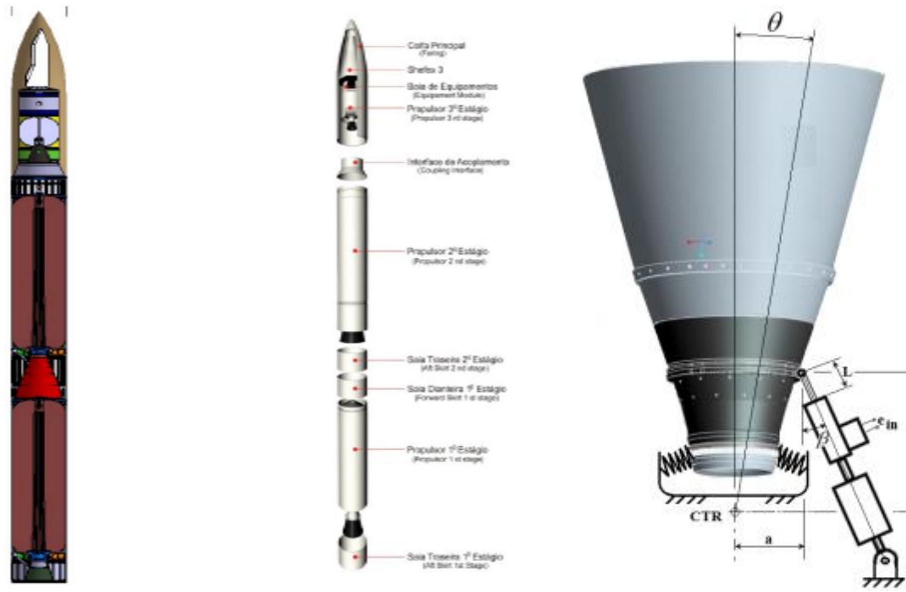

Figure 1, VLM-1 Basic configuration and the TVA system.

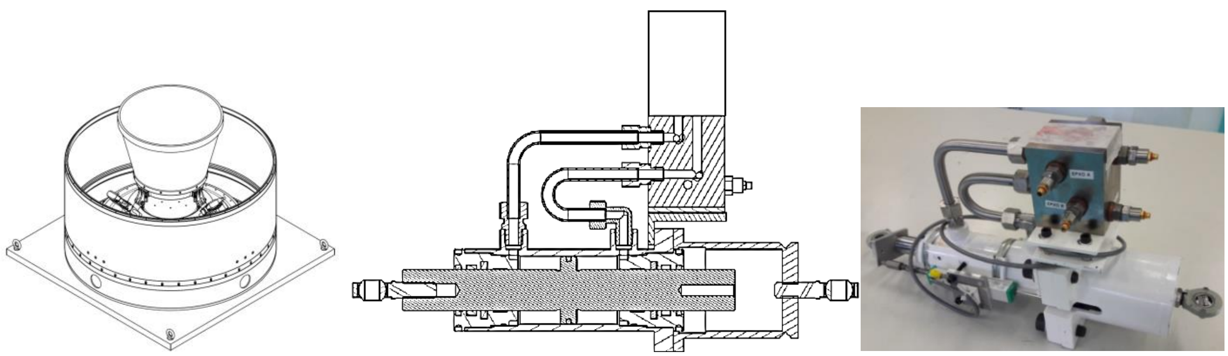

Figure 2: (left) TVA mechanical assembly, (center) MAQDRAU FEHA model and (right) MAQDRAU FEHA.

PFS/FEHA MODELING AND SIMULATION

The Figure 2 (right) presents the hydraulic actuator consisting of cylinder (steel), cube interface (steel), stainless steel pipes, an external linear LVDT sensor, two rod ends, 120/210 bar pressure performing 20 kN of static force. The four pressure sensors are used for tests and system identification. A BOSCH servo-valve is mounted over the mechanical interface to control the fluid flow through the cylinder. The closed-loop operation is implemented using the LVDT sensor and a real-time digital controller (*CompactRIO*). AMEsim can produce mathematical models using state space equations (Equation (1)) as well as Bond-Graph technique to the complete system PFS/FEHA.

$$\dot{x} = f(x,u) \tag{1}$$

The PFS and the hydraulic actuator, shown in the Figure 4, can be modeled [3, 4] using the well-known Bond-Graph approach [5] or using the software AMESim from Siemens. The AMEsim is a mechatronics system simulation platform, from LMS International society, based on Bond-Graphs that models and simulates all system/subsystems of the PFS and hydraulic actuator. Thanks to a numerical solver, its Graphical User Interface allows modelling and analysis of multi-domain systems in different levels, depicted in Figure 5: functional and physical modelling, block-diagrams and programming. The block diagram of the TVA is depicted in Figure 3.

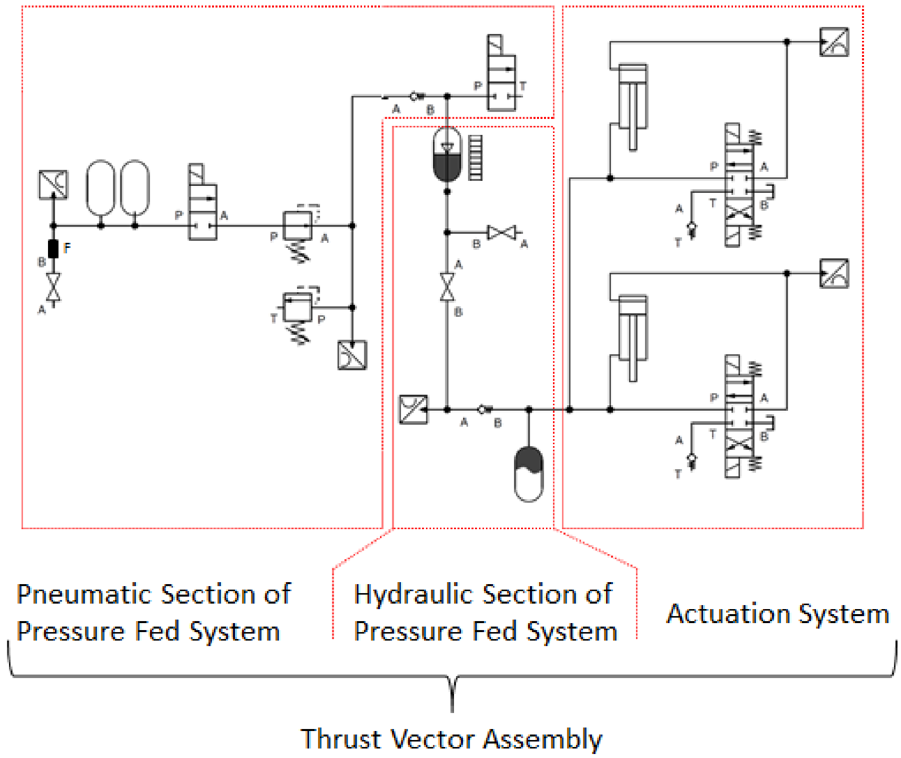

Figure 3: PFS/FEHA Hydraulic scheme.


Figure 4: IAE hydraulic test facilities.

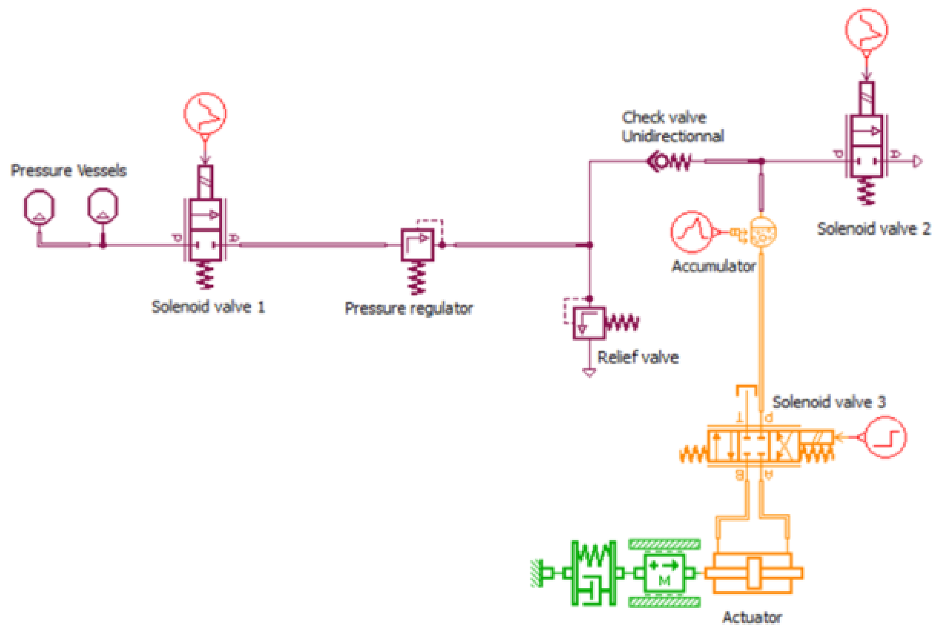

Figure 5 - Simplified Model of PFS/FEHA (AMESim environment).

The Figure 6 shows the PFS unit-step response using helium and nitrogen gas obtained from AMEsim simulation. For that, the gas parameters are presented in the Table 1.

Table 1 – Properties of Nitrogen and Helium

	Nitrogen	Helium
Symbol	N	He
Atomic number	7	2
Atomic mass	14.0067	4.0026
Boiling point	77 K	4 K
Triple point	63.153 K	-
Triple point	12.53 kPa	-
Critical point	126.19 K	5.19 K
Triple point	3.398 MPa	0.227 MPa
Heat of Vaporization	5.56 kJ/mol	0.0829 kJ/mol

As depicted in Figure 6, helium provides a shorter rise time (observed in the actuator piston displacement) than nitrogen. Indeed, helium pressure increases and decreases much faster than nitrogen pressure. The Figure 7 shows the step response obtained from the PFS and the MAQDRAU operation, using nitrogen gas.

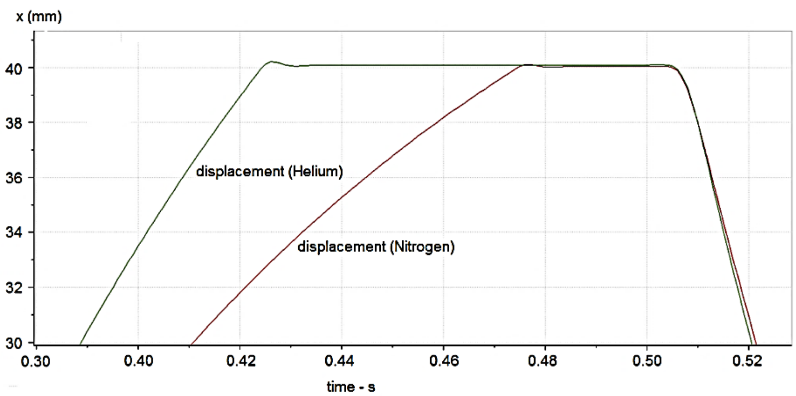

Figure 6: AMEsim simulation: input signal and response for gas helium and nitrogen.

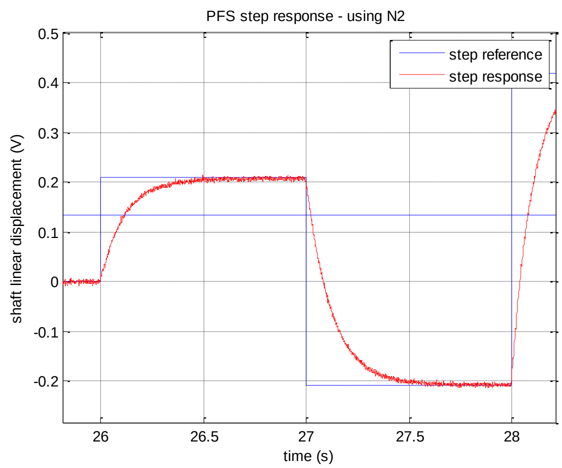

Figure 7 - PFS and hydraulic actuator step response using nitrogen.

A testbed can perform time and frequency domain test with and without a known load, consisting of a mass-spring-dumper in which its parameters are listed in the Table 2.

Table 2 – hydraulic actuator test bench parameters

Masses [kg]	Springs [kg/mm]	Pressure [bar]	Sensors
10.10	0.43	128	Displacement sensor
20.55	1.10	200	Oil temperature sensor
30.30	2.48	-	Oil temperature sensor
40.50	4.25	-	Load cell
-	6.03	-	Flow meter

Results from frequency test were performed to the FEHA and plotted in the Figure 8 as well as the frequency response function to the lower order equivalent system (LOES) from system identification. The LOES transfer function to the closed loop operation MAQDRAU actuator is

$$T(s) = \frac{18.8}{s + 18.8} \quad (2)$$

in which the bandwidth is $B_w = 3Hz$, pointed out in the Bode diagram shown in Figure 8 for -3dB gain and 45° phase.

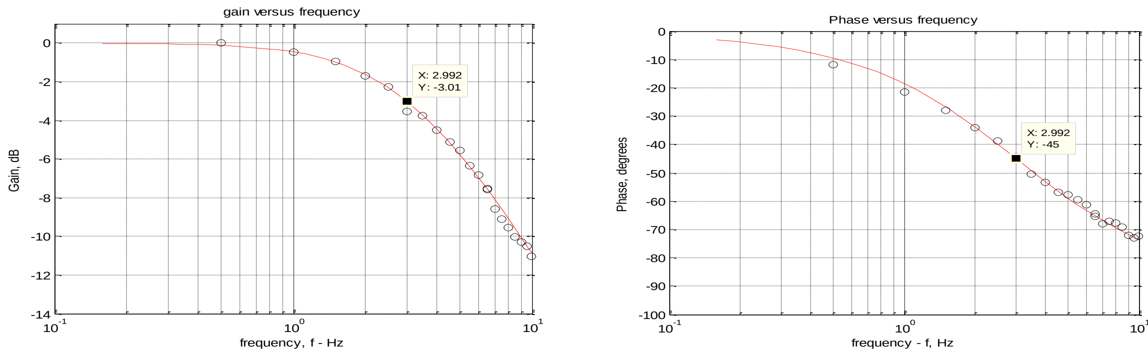

Figure 8 – MAQDRAU actuator Bode diagram (left) gain and (right) phase
circles = from experimental data; solid = from system identification.

CONCLUSION

This work presents a PFS and a hydraulic actuator that can be applied to Brazilian vehicles with TVA systems for attitude control, encouraged by the restrictive international acquisition of such equipment for rocket and launcher application. Engineering models were mounted at IAE's laboratory and are under testing for performance verification. Actually, some mechanical optimization is in course focusing the bandwidth improvement as well as mass and volume minimization. The choice of helium to the PFS leads on technological components and very expensive devices as well as the development of fast servovalves to space application.

Hydraulic actuators have nonlinear behavior according to the amplitude of excitation, and for small displacements we can obtain first and second order linear models. The main nonlinearities are presented as flow saturation, hydraulic flow equation and voltage-to-electromagnetic force conversion in the servo-valve.

The bandwidth is a very important parameter for rocket and launcher control design, just because it relates directly the vehicle control capability against external disturbances (wind and inter stage separation efforts, aerodynamics and mechanical inaccuracy). The actual engineering model to the PFS and hydraulic actuator MAQDRAU has presented good performance (Bw > 3.0 Hz, 140 mm/s rod linear velocity, 20 kN static force) and the improvements mentioned in this work, together with other kind of hydraulic control (digital servovalve), certainly will produce fast hydraulic actuators.

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POSITIONING SYSTEM OF A PNEUMATIC ACTUATOR DRIVEN BY PROPORTIONAL PRESSURE REGULATOR VALVES

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ABSTRACT

This paper presents a positioning system of a linear double acting pneumatic cylinder commanded by two proportional pressure regulator valves. The advantages presented by pneumatic systems make this technology reason for constant research in the scientific field. But the nonlinearities related to the use of compressed air and the involved frictions in the movement make the control complex. In many researches about this subject, the authors adopted proportional valves to control the air mass flow directed to the rear and front chambers of the pneumatic cylinder. In the present research, the proportional valves controlled the air pressure instead of air mass flow. The pneumatic cylinder was equipped with an internal linear resistive transducer and the proportional pressure regulator valves were set to work in double loop mode, monitoring and controlling the input and output signals of the process. Each valve was equipped with an onboard proportional integral (PI) controller which were tuned according to the second technique proposed by Ziegler-Nichols. To make possible the execution of simulations, mathematical models were developed taking into account the piston dynamics, the compressed air behavior inside the front and rear chambers, the static and dynamic frictions and the valves dynamics. To validate the mathematical model proposed, comparisons between the experimental data, collected from a prototype connected to the software Labview, and the computational simulations results, that were performed in the software Matlab / Simulink, were done. The results obtained from the experimental data returned a maximum position error of 4,48mm for positive steps inputs, which was considered satisfactory for industrial applications. The comparison between simulated and experimental responses shows that the mathematical model presents a satisfactory approximation from the real system, although the experimental results have a faster stabilization time than the simulation, the transient response and the errors were similar.

Keywords: positioning system, pneumatic actuator, proportional pressure regulators, PID control, pressure control.

INTRODUCTION

The use of pneumatic actuators presents some advantages when compared with other systems like hydraulic and electric, such as: economic operation; efficiency; durability; reliability; adaptability to hostile environments; safety for use near to flammable materials; are environmentally friendly; and have a low implementation cost [1]. However, there are nonlinearities that make difficult the position control of pneumatic actuators, such as: compressibility of the air; dead-zone; dynamic friction; and the nonlinear relation of the flow in the control holes [2]. Pneumatic systems have applications in different industries, for example: industrial automation; robotics; medical rehabilitation; automotive industries and mining plants.

Many studies about positioning systems using pneumatic actuators perform the proportional positioning through the control of the air mass flow driven to the actuator chambers, like presented in [1-3]. This type of operation limits the options of valves to the expensive proportional directional models. With the objective of cost reduction, some researches adopted cheaper on/off 2-way valves commanded by the Pulse Width Modulation (PWM) technique to the control of the air mass flow directed to the cylinder chambers. In this research, the positioning was made by the pressure control of the air directed to the front and rear chambers of the pneumatic cylinder. This configuration presents an alternative to the traditional proportional directional valves, allowing the designer to analyze the best cost x benefit to the project. The system was composed by two proportional pressure regulator valves that were set to work in double loop mode and each valve was equipped with one onboard PI controller. The PI tuning was done following the second technique proposed by Ziegler-Nichols.

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SYSTEM DESCRIPTION

The system was mainly composed by:

- 1 pneumatic cylinder, simple rod, double action (2” bore x 10” stroke) provided with an internal linear resistive transducer (linearity of ± 1% of full stroke and ± $2{,}54.10^{-5}$m mechanical repeatability). Model 20AM2-10A / Manufacturer Asco Numatics;
- 2 proportional pressure regulator valves. Model 609212611-A00 / Manufacturer Asco Numatics (Hysteresis <1% of the pressure range and Linearity / Repeatability <0,5% of the pressure range);
- 1 communication module with protocol Ethernet-IP. Model 240-181 / Manufacturer Asco Numatics;
- 2 pressure transmitters. Model 2088G2S22A1M5Q4 / Manufacturer Rosemount (Precision 0,075%);
- 1 power supply 24Vcc/5A. Model 2320908 / Manufacturer Phoenix Contact;
- 1 process controller. Model 199.20166 / Manufacturer Contemp;
- 1 process indicator. Model 199.20469 / Manufacturer Contemp;
- 1 signal splitter 4-20mA. Model 857-423 / Manufacturer Wago;
- 1 data acquisition (DAQ) board. Model USB 6008 / Manufacturer National Instruments.

In this system, the valves control the air pressure inside both front and rear chambers of the cylinder. The pressure transmitters monitor these pressures and send the data to the DAQ. The setpoint is in the form 4-20mA and can comes from the process controller (local setpoint) or from the communication module with industrial protocol (remote setpoint), the selection is made by the change-over switch. The same setpoint signal is sent to the both valves, but the valve responsible to control the pressure in rear chamber receives the signal in the form 0 to 100%, while the other valve receives in the form 100 to 0%, balancing the pressures and positioning the cylinder rod in the desired position. The feedback signal comes from the linear resistive transducer located inside the cylinder rod and it is distributed to the valves, process indicator and DAQ. The process indicator, in addition to the function of showing the current cylinder position, is also responsible to supply the transducer inside the cylinder rod with 10Vcc. The Figure 1 presents the prototype developed for tests.

Figure 1 – Prototype

The Figure 2 presents a schematic diagram of the system.

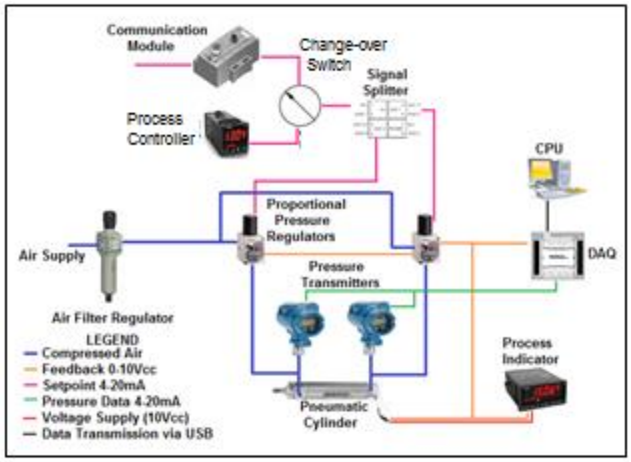

Figure 2 – Schematic Diagram of the System

A simplified block diagram of the system is showed in Figure 3.

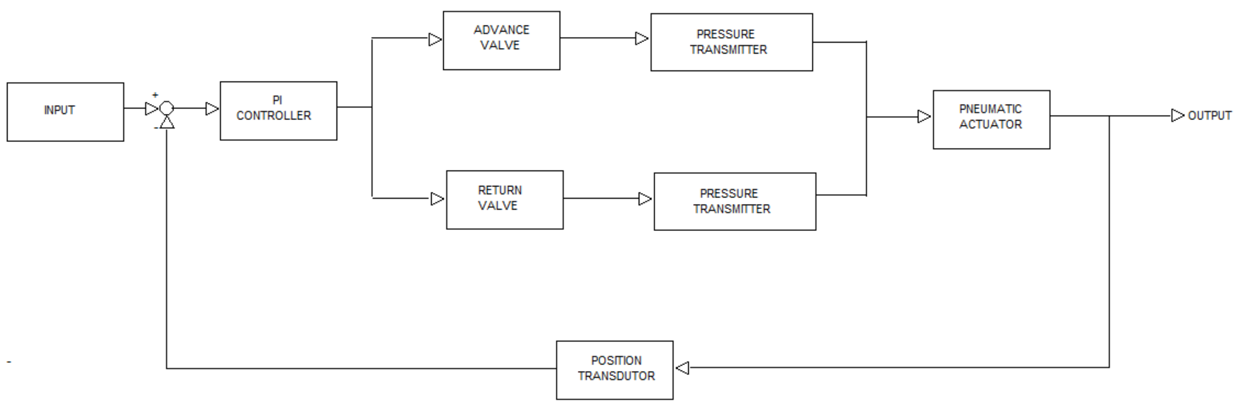

Figure 3 – Simplified block diagram of the system

In addition to the pressure transmitters installed in the pneumatic cylinder ports to allow the data collection, each valve has an internal pressure transmitter that allows the double loop configuration. This means that the valves have an internal pressure transmitter that sends the output pressure signal to the controller. Also, the PI Controller in the block diagram showed in the Figure 3 is an onboard controller located inside the proportional valves. The both controllers were tuned with the same parameters, so the block diagram is simplified with only one PI Controller to enable better understanding.

MATHEMATICAL MODELLING

The mathematical model of the system can be divided in two parts: Equation of Motion and Pressure Dynamics. The Equation of Motion describes the balance of forces, considering the friction compensation, and the Pressure Dynamics takes into account the air volume and the internal pressure variation, besides to present the relation between the front and rear chambers of the pneumatic cylinder.

The Equation of Motion and the Pressure Dynamics were defined based in the model suggested by [4]. Once the author adopted in his research a symmetrical cylinder, it was necessary to bring the model to the reality of the present research, where was adopted a non-symmetrical simple rod actuator that has different piston areas in the rear and front chambers. The Equation of Motion adopted in the present research is showed in Equation 1.

$$\ddot{x} = \frac{1}{m}(A_A.P_A - A_B.P_B - F_f - \beta\dot{x}) \tag{1}$$

Where $\ddot{x}$ is the piston acceleration, $\dot{x}$ is the piston velocity, $\boldsymbol{m}$ is the load and piston mass ($\boldsymbol{m = m_p + m_L}$), $\boldsymbol{A_A}$ and $\boldsymbol{A_B}$ are the piston area in the rear and front chambers respectively, $\boldsymbol{P_A}$ and $\boldsymbol{P_B}$ are the pressure inside the rear and front chambers respectively, $\boldsymbol{F_f}$ is the friction force and $\boldsymbol{\beta}$ is the viscous friction coefficient.

The Pressure Dynamics for the rear and front chambers are presented in the Equations 2 and 3.

$$\dot{P}_A = \frac{P_0 . K_v}{V_t/_2} . \frac{U}{U_n} - \frac{P_A . A_A}{V_t/_2} . \dot{x} \tag{2}$$

$$\dot{P}_B = -\frac{P_0 . K_v}{V_t/_2} . \frac{U}{U_n} + \frac{P_B . A_B}{V_t/_2} . \dot{x} \tag{3}$$

Where $\boldsymbol{P_0}$ is the ambient pressure, $\boldsymbol{K_v}$ is the valve flow coefficient, $\boldsymbol{V_t}$ is the total air volume, $\boldsymbol{U}$ is the current position signal and $\boldsymbol{U_n}$ is the maximum position signal.

The friction compensation adopted was based in the model suggested by [3] and takes into account the viscous friction coefficient β and the Static-Coulomb friction force F_f, where F_f is defined by:

$$F_f = \begin{cases} F_{sf}\ sign(Fp) & if\ \dot{x} = 0 \\ F_{df}\ sign(\dot{x}) & if\ \dot{x} \neq 0 \end{cases} \tag{4}$$

Where $\boldsymbol{Fp}$ is the pneumatic force ($\boldsymbol{Fp = A_A . P_A - A_B . P_B}$), $\boldsymbol{F_{sf}}$ is the static friction force, $\boldsymbol{F_{df}}$ is the Coulomb friction force and $\boldsymbol{sign}\ (\dot{x})$ is given by:

$$\text{sign}(\dot{x}) = \begin{cases} -1 & if\ \dot{x} \leq -1 \\ 0 & if\ \dot{x} = 0 \\ 1 & if\ \dot{x} \geq 1 \end{cases} \tag{5}$$

The Figure 4 presents a schematic representation of the system.

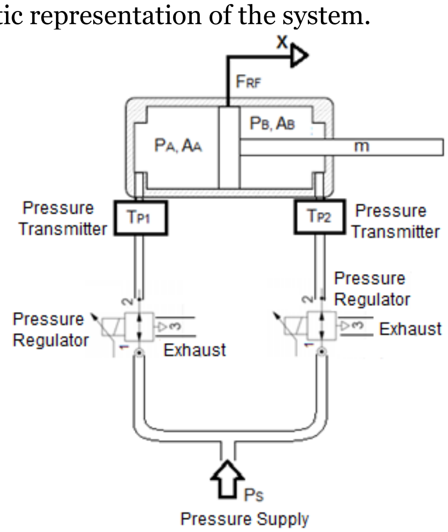

Figure 4 – Schematic Representation of the System

The Table 1 shows the real values adopted for the parameters.

Table 1 – Parameters of the cylinder

Parameter		Value
Effective piston area (advance)	A_A	18.67 × 10⁻⁴ [m²]
Effective piston area (return)	A_B	16.8 × 10⁻⁴ [m²]
Total air volume	V_t	4.47 x 10⁻⁴ [m³]

Viscous friction coefficient	β	4.47 [N/(m/s)]
Absolut ambient pressure	P_0	1 x 10^5 [Pa]
Valve flow coefficient	K_v	3.33 x 10^{-4} [m^3/s]
Mass of the assembly piston + rod	m	0.49 [Kg]
Dynamic friction force	F_{df}	0.49 [N]
Static friction force	F_{sf}	3.82 [N]
Pressure supply	P_s	6 x 10^5 [Pa]

RESULTS

The PI tuning was done following the second technique presented by Ziegler-Nichols, where a proportional gain is raised until the system reaches periodic oscillations, then it is possible to measure the critic period and apply the results in the equations. The PI parameters were defined as K_p = 6,3 and T_i = 1,325. The results comparison showed that, despite the simulated curve was not identical to the experimental result, the model has given a satisfactory approximation to the real response. Although the real system presented a stabilization time of 4,5s and the simulation presented a stabilization time of 16s, the transient response and errors were similar. The maximum error obtained in the permanent regime of the experimental result was 4,48mm for positive steps inputs and 3,61mm for negative steps inputs.

The comparison between the experimental and simulated results with a positive step input is showed in the Figure 5.

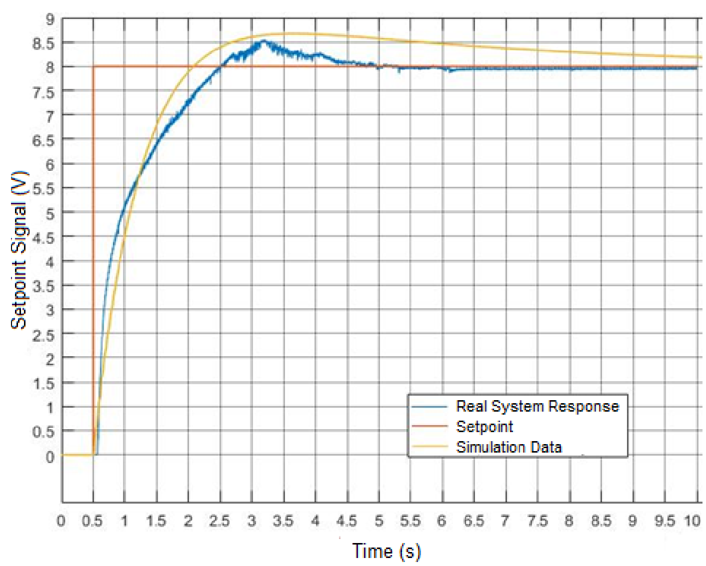

Figure 5 – Results comparison for a positive step input

CONCLUSION

The results analysis permits to conclude that the proposed model gives a satisfactory approximation to the real results and allows the realization of studies with different applications and parameters. The experimental results were considered satisfactory for the use of the system in industrial applications.

Other results and analysis, besides more information regarding the mathematical model development and computational simulation are described in [5].

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SIVOR: A TESTBED FOR THE EVALUATION OF ON-OFF VALVES ON AN F16 AIRPLANE – VIABILITY ANALYSIS

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ABSTRACT

In this paper, the viability for the utilization of the SIVOR (Simulador de Voo Robótico – Robotic Flight Simulator) as a testbed for the evaluation of the dynamics changes caused by the replacement of conventional servovalves by on-off valves on an F16 airplane will be analyzed. The current version of the SIVOR consists of an industrial robotic arm that carries a cabin which contains a seat, a curved 55-inches TV, a joystick, a throttle stick, pedals and a black cover to avoid external interferences from the peripheral vision, which can break the immersion of the simulation. The replacement of conventional servovalves by on-off valves has been considered in order to increase the energy efficiency of the airplane hydraulic actuators. However, on-off valves might cause undesirable effects on the flight dynamics. Therefore, this replacement must be adequately evaluated through simulations before being tested on an actual airplane. In order to conclude if the SIVOR is a viable solution for this analysis or not, the necessary workspace for the simulation to be representative will be defined. This study will consist of a comparison between the linear accelerations and angular velocities sensed by a pilot inside the airplane and inside the SIVOR cabin, which are estimated through vestibular system models. The SIVOR will be considered viable if it is able to provide a workspace that generates a small enough motion sensation error between the F16 airplane and the simulator cabin.

Keywords: Robotics, Aircraft actuation systems, Efficiency, On/off valves, Hydraulic systems.

INTRODUCTION

The replacement of conventional servovalves by on-off valves has been considered in several applications. For instance, the actuators of airplane control surfaces. The main reason is the lack of energetic efficiency of the servovalves [1]. Over the past few years, several studies have investigated increasing the efficiency of hydraulic systems. One approach with particular potential is the use of digital hydraulics. Although many ideas regarding digital hydraulics were presented decades ago, such research has only achieved significant development in recent years [2]. The main advantages of digital hydraulics include not only higher efficiency, but also redundancy, robustness, among others [3]-[6].

However, the effects that such replacement would have on the controllability of an airplane have not yet been investigated. In order to maximize the safety of such investigation, the analysis of the viability for the utilization of the SIVOR platform [7] is proposed in this study.

The present work is organized as follows. A description of the SIVOR platform is presented in the following section. An overview of the algorithm that converts the dynamics of the F16 airplane to the dynamics of the robot will be detailed in the "Washout Filter" section. The vestibular models used to estimate the pilot's sensations in the airplane and in the SIVOR platform will be introduced in the "Vestibular Models" section. The comparison between the pilot's sensations in the airplane and in the SIVOR platform for both configurations of the F16 airplane (with servovalves and on-off valves) will be made in the "Results" section. Finally, the conclusions will be presented in the "Conclusions" section.

THE SIVOR PLATFORM

The current and the future versions of the SIVOR prototype are illustrated in Figure 1. The current version is composed of an industrial 6-DOF anthropomorphic robot with 500kg payload capacity and a single seat attached to it as its end-effector. Onboard, the pilot has the essential aircraft commands, such as sidestick, pedals, power lever, flaps selector, among others. The visual system consists of a single monitor. A blackout cover reduces external disturbances. The future version will consist of an industrial 6-DOF anthropomorphic robot with 1000kg payload capacity mounted over a 10m long linear axis (making it a 7-DOF robotic platform), a cabin with actual airplane-like dimensions and inceptors, as well as a screen that covers 180° horizontal and 40° vertical field of view of the pilots.

Figure 2 – Current version of the SIVOR platform (left), future version (right)

WASHOUT FILTER

The washout filter [8] is the algorithm that transforms the airplane dynamics into the robot dynamics, such that the pilot has similar motion sensations, in the simulator, when compared to those he/she has on the real airplane. It is organized in three channels that generate the desired Cartesian trajectory that the robot must track, as depicted in Figure 2.

The translational channel defines the translational movements of the end-effector. It receives as input the linear accelerations of the aircraft, measured at the estimated position of the pilot's head using a coordinate system attached to the aircraft CG, passes the high frequency components of its input signals and integrates them in order to estimate the robot position.

The tilt coordination channel passes the low frequency components of the linear accelerations and converts them to angular positions. The concept behind this channel is to use the projection of the gravity acceleration (G) to emulate a sustained linear acceleration.

Finally, the rotational channel processes the cockpit angular velocities. It converts the airplane angular velocities to end-effector angular velocities by passing the high frequency components of the airplane angular velocities and integrating them in order to obtain angular positions. The final desired orientation of the end-effector is obtained by the addition of these angular positions to the ones obtained through the tilt coordination channel.

VESTIBULAR MODELS

In an attempt to quantify and compare pilots' motion perceptions in the airplane and in the SIVOR platform, the vestibular models used in the present work are given as follows [9]:

$$H_{OTO} = \frac{0.4(13.2s + 1)}{(5.33s + 1)(0.66s + 1)}$$

for the otolith, which senses linear forces, and

$$H_{SSC} = \frac{456s^2}{(5.7s + 1)(80s + 1)}$$

for the semicircular canal, which senses angular velocities [10]. The inputs of these transfer functions will be the linear accelerations and angular velocities of the airplane, respectively, as well as the equivalent outputs of the washout filter (SIVOR platform desired trajectories), for comparison purposes. The output of the vestibular models to the airplane dynamics and to the SIVOR platform dynamics will be compared in order to define if the SIVOR platform is expected to provide a good enough motion realism to the pilots or not.

RESULTS

In the present work, the behavior of the F16 airplane to altitude commands was evaluated for both F16 hydraulics system configurations (using servovalves and on-off valves). The performed flights with the servovalves and the on-off valves are displayed in Figure 3.

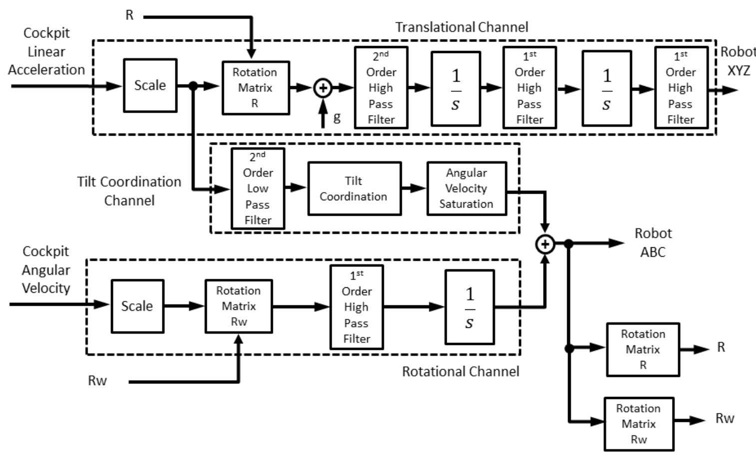

Figure 2 – Block diagram of the classical washout filter

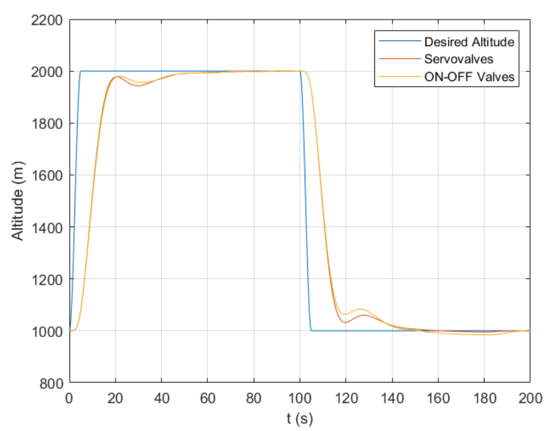

Figure 3 – F16 performed flight with servovalves and on-off valves

The analyzed washout outputs (which become the SIVOR inputs) were the translations in the Z axis (vertical) and the rotations around the B axis (equivalent to the pitch in the airplane). The Z axis' translation range goes from -1.5m to 1.5m and the B axis' rotation range goes from -40° to 40°. A comparison between the outputs of the vestibular system models to the same flight performed in the airplane and in the SIVOR platform, as well as the illustration of the SIVOR platform workspace usage in these flights are provided in Figures 4 (servovalves setup) and 5 (on-off valves setup).

It is possible to notice that in both cases the SIVOR platform can generate motion sensations that are similar to those the pilot would have in the real airplane, without reaching the limits of the robot's workspace. It is also possible to notice that the pilots are expected to feel the handling differences when performing the simulated flight with the airplanes having the servovalves setup and the on-off valves setup.

CONCLUSION

The main objective of the present work was to analyze the viability for the utilization of the SIVOR platform as a testbed for the evaluation of the F16 behavior changes when using on-off valves instead of the conventional servovalves. According to the presented results, it is possible to conclude that the SIVOR platform is expected to provide adequate motion perception for the pilots without reaching its workspace limits, therefore confirming that it has the potential for the proposed task.

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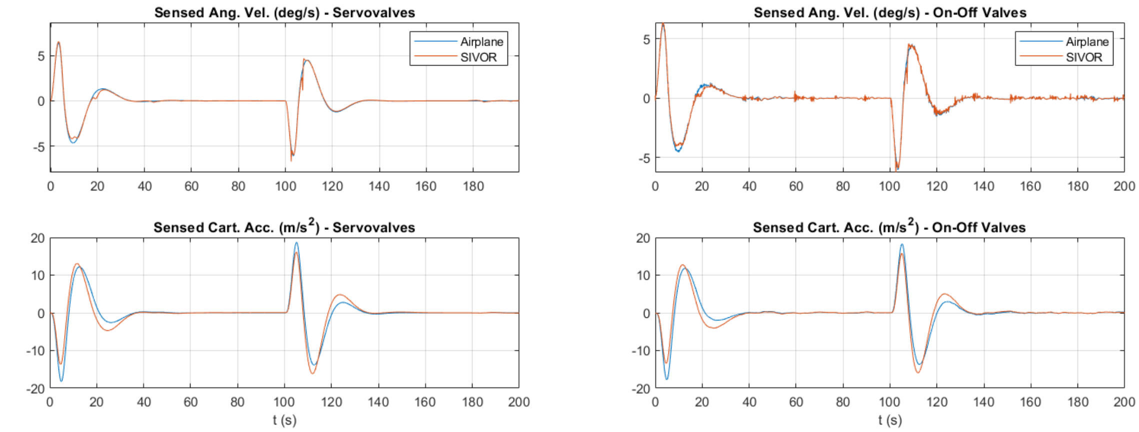

Figure 4 – Comparison between motion perceptions in the airplane and in the SIVOR platform

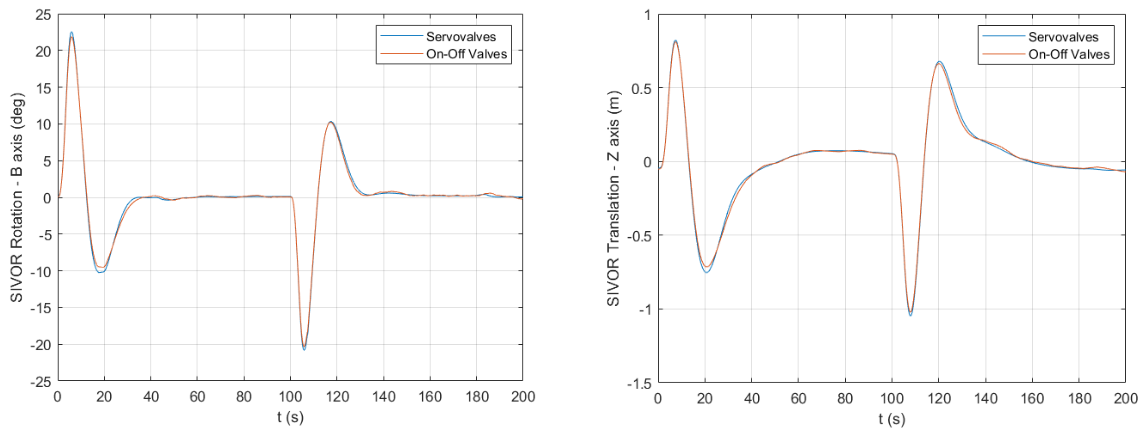

Figure 5 – Workspace usage of the SIVOR platform to simulate the proposed flight

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OVERVIEW OF THE DIGITAL HYDRAULIC ACTUATOR (DHA) CONCEPT FOR AIRCRAFT

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ABSTRACT

Research of new conceptions for aircraft actuators are gaining prominence, mainly due to the low energy efficiency of the current dominant systems in the sector. More Electrical Aircraft – MEA is a concept that has guided the realization of several researches on electro-mechanical (EMA) and electro-hydrostatic actuators (EHA). Airbus A380 and Boeing 787, for instance, present some innovations with origin in these researches. However, for safety reasons, the primary control surfaces are normally driven by conventional servo-hydraulic systems, which leaves this subject open to new researches. Presented this scenario, the Laboratory of Hydraulic and Pneumatic Systems – LASHIP, the Division of Fluid and Mechatronic Systems – FLUMES, and the Svenska Aeroplan AB – SAAB started the development of a new conception of flight surface actuation, applying digital fluid power strategies, thus appointing the Digital Hydraulic Actuator – DHA. In this scope, this abstract aims to present all the steps of the DHA development, furthermore, shows the research's status and future challenges to bring closer academic studies with the aero industry. The extended abstract was organized through a timeline with all publications about the DHA concept written by these research groups. Also, the existing research project is presented, where the goals are the solution of intrinsic problems of the digital hydraulic systems and the reliability analysis of this concept.

Keywords: Digital Hydraulic Actuator, Digital Hydraulics, Aircraft Actuator, Energy Efficiency

INTRODUCTION

The advent of research about new conceptions for flight control actuation systems is undeniable, for example, More Electrical Aircraft – MEA is a concept that has guided the realization of several researches on Electro-Mechanical (EMA) and Electro-Hydrostatic Actuators (EHA), cited by [1], flight control actuation experts from Airbus in the R3ASC in 2018, France. Still, according to by [1, 2], advantages of MEA includes weight and costs saving, aircraft manufacturing cost and lead time, overall reliability and availability of systems, maintainability, and environmental footprint. However, for safety reasons (jamming in fault), the primary control surfaces are driven by conventional servo-hydraulic systems [1], which leaves this subject open to new researches of aircraft actuator systems as safe as the conventional actuators, however highly efficiency.

The advantages and disadvantages of traditional hydraulic systems are widely known, among them, the great villain in aviation is the low energy efficiency, since reducing the power consumption, and thus the fuel burn, is a major target for the next generation of aircraft [3]. In this decade, researches about digital fluid power gained visibility in congresses and journals of fluid power [4], mainly because this technology offers several new ways to implement highly efficient hydraulic systems [5], in other words, solving the main disadvantage of traditional hydraulic systems.

Currently, research centers with greater emphasis on digital hydraulic are located in Tampere, Finland, whose laboratory's head is Matti Linjama, and in Linz, Austria, with Bern Winkler as laboratory's head. Analyzing their last publications, it is observed the interest in the digital switching valves [6] and fault studies on digital systems [7]. According to [4, 8], it is possible to highlight the research centers in the following countries: United Kingdom, Germany, Denmark, France, United State American, Russia, Bulgaria, and China, where there are digital fluid power researches.

Involved in this scenario of aviation and digital fluid power, the Laboratory of Hydraulic and Pneumatic Systems - LASHIP of the Federal University of Santa Catarina - UFSC from Brazil and the Division of Fluid and Mechatronic Systems - FLUMES of the Linköping University - LiU from Sweden, in a partnership with the company Svenska Aeroplan AB – SAAB from Sweden, started a research about the use of the digital hydraulic for primary flight control actuation system. This partnership produced the first publication in 2014, since then, two master theses, a doctoral thesis, and a development and research project were concluded, also an experimental test bench was built for proof of concept.

This extended abstract presents a timeline with all publication related to the research and development of the Digital Hydraulic Actuator (DHA). The timeline starts in 2014 [9] and includes the publications made until the present date. In the end, the current search state will also be presented. Thereby, the reader will know the DHA development process and the current and future challenges.

HISTORICAL

Figure 1 presents a timeline of the Digital Hydraulic Actuator (DHA) development publications. This timeline exposes all steps related to the DHA concept development and the experimental bench building, furthermore, the beginning of the current processes of this development.

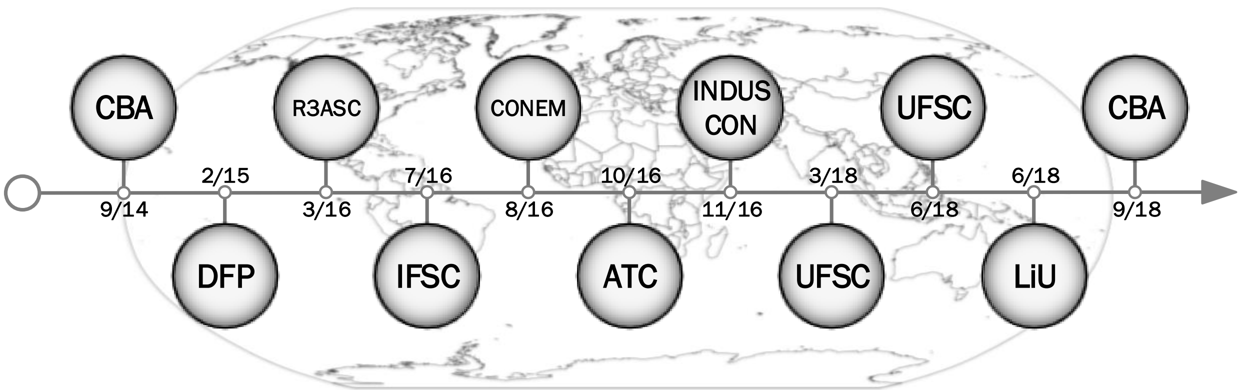

Figure 1 –Timeline of the Digital Hydraulic Actuator (DHA) development publication

The first publication [9] (CBA – 9/14) is considered the first one about digital fluid power published in Brazil. In this paper, new researches about the technology were discussed, as well as a classification of digital hydraulic systems, according to traditional hydraulic systems, are suggested, which are: Conditioning unit and reservoir, primary conversion unit, limitation and control unit and secondary conversion unity. The main results of this publication were the motivation of Brazilian researchers about digital hydraulics and the proposal of common technical terms in Portuguese [9].

In next year, with the paper [10] (DFP – 2/15), the first idea to use a digital secondary control for linear actuator to be used in aircraft is described. The proposed system is composed of three pressure lines, a valve-pack of 12 on/off valves and multichamber tandem cylinder. The valve-pack connects the three pressure lines with each cylinder's chamber generating 81 different forces, which is the result of the combination between pressures and areas, and it is made by a specific combination of on/off valves activation. This hydraulic circuit concept is used until today. The paper also presents the description of two Matlab® routines used to determine the multichamber piston's areas and pressures levels of the system. These routines are the main tools in designing this system for a given application.

The term Digital Hydraulic Actuator (DHA) is introduced in [11] (R3ASC – 3/16), where a more detailed version of the system proposed in [10] is presented. In this paper, safety components are added and the possibility of two different reservoir pressure levels are considered, which results in a more robust system and the possibility to obtain 256 discrete force values. New discussions are presented in the context, such as the reduction of heat production in the aircraft which leads to a further weight and energy saving, and system reliability which is expected to be higher due to the number of valve's redundancy. The applicability to aircraft is also pointed out, thus the redundant pressure sources and the pressurized reservoir can be used for the three pressure lines of the DHA. On the other side, few challenges are also addressed, for instance, the different dynamics of the on/off valves, which requires the development of a controller capable to identify dynamically the optimum time delay to be applied to the digital valves in order to improve the piston's movement and avoid dissipative actions.

The switching time of the on/off valves is analyzed with more details in [12] (IFSC – 7/16). This paper is a final term paper, therefore it was published in [13] (INDUSCON – 11/18), where the main objective is the development of an electronic device to accelerate the switching time of the valves. The strategy used to reduce the switching time of the digital valves is called Peak and Hold, it consists of applying a voltage peak for a short period of time, increasing the valve's acceleration and afterward reduce the voltage to lower value, which might be even lower than its nominal voltage. Several experiments were performed to analyze the valve's response to different peak times and peak voltages, where a saturation of the switching time was observed as a function of the peak time. The minimum switching time was obtained with the highest peak voltage (48 V) and a peak time of 3 ms, the hold voltage of 6 V, which is half of the nominal voltage, was capable to keep the valve open and also reduce the valve's temperature. With this configuration of Peak and Hold, the opening time was reduced from 14 ms to 4.7 ms, the closing time was reduced from 50 ms to 44 ms and the dissipated power was reduced from 14.4 W to 8.2 W.

The digital hydraulics test bench design and construction is described in [14] (CONEM – 8/16), where the main objective is the experimental validation of the Digital Hydraulic Actuator concept. The test bench uses a conventional power unit with just one pressure line, the other two pressure levels are obtained from a pressure control block, where two pressure reducing valves are used to reduce the high pressure from the power unit to the other two pressure levels. The system load is obtained by a set of five metal blocks, which weights 18.5 kg each one, and spring with an elastic constant of 27.56 kN/m, which results in a total force of 8.63 kN.

In the paper [15] (ATC – 10/16), the use of the digital hydraulic instead of the conventional circuits in aircraft application is discussed. The considered aspects were control design, safety, and energy issues. In the control context, the use of switched control theory and modern control approach, for instance $H\infty$, showing the feasibility of the approach is explored. Regarding safety aspects, redundancy is a common practice to increase reliability, thus it is pointed out that the redundancy is intrinsic in the digital hydraulic due the parallel valves. Finally, with respect to energy issues, numerical results showed that the digital hydraulic had a significant increase in energy efficiency, which can be as large as 80% compared to conventional circuits.

At this stage of the research the idealizer of the DHA's concept concluded his doctoral thesis [16] (UFSC – 3/18), this document makes a complete description of the previously mentioned steps, furthermore, the first experimental results of test bench are presented. The main objective of the doctoral thesis was to develop a control strategy, for the digital hydraulic system, capable to result in a good performance in terms of energy efficiency. Thus, the control structure was implemented using a feedback control, with PI control and an adaptative gain, and a simple feedforward control, compensating the spring force and friction force. With this control structure, an efficiency gains of 90% was reached in comparison with the traditional hydraulic systems used in aircraft.

Three months later two master theses were concluded, one in LASHIP [17] (UFSC – 6/18), and other in FLUMES [18] (LiU – 6/18). The first one had the main objective the comparison of conventional hydraulic systems with digital hydraulic systems regarding energy efficiency, considering the internal leakage of servo-valves. Results showed that in a common movement of the aileron, the DHA have a reduction of about 93% when compared with a servant-led hydraulic system with internal leak. The second master thesis was focused on safety analysis, it had two main objectives, which were the reliability analysis and the fault analysis of the DHA. The results include a method to calculate the reliability of the system and the fault analysis concluded that DHA is not fault tolerant by default but can be if designed correctly.

CURRENT OBJECTIVES

Currently, a project to bring together a new consortium was started, consisting of SAAB and LiU in Sweden, UFSC and CERTI in Brazil, to collaborate with further development of the DHA. Safety and redundancy will mainly be addressed and a diagnostic function will be developed to handle the requirements. It includes the study of sensor technology to be incorporated in the system and further development of the test rig to provide means to assess the performance. In parallel with this project, there is a master thesis in progress, which aims to improve the performance of the system and maintain energy efficiency, through an analysis of the switching between valves and its variables. The beginning of this research already produced a paper [19] (CBA – 9/18).

CONCLUSION

The system presented in this extended abstract is part of a research which started in 2014, the research has already proved some outstanding advantages of a digital hydraulic actuator over traditional hydraulic systems, but it also has some limitations. In the pursuit to solve the drawbacks of the proposed system, eight papers and three theses have been published in the last four years. The present abstract describes the steps taken during this research and outlined the most relevant difficulties and accomplishments, allowing the reader to have a complete overview of the Digital Hydraulic Actuator technology.

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ANALYSIS OF THE COOPERATION MODEL BETWEEN INDUSTRY, UNIVERSITY, RESEARCH CENTER AND GOVERNMENT FOR THE SCHEDULING OF TECHNOLOGIES

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ABSTRACT

Member of a globalized economy focused on innovation, the ABC region of São Paulo state represents an important pole of national economic development. With a strong industrial presence and a relevant role in the production of goods and services, the region has important research, development and innovation (R&DI) hubs, including universities and governmental / industrial support agencies. Although there are incentives for the development of new technologies in basic research, insufficient effort has been done to foster innovative research and development projects in the stage of scheduling (TRL4 +). Based on the concepts of the triple helix, this research had the objective of evaluating the cooperation models existing in 13 companies that worked in the development of new technologies and presented interruptions in the development of their R&DI projects. The selection of the participating companies was made by the adequacy to the theme, availability and adoption of development and innovation practices. The method was applied through the application of a semi-structured questionnaire, the use of interviews to deepen the data collected in the first phase, at the same time, interviews were made with regional development agencies, including economic development secretariats of the municipal government. An analysis of existing and in development innovation incentive programs and their possible adaptation to the studied research problem was carried out. The results of the present research point to the existence of the so-called death valley of scientific research (TRL4 +) in the region, pointing out as one of the main causes for this fact, the inherent costs of acquiring and maintaining a scientific research infrastructure in micro and small enterprises (MSE) analyzed. The research points to the need to review the existing models of cooperation and development of new technologies, positioning the sharing of R&DI infrastructures in phase TRL4+ as a possible solution to strengthen the regional and national economy and increase the efficiency of research conversion rates technologies for the market.

Keywords: infrastructure r&d; valley of death; technology readiness level (trl); triple hélix; innovation

INTRODUCTION

The concept of Valley of Death (stages of the method of evaluating the maturity level of a technology - Technology readiness level - TRL) is object of study in the field of knowledge and management of innovation. These steps refer to the need to raise resources for the development of prototypes for technology scaling, which represent a critical point for the development of products and services [1].

Brazil has been making efforts to foster innovation through the strengthening of research practices through the National Innovation System (SNI). Although there are some efforts made for the promotion of R&DI (Law of Innovation, Law of Good, Law of the National Fund for Scientific and Technological Development - FNDCT), further studies are necessary to understand the variables involved in abandoning research during the stages of new technology. And the difficulty to overcome this stage of the development of new products and services is even more relevant when it comes to micro and small enterprises (MSE).

According to the general law of micro and small enterprises (2006), MPE are legal entities that have annual revenues of less than or equal to R $ 3,600,000.00. Filion (1990) [2], defines micro and small companies as legal entities that depend mainly on a source of internal capital for their growth. Similarly, according to data from SEBRAE (2017) [3], based on its analysis report on the register of employees and the unemployed (CAGED), small and medium-sized Brazilian companies represent one of the most important national economic pillars through job creation and local economy.

Although it is a sector of great relevance in the national economy, the MSE market is prone to specific bottlenecks especially regarding the costs related to the acquisition of infrastructure for research and development of a new technology. Pavitt et al. (1987) [4] defines sectorial patterns of innovation, categorizing companies into groups according to the technological opportunities identified through Research, Development and Innovation (R&DI) projects and their particularities and limitations. In this context, SMEs are more dependent on sources of external capital for the development of their projects.

Schumpeter (1934) [5] defined innovation as a fundamental element for economic development with the capacity to substantially change relations between producers and consumers. The technological innovation, according to Neto and Longo (2001) [6], refers to how the market has absorbed this technology. Brown (1993) [7] defines innovation as "a new product, process or system that has the potential to create an entirely new market or change an existing market".

Through this innovation process, companies can constantly develop technologies and create processes to share and improve knowledge, techniques and production methods within the production chain. In addition to the transfer of knowledge, companies seek partnerships for the transfer of technologies in order to ensure that the development of this new product becomes possible, a step that Barbiere (1990) [8] calls technology transfer. According to Neto and Longo (2001) [6], "Trade, technology transfer and technological innovation are, by their own peculiarities, different stages of the same process, more comprehensive and complex, beginning with the basic / applied research phase and concluded when innovation is carried out (p.96)"

Technology usually goes through a non-linear innovation process flow that involves several stages, starting with basic or applied research, passing to a stage of technological development, and finally passing through a prototyping and system development stage. Thus, universities and institutions of Science and Technology - ICT have an extremely important role in generating knowledge for the development of a technology, especially in the initial stages of this flow.

The current problem with innovation and technology development is that some of the idealized researches are not capable of reaching its final stage, that is, its commercialization. Although part of this rate of abandonment of new research is related to technical unfeasibility, research abandoned due to lack of physical and financial resources represents a significant loss of knowledge and technologies improvement in the market.

Faced with this question, the present work aimed to identify the causes of abandonment of research projects during the stages of scheduling in the new product or service development. It investigated abandoned projects due to lack of resources and adequate infrastructure, as well as evaluated the role and relevance of the triple helix (University / ICTs, government and companies) as a tool to reduce this type of events.

The concept of Death Valley and its relation with the development of new technologies for an assessment of costs is important for new technologies. We looked at a possibility of infrastructure sharing as a way to reduce this kind of gap.

With a focus on the research and development field, especially regarding innovation in micro and small companies, the set of R&DI infrastructure opportunities for the scaling of new technologies in the context of the National Innovation System (SNI).

METHOD

We interviewed 13 chemical companies that worked on the development of new products in the region of the great ABC Paulista. The selection process of the individuals composing the sample was based on the following factors:

• Acting in the region of the great ABC in the state of São Paulo;
• Participate in the chemical segment;
• Investing efforts and resources in the development of new technologies;
• Previous participation in a consulting project to promote regional innovation.

For purposes of comparison and analysis of the results, the participating companies were divided into two groups: a) Group of companies with a tax frame-work such as micro or small enterprise (MSE), with a turnover of less than or equal to R $ 3,600,000.00 and up to 99 employees, and; b) Group of companies with a fiscal environment such as medium or large companies, including multinationals and corporations (S / A), with a turnover greater than or equal to R $ 3,600,000.01 and above 100 employees.

The initial data collection was performed through an electronic questionnaire with seventeen questions applied to Brazilian entrepreneurs, investigating the relevance of a R&DI infrastructure in the development of new technologies. After that, in a second stage of data collection, three relevant cases were chosen regarding the current model of cooperation between universities, research centers and government for the scheduling of new technologies.

The data resulting from the present research were statistically analyzed, composing a current scenario about the mortality in the development of new products in the companies analyzed and its relation with the possible absence of adequate research infrastructure for the development of technologies and innovation.

With the purpose of organization and rational analysis of the data, the questionnaire was divided into four axes of information, as described below:

• Axis 1 - Basic characteristics and delimitation of the public;
• Axis 2 - Offer of new products and innovation:
• Axis 3 - Knowledge and use of partnerships;

• Axis 4 - Infrastructure for technology development.

The first axis refers to the obtaining of basic characteristics, aiming the delimitation of the target public. Issues related to the area of activity of the company, fiscal framework and other profile delimiters were discussed.

The second axis refers to the offer of new products and innovation. Analyzing if investments were made in the development of technologies and new products for the market, including patent registration and innovative ambience.

The third axis is called knowledge and use of partnerships and analyzed the company's participation in government programs to foster innovation and obtain lines of credit for research.

The fourth axis analyzed aspects related to infrastructure for the development of technologies, addressing issues related to the purchase and costs of R&DI equipment and their impact of technology development.

This article will focus on research axes 3 and 4 of the scientific study carried out. The other axes will be approached in a timely manner.

MAIN RESULTS AND CONCLUSION

Analyzing the data, it was possible to notice that 23% of the companies had problems in the finalization of the R&DI projects initiated, of which the totality is composed of MSE.

After analyzing the existence of interruption in the development of new technologies by 23% of the companies surveyed, it was sought to address this reality more deeply identifying the causes for this abandonment of research. Among the answers obtained, the following variables were verified: a) lack of financial resources; b) lack of knowledge of the processes; c) lack of skilled labor; d) lack of research and development infrastructure; e) lack of theoretical knowledge; f) short deadlines; g) market change; h) location of part of the R&DI infrastructure outside the national territory (United States and Germany); i) need to maintain productivity.

The most mentioned items as an integral part of the difficulties in the development of new technologies were the lack of skilled labor with 36% of the answers, followed by a lack of R&DI infrastructure with 24% and lack of financial resources with 16% respectively.

An interesting fact to note is that although it is a determining factor in the development of a technology, the lack of financial resources is not the main difficulty addressed by the companies analyzed in this study. This demonstrates that more than cash on hand, the companies surveyed need skilled professionals and appropriate equipment for the development and scheduling of a new technology.

The identified scenario corroborates the hypothesis formulated that there are some gaps in the actual model of cooperation between the triple helix agents, as well as, the inherent costs of obtaining and maintaining a R&DI infrastructure is a relevant factor for the abandonment of researches of new technologies in the chemical sector of MSE analyzed in this study.

The results reinforce the idea that by sharing a R&DI infrastructure, MSE could benefit from greater efficiency in converting basic research into new technologies for the market, since this alternative directly addresses the three main bottlenecks raised by micro and small entrepreneurs.

With regard to the lack of skilled labor, through the sharing of infrastructure by institutions of science and technology and the government, MSE would have the support of technical specialists in each equipment. The project management itself is still in charge of the company, but the operationalization of the activities will count with the support and knowledge of a laboratory technician or researcher of a partner institution. Issues regarding patents, research secrecy and intellectual property should be well delimited and established for the success of this initiative.

Continuing the analysis of the factors relevant to the interruption of research projects, the second variable most mentioned by the entrepreneurs was the lack of research infrastructure itself, which demonstrates a lack in the appropriate infrastructure segment for the development of new technologies. Although there are some lines of government funding to obtain equipment, the risk associated with the development of innovative products may inhibit the completion of projects with disruptive innovations. By sharing research and development infrastructures, the science and technology institutions are part of the risk inherent in this process, being responsible for the cost of infrastructure and specialized technical capital for management and maintenance.

Considering the point of view of Science and Technology Institutions, in addition to the high costs of purchasing some equipment, R&DI laboratories face great challenges in terms of balance and financial sustainability. Expenses with the management of the laboratory environment, including costs with specialized technical labor consumables and equipment maintenance, represent a considerable share of its operating costs. By dissolving these costs in various development projects, these institutions can enjoy greater efficiency in managing the operations and their core business.

As for the third aspect relevant to the failure of the researches in the analyzed companies, it was verified that the lack of financial resources can directly impact on the abandonment of these researches, evidencing the necessity of an analysis of the role of the agents of the triple helix in this scenario. The government is involved through the creation of policies to foster innovation, the provision of credits and incentives for the development of new products and the strengthening of MSE; Likewise, institutions of science and technology, including universities, play an extremely important role in strengthening this market, not only through basic research and the supply of intellectual capital to the market, but also by promoting practices for optimizing available resources and processes. The sharing of research infrastructures by Science and Technology Institutions may in conjunction with government policies reduce the cost with: a) acquisitions of equipment; b) physical and structural adequacy; c) training and management of intellectual capital; d) preventive maintenance.

As a result of the present study it was verified a lack of incentive programs focusing on the phases related to the scheduling of a technology (4 to 7 - TRL). As well as a high rate of interruption of scientific research due to the cost of acquisition and maintenance of R&D equipment.

Existing government incentive programs have a priority focus on fostering basic research, leaving open the possibilities of studying new sharing models that result in a greater interaction between the triple helix agents and consequently greater efficiency in the conversion of basic research into new technologies for the market.

Although much has been done to foster research and development of technologies, the present study demonstrated that the current model of cooperation between triple helix agents has sought to keep up with the market changes that have occurred over the centuries. The university is no longer an external market agent with the sole purpose of generating theoretical knowledge. Leading universities have sought greater interaction with the market, developing knowledge and also technologies focused primarily on the development of basic research, anyway. Likewise, the government and research centers seek to adapt to this new economic reality with a focus on sustainable development and sharing economy. There is great market potential for the development of partnerships for the scheduling of technologies among triple-helix agents, which models require more studies.

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A PROPOSED FRAMEWORK TO IDENTIFY DIGITAL TRANSFORMATION MATURITY IN SMALL INDUSTRIES

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ABSTRACT

Over the last decade, the landscape for business has become more dynamic. There are several variables that contributes to it, mostly directly related to technological innovation. One of these phenomena is the digitalization, that enables information to be processed universally, in high speed and relatively low costs, while the cycle gets globalized reducing multiple barriers. Inside this process, companies start to interact with technologies using new platforms, that's when business begins its digital transformation, by implementing new digital technologies, which modifies the relationship with components of the entrepreneurial ecosystem, affecting internal scenarios and spheres of relations outside. Thus, it is relevant to understand how companies can embrace digital transformation as an opportunity to innovate, differentiate and growing. Therefore, in this paper we ask if there is a tool that could help innovation managers to evaluate the company's maturity regarding digital transformation? To answer this question, we have been proposed a framework that can identify in which part of the organizational structure innovations have been present. In addition, it can establish the achieved level of maturity. For that, the methodology applied began by developing a digitalization management framework, with seventeen questions concerning eight organizational dimensions and the adoption of technological innovations. The framework passed by an evaluation process and went available for collecting data of small enterprises through digital survey platform, sent by e-mail. The framework application permitted us to characterize 346 companies in São Paulo, from those 77 were industries, our focus on this paper. The results showed that not even one industry was characterized fully digitally transformed, most of all stayed in primary levels of maturity. It is possible to conclude that the framework can be applied in companies of diverse segments, size and locality. Its execution can be helpful for organizations themselves, serving as a basis for creating actions and plans that facilitate their evolution

Keywords: digital transformation, digitalization management framework, technology innovation management, organizational structure, digitalization

INTRODUCTION

There is a changing movement in business scenarios caused by internet, communication technologies, connectivity and other various devices that combine the most varied functions when applying those resources, pointing out that one of the variables of the success in this journey refers to the expertise in the application of digital technologies [1]. This new scenario impacts all parts of the company, which in turn must evaluate the procedural, structural and functional changes, also considering the business model adopted. Then, arrives a moment that is necessary to verify which are the digital technologies that become good alternatives for the business, and know the consequences for the organization [1].

Considering small companies, adapt to globalization involves a proper management to deal with structural, systemic, cultural and technological changes, so recognizing the opportunities inside this cycle is a competitive advantage for this public [2]. It is known that the number of entrepreneurs is increasing in Brazil, currently there are more than twelve million micro and small enterprises (MSE) with national registry of active legal person, according to the Brazilian Service of Support to Micro and Small Enterprises [4]. Micro and small companies are those that invoice annual gross revenue in the amount of 3.6 million reais or less and, in the Brazilian context, the participation of these entrepreneurs is significant, generating more than half of the formal jobs, representing 27% of gross domestic product (GDP) in 2011[5].

Because of this economic relevance, a question emerges, how small businesses can take advantage of the opportunity to innovate, differentiate and grow, managing the changes brought by digital transformation? Considering this, the present study seeks to evaluate the maturity of these companies in relation to the adoption of innovations resulted from digital transformation, as well as it is important to know which profile is more receptive to the consequent organizational changes. Therefore, the focus is on the identification of which part of the organizational structure of the MSEs the digitalization has been more present. For this, is presented theoretical fundaments, description of the process of creation and validation of the tool, main results, conclusion and future opportunities.

DIGITAL TRANSFORMATION IN MICRO AND SMALL BUSINESS

The digital transformation is a frequent phenomenon within the business, its incidence is a result of the high volume of changes brought by the high interaction of the agents of the value chain with new digital technologies. Thus, companies need to define which of these technological innovations will be inserted in their structure, to gain differentiation and growth. Hence, this challenge leads institutions to try to improve their processes, effectively and sustainably, promoting transformation of business model [6].

Considering the process of transformation, some aspects are impacting and concern institutions. There are some relevant features of the developments that become digitized, the first is the worry with the compatibility of the adoption of digital technologies with the processes and culture of the company, since the modifications can cause resistance and ends up damaging the transformation. A second point is the preoccupation for the security of the digital operation. Following, comes the identification of the relation of the size of the company with the adoption of new technologies, it is believed that large companies can find greater difficulties, because changing old systems can generate inconsistencies difficult to control [7].

In the case of industries, this phenomenon is evident, causes changes in the operations of the company. The production is modified due to digital transformation, and some benefits are recurrent in the management of the factory floor. It is evidenced that performance control is improved due to the automatic updating of information, processing and more integration of productive data. Prior to problem detection and documentation of solutions for knowledge management of the production system, among other advantages [8]. Accessibility to artificial intelligence has made it possible to assign technologies to the most diverse types of companies, so that the automation of processes ends up occurring gradually. Regarding automation, it is understood that among the activities performed by an employee, up to 45% can be automated, bringing countless benefits in process conversion, such as cost reduction, quality gain and productivity that are often not possible with the traditional workforce. However, there is the challenge of managing the companies that apply these technologies. It is up to the company to be able to use automation for operational activities, freeing employees to perform tasks that require more creativity and emotions, difficult features for replicate technology [9].

There are also other innovations present in the industry, which is explicit within Industry 4.0. Advance from the fourth industrial revolution, it covers the new technologies and the digitization in the main industrial components, that begin to have high levels of integration among each other, like the machinery that are connected and promote the exchange of information automatically. Control, maintenance, production planning and the high exchange of information among the value chain agents represent well the spheres that change in Industry 4.0 [10].

Creation and validation of the Management instrument for digital transformation

In this study, the data collection happened by applying a digital survey to a selected sample, which was based on eight dimensions: *strategy, leadership, products, operations, culture, people, governance and technology* [11]. Initially, 5 classification questions were created, plus 24 closed-ended multiple choice questions, using the Phrase Completion.

This scale presents a continuous score from 0 to 10, with the addition of complementary phrases to a statement, in case of "0" there is an association with the missing attribute, while "10" relates to the maximum intensity of its presence [12]. Thus, the present study created a process for the validation of the research instrument, which consisted of three main phases: initial validation and a restructuring, followed by a second evaluation and ending with evaluation and layout methods. The process of evaluating the questionnaires resulted in the exclusion of one question and the revision of other two questions, resulting in a final instrument, presenting the sample characterization questions and 17 questions, two in each of the eight organizational dimensions and one about the volume of innovations (22 questions).

The digitalization management framework created has passed by evaluation process already described and presented its final version registered in professional research software, SurveyMonkey, with a brief invite sent by e-mail. After this evaluation stage was finalized, the collection of data began, and the survey stood opened for one month. The total number of emails sent to companies in the Metropolitan Region of São Paulo was 13,288, of which a total of 346 companies completed answered all questions. Although in percentage the number of respondents is reduced (2.6%), the absolute value is relevant (346), even emphasized by the participation of different segments organizations, enriching the study.

Main results

After the general view of the scope of the research instrument, it is relevant to describe the characteristics of the respondents, through the analysis of demographic variables. The attributes collected were type of company, number of employees, average annual gross revenue, time of operation and business segments. The sample used for this study holds a complete business scenario considering this classification level (trade, industry and services). Another important aspect of this sample is the volume of companies in each defined type, it is considered that there is an expressive volume of resentatives of each type of company. The commerce was represented by 152 respondents (44%), service by 177 (34 %) and industry by 77 (22%), however, the focus on this study is industry. In relation to the volume of respondents according to the number of employees and the revenue obtained, is possible to see that a big part of the sample size is composed by micro and small enterprises, 96%. With this, another demographic variable analyzed is the average time of existence of the organizations. Among survey respondents, 4% indicated they had less than two years of service, 32% between 3 and 9 years, while 64% had already surpassed 10 years of existence.

Through the methodology developed, the results achieved enables identification of the maturity degree in digitalization of the companies analyzed. Figure 1 shows that none of the industries evaluated was classified as transformed, and it was realized that micro and small organizations studied were in primary stages of digital transformation. That because, 19.5% indicated that the actions for the digitization of the business are in the Unconscious stage, while 39% indicated the Conceptual phase. Among the companies that already have defined activities to guarantee digital transformation, there were 29.9% of the industries, but only 11.7% already have an integration between strategy, leadership, products, operations, culture and people management, governance and new technologies, which were aligned with the digital strategy.

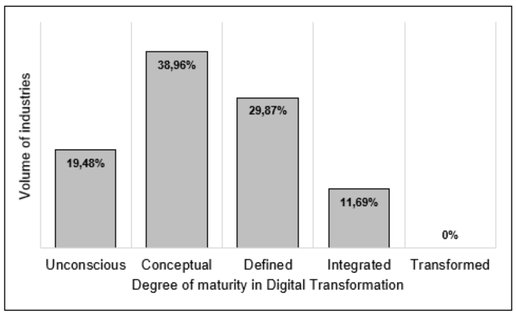

Figure 3 – Degree of Digital Transformation maturity

In addition, it was possible to know more about the management profile considering the digital transformation of the industries studied. For this purpose, it was selected the organizational aspects of the dimensions studied, those that the managers affirmed to be present in their organizations. The worst performance among the organizational dimensions evaluated (from 0 to 3 on the scale) was *products*, p*eople management, governance and technology*. While in the remaining dimensions, the performance was in the average zone, presenting intensity between 4 and 7 at the Phrase Completion scale.

The company profile that showed to be more opened to digital transformation in case of industries is related to the strategy, 55% of the participants showed that there is a strategy plan, documented and communicated formally to digitalization, and that it caused partially changes the business model (60%). Also informed that the leadership promotes the culture of changes (68%), and the responsibility of implementing the digital strategy is led by the owner of the company (65%). Another indicated benefit stated was the influence of digitization on the speed of decision making is significant, facilitating the decision-making process (56%) and the permanent transformation of the corporate culture is significant, there are stimulus of changes and innovations (57%).

In relation to the modifications of the products, it was alerted that by digitalizing the company's range of products, no new market segments were created (48%). About the resources applied, affirmed that the resources (personnel, money) available to implement the digital strategy are significant (49%). Besides all these aspects, there is the information about the volume of innovations performed to guarantee that the full digital transformation process is going to occur,45% of the companies participating indicated that one to two innovations was performed, while 25% said that it was between three and four innovation, but only 8% expressed to accomplish five or more innovations.

CONCLUSION

Considering the complexity situations the business faces to understand the digital technologies available in the market, to present the necessary resources to implement some of them, the difficulties to select which one might be, besides the necessity to present a leadership that performs a good change management to apply the digital strategy created, is possible to understand that the digital transformation of an enterprise it is a challenge.

The micro and small Brazilian industries studied showed that they started the process of digitalization, but they are in the moment of developing strategies to make the necessary adjustments in the organizational structure, so by the end they accomplish this goal. Also, was observed that the most defying dimensions for them were related to the changes in their range of products, commercial model and digital value chain. As also, about appliance of technology at the process, such as software, cloud infrastructure and all the other possibilities inside the industry 4.0 concept. Besides, industries apparently struggled to manage the company's tasks and capacities, to allocate human resources in those actions needed to innovate. At last, there was also difficulties with the governance dimension, through the appliance of a communication plan and control of initiatives on going, as well as the performance assessment.

So, our study provides research contributions, by presenting a framework to classify business in degrees of maturity concerning digitization, enabling the characterization and comparison of a group of companies, of any region, size, type of activity or segment of actuation. Additionally, presents practice contributions, once allows companies to understand how they are performing the process for digital transformation. And works as a guidance for future necessary actions to achieve digital transformation. Future opportunities for the development of this study, would be related to the appliance of the methodology in companies of bigger structures, to understand if the needs look the same. Would be interest to collect data from bigger number of business, so it is possible to have more company classified as transformed, so the profile and good practices of those enterprises could be benchmarked.

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AIRCRAFT BRAKING DYNAMICS AND BRAKE SYSTEM MODELING FOR FAULT DETECTION AND ISOLATION

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ABSTRACT

Due to the increasing complexity of aeronautical systems, it became more and more important to detect accurately failures that may occur, avoiding costs with maintenance and time out of operation. With the aid of modeling techniques and computational software, it became possible to analyze systems behaviors under normal and failures conditions, helping to prevent these problems. In this work, an aircraft anti-skid brake system is considered as a study case. Therefore, the aircraft dynamics and the main elements of the hydraulic brake system, such as servo valve, hydraulic line and brake actuator, are modeled and simulated using the software Simulink®. The integration of the hydraulic brake system model with the aircraft braking dynamics is made, being possible to simulate the aircraft anti-skid control system. In the hydraulic brake system model, some common faults are introduced in order to observe its impacts on the aircraft braking performance. A fault detection and isolation (FDI) method based on analytical redundancy relations (ARRs) is proposed. The ARRs are equations relating the system constraints, receiving as inputs the system behavior model parameters, sources and measurements (sensors readings as sources). The numerical evaluation of these equations generates the residuals. The residual value indicates the systems deviation level from its normal operation. The coupling of the Simulink® system behavior model with the ARRs is presented, permitting the residual analyses for each failure mode introduced in the hydraulic brake system model.

Keywords: Aircraft anti-skid brake system, Fault detection and isolation, ARRs, Hydraulic Brake System, Physical Modeling

MODELING METHOD

To perform the system modeling, the physical modeling was used. This methodology is a simplified representation of a system through idealized elements with the intention of representing the dynamics phenomena of real systems. These elements simulate supply sources, as well as the storage, dissipation and transformation of the system energy. Based on this concept, it is possible to represent the system in a unified way, taking into account only the elements energy interactions. Thus, in this work, electrical equivalents were used to perform mathematical modeling, representing the entire system.

Aircraft and wheel dynamics modeling

The main part of the aircraft kinetics energy is dissipated by the brake system during braking time. The brake force is generated from the brake system actuators. The Figure 1 shows the forces acting on the aircraft and wheels during braking time, its electrical equivalent and the state equations extracted from it.

Servo Valve, hydraulic line and brake actuator modeling

The Figure 2 a) shows the servo valve schematic and 2 b), its corresponding electrical equivalent circuit. This valve controls the brake pressure. Analyzing the circuit shown at Figure 2 b), it is possible to extract the state equations that describes the hydraulic brake system dynamics. The Figure 3 relates all the states and parameters used for the modeling.

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Anti-skid brake system

The anti-skid system model is based on the differential equations that describe the wheel and aircraft dynamics. The Figure 4 illustrates the anti-skid system control loop diagram. A PI controller modulates the voltage acting on the servo valve, modulating the pressure that drives the brakes in order to maintain the slip ratio at an optimum position, ensuring a maximum efficiency at the brake moment. To perform the simulations, a Simulink model was created. With the model it was possible to simulate the aircraft braking performance for several conditions and it was noticed a great loss in the braking performance with the faults introduction in the servo valve.

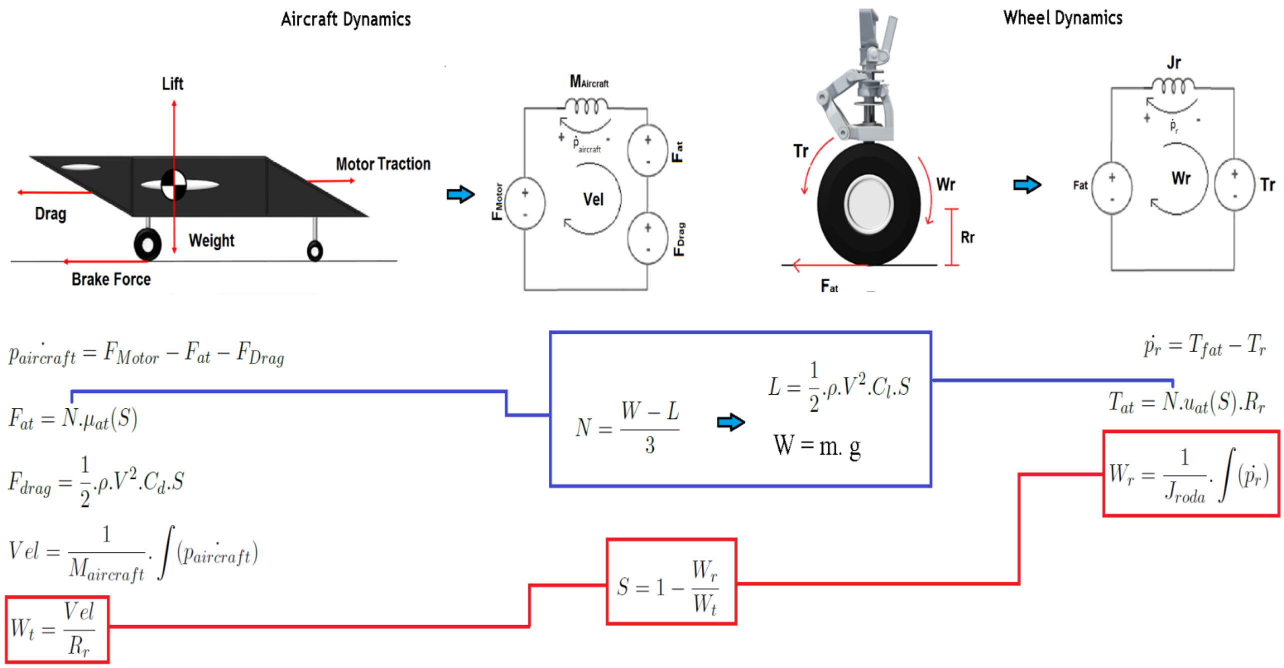


Figure 4 – Aircraft and wheels free body diagram during braking time, the corresponding electrical equivalent and state equations

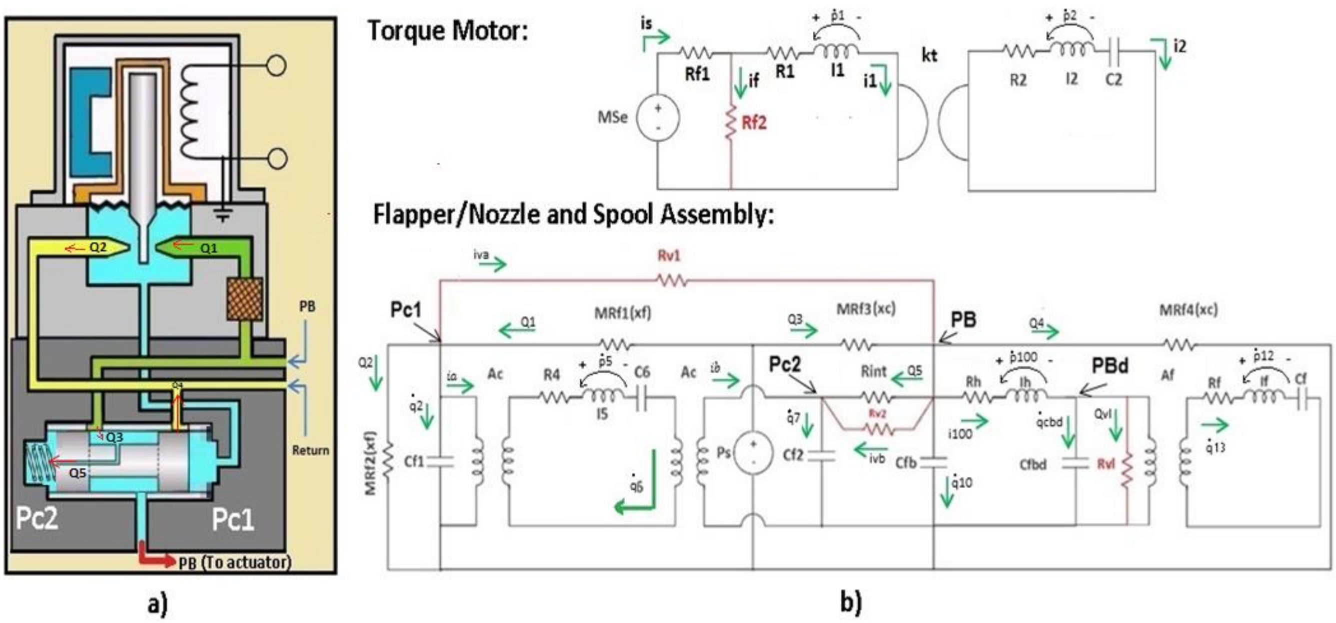


Figure 2 – a) Servo-valve schematic. b) Servo-valve, hydraulic line and brake actuator electrical equivalent

$$\dot{p}_1 = \frac{M_{SE} - R_{f1}.\frac{p_1}{I_1} - (\frac{R_{f1}}{R_{f2}}+1).(R_1.\frac{p_1}{I_1} + \frac{p_2}{I_2}.K_t)}{(\frac{R_{f1}}{R_{f2}}+1)}$$

$$\dot{q}_7 = Q_5 + i_b + i_{vb} \quad \begin{cases} Q_5 = \frac{PB-Pc2}{Rint} \\ i_b = Ac.\frac{p_5}{I5} \\ i_{vb} = \frac{PB-Pc2}{Rv2} \end{cases}$$

$$\dot{p}_2 = V_2 - R_2.\frac{p_2}{I_2} - \frac{q_{C2}}{C_2}$$

$$\dot{q}_{C2} = \frac{p_2}{I_2}$$

$$\dot{q}_2 = Q_1 - Q_2 - i_{va} - i_b \quad \begin{cases} Q_1 = C_d.\pi.dn.xf.\sqrt{\frac{2}{\rho}.(P_s - P_{c1})} \\ Q_2 = C_d.\pi.dn.(L-xf).\sqrt{\frac{2}{\rho}.(P_{c1})} \\ i_{va} = \frac{P_{c1}-P_B}{Rv1} \\ i_a = Ac.\frac{p_5}{I5} \end{cases}$$

$$\dot{q}_{10} = Q_3 - Q_4 - Q_5 - i_{vb} + i_{va} - i_{100} \quad \begin{cases} Q_3 = C_d.w.xc.\sqrt{\frac{2}{\rho}.(P_s - PB_{bd})} \\ Q_4 = C_d.w.xc.\sqrt{\frac{2}{\rho}.(PB_{bd})} \\ Q_5 = \frac{PB-Pc2}{Rint} \\ i_{vb} = \frac{PB-Pc2}{Rv2} \\ i_{va} = \frac{P_{c1}-P_B}{Rv1} \\ i_{100} = \frac{p_{100}}{I_{100}} \end{cases}$$

$$\dot{p}_5 = V_1 - V_{R4} - V_{C6} - V_2 \quad \begin{cases} V_1 = Ac.P_{c1} \\ V_{R4} = \frac{p_5}{I5}.R4 \\ V_{C6} = \frac{q_6}{C6} \\ V_2 = Ac.\frac{q_7}{C7} \end{cases}$$

$$\dot{p}_{12} = V_f - V_{Rf} - V_{Cf} \quad \begin{cases} V_f = Ac.PBd \\ V_{Rf} = Rf.\frac{p_{12}}{I_{12}} \\ V_{Cf} = \frac{q_{13}}{Cf} \end{cases}$$

$$\dot{q}_{cbd} = i_{100} - Q_{vl} - i_e \quad \begin{cases} i_{100} = Ac.if \\ Q_{vl} = C_d.Avl.\sqrt{\frac{2}{\rho}.(PB_d)} \\ i_e = Af.\frac{p_{12}}{Cf} \end{cases}$$

$$\dot{q}_{13} = \frac{p_{12}}{I_f}$$

$$\dot{q}_6 = \frac{p_5}{I_5}$$

$$\dot{p}_{100} = V_{Cfb} - V_{Rh} - V_{Cfbd} \quad \begin{cases} V_{Cfb} = PB \\ V_{Rh} = Rh.\frac{p_{100}}{I100} \\ V_{Cfbd} = PBd \end{cases}$$

Af = Brake actuator area
Avl = Hydraulic line leakage
Cd = Discharge coefficient
xc = Spool position
Ac = Spool walll area
w = Spool nozzle width
xf = Flapper position
dn = Flapper nozzle diameter
L = Distance between nozzles in the flapper

Flow rate pressure nozzle: $Q_1 = C_d.\pi.dn.xf.\sqrt{\frac{2}{\rho}.(P_s - P_{c1})}$

Flow rate return nozzle: $Q_2 = C_d.\pi.dn.(L-xf).\sqrt{\frac{2}{\rho}.(P_{c1})}$

Flow rate pressure spool nozzle: $Q_3 = C_d.w.xc.\sqrt{\frac{2}{\rho}.(P_s - PB_{bl})}$

Flow rate return spool nozzle: $Q_4 = C_d.w.xc.\sqrt{\frac{2}{\rho}.(PB_{bl})}$

Flapper volume: $C_{f1} = \frac{V_{flapper}}{\beta}$

Fluid resistance between internal and left spool side: $R_{int} = \frac{128.\mu.L_{int}}{\pi.D_{int}^4}$

Spool left side volume: $C_{f2} = \frac{V_{feedback}}{\beta}$

Fluid inertance hydraulic line: $I_h = \frac{L_h.\rho}{A_h}$

Spool viscosity: $R_4 = b_{spool}$

Fluid resistance hydraulic line: $R_h = \frac{128.\mu.L_h}{\pi.D_h^4}$

Spool mass: $I_5 = M_{spool}$

Spool wall leakage right/left side: $R_{v1} = R_{v2} = \frac{128.\mu.Ls_h}{\pi.Dvs_h^4}$

Spool rigidity: $C_6 = \frac{1}{K_{spool}}$

Internal spool and hydraulic line volume: $C_{fb} = \frac{V_{bl}}{\rho}$

Hydraulic line leakage flow rate: $Q_{vl} = C_d.Dvl.\sqrt{\frac{2}{\rho}.(PB)}$

Brake actuator volume: $C_{fbd} = \frac{V_{brake}}{\rho}$

Brake pressure: $P_B = \frac{q_{10}}{C_{fb}}$

Pressure left spool side: $P_{c2} = \frac{q_7}{C_{f2}}$

Pressure right spool side: $P_{c1} = \frac{q_2}{C_{f1}}$

Brake pressure before brake line: $P_{Bd} = \frac{q_{cbd}}{C_{cbd}}$

Figure 3 – State equations derived from the electrical equivalent in the Figure 2 b) and parameters used for the hydraulic brake system modeling also shown in the Figure 2 b)

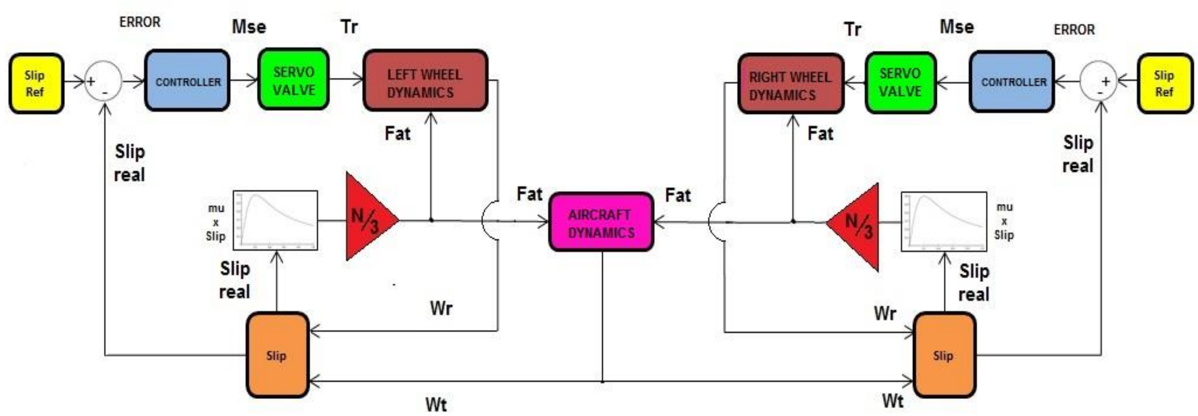
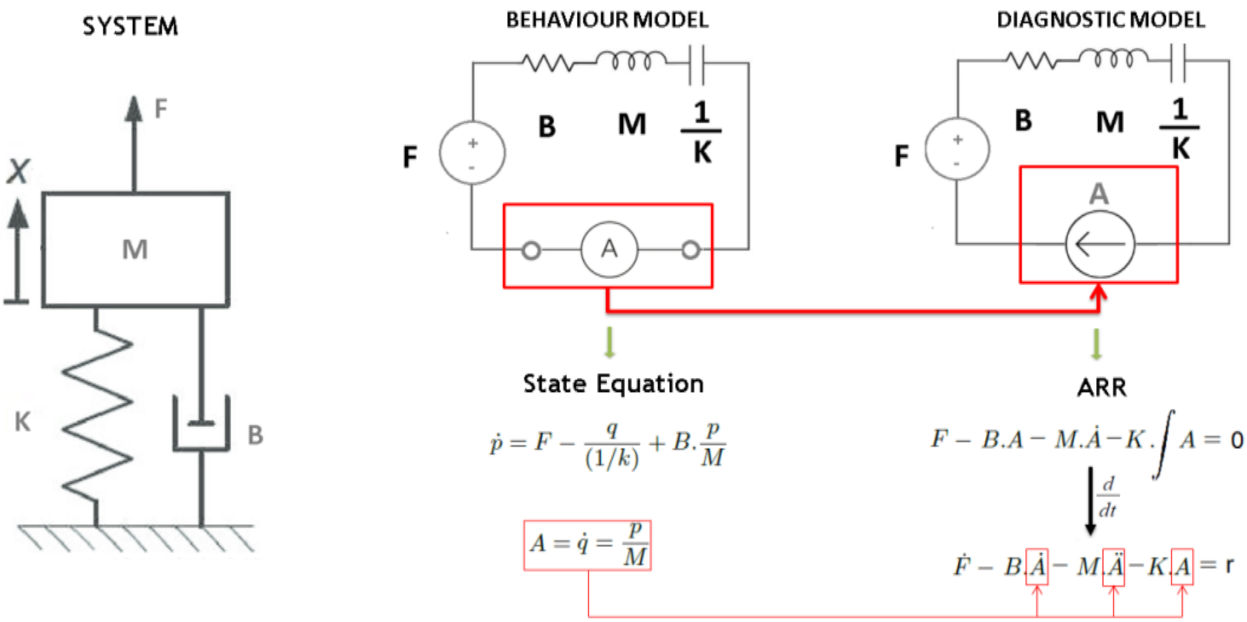


Figure 4 – Anti-skid system control loop diagram

FAULT DETECTION AND ISOLATION METHOD

The first step is to create a behavior model where the state equations describing the dynamic behavior of a given system, can be derived. In this model, some sensors are introduced in order to monitor the states. The second step is to create a diagnostic model. In this model, instead of measuring the states, it will receive from the behavior model the sensor measurement as a source. This way, the equations describing the system dynamics (the system constraints) will be written in terms of the real system sources, original parameters and sensor measurements. Thus, these equations will have a redundancy, creating a real test from the actual system. The Figure 5 shows a mass, damper and spring system, its electrical equivalent behavior model with a flow sensor (mass velocity sensor) and the diagnostic model with the sensor measured source. From the behavior model, the state equation describing the system dynamics is extracted. From the diagnostic model, the ARR equation is extracted. The numerical evaluation of the ARR equation is the residual value. If the sensor measurement comes from the original system, without faults, the residual value (r) must be zero. However, if the sensor measurement comes from the same system, but with some parameter differing from its original value due to some fault, the residual value will differs from zero, indicating the fault. The FDI method was applied, using the servo-valve model. The Figure 6 shows the behavior model with the sensor placement, the diagnostic model and the ARRs extracted from it. With this sensor placement configuration, it is possible to extract the ARRs. Thus, from each measured source, there will be an ARR. The Simulink model linking the behavior model and the diagnostic model, generating the states and the residuals was developed. The simulations were made introducing some failure modes in the behavior system, making it possible to observe the residual response.



$$\dot{p} = F - \frac{q}{(1/k)} + B.\frac{p}{M}$$

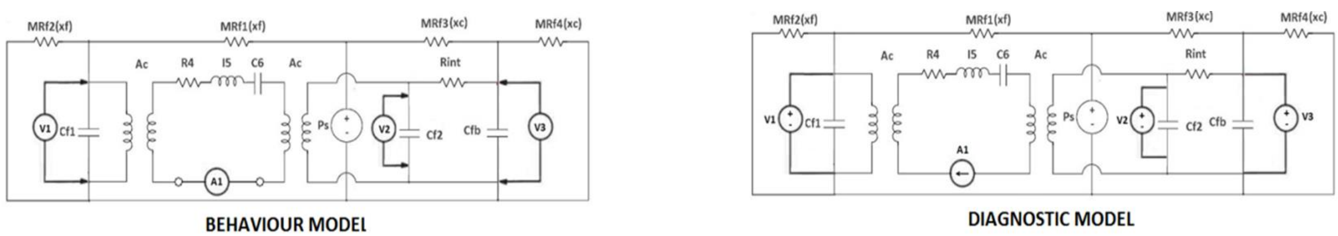
$$A = \dot{q} = \frac{p}{M}$$

$$F - B.A - M.\dot{A} - K.\int A = 0$$

$$\frac{d}{dt}$$

$$\dot{F} - B.\dot{A} - M.\ddot{A} - K.A = r$$

Figure 5 – Mass, spring and dumper system example, electrical equivalent behavior and diagnostic model, state and ARR equations.



$$ARR\,1: \quad Q_1 - Q_2 - i_1 - i_{V1} - i_{Cf1} = r_1 \qquad \begin{cases} Q_1 = C_d.\pi.dn.xf.\sqrt{\frac{2}{\rho}.(P_s - V_1)} \\ Q_2 = C_d.\pi.dn.(L - xf).\sqrt{\frac{2}{\rho}.(V_1)} \\ i_1 = Ac.\dot{x}_c \\ i_{V1} = 0 \\ i_{cf1} = \dot{V}1.C_{f1} \end{cases}$$

$$ARR\,2: \quad Ac.V_1 - R4.\dot{x}_c - I5.\ddot{x}_c - \frac{1}{C_{f1}}.x_c - Ac.V_2 = r_2$$

$$ARR\,3: \quad i_2 - i_{cf2} + i_{Rint} + i_{V2} = r_3 \qquad \begin{cases} i_2 = Ac.V_1 \\ i_{cf2} = Cf2.\dot{V}_2 \\ i_{Rint} = \frac{V3-V2}{R_{int}} \\ i_{V2} = 0 \end{cases}$$

$$ARR\,4: \quad Q_3 - Q_4 - i_{Rint} - i_{cfb} - i_{V3} = r_4 \qquad \begin{cases} Q_3 = C_d.w.xc.\sqrt{\frac{2}{\rho}.(P_s - V3)} \\ Q_4 = C_d.w.xc.\sqrt{\frac{2}{\rho}.V3} \\ i_{Rint} = \frac{V3-V2}{R_{int}} \\ i_{cfb} = Cfb.\dot{V}_3 \\ i_{V3} = 0 \end{cases}$$

Figure 6 –Sensor placement in the behavior model, diagnostic model and ARR equations from diagnostic model.

From the ARRs it is possible to obtain the fault signature matrix, shown in Table 1. The fault signature matrix makes the relationship of the residuals sensibility for each parameter in the model. Taking as an example the residual 1 (r1), the parameters that most affect its value are Q1, Q2, Ac, and the Pc1 measurement V1. So, thinking about failure modes, if there is a pressure nozzle obstruction (the nozzle that controls the flow Q1), the flow Q1 will be smaller and, depending on the obstruction level, the pressure Pc1 will be significantly smaller than it would be without the nozzle obstruction, thus, the residual r1 will not be zero anymore, if there is a pressure nozzle obstruction. The two last matrix rows relate the detectability and the isolation of the parameter fault. So, if at least in one residual row the true value appears, then it is detectable. For example, the parameter Q1 is detectable because, if it has a disturbance from the original value, the residue 1 would be affected. For one parameter fault isolation, the pattern of the residual appearance must be unique. For example, the parameter xc (spool position) is isolable because, if there is an abnormal condition and the spool position differs from its normal movement (in a hydraulic line leakage or increased spool friction), the residuals r2 and r3 would be modified and this residual appearance pattern is unique for the xc failure mode.

Table 1 - Servo valve fault signature matrix.

	Q1	Q2	xc	Ac	Ps	V1	R4	I5	C6	V2	V3	Rint	Q3	Q4
r1	1	1	0	1	1	1	0	0	0	0	0	0	0	0
r2	0	0	1	1	0	1	1	1	1	1	0	0	0	0
r3	0	0	0	1	0	1	0	0	0	1	1	1	0	0
r4	0	0	1	0	1	0	0	0	0	1	1	1	1	1
D	1	1	1	1	1	1	1	1	1	1	1	1	1	1
I	0	0	1	0	1	0	0	0	0	1	0	0	0	0

The Figure 7 shows the simulation results (numerical evaluation of the four ARRs, generating four residuals values r1, r2, r3 and r4) for different faults, applying a step input voltage in the torque motor terminals.

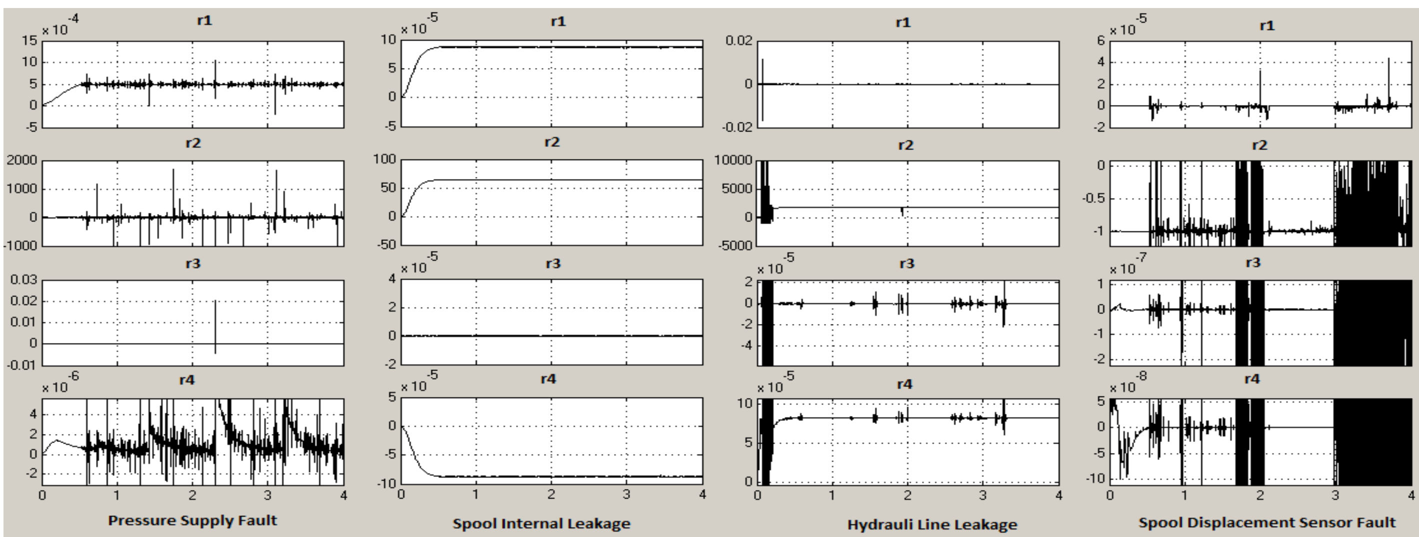


Figure 7 – Residual response for different failure modes.

With the simulations results, it is possible to see that the residual response reflects the fault signature matrix. For the pressure supply fault, the matrix indicates that the most sensitive residuals are r1 and r4. The Figure 7 indicates variation on these two residuals, as expected. Analyzing the spool internal leakage fault, the deviation occurs in more than one parameter. In this case, the most affected parameters are the spool displacement and the flows Q1, Q2 and Q3. Thus, based on the matrix, the residuals sensible to these faults are r1, r2 and r4 as confirmed by the simulation results in Figure 7. The hydraulic line leakage directly affects the spool displacement and the flows Q3 and Q4. These parameters affects the residuals r2 and r4 as confirmed by the simulation. Introducing a measure fault in the displacement sensor, caused a deviation in the residue r2, as expected according to the matrix.

CONCLUSION

The objective of this work was to develop a model for the aircraft braking dynamics and its hydraulic brake system, demonstrating, besides its normal operation behavior, what some common failure modes could cause on the system performance. The FDI method proposed was able to detect all the faults introduced. Thus, this methodology is a viable solution, helping to support early failure identification.

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DEVELOPMENT AND CONSTRUCTION OF AN INSTRUMENTED WORKBENCH FOR CHARACTERIZATION OF HYDRAULIC MOTORS

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ABSTRACT

This work addresses the design and construction of an instrumented workbench for characterization tests of hydraulic motors. The main objective is the workbench construction for future characterization of a gerotor hydraulic motor with proportional directional valve. The gerotor hydraulic motor has as advantage to work in a situation of low rotation and high torque. The workbench must be able to identify the characteristic parameters of the dynamic model, besides the elaboration of experimental curves involving flow, pressure, rotation and torque, depending on the variation of the applied load. The workbench basically consists of a gerotor hydraulic motor, proportional valves, valve amplifier, sensors and a hydraulic power unit. The mathematical modeling of hydraulic system involved in this motor drive provides valve spool dynamics, dead zone non-linearity, valve orifice flow, pressures dynamics, static and dynamic friction and angular movement dynamics. The mathematical modeling of dynamic systems is important in machine design, because it allows predicting problems and opportunities for optimization of constructive parameters through computational simulations, which, together with experimental laboratory practices, allow the validation of the behavior of its variables in machine and equipment prototypes in conditions similar to those found in the field. Considering the experimental data to be obtained from the workbench, simulating the real operating conditions and the dynamic modeling, it will allow us a systematic analysis of the rotation, torque and pressure behavior, which allows to properly size the input parameters, identify critical points of and propose solutions. This workbench will contribute to the research and development of innovative technologies for use in proportional hydraulic systems, facilitating rotation and torque control and optimizing energy use.

Keywords: Gerotor hydraulic motor, instrumented workbench, proportional valve, characteristic curves.

INTRODUCTION

The identification of the characteristic parameters of the dynamic model of a hydraulic motor through mathematical modeling allows to know adequately the relationships between them, allowing the elaboration of characteristic curves such as torque versus rpm, pressure drop versus flow, pressure versus rpm and curves involving three or more parameters for its identification, as the efficiency of the system. The validation of these models will be through practical experimentation with the use of this instrumented workbench.

For a better characterization of these parameters, it is necessary to use a proportional directional valve which is directly controlled by two solenoids, with a spring-centered central position and a spool position transducer. The operation of this type of valve requires an electronic controller/amplifier that receives both the external reference signal and the feedback signal from the position transducer, processes them and sends electrical signals to the solenoids [1].

Proportional electro-hydraulic directional valves are widely used in most pressure and flow control applications for industrial or mobile hydraulic systems [2]. Hydraulic systems have been widely applied in engineering machinery, metallurgy and extrusion equipment, due to its high power / weight ratio and high rigidity. Especially, when the hydraulic system drives the high-power load, the advantages of small volume and stable performance are highlighted [3].

The engine will be of the gerotor type consisting of a set of gears, an internal gear that rotates and orbits in contact with an external gear. These motors are suitable for delivering high torque at low speed. The internal gear rotates a n times for each revolution of the cardan shaft. For this reason, the inherent volumetric displacement of the unit will be n times larger than that of existing pumps and gear motors [4]. The use of these motors with the respective control of the hydraulic system, applied in machines and equipment, is one of the directions of the development of high technology in industrial applications. It is because of its outstanding features such as compact structure, large torque transmission, fast response speed, self-lubricating and heat transfer properties in liquid and good system life that are used in industrial and mobile machinery. The volumetric and mechanical efficiency of these engines has been widely referenced in terms of volumetric and torque losses, in which a proposed analytical model [6] of a generalized equation relating the general efficiency to the pressure and angular velocity for pumps and motors and showing how the model can be adjusted to real experimental data.

The high temperature of the hydraulic fluid implicate the overall efficiency of the entire system, requiring its monitoring and prescription a model capable of predicting the working temperature of the hydraulic fluid in the casing volume and in the outlet port. The working temperature is estimated [7] considering the power losses associated with the fluid flow at the lubrication interfaces, the agitating movement of the oil in the machine housing and the losses due to the compressibility of the hydraulic fluid.

Technological trends and the impact on existing pump and motor designs used in actuators controlled by displacement, continuously variable transmissions and hydraulic hybrid powertrains [8] allow for large fuel savings and emission reductions, but change the positive displacement of pump and motor performance requirements. The main challenges of these trends are related to efficiency improvements, noise reduction and advances in the control of pumps and motors.

OBJECTIVES

The main objective is the design and construction of a workbench for characterization of a gerotor hydraulic motor with proportional directional valve, in situation of low rotation and high torque, through the identification of the characteristic parameters of the dynamic model.

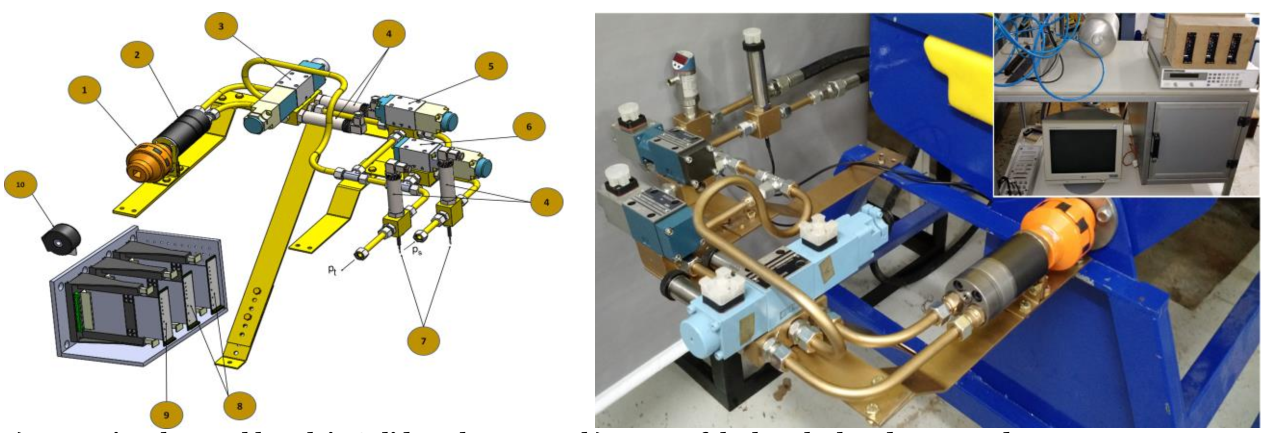
As specific objectives of this work we can cite:

- Allow the easy characterization of commercial hydraulics motors comparing it with the information available in the manufacturer's catalogs;
- Allow to identify the parameters of mathematical modeling suitable for the representation of the dynamic behavior of the friction and temperatures, and the inclusion of the main nonlinearities.
- Allow perform experimental validation tests of the proposal of mathematical modeling and control of the drive of the hydraulic motor, including the analysis of the obtained results.

DESIGN OF THE EXPERIMENTAL WORKBENCH

The conceptual design is the part of the design process where the techniques of creativity, the elaboration of function structures, the search for principles of solution, their combinations in the synthesis of conceptions and the techniques of evaluation are applied with the purpose of reaching a conceptual solution that is possible to solving the problem [9].

For the development of the workbench, the resources and equipment available were used in the Center of Innovation in Automatic Machines and Servo Systems (NIMASS) at Regional University of the Northwest of Rio Grande do Sul State.



a) Drawing the Workbench in SolidWorks **b) Image of the bench already mounted**

Figure 1 - Instrumented workbench for characterization tests of hydraulic motors.

The main workbench components are shown in Figure 1a and 1b. The hydraulic power (pressure and flow) will be used of a hydraulic power unit available in NIMASS, but not shown in the figure, will be used, which has pressure and flow control through valves and hydraulic oil temperature through a cooler.

Flow rate and pressure control of the hydraulic system will be controlled directly through the flow and pressure proportional valves. The control of the hydraulic motor rotation will be carried out through computerized software connected to the electronic system of the proportional valves. The workbench sensors will also be connected to the software providing in real time the data required for the experimental tests and allowing comparison with the data of the computer simulation through the mathematical models.

The test rig used for the purpose of investing in the determination of the characteristic parameters in hydraulics valves and motors according with what is depicted in Figure 1, it is formed by one acquisition and control system mounted in a PC microcomputer and one hydraulic system, that is composed by one proportional directional valve (3), one proportional flow valve (5) and one proportional pressure valve (6). Sensors (4) permit measure hydraulic system inlet (ps) and outlet (pt) pressure, inlet (pa) and outlet (pb) pressure in the hydraulic motor and speed of the hydraulic motor. For the acquisition and control system used is a dSPACE DS 1102 board which control the amplifiers signals (8) e (9).

In Figure 2, is cited the proposed hydraulic scheme for the hydraulic motor drive. It includes the power unit, the three proportional valves (directional, pressure and flow), hydraulic motor, drive shaft, hydraulic connections and sensors.

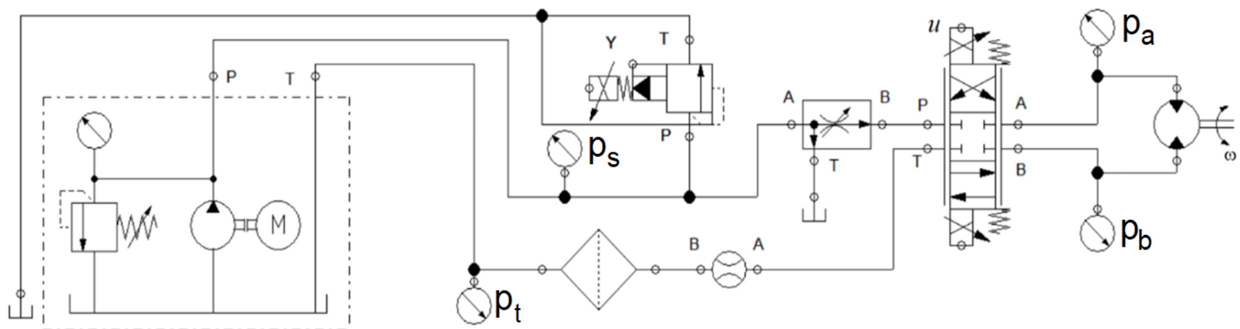


Figure 2 - Hydraulic workbench layout according to ISO 1219

The validation of the dead-zone mathematical modeling, the friction dynamics [10] and the flow dynamics in the proportional directional valve holes, the dynamics of the pressures in the chambers [11] and the axis movements in the hydraulic motor, as depicted in Figure 3.

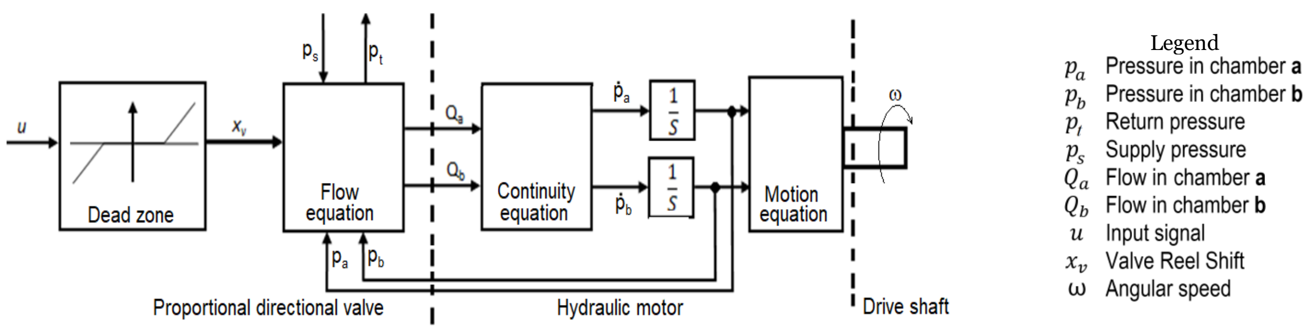


Figure 3: Functional Diagram of workbench with hydraulic system variables

The dead zone of a proportional directional valve is a static input-output relationship in which there is no output for a range of input values [10]. Figure 4**a** shows a graphical representation of the dead zone where $\boldsymbol{u}$ is the input signal, $\boldsymbol{u_{zm}}$ is the output value, $\boldsymbol{zmd}$ is the right edge of the dead zone, $\boldsymbol{zme}$ the left value of the dead zone, $\boldsymbol{md}$ is the right slope of the dead zone, and $\boldsymbol{me}$ is the left slope of the dead zone.

The dead zone analytical expression is given by Eq. 1.

$$u_{zm}(t) = \begin{cases} md(u(t) - zmd) & se\ u(t) \geq zmd \\ 0 & se\ zme < u(t) < zmd \\ me(u(t) - zme) & se\ u(t) \leq zme \end{cases} \quad (1)$$

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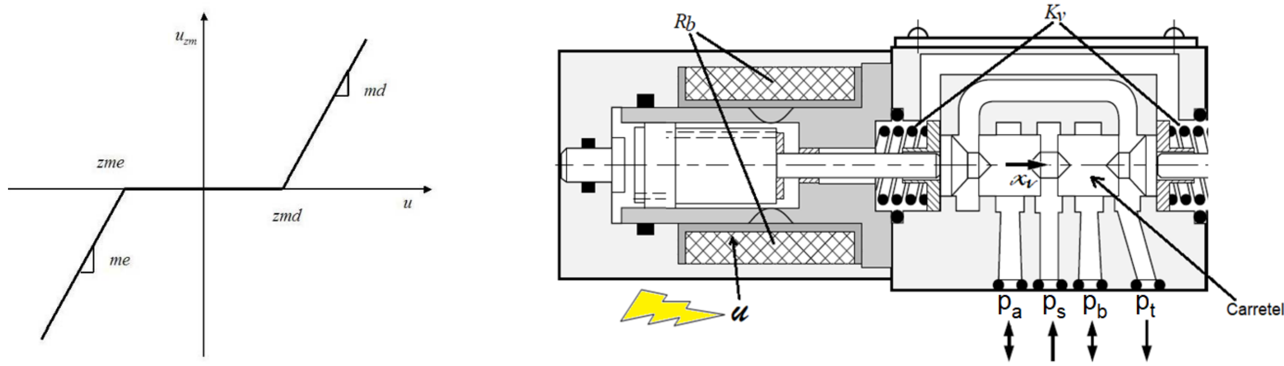


(a) (b)

Figure 4 – Parameters characteristic of the directional valve: (a) Graphical representation of the dead zone and (b) schematic drawing of a proportional directional valve.

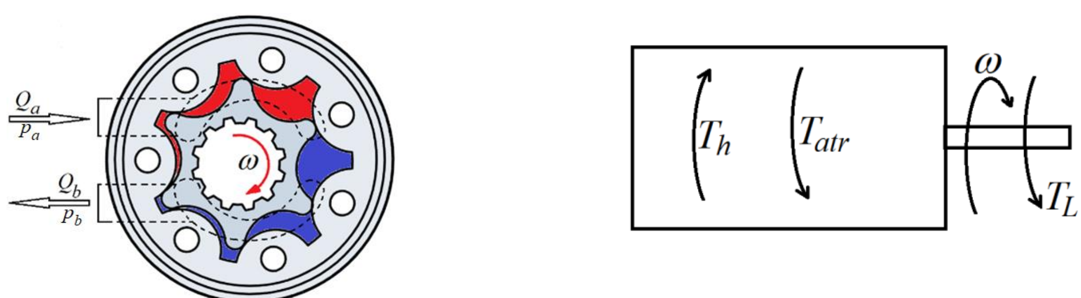
The determination of the flows in the proportional directional valve holes through the displacement $\boldsymbol{x_v}$, decipted schematically in Figure 4**b**, can be done from the Bernoulli equation [13] resulting in Eqs. 2 and 3.

$$Q_a(x_v, p_a) = \begin{matrix} k_s \,.\, x_v \,.\, \sqrt{p_s - p_a} & para\ x_v \geq 0 \\ k_s \,.\, x_v \,.\, \sqrt{p_a - p_t} & para\ x_v < 0 \end{matrix} \qquad (2)$$

$$Q_b(x_v, p_b) = \begin{matrix} k_s \,.\, x_v \,.\, \sqrt{p_b - p_t} & para\ x_v \geq 0 \\ k_s \,.\, x_v \,.\, \sqrt{p_s - p_b} & para\ x_v < 0 \end{matrix} \qquad (3)$$

The relation between the areas of the control holes is equal to the ratio between the cross-sections of the chambers of the differential cylinder, when displacing the spool from a distance $\boldsymbol{x_v}$, flow rates can be calculated which can be calculated through Bernoulli Equation, where, $\boldsymbol{Q_a}$ $(\boldsymbol{x_v}, \boldsymbol{p_a})$ and $\boldsymbol{Q_b}$ $(\boldsymbol{x_v}, \boldsymbol{p_b})$ are the inlet and outlet flow rates, $\boldsymbol{k_s}$ is the flow coefficient of the valve chamber $\boldsymbol{a}$ and $\boldsymbol{b}$, $\boldsymbol{x_v}$ is the valve spool displacement, $\boldsymbol{p_s}$ is the supply pressure, $\boldsymbol{p_t}$ is the return pressure, $\boldsymbol{p_a}$ and $\boldsymbol{p_b}$ are the pressures in chambers $\boldsymbol{a}$ and $\boldsymbol{b}$ of the hydraulic motor, respectively.

The model of hydraulic motor of the gerotor type that will be used will be of the brand Danfoss OMM 50. The description of the mathematical model of the hydraulic motor follows the hypothesis, in this case, that the motor will be unidirectional, in which the fluid flow will enter the chamber $\boldsymbol{a}$ and will exit through chamber $\boldsymbol{b}$, as shown in Figure 5**a**.



(a) (b)

Figure 5 – Parameters characteristic of the hydraulic motor (a) Diagram of the operation of the hydraulic motor gerotor type and (b) Torques in the hydraulic motor.

Initially it is necessary to derive the motor continuity equation for one chamber and ends in the differential pressure equation as a time function for the equations of the chambers $\boldsymbol{a}$ and $\boldsymbol{b}$, according to Eqs. 4 and 5.

$$\frac{dp_a}{dt} = \frac{\beta}{V_a}\,(Q_a - D\,.\,\omega) \qquad 4)$$

$$\frac{dp_b}{dt} = \frac{\beta}{V_b}\,(D\,.\,\omega - Q_b) \qquad (5)$$

Consider the schematic of a hydraulic motor with what is depicted in Figure 5**b**, the shaft is responsible for transmitting the rotation of the hydraulic motor to the drive shaft. The modeling of the drive shaft will be based on the torque that the hydraulic motor must have to overcome the load torque and the reactions that will occur in the form of friction torque. According to Eq. 6, the drive of the shaft is performed by a torque of the hydraulic motor $\boldsymbol{T_h = D.(p_a - p_b)}$ which generates a reaction that is contrary to the movement due to the friction caused by the rolling bearings or bushings of the motor, friction between the internal gears of the gerotor and the viscosity of the fluid, called the friction torque $\boldsymbol{T_{atr}(\omega)}$ and the torque related to the load that must move $\boldsymbol{T_L}$. $\boldsymbol{D}$ is the volumetric displacement of the hydraulic motor. The torque unit is in N.m.

$$I_{eq\,.}\ \dot{\omega} + T_{atr(\omega)} = D\ .\ (p_a - p_b) - T_L \qquad (6)$$

Friction is generally described as the resistance to movement of two surfaces in contact that affect or deteriorate performance and impair movement. Friction is the force contrary to movement and its characteristics are always present in the interaction between mechanical mechanisms [14]. For the study of the dynamics of the movement, the effect of the friction will be considered to compensate or to reduce its effects.

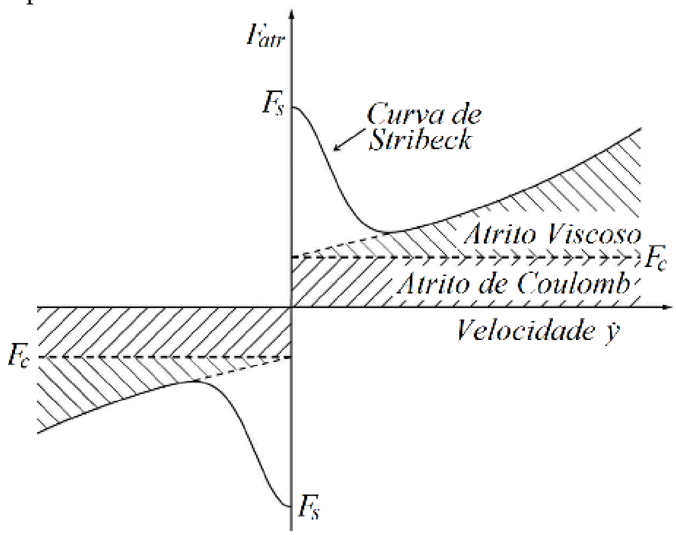


Figure 6 – Graph of the combination of permanent friction characteristics

Figure 6 presents, through a graph, some of the characteristics cited and used for the modeling of the friction dynamics in steady state according to Eq.7 [12].

$$T_{atr}(\omega) = T_c + (T_s - T_c)e^{-\left(\frac{\omega}{\omega_s}\right)^2} + B\ .\ \omega \qquad (7)$$

Where $\boldsymbol{T_{atr}(\omega)}$ is the friction torque as a function of the angular velocity, $\boldsymbol{T_c}$ is the Coulomb friction torque, $\boldsymbol{T_s}$ is the static friction torque, $\boldsymbol{\omega_s}$ is the Stribeck velocity, $\boldsymbol{\omega}$ is the relative velocity between the two surfaces and $\boldsymbol{B}$ is the viscous friction coefficient.

The main characteristic parameters that the workbench is able to identify with regard to mathematical modeling are listed below.

zmd – Right edge of the dead zone,
zme – Left value of the dead zone
$Q_a\ (x_v, p_a)$ – Inlet flow rates
$Q_b\ (x_v, p_b)$ – Outlet flow rates,
k_s – Flow coefficient of the valve chamber ***a*** and ***b***,
T_h – Torque of the hydraulic motor
$T_{atr}(\omega)$ – Friction torque as a function of the angular velocity,
T_c – Coulomb friction torque,
T_s – Static friction torque,
ω_s – Stribeck velocity,
B – Viscous friction coefficient

CONCLUSION

The design and construction of this workbench is important to characterize hydraulic motors by comparing them with the commercial characteristics through the experimental tests, besides validating the mathematical model of the valve and hydraulic motor dynamics. The results of these practical tests and the simulations will be published in form of publications in congresses and scientific journals of national and international recognition.

ACKNOWLEDGMENTS

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PROPOSED BUSINESS MODEL OF A MICROLEARNING-BASED PLATFORM FOR CONTINUING PROFESSIONAL EDUCATION OF INDUSTRY MEMBERS

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ABSTRACT

The increasing mobility of people, objects and information resources opens up new perspectives for teaching and learning processes, especially for people who carry out their work while being mobile. This research proposes a business model innovation (BMI) in e-learning through a microlearning-based platform for continuing education of professionals. Microlearning is a type of learning based on micro content, that consists of fragmented multimedia content that provides quick responses to an idea envisioned in a previously well-delineated and purposeful scope. Such content may also be used to deal with broad and / or complex subjects by using chaining or sequencing techniques, so the fragments are grouped in a chronological fashion to create a broader idea on the topic being studied, and each fragment must be independent from each other. In addition, this content format has high power to hold the audience's attention and motivate the viewer's engagement. When people are looking for quick answers in video tutorials, they typically skip ahead at intervals of the video timeline until they find the stretch that contains the solution they need. For this reason, the format design of the videos consists of presenting the quick solution at the beginning, then a more detailed demonstration of the solution, accompanied by the theoretical conceptualization when necessary for its understanding. The proposed platform breaks the paradigm of the strongly structured and static teaching-learning process, bringing the possibility of dynamic and personalized reorganization of micro contents.

Keywords: learning, microlearning, professional education, vídeo lectures, mobile learning.

INTRODUCTION

With the increasing use of the Internet for educational purposes over the last years, several eLearning platforms have become sources of information to learners all over the world. Now, there is an increasing interest and need in evaluating the effectiveness of such learning processes spread across the web. This is of special interest to the industry, since its need for ever increasing quality of specialized workforce, and the coming challenges related to the development of a new production style based on intelligent processes, known as Industry 4.0. The connectivity brought by mobile devices with internet access influenced the means by which people look for new knowledge, even related to their carrier and personal development. Those devices have made finding information an easy and fast task, and that change affected how people learn and consume educational contents. Understanding the patterns of consumption of educational content offers an opportunity to increase the quality of training offered to manpower, thus cooperating with the development of the industry in Brazil.

This paper aims to present a business model of a microlearning-based educational platform, aligned with the educational content consumption profile of industry professionals. The main innovation aspect of this business model consists in how information is delivered to the platform user, in a microlearning fashion. Microlearning is a pedagogy centered around the concept of chunks of content which can be easily assimilated. It goes well with ever changing, velocity-based ways of information consumption, and has been seen as a promising strategy for delivering corporative training to employees. However, only few corporations are exploring this approach to professional education in Brazil, yet. In the next sections of this article, the foundations of a microlearning approach to eLearning are discussed, along with its relevance to the audience interested on learning through the internet. Based on this theoretical framework, and using a tool known as Business Model Canvas, it's offered a business model to the platform, centered around the demands of the audience.

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FOUNDATIONS

In the last two decades, mobile devices have become increasingly present in everyday life, and significant investments have been made to provide resources for the integration of these devices into educational contexts [1,2]. In addition, the eLearning market has grown dramatically in recent years [3], with promising growth estimates for the coming years. Despite the increasing demand for online educational content, institutions that offer this type of service suffer from high dropout rates in their courses [4]. Although the development of technology opens new possibilities in the pedagogical field, it has been argued that these devices have been used to reinforce traditional, *one-size-fits-all,* teacher-centered teaching practices [5]. In order to reduce high dropout rates in courses, not only do students need to adapt and develop new skills that online learning demands, but also instructors must revise traditional design and pedagogical approaches. With the rise of Generation Z as the main consumer segment, starting in 2020, in the online video market (representing around 40% of consumers), pedagogical approaches need to consider what this generation values when searching content in the Internet. In a study carried out by SENAI [6], it was evidenced that the profile of video consumers, among professionals in the industry, values quality content (from the point of view of information, as well as design and oratory / charisma of the instructor), which can be easily accessible and that directly addresses the problem to be solved in the video, without deviating from this solution, unless to address a history of difficulties that the student may face when faced with the problem situation. Based on this scenario, we propose in this article a business model for an educational platform based on microlearning, which is a pedagogy adapted to the needs of the clients of this Market, focusing on the ease and speed of content absorption, addressing complex themes in the form of small segments (*chunks*) of information and content [7], which has been very promising, especially in the mobile learning environment, with the help of the rapid development of technologies related to mobile devices [8]. A business model describes the rationale of how an organization creates, delivers, and captures value, and the BMC (Business Model Canvas) is a tool for describing, analyzing and designing those models. In the next section of this article, it's described how the Canvas was elaborated.

METHODOLOGY

A business model is defined as a system that solves the problem of identifying who the consumers are, engaging with their needs, delivering satisfaction and monetizing value [14]. It is a description of how your company intends to create value in the market, and includes a unique combination of products, services, image and distribution that the company carries out. It also includes the subsequent organization of people and the operational infrastructure they use to carry out their work. [15] In a study carried out by Osterwalder [16], several business construction models were compared, aiming to identify the most mentioned in the literature. The components proposed by Ostenwalder and Pigneur (2011) [17] are: customer segment, value proposition, channels (communication, distribution and sales), customer relationships, revenue sources, key resources, key activities, key partnerships and cost structure. The detailed description of each of these components can be found in Table 1, below. Based on these components, the authors developed a tool to describe, visualize, evaluate and change business models, called Business Model Canvas, which can be visualized in Figure 1, below (adapted illustration).

The Figure is divided strategically into three macro topics of interest: Cost Structure: aspects of the business that cost money; Revenue Streams and Pricing Model: aspects that make money; and a mission.

Mission

The mission consists of what problem the business wants to solve, and how it intends to do so. It is the core of the business activities, stating a need for objectiveness and clarity to guide all the development of the business model.

Cost Structure

Over the Cost Structure, there are three key points that should be evaluated: Key Partners: who is needed to work with in order to be able to deliver the proposed solution; Key Activities: what is need to do to run the business; and the Key Resources which consists of what is a "must have" to run the activities of the business. All these questions should be summarized and thought in light of their costs.

Revenue Streams and Pricing Model

The key aspects that generate money to the business include the Customer Relations: how the business get more clients and stablishes communication with them; The Channels by which the solution is delivered to the clients; and the

Market and Customers Segments which consists of an analysis of the needs of customers, how many people need the solution, and how many will need the solution eventually.

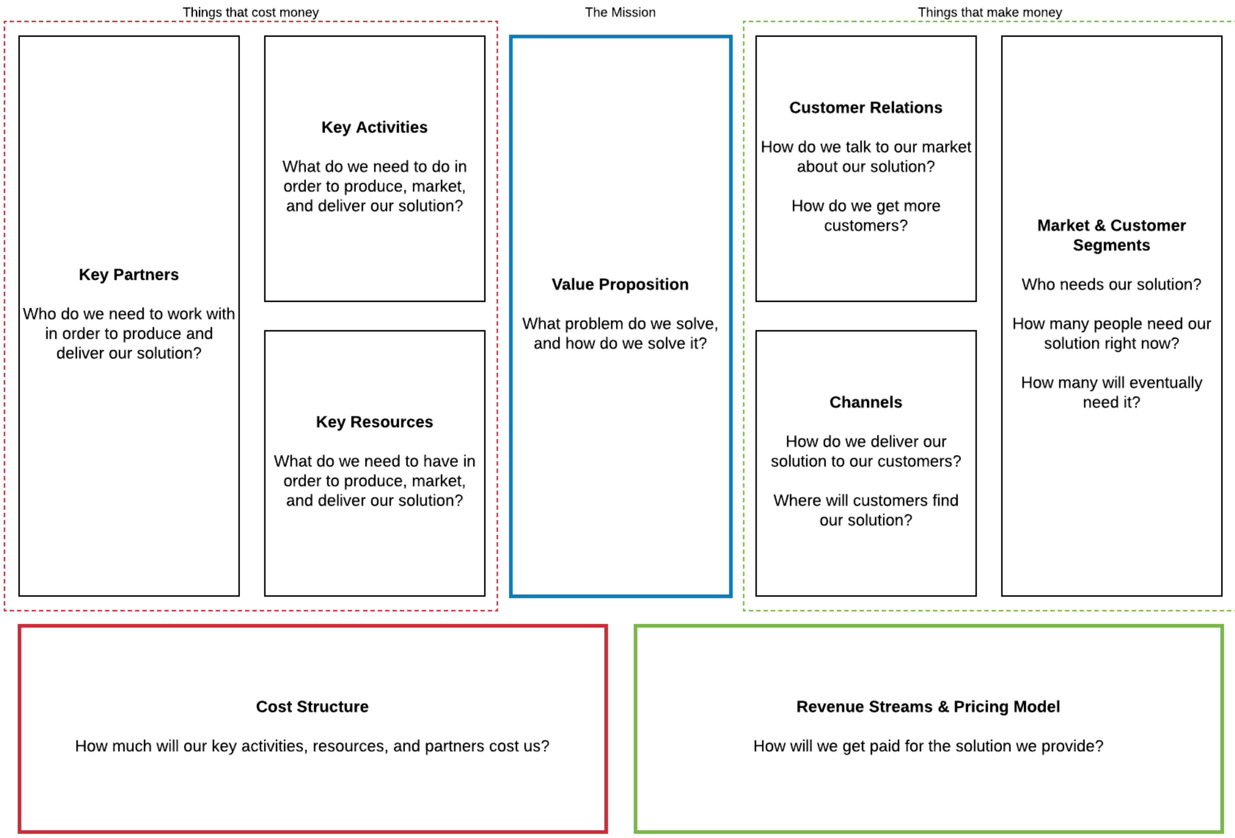

Figure 1. Ostenwalder and Pigneur's Business Model Canvas Components. The business canvas can be used to guide the elaboration of a business plan for a product, service, or company.

Based on this tool it was created the business model for the platform. In the elaboration process, the team from *Escola SENAI de Informatica* organized a series of meetings to discuss the nine main components of Osterwalder's BMC, and the findings will be discussed in the next section (Results).

RESULTS

Next, we present a frame (adapted from Macedo et al, 2013 [13]) that summarizes the answered basic questions which should guide the development of our proposed service, based on that business model canvas structure mentioned above. It is presented here segmented by Cost Structure, Revenue Streams, and Mission, to enhance the visualization of each topic.

Mission: What value do we deliver to the customer? What problem are we helping solve? What needs are we satisfying? What set of products and services are we offering for each customer segment?

Figure 2 shows the core objective of the microlearning-based platform we propose. The mission of the project is to deliver quality educational content, which could be easily accessed and assimilated, and that the industry workers could benefit from, in order to develop their professional skills. In this platform, the user can access its contents, be evaluated by his/her progress, and own certifications if approved. All aspects of Cost Structure and Revenue Streams are centered in this concept of business, which is aligned with the needs of the public consuming educational videos in the web which work in industry in Brazil, according to previous research conducted by SENAI, with results mentioned in the Foundations section of this article: they need content which is objective and goal-oriented (not deviating from the issue being discussed in the video) that praises for quality of information and oratory / charisma skills of the tutors, and can be easily accessed from anywhere, at any time.

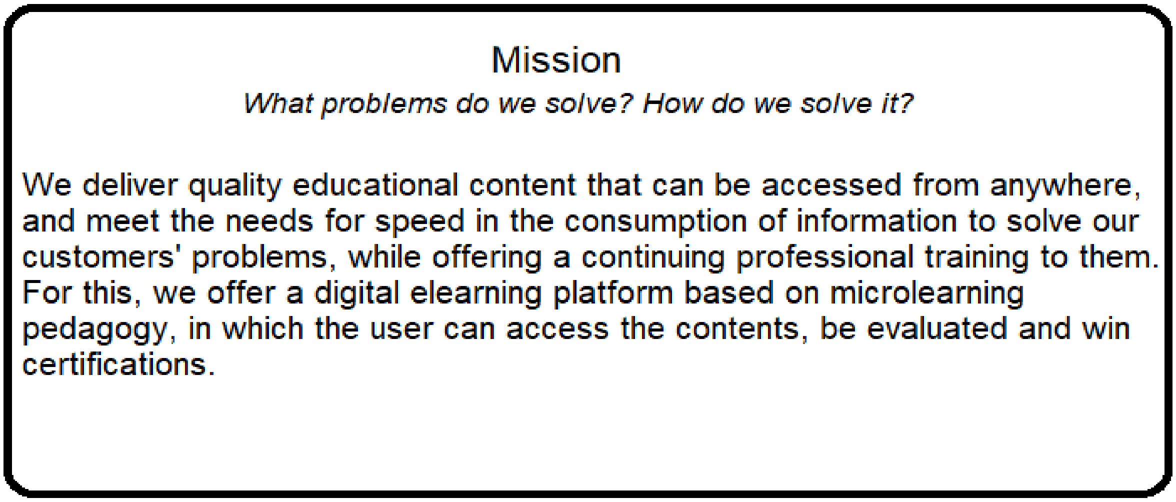

Figure 2. Mission of the proposed project.

Cost Structure: What are the most important costs in our business model? What major features are more expensive? Which key activities are more expensive?

Figure 3 below describes the three Key Factors concerning the Cost Structure. The Key Partners of our project, specifically, are other SENAI schools and member companies of the Industry. The schools could offer their expertise to the production of content, and the companies could afford costs of the project, e.g. in exchange of designing special qualifications in the area of actuation of the company, so we could deliver qualification to their manpower. Also, it is important to highlight the role of the suppliers in the partners section. In order to create the video contents for the platform, the main suppliers include distributors of audiovisual material (e.g cameras, computers, microphones and the like). The Key Activities consists of the production and curation of the educational content; the development of a website to allocate the platform, even UX as though Dev matters; and the monitoring and evaluation of students, and issuance of certificates for those willing to obtain professional certification from our institute. Other important activities are worthy highlighting, such as administrative and marketing routines. The Key Resources include an environment and team to create the audiovisual content aiming the mission of the project; Online platforms such as YouTube and its own website for allocate and distribute content; and a Marketing Team to run actions towards reaching the customers.

Figure 4 summarizes the components of the Revenues Streams and Pricing Models of the BMC. The Customer Relations states about the target public of the platform. In our case, we set the public as being professionals of the industry who seek professional or educational leverage. Based on the report published by SENAI [6], those professionals consist mainly in youngster and adults, aged 20-35. Thus, learners seeking acquiring new knowledge, or solving a specific problem of the areas/subjects covered by the platform may benefit from it as well. The main channels of distribution of content would be the platform itself, and the YouTube, since it is, today, the most accessed platform in terms of video content, even for educational purposes. In the end, it will be stablished a direct communication channel with the audience, as Customer Relationships politics, so they can send their feedback and suggestions, not only about the platform functionality or the content already provided but aiming to get new relevant content suggestions for creation, too. The business main source of resources is the support of SENAI itself, but partnerships with industry corporations and the issuance of certificates to those willing to get a certification of their knowledge by a traditional and recognized by the market institution also constitutes sources of revenue to the project.

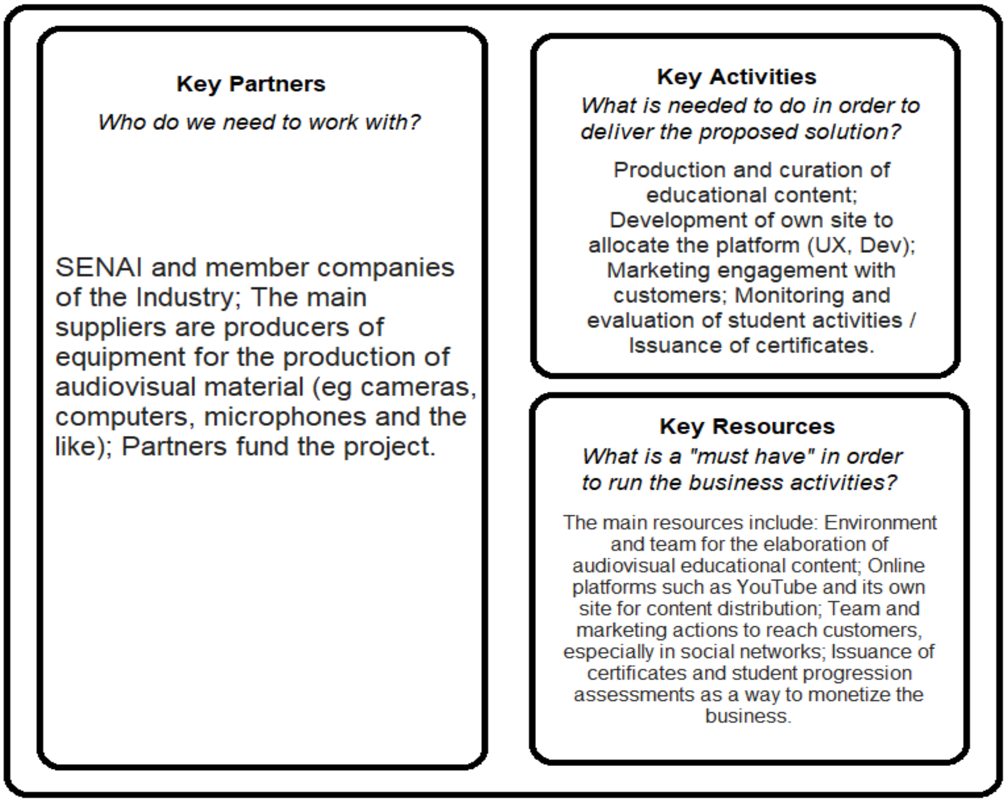

Figure 3. Cost Structure components of the BMC.

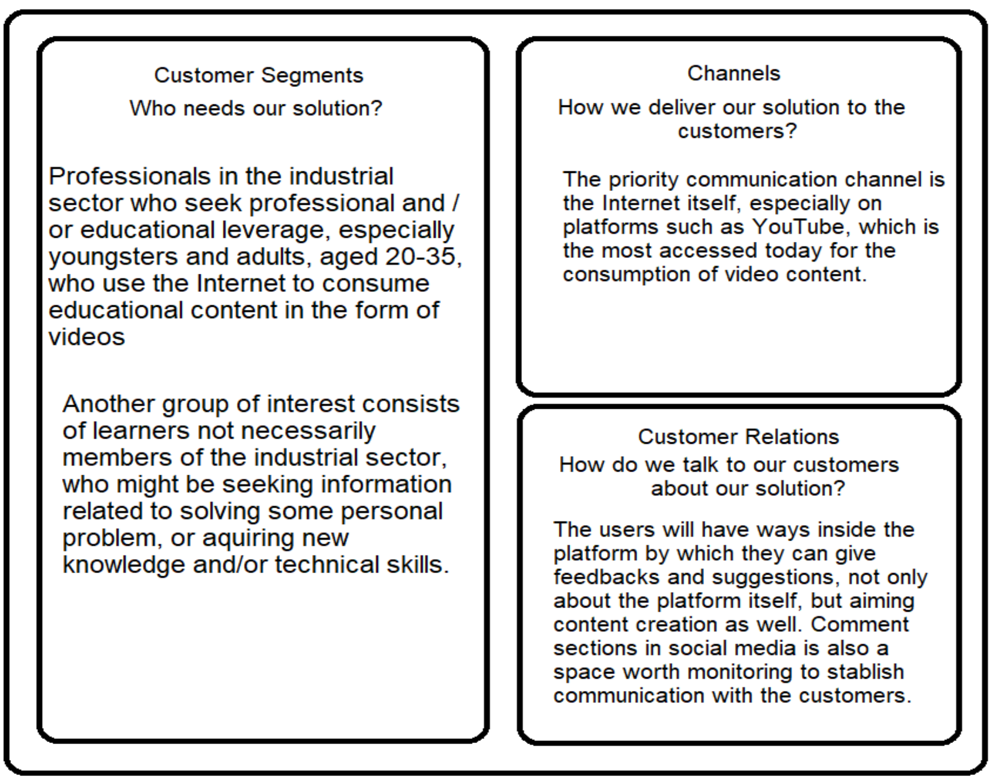

Figure 4. Revenue Streams components of the BMC.

CONCLUSION

As discussed in this article, the proposed microlearning-based platform aims to deliver quality educational content so that industry professionals, mostly young people and adults aged 20 to 35, have access to a continuous formation focused on their urgent needs, identified in a research previously done by *SENAI*. One of these aspects raised by the research is of vital importance to the business, since it deals with how the services provided can be monetized. The survey identified that only a small portion of video consumers and online courses are willing to pay for the content consumed, suggesting that a *freemium* monetization approach would be more appropriate. In a freemium business model, the user would have access to content for free, and the revenue would be generated by issuing certificates and assessing student performance. Another important point to note is the participation of funding partners for the project, which in this case are the state-owned *SENAI*, and other partner companies, which are part of the industry. The main activities required for the delivery of the business are the production of the contents to be made available (from its pedagogical conception to its availability), dissemination of the content and the platform in digital media and social networks, and evaluation and issuance of certificates for students.

The relationship with the client will occur in an iterative way, allowing feedback on the available content and suggestion of new topics to be addressed, going against the profile of clients who are interested in customizable services.

In this way, we have a business model with potential to face the main difficulties faced by eLearning currently, considering the pains and needs of customers, and the economic scenario of the digital courses market for the coming years in Brazil. Although a beta version of the platform has already been developed, currently, the content to be provided is still being produced and being evaluated. The platform is still in its primary stages, so future studies will be needed to evaluate the aspects of this BMC, as the business develop. Then, it will be able to analyze the strengths and weaknesses of the model, though the successes and attention points raised by the iteration of the platform to its audience.

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DESIGN OF AN EXPERIMENTAL WORKBENCH FOR FORCE CONTROL TESTS WITH PNEUMATIC ACTUATORS

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ABSTRACT

The need of the use of mechatronic systems and manipulator robots performing tasks of precision and repetitiveness in the most diverse areas of industry, agriculture and services, require in some situations the contact between the manipulator and the environment, in the desired and programmed movements for the execution of robotized work. These situations, of contact of the mechanism and / or final effector with the environment, are characterized in a problem of force control. Pneumatic actuators are used for interaction between the robot and the environment, due to controllable stiffness. It is perceived that due to the compressibility of the air, it is more advantageous and safer in applications involving the risk of accidents and the need to limit the forces of interaction with the environment. The main objective of this paper is to show the design of an experimental workbench for position control and force control for pneumatic actuators. The used methodology is based on phases that can be named as Need Analysis, Conceptual Design, Preliminary Design, Detail Design, Prototype Construction, Test and Evaluation; and Final Documentation. The experimental prototype is being developed and tested at the Innovation Center for Automatic Machines and Servo Systems (NIMASS) in UNIJUÍ University (Brazil), which has adequate computational and experimental infrastructure for the construction of a bench of tests to verify and to validate the performance of the modeling and control of force on pneumatic actuators. It is concluded that the developed workbench can contribute to the study of the modeling and design of pneumatic systems applications in machines. Theoretical and experimental knowledge enhances the development of innovations and the transfer of technology to the productive sector.

Keywords: control force, pneumatic actuators, experimental workbench

INTRODUCTION

This work addresses the design of an experimental workbench for position control and force control for pneumatic actuators. In robotics, the force control is one of the most studied topics, where it is used to describe the interaction between a robot and an unknown environment with applications in the industry, agriculture, medicine and services. [1, 2, 3, 4]

Currently, in a large number of robotic systems, the need for a natural interaction with the environment requires the actuator to be treated as a source of actuation force, i.e., a force generator. As such, the capability of precisely modulating the output force in the presence of external disturbance makes a significant research topic in the robotic application of pneumatic actuators. [5, 6]

Today pneumatic actuators are widely used to perform various industries motion tasks. They have the advantages of low purchase price and robust design, but show high energy consumption in comparison with electric drives. Existing energy saving measures lead to the reduction of energy consumption, but at the same time they cause the increase of the life cycle costs. All in all, the selection of pneumatic drives has been done regarding their functionality, efficiency and costs. [6, 7]

Friction is an important phenomenon in many mechanically driven systems. The friction force Fatri has a highly non-linear behaviour. Friction is a multifaceted non-linear phenomenon that exhibits many non-linear characteristics. They are composed by well-known and classic static friction (stiction), Coulumb friction, viscous friction and drag friction, that compose the simpler models based in static maps. Otherwise, they are composed by more complex dynamic phenomena known as Stribeck friction, rising static friction, frictional memory and presliding displacement. It is important to emphasize that, in general the friction characteristics are dependent of velocity, temperature, movement direction, lubrication and the wear between contact surfaces, and even position and movement history. [8, 9]

METHODOLOGY

In order to increase the probability of success of new pneumatically driven robotic workbench with force control, the design process was planned carefully and executed systematically. In particular, an engineering design method must integrate the many different aspects of designing in such a way that the process becomes logical and comprehensible. To that end, the design process of robotic system must be broken down, first into phases and then into distinct steps, each with its own working methods. It is with these aims in mind that several authors split the design process into main phases that can be named as Need Analysis, Conceptual Design, Preliminary Design, Detail Design, Prototype Construction, Test and Evaluation; and Final Documentation of Robot Drives and Mechanism as shown in Figure 1. [10, 11]

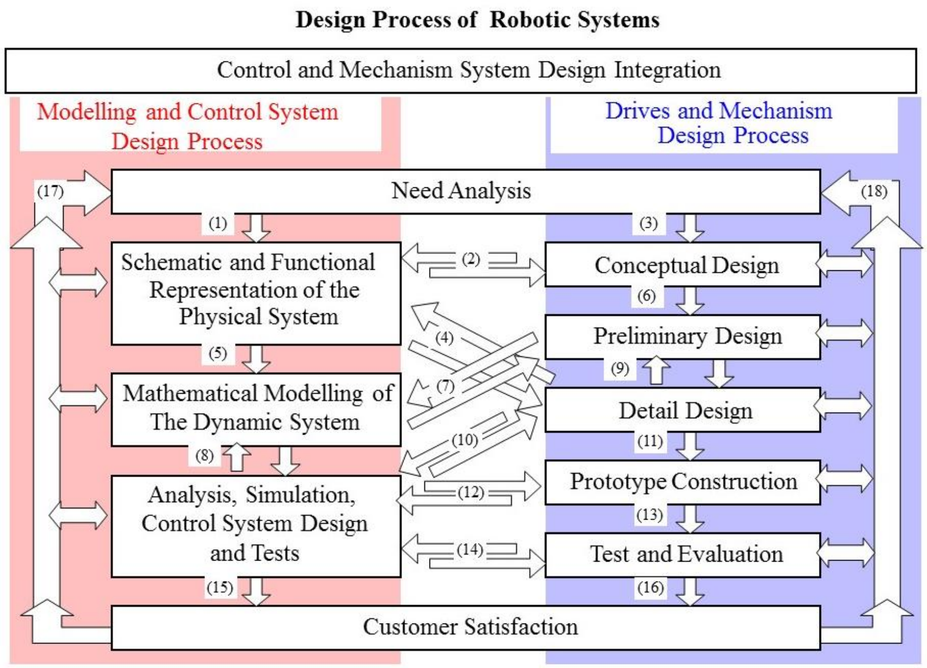

Figure 1 – Design Methodology of smart machines and robots (adapted from [10])

According to [10], from the Needs Analysis phase, the modelling and controller design methodology can be divided into the three main phases and illustrated in Figure 1: schematic and functional representation of the physical system; mathematical modelling; and analysis, simulation, controller design and tests.

RESULTS

This section presents the results of the design and construction of an experimental workbench for position control and force control for pneumatic actuators and experimental tests used to identify some parameters in pneumatic actuators. All programs were implemented on MATLAB.

Design and Construction of Experimental Workbench

The 2 illustrates the detailed design and construction of an experimental workbench for force control tests with pneumatic actuators that is being developed and tested at the Innovation Center for Automatic Machines and Servo Systems (NIMASS) in UNIJUÍ University (Brazil). The laboratory has adequate computational and experimental infrastructure for the construction of a bench of tests to verify and to validate the performance of the modeling and control of force on pneumatic actuators.

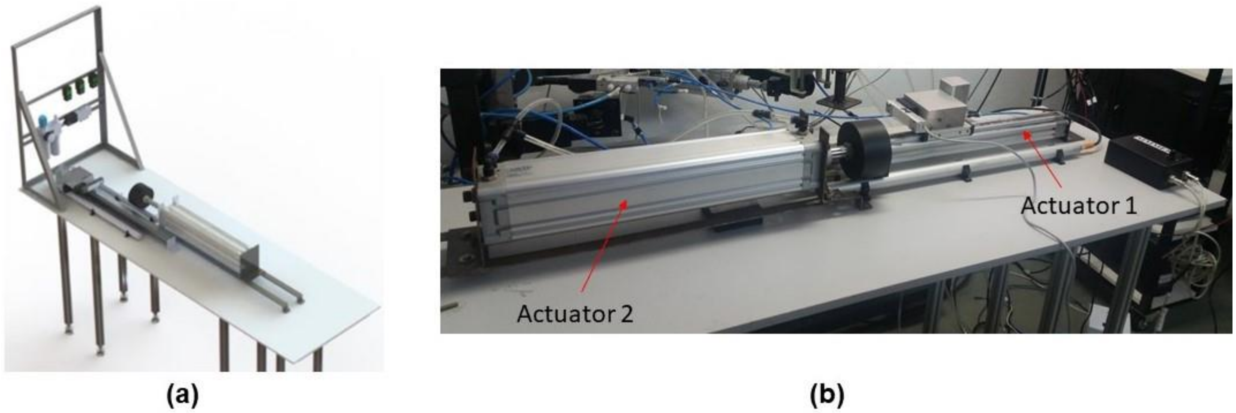

Figure 2 – Design of an experimental workbench for force control (a) Design in CAD model; (b) Photograph of experimental prototype

The developed workbench study contributed to the modeling and design of pneumatic systems applications.

Simulated and Experimental Results

The Figure 3 shows static map of the actuator 1 and Figure 4 presents static map of the actuator 2. The graphics were obtain through many experiments carried out with velocity values being changed from around null velocity to maximum system value. These experiments were fulfilled with test apparatus configured as an open loop system, when a constant pneumatic valve opening possibilities that pneumatic actuator moves with constant velocity.

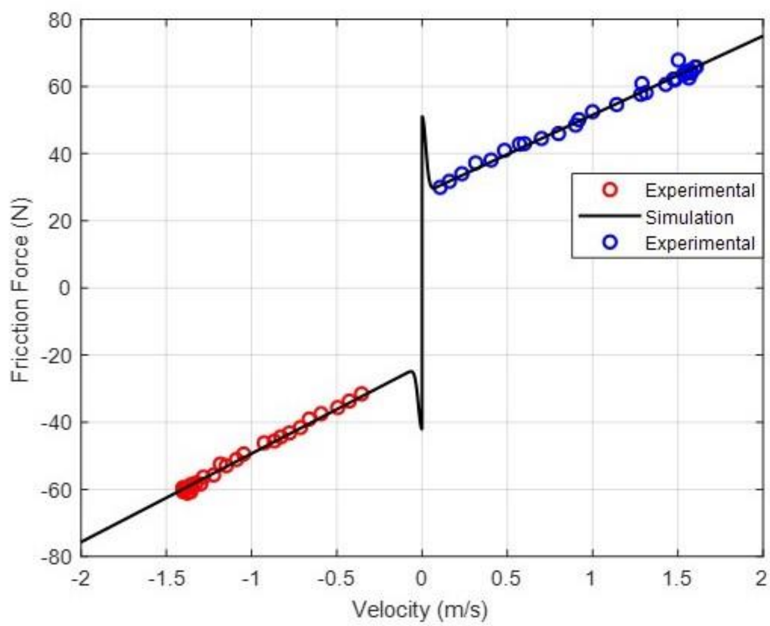

Figure 3 – Static friction-velocity map in steady state to pneumatic actuator with experimental values to actuator 1

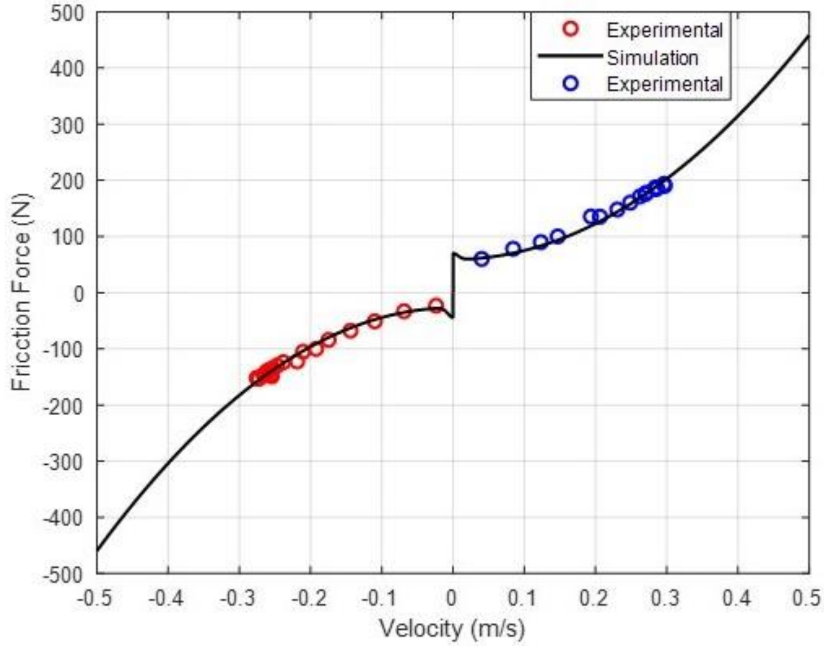

Figure 4 – Static friction-velocity map in steady state to pneumatic actuator with experimental values to actuator 2

The identification of steady state friction ($F_{atri,ss}$) is important because we can consider at constant speed that the result of the forces in the pneumatic actuator is

$$f_{Li} = F_{pi} - F_{atri,ss} \tag{2}$$

Where F_{pi} is pneumatic force to each pneumatic actuator and f_{Li} is load force.

Figure 5 gives the comparison of the results in open-loop between the pneumatic force simulation and the load force in actuator 1. According to Equation (1) the force control is useful with friction compensation of the pneumatically driven robotic workbench.

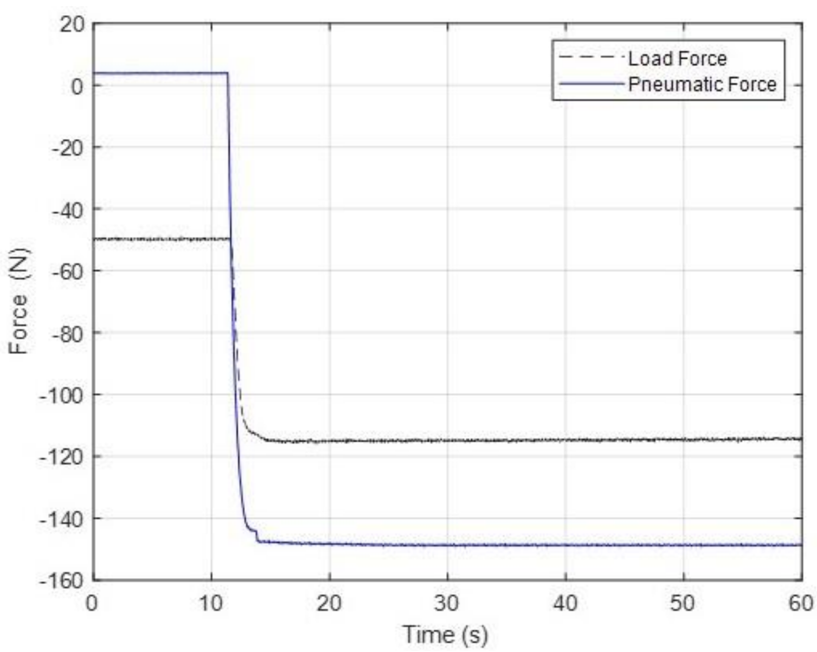

Figure 5 – Results of open-loop dynamics of Load Force and Pneumatic Force in Actuator 1

From Figure 6, it can be seen that the results of force feedback control in actuator 1. In this experiment the actuator 2 was stopped, thus simulating the environment.

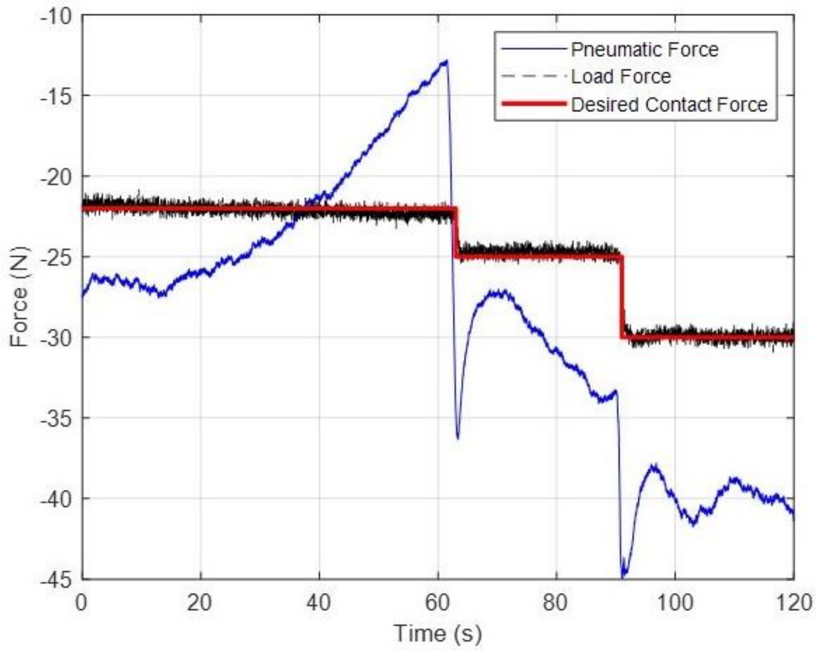

Figure 6 – Results of Force Feedback Control in Actuator 1

In this experimental workbench was also made the calibration of the load cell. The results were obtain experimentally for the calibration of the load cell and the adjusted curve.

CONCLUSION

This work presented a detailed prototype of an experimental workbench for position control and force control for pneumatic actuators. In addition, friction dynamics were experimentally identified in pneumatic actuators, which exhibit nonlinear behavior at low speeds. These results will be used for the benefit of the prototype with respect to determination of parameters, validation of the robot's mathematical model and control strategies.

ACKNOWLEDGMENTS

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CONTROLLING OF GEARBOX LUBRICANT VOLUME FOR A GEAR TEST RIG

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ABSTRACT

The lubricant oil in experimentation of gear performance is highly influent on the tests results. This paper carries out a pump system control strategy to control the lubricant volume inside a gearbox of a test rig. Back-to-back test centers consist of one or more pairs of gearboxes connected back-to-back, what allows recirculation of mechanical power. These tests rigs are used to test fatigue life and efficiency of gears. The back-to-back rigs are made meeting standards requirements, which increase the reliability of results comparison between different sources. In fatigue life experiments, pitting and micro-pitting failures modes are highly sensitive to lubricant variations, due the oil capacity of decrease friction. The lubricant volume inside a gearbox also has high influence in efficiency, once high-volume levels relate to increased inertia and churning losses. Worldwide back-to-back tests rigs use constant oil volume in the gearboxes and controls the temperature inside the boxes. Once the back-to-back test rig presented in this paper has outside temperature control, due performance, two pumps are used to control the lubricant volume inside the gearboxes. This system has non linearities related to the motor pump torque response and the inside geometry of the gearboxes. With the objective of controlling the oil volume inside the gearbox, a Proportional Integrative Derivative (PID) controller was implemented to one hydraulic pump's motor. It is defined ranges and limitations in the pump system operation to maintain the oil propagation in a linear relation to frequency regime. Using empiric experimentation, the PID parameters are defined. By controlling different oil volumes under the influence of different gear rotational speed, the controller has proved effectiveness by maintaining linear relation oil propagation and the volume variation inside the maximum permissible. The results leveraged the test rig to a high-precision level of torque efficiency and contact fatigue assessment in gears.

Keywords: control system, PID, gear lubricant, torque efficiency

INTRODUCTION

In gears characterization and testing, the studied parameters, as geometries, material and lubricant oils, are quantified and qualified by analyzing the propagation of different failures modes. In oils lubricant analyses, the most sensible variable failure mode to the oils properties is the pitting and micropitting, which are highly connected to the sliding speed between a geared pair of gears. The oil has the function of dissipate temperature and decrease friction losses. In other hand, higher the oil amount, higher are the losses related to the lubrication excitation, and consequently, less is the transmission efficiency. In gear testing, there are standards with the objective of increase the reliability of experiments comparison between different test centers sources. Between the requisites for pitting test, the oil volume must be constant during the testing and must be maintained at the center of the tested gear [1]. Although, there are researches has [2] which pursuit optimum efficiency by searching the best relation between efficiency and temperature dissipation and lubrication. This work carries out a PID controller to control the oil volume in transmissions boxes. Enabling the test center to perform pitting fatigue experiments and test influence of lubricant oil in the gear's performance.

PROBLEM DESCRIPITION

The back-to-back center utilized is made by four transmission boxes with distance between center of axis 71 mm and 114 mm. The Figure 1 presents the structure of the test centers and the boxes used for gears testing.

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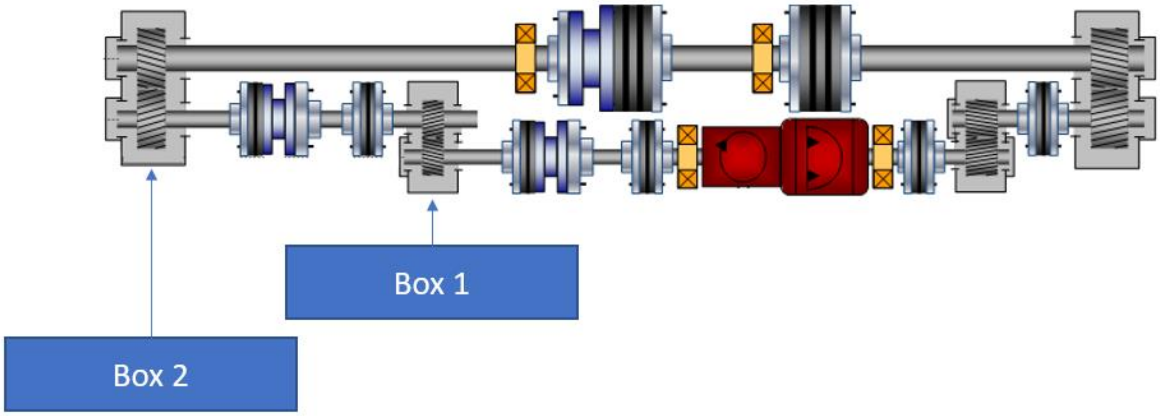

Figure 5 - Test rig overview and testing boxes. Box 1 is the used box.

Meeting the standards, the gear box with the tested gears must has a constant volume of lubricant oil. Besides the oil lubricant volume, the temperature also must be controlled. Therefore, the major back-to-back rigs, as the test rigs of [3, 4], use resistors and cooling coils within the transmission boxes. In the presented test center, the strategy is different. The oil is heated or cooled in a machine outside the boxes, which due its volume (size proportional to potency), would not fit in the transmission boxes. During the experiments, the temperature must be alternated several times, between standard test temperature and temperature of inspection.

Although there is no standardization of the maximum variation value of the oil lubricant volume within the transmission boxes, it is usual to complete the oil amount between inspections stops. There is a tubular visor (Figure 2) installed to the boxes to visual monitoring, once the box in complete sealed. Based in the mean losses between the inspections of the used test center, it was possible to identify a maximum variation, through an external tubular visor, of 3 mm (approximately to 46,96 milliliters, from the gear's center height). In the same way, there is no standardization of the maximum time to the stabilization of the oil lubricant volume inside the transmission boxes. As a reference, it is utilized the medium time of an operator completing the oil lubricant in non-controlled oil volume boxes.

The oil is inputted in the box through the superior plate and the oil is pumped out via the lowest level inside the box. All boxes are equipped with outside tubular visors to visual inspection and sensor measurements. The Figure 2 presents the box number 1, its outside view and cutting inside view.

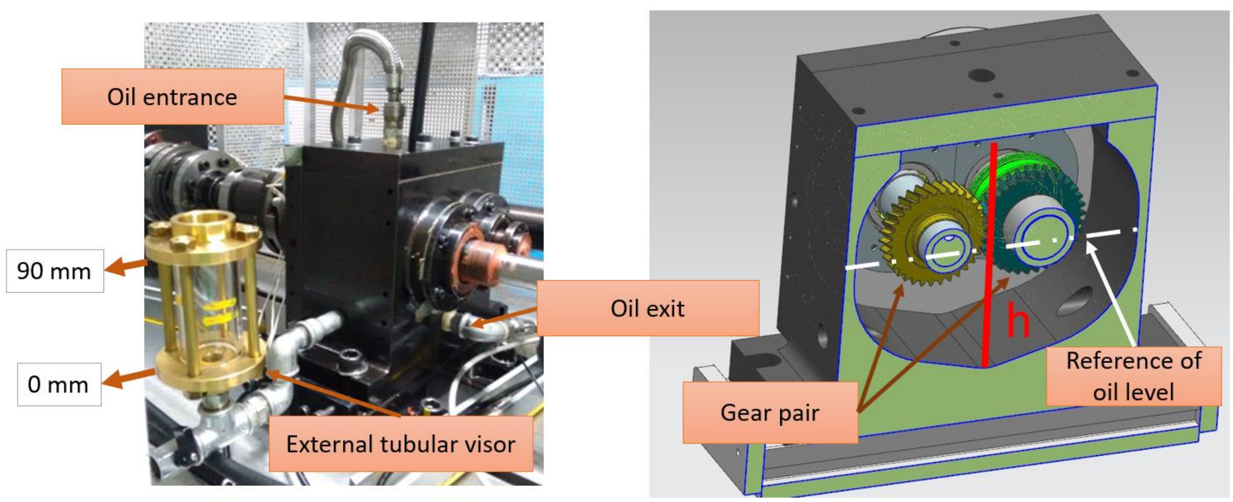

Figure 6 - Transmission box structure: entrance and exit oils points, tubular visor range reference and inside box

The oil transport between the external temperature control unit and the boxes is made by using of two pumps. The first one pumps the oil towards the box inside and the second one pumps out the oil. Both pumps work with tri-phase inductive motors of power of approximately 4 kW. The motors are controlled by two frequency inverters and has variation of torque available as a function of speed, as presented in Figure 3.

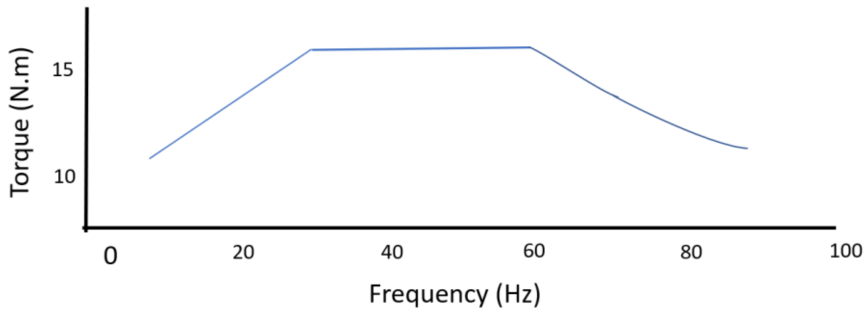

Figure 7 - Frequency/Torque relation from inductive motor and inverter set

From the experiment requirements to gear testing and the observations made, it is defined as requirements to the control system: maximum variation of ± 3 mm of oil level and stabilization in 0,5% of the total experiment period (~ 6 minutes).

MEASUREMENT SYSTEM

The measurement is done by measuring the oil level in a tubular visor presented in Figure 2. Due angles and short sections of the connections between the box and the visor, the kinetic energy inside the visor is smaller. Although it induces delay in the equilibrium of the levels of inside and outside the box, the variation is small enough to be inexpressive when compared to the maximum allowed variation.

The reference 0 mm to the control system is the visor's base and it is increased up to 90 mm, in the up face, as presented in Figure 2.

CONTROLLER

It is supposed that there is a constant flow in the transmission box entrance. It is analyzed the oil level "h" measured through the time, of the box's base to the box's top (Figure 3). Due the inside geometry of the box, the level increasing would not present a linear behavior. Furthermore, the torque response of the ensemble motor and frequency inverter is not linear as well. These two characteristics of non-linearities make that a PID controller does not be am optimum option to this application [5].

By limiting the motor's speed inside the torque zone which generates linear proportional flow variation (10 Hz to 30 Hz), although decrease the range of controller's response, guarantee the robustness of the available operational zone. Despite the inside area of the box variates over the box's height, for the volume which comprehends the gear pair, the area is constant.

The pump which pull out the oil from the box is set to a constant flow, while the entering oil flow is controlled. The proposed controller is limited in regardless of the zone with minimum torque to achieve constant flow, besides, it is defined a minimum speed of 10 Hz, equivalent to a command voltage of 4 V to the frequency inverter, to the entrance pump oil. The minimum speed guarantees that there is no non-linearities in the oil supply, due the nonlinear torque availability, which could generate more controlling instability. The controller is a parallel PID controller with gains defined empirically to robustness in the working zone. The controller output is a voltage between 0 and 10 V and there is a limiter in the error integration as a measuring of safety. The exit pump keeps the flow constant and its speed is superior to the minimum speed of the entrance pump.

TEST PARAMETERS

Regardless the validation of the controller in transient regime, there were defined 3 levels of oil to be maintained for a short period. These levels are respectively: 20 mm, 40 mm and 80 mm. In the validation of the controller during the experiments, it was defined 60 mm (gears center) and the speeds where referenced by the real experimentation speed, it is: 2250 rpm for pre-testing and 3500 rom for testing.

RESULTS

The PID parameters where defined empirically to achieve maximum variation of ± 3 mm of the oil level and maximum stabilization time of 6 minutes. The Table 1 presents the achieved parameters.

Table 2 – PID's parameters

Controller's fractions	Gains
P	0,140
I	0,008
D	0,000
Limiter I (mm)	5,000

Pump Frequencies Strategy

To maintain the pumps working in a linear regime, the exit pump was fixed in 25 Hz and the entrance pump with a minimum of 10 Hz and maximum of 30 Hz.

Oil Level for Non Rotational Scenario and Rotational Scenario

From the graphic of Figure 4, it is possible to identify the stability of the oil level afterwards the transient period. It is also possible to identify the doubling of the overshooting between the 20 mm and 40 mm levels, although a less expressive difference between 40 mm and 80 mm. The fact that the time evolution of the oil levels, from the 0 mm, is like a straight line, represents that the pumps are working in a linear proportional to speed regime and the nonlinearities due volume variation are not so relevant.

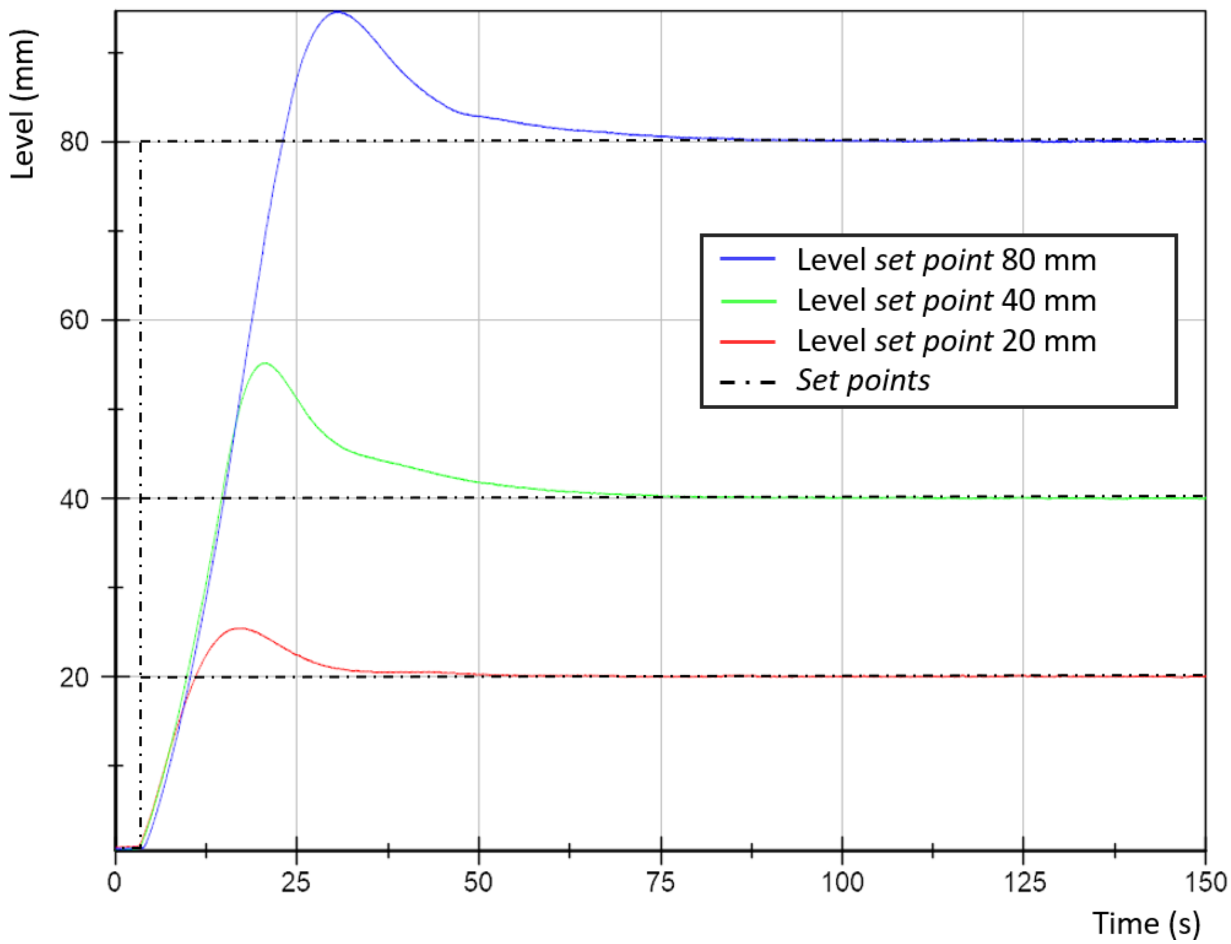

Figure 8: Oil control responses comparison for three different set points

The variable which most influences the oil turbulence inside the transmission box and, consequently generates instability to the controlling, is the gear speed. To validate the controller performance in a rotational scenario and the speed influence, the graphic in Figure 4 presents the comparison of the controlled oil level under the influence of three different speeds.

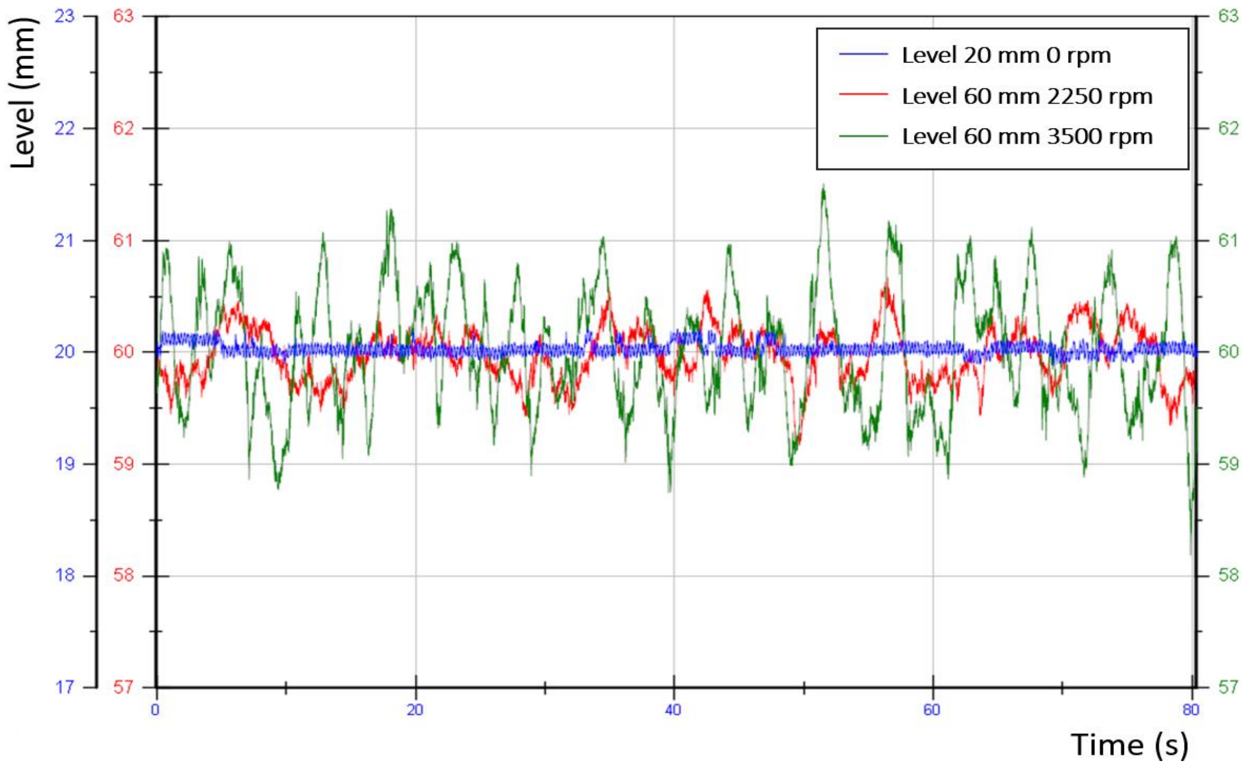

Figure 9 – Oil level stability for different rotational gears speed comparison

CONCLUSION

From the temporal evolution of the oil level of three different set points, it is possible to determinate the flexibility of the control system for a set of amounts of oil volume. Analyzing the stability of the oil level during the tests, it is realizable that the rotational speed has high influence on the control system. However, at the pre-testing speed (2250 rpm) and the testing speed (3500 rpm), the controller maintained the oil level inside the maximum variation permissible of ± 3 mm. By analyzing the step response of the controller, it is possible to say that the restrictions imposed were effective and the volume nonlinearities were no so relevant. Future analysis could be done regardless to the influence of the oil temperature in the system's dynamics and the rotation direction in the oil turbulence.

No longer, all proposed requirements were achieved, the controller proved to be effective in the oil volume controlling, has defined by the fatigue gear testing standards. What enables the presented test center to generate comparable results to similar test centers.

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PREDICTIVE CONTROL DESIGN BASED ON SYSTEM IDENTIFICATION OF AN ELECTRO-HYDRAULIC ACTUATOR APPLIED TO BRAZILIAN SOUNDING ROCKETS AND MICROSATELLITE LAUNCHERS

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ABSTRACT

This paper presents the modeling and control design to new hydraulic actuator being developed for thrust vector assembly applied to Brazilian rockets. Traditionally PID controllers are used for this issue but based on discrete models is proposed a new digital control for best performance. It is based on models obtained from closed-loop system identification of a Brazilian electro-hydraulic actuator using Nitrogen pressure-fed system applied to Sounding Rockets and Microsatellite Launcher (VLM). The vehicles are developed at the Aeronautics and Space Institute (DCTA/IAE) and a new actuator under test is being proposed using Helium gas to the Pressure-Fed-System. Traditionally the Nitrogen gas is used in low pressure operation to feed hydraulically the actuator and a new controller is being implemented to improve the system performance. Simulations developed in AMEsim and Matlab codes show best performance using Helium gas dealing on fast movements to the high pressure hydraulic cylinder, increasing the system bandwidth. The modeling of the hydraulic actuator is presented for linear and nonlinear analysis as well as their influences on system identification algorithms. The fluid flow through the internal pipes and spool are modeled using its nonlinear flow equation while the spool linear dynamics are obtained from Newton's law and the magnet-force from Biot-Savart law. Discrete models are obtained from system identification using experimental data from the hydraulic closed-loop operation while a digital controller is designed based on that discrete models and finally implemented in the loop. A real-time electronic system with digital-to-analog and analog-to-digital converters performs the digital control, using Labview programming environment. The linear and nonlinear dynamics associated to each sub-system are discussed and simplifications hypotheses are presented in order to obtain the Low Order Equivalent System (LOES) to the entire hydraulic actuator, as well as the influences on the predictive control strategy and linear system identification. According to results in time and frequency domain the performance attends the rocket design requirements.

Keywords: electro-hydraulic actuator, control system, system identification

INTRODUCTION

The new electro-hydraulic actuator consists of a hydraulic cylinder mounted on servo-valve system presented in the Figure 1, discussed in Barbosa [7,8] and can perform high linear force, widely applied on linear servomechanisms, e. g. the well-known Thrust Vector Assembly (TVA) or nozzle as shown in the Figure1. A complete knowledge of its dynamics is of very interest for control system design [1, 12], primordially in rockets attitude control design [13] (Sounding Rockets or Launchers). The Figure 1 (left) presents the actual Brazilian hydraulic actuator being developed at DCTA-IAE. The Figure 2 shows the mechanical cylinder, the linear motion sensor and the digital controller in closed-loop operation, discussed in [8].

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Figure 1 - (left) Actuator, (rigth) the TVA.

The modeling process of such multi-disciplinary system is done using mechanical and electronic classical laws: Newton's laws, Fluid Dynamics, Navier-Stokes Equation, Biot-Savart law and Fluid Continuity Equation [3, 4], aided by Bond-Graphs technique [5, 11].

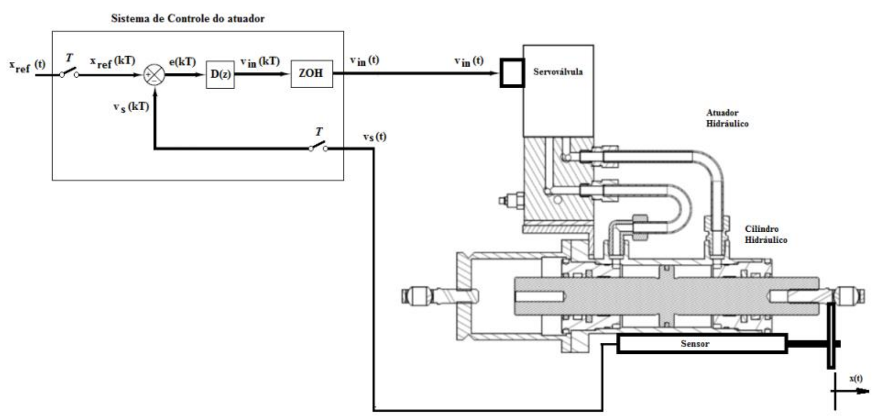

Figure 2 - actuator in closed-loop operation.

SYSTEM MODELING

The TVA system consists of a nozzle or divergent and a flexible joint controlled by a hydraulic actuator, shown in the Figure 3, and the hydraulic subsystem is modeled as an equivalent Wheatstone Bridge.

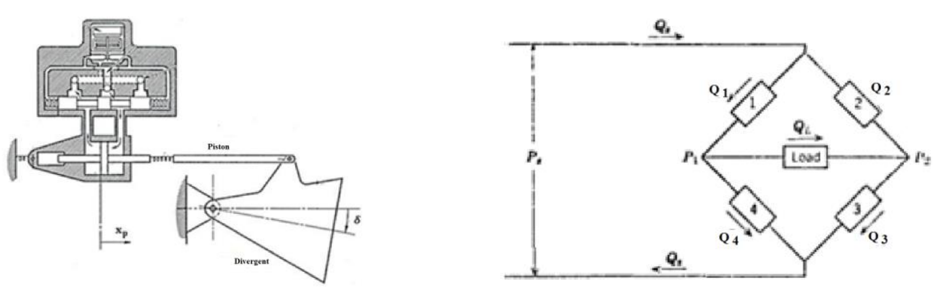

Figure 3 - (left) The servo-valve and nozzle diagram and (right) the equivalent Wheatstone Bridge to the hydraulic system.

Fluid flow through the internal pipes and spool are modeled using the nonlinear flow equation

$$Q_L = C_d A_1 \sqrt{\frac{1}{\rho}(P_s - P_L)} - C_d A_2 \sqrt{\frac{1}{\rho}(P_s + P_L)} \quad (1)$$

and the linearized flow equations are

$$Q_L = K_q \Delta x_v - K_c \Delta P_L \quad (2)$$

$$K_q = \partial Q_L / \partial x_v \qquad K_c = -Q_L / \partial P_L \quad (3)$$

while applying the Newton's law to the piston we get

$$F = Ma = \rho L A_v \frac{d\left(\frac{Q}{A_v}\right)}{dt} = \rho L \frac{dQ}{dt} \quad (5)$$

$$F = AP_L = M_t \frac{d^2 x_p}{dt^2} + B_p \frac{dx_p}{dt} + Kx_p \quad (6)$$

and the magnet-force using the Biot-Savart law becomes

$$dB = \frac{\mu N i}{4\pi L}\left(\frac{L - x_0}{\sqrt{(L - x_0)^2 + d^2}} + \frac{x_0}{\sqrt{x_0^2 + d^2}}\right) d\theta \quad (7)$$

The input voltage to force acting to the spool transfer function is

$$F = \frac{2}{L} \frac{\left(\left(K_p + sK_d + \frac{K_i}{s}\right)(V_{ref} - V_s) - V_T\right)}{\left(s + \frac{2}{L}\left(\sqrt[4]{\frac{4K_F}{\beta^2}} + R\right)\right)} \quad (8)$$

A linear state space model is obtained from the modeling process as follows. The state space model, Eq. (9), is used for open and closed-loop system identification and after that, the discrete controller design is based on these plant discrete models.

$$\frac{d}{dt}\begin{pmatrix} x_p \\ v_p \\ P_L \\ x_{vint} \\ x_v \\ I_s \\ V_{int2} \\ V_{int} \end{pmatrix} = A \begin{pmatrix} x_p \\ v_p \\ P_L \\ x_{vint} \\ x_v \\ I_s \\ V_{int2} \\ V_{int} \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ \frac{2K_d}{L} \\ 0 \\ 1 \end{pmatrix} V_{ref} \quad \begin{cases} a_{12} = 1 \\ a_{21} = -K/M_t \\ a_{22} = -B_p/M_t \\ a_{23} = A/M_t \\ a_{32} = -2\beta A/V_0 \\ a_{33} = -\frac{2\beta}{V_0}\left(C_{im} + \frac{\pi w r_c^2}{32\mu}\right) \\ a_{35} = C_d w \sqrt{P_s/\rho} \\ a_{45} = 1 \\ a_{54} = -\frac{K_s + 2C_d C_v w \cos(\theta) P_s}{M_s} \\ a_{56} = 1/M_s \\ a_{66} = -\frac{2}{L}\left(\sqrt[4]{\frac{4K_F}{\beta^2}} + R\right) \\ a_{67} = 2K_i/L \\ a_{68} = 2K_p/L \\ a_{78} = 1 \end{cases} \quad (9)$$

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$$y = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} x_p \\ v_p \\ P_L \\ x_{vint} \\ x_v \\ I_s \\ V_{int2} \\ V_{int} \end{pmatrix}$$

DIGITAL CONTROLLER DESIGN

The predictive control strategy was applied to obtain a digital closed-loop control based on the discrete models obtained from the linear system identification using experimental data. The predictive controller assumes a 40 step prediction and step of *1 ms* of time duration. The predictive control implementation is based on a matrix predictor as the following equation

$$\hat{y} = Gu + H\hat{u} + Fc \tag{10}$$

where the size of $\hat{y}$-vedtor is the prediction window. In this work the predictor adopted is an adaptation of Eq (10), in the following equation

$$\hat{y} = Gu + Fc \tag{11}$$

The $\hat{y}$ and $\hat{u}$-vectors are as follows

$$\hat{y} = \left[\hat{y}\left(k + \hat{d} + 1\right), \ldots, \hat{y}(k + Hp)\right]^T \qquad u = \left[u(k), \ldots, u\left(k + Hp - \hat{d} - 1\right)\right]^T$$

$$\hat{u} = \left[\frac{u(k-1)}{\hat{A}}, \frac{u(k-2)}{\hat{A}}, \ldots\right]^T \qquad c = [c(k), c(k-1), \ldots]^T \tag{12}$$

The predictive control implementation can be stated as a simultaneous design of F, C and H blocks, in the block structure represented in the Figure (4).

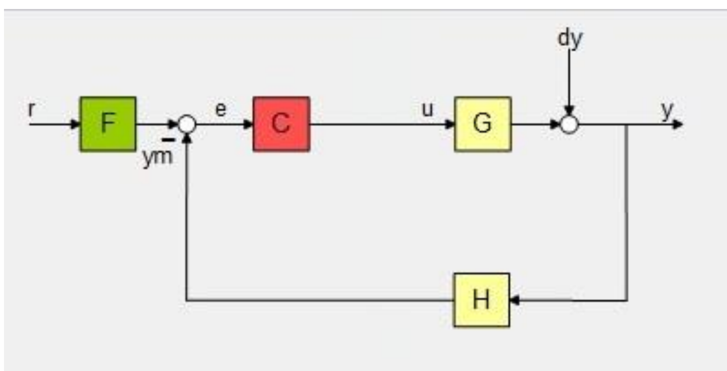


Figure 4 - Block diagram of the predictive control structure.

A cost function is described in the matrix equation and the problem turns on analogous to the Least Squared Problem (LS), so that do exist an optimum solution – and unique – to the parameters.

SYSTEM IDENTIFICATION AND TEST RESULTS

Experimental test was performed using input signal as the Pseudo-Random Binary Signal (PRBS) and Random Gaussian Signal (RGS). The Fig. 5 (left) and (right) show the input time histories as well as the measured piston linear displacement.

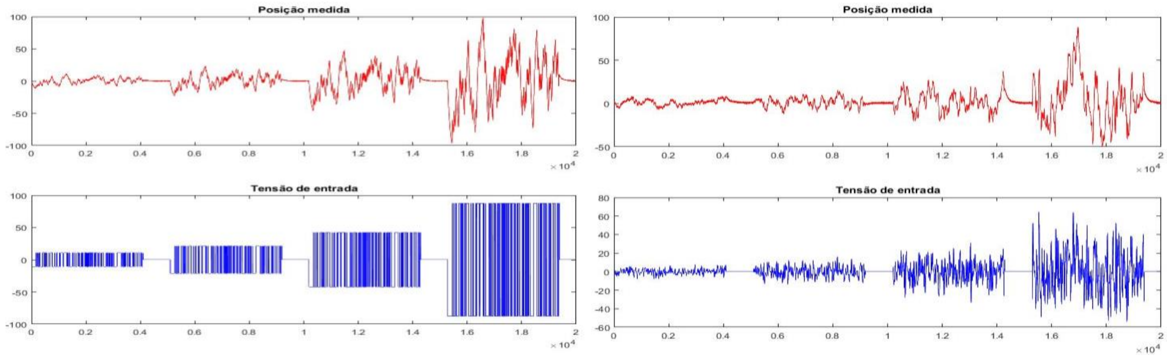
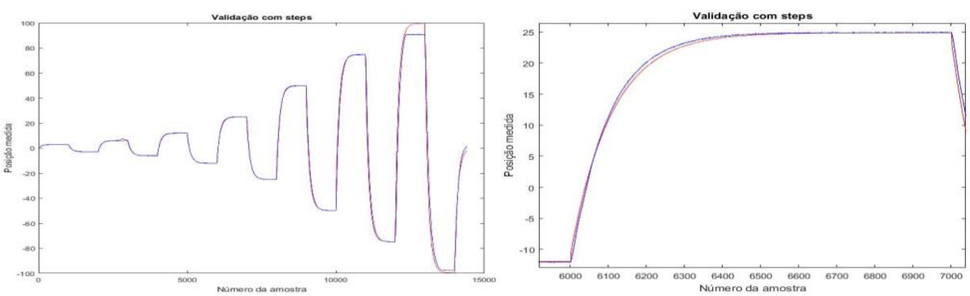


Figure 5 - (Left) Input PRBS (red) and output (red) time histories; and (right) RGS input signal (blue) time history and output linear position (red).

The Akaike information criterion (AIC) is a fined technique based on in-sample fit to estimate the likelihood of a model to predict and to estimate the future values. It uses the information theory and entropy to determine the best regression. The experimental data used for the AIC, and several discrete models were tested regarding to the numerator and denominator order, and the best discrete model obtained consists of one discrete zero and one discrete pole. Assuming the low order equivalent system (LOES) as a typical discrete model, Equation 13

$$\frac{a_2 z^2 + a_1 z + a_0}{b_2 z^2 + b_1 z + b_0} \tag{13}$$

The cost function used for model parameters determination becomes $I(\theta) = 0.5 e^T Q e$, where the e-vector is the error vector, Q is the inverse of the error covariance matrix, I is the cost and θ is the parameters vector. The discrete model validation was performed using another different signal time history, e.g. a unit-step was used. The predictions to the discrete model are shown in the Figures 6 and 7.



(a) (b)

Figure 6 - (a) Predicted output: Input step for validation – experimental (blue) and output prediction from model simulation, (b) detail of step response.

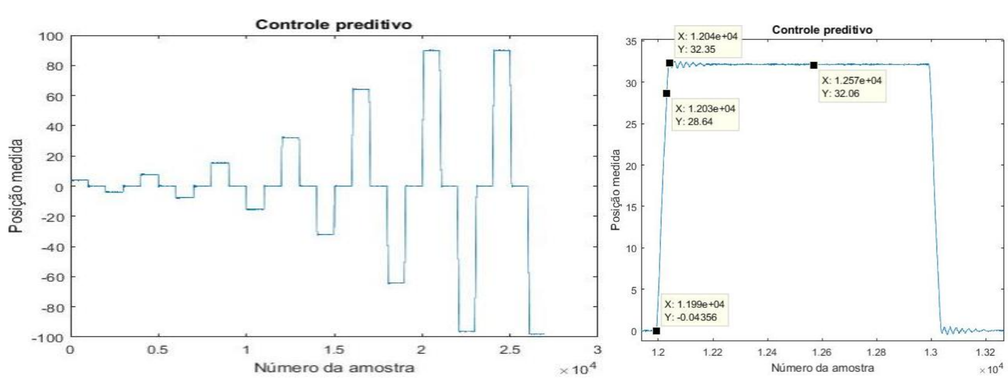


Figure.7 - (left) multi amplitude step input and output response, (right) details in the unit-step response from experimental tests.

The experimental tests were performed using a real-time system named CompactRIO based on the FPGA architecture. The Figures 7 show the results obtained using a step as excitation.

CONCLUSIONS

Step-unit response requirements were obtained from the implementation of the predictive controller, validating the control design. The low order equivalent system discrete model obtained from linear system identification can represent the dynamics of the hydraulic actuator (electronics, servo-valve, cylinder and LVDT linear position sensor) and many control strategies can be accessed to improve time performance due to unit-step of excitation in order to obtain the best closed-loop bandwidth. The linear models were obtained from system linearization, in some cases assuming simplification hypothesis to the nonlinear dynamics, e. g., the electro-magnetic force and fluid flow equation.

This work has shown reliability on model identification procedures that are common in the literature, as the Akaike Information Criterion (to obtain the best model order) and minimization of cost functions (to obtain the best model for a given order). As exposed above, the identification of a low order plant and the development of a controller were obtained very successfully with the presented theory.

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HARDWARE-IN-THE-LOOP SIMULATION OF COMPLEX HYBRID HYDROMECHANICAL TRANSMISISONS

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ABSTRACT

Fuel efficiency and environmental concerns are factors that drive the development of complex solutions for propulsion in heavy working machines. Although these solutions, such as power-split hydromechanical transmissions and hydraulic hybrids, indeed are promising in terms of energy efficiency, they also tend to increase the dependency on accurate, stable control. The realization of this aspect, in turn, relies on continuous testing throughout the development process, usually carried out on expensive, time-consuming prototypes. To lower the development costs and time, hardware-in-the-loop (HWIL) simulations may be introduced as a middle-way between pure prototyping and computer-based simulations. In this concept, some parts of the transmission are represented as hardware while others are included as mathematical models running in real-time in a data acquisition system. This mix of hardware and software allows for high versatility while maintaining a high level of reliability of the results. This paper reports on parts of a study on HWIL simulations of heavy complex hybrid hydromechanical transmissions. Control algorithms for the hardware/model interface in a test rig are derived and their performance are evaluated in HWIL simulations of a mid-sized wheel loader. The results show the importance of fast rig controllers to capture the fast dynamics of the software simulations. It was also found that an important aspect of HWIL simulations is that they are well aligned with their purpose. If so, the simulation yields more reliable knowledge, which is of higher use in the design process of these complex systems. To summarize, HWIL simulations may, if implemented properly, be an important asset in the development of heavy complex hybrid hydromechanical transmissions.

Keywords: hardware-in-the-loop-simulations, hydromechanical transmissions, heavy hydraulic hybrid vehicles

INTRODUCTION

In the strive for energy efficient propulsion of heavy construction machinery, such as wheel loaders, hydromechanical transmissions (HMTs) are competitive alternatives to the hydrodynamic (torque converter) transmissions often used in this application today. Commonly mentioned advantages with HMTs are high power transmission efficiency as well as an ability to decouple the transmission input and output speeds, thereby enabling optimal control of the prime mover [1]. For heavy wheel loaders, so called power-split HMTs with planetary gear trains are typically required to ensure wide operating range with maintained acceptable efficiency of the transmission [2]. To further improve the fuel efficiency, hydraulic hybridisation may be realised by including a hydraulic accumulator in the transmission circuit [3], thereby enabling energy recuperation and thus further fuel savings [4]. Heavy Hybrid HMTs is the focus of this paper.

The high level of complexity of the considered systems implies an increased dependency on control. In the context of developing these transmissions, this increase, in turn, results in a greater need for testing control strategies throughout the development process. Tests of control algorithms are usually carried out in computer-based simulations followed by some sort of validation in a prototype machine. Prototypes are, however, expensive and time-consuming, especially if there are many candidates available for evaluation. As a middle-way alternative, HardWare-In-the-Loop (HWIL) simulations may be introduced as a compromise between computer-based simulations and pure prototyping. In this concept, parts of the system are included as hardware and the surroundings are represented by models executed in real-time. This approach has been common in academia for research on HMTs for some time, see e.g. [5], and the use in the automotive industry has increased as well [6]. The following sections briefly describes a test rig used at Linköping University for HWIL-simulations of complex hybrid HMTs, the control of it and some preliminary results of HWIL-simulations of a mid-sized wheel loader.

TEST RIG

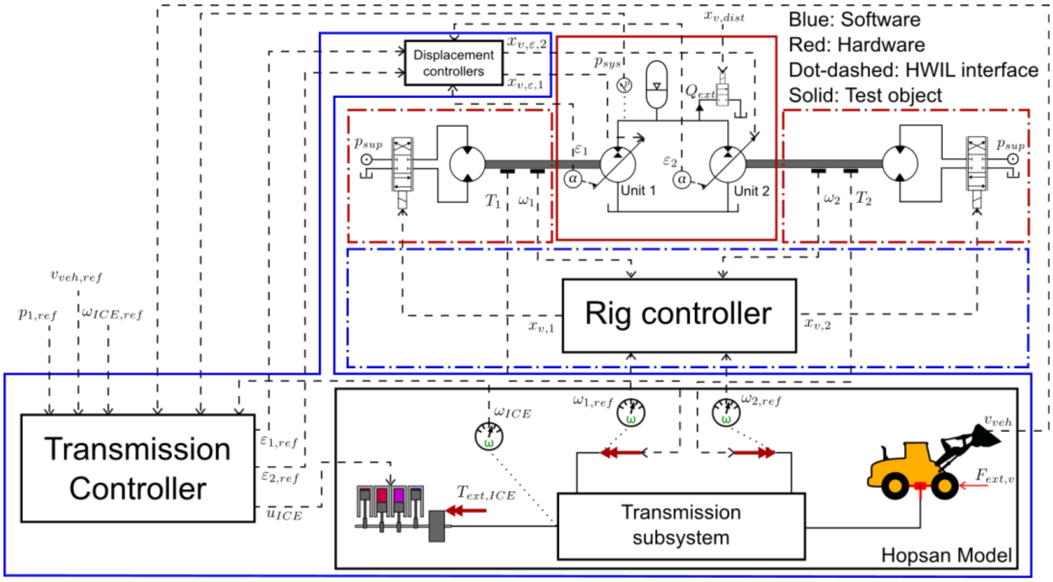

Figure 10 - Overview of the principle of operation of the HWIL simulation test rig used in the study.

Figure 10 shows a schematic overview of the HWIL simulation rig that is used in the study. The "cut" between the model and the hardware is made at the shafts of the two hydrostatic units. The shaft torques are measured and sent to a model of the rest of the transmission (transmission subsystem, engine and vehicle) which calculates the resulting shaft speeds and sends these values as references to the rig controllers. This causality (measure torque → control speed) is motivated primarily by the strong coupling between torque and relative displacement of the hybrid circuit [7]. The rig controllers (compiled Simulink-models) and the Hopsan [8] model are executed in real-time on a National Instruments PXI computer running with a sampling frequency of 1 kHz.

The basic idea of the setup is to validate a control strategy for a certain transmission concept. A Multiple Input Multiple Output (MIMO) control approach that is applicable to a high number of transmission configurations has been proposed earlier by the authors [9] and is used in this paper. The displacement actuators consist of hydraulic servo circuits in the two identical in-line axial piston transmission units (Bosch Rexroth A11, 110 cm3/rev) and the displacements are measured using Hall-effect sensors. The control loops for the displacement controllers have been analyzed and designed by the authors in previous studies [10]. A servo valve is installed in the transmission circuit to study the effects of flow leaving the circuit.

Rig Control

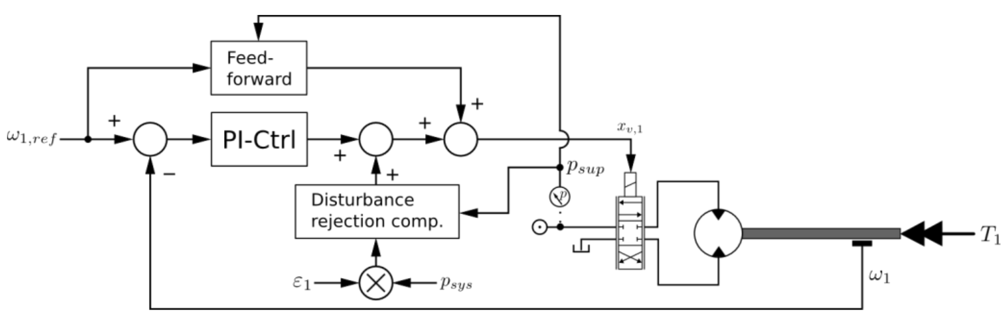

Figure 11 - Principal strategy for the speed control of unit 1.

The control strategy is identical for the two units and Figure 11 shows the strategy of unit 1. The control problem may be described as a valve-controlled hydraulic motor with an inertial load and a disturbance torque. To ensure high reliability of the results, the control must be very stiff and fast, and exactly follow the output of the simulation model. To achieve a high bandwidth a feed-forward term from the reference speed is used. This uses the supply pressure to estimate the valve pressure drop and calculate the necessary valve displacement. Furthermore, the transmission pressure and the measured displacement setting of unit 1 are used to compensate for the torque disturbance. This compensation estimates the required additional valve displacement needed to account for the change in pressure drop over the valve caused by the change in shaft torque. The feedback part handles the modelling errors and consists of a PI-controller with an integrator window to avoid big overshoots of step responses.

RESULTS

Figure 12 shows the performance of the rig controller for a step response without torque load. As can be seen, the control loop is well-damped and fast. It is, however, not infinitely fast, which in turn sets the limit of how fast dynamics may be tested in the final HWIL-simulation.

Figure 13 shows the influence on shaft speed when a step in displacement setting is carried out, with and without disturbance compensation. Clearly, the compensation is needed to avoid too big deviations from the reference. Naturally, perfect rejection is not always possible to achieve in all operating points, which further emphasizes the limitations in what dynamics that may be tested in the final HWIL-simulation.

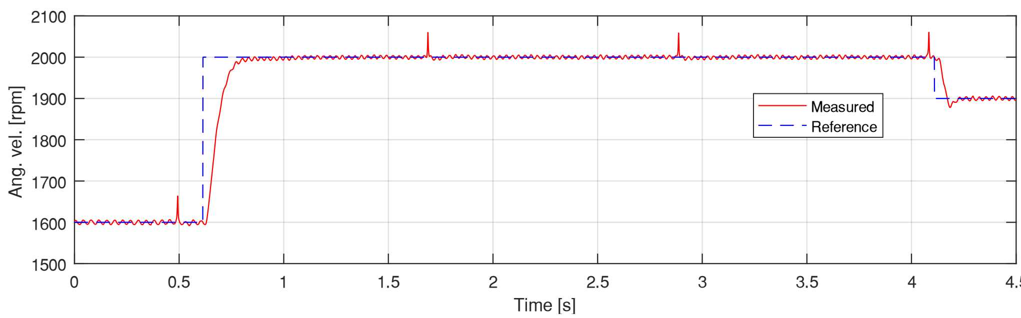

Figure 12 - Step response of the unit 1 shaft speed controller, with zero load.

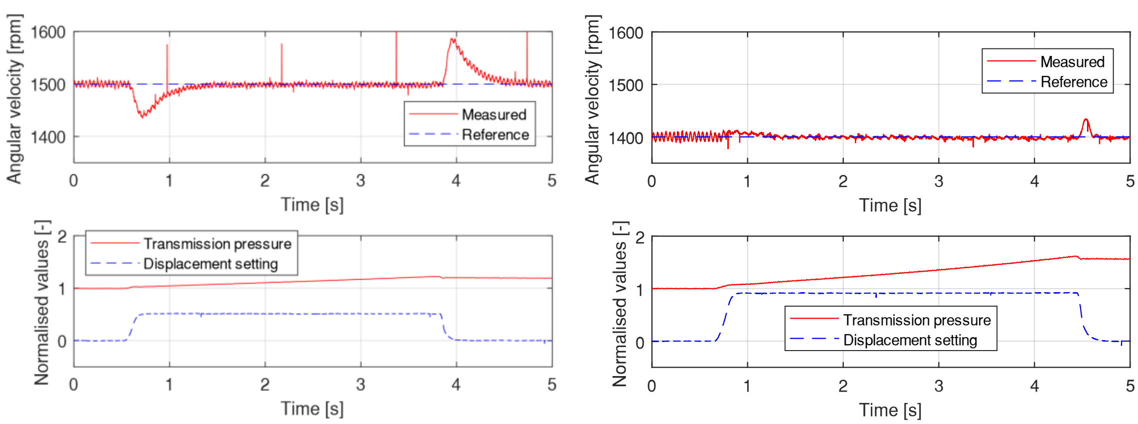

Figure 13 - Disturbance rejection (step in unit 1 displacement) of the unit 1 speed controller without (left) and with (right) compensation. Note that the transmission pressure curve has been normalized with a value of 100 bar. Note also the significantly bigger step magnitude in the right graph.

Figure 14 shows the results of a short HWIL-simulation of an example vehicle, a wheel loader with a mass of 5500 kg equipped with an Input-Coupled Power-Split (ICPS) hydraulic hybrid transmission (see [8] for more details). In this example, the engine speed is controlled at 1600 rpm and the transmission pressure is controlled at 100 bar. In an ICPS hydraulic hybrid, the unit 1 speed is determined by the engine speed and the unit 2 speed is a consequence of the vehicle speed and the engine speed. As can be seen, the rig controllers manage to follow the model outputs with acceptable response. The reference is ramped to ensure that too high response, and thus non-realizable HWIL-simulations, are required. In an ICPS hydraulic hybrid, the vehicle output torque is determined by the unit 2 displacement, which may be observed in the measurements. To maintain a constant pressure in the transmission circuit, the displacement of unit 1 compensates for the flow caused by unit 2. This may be observed as the curve for the unit 1 displacement mirrors that of unit 2 in the measurements.

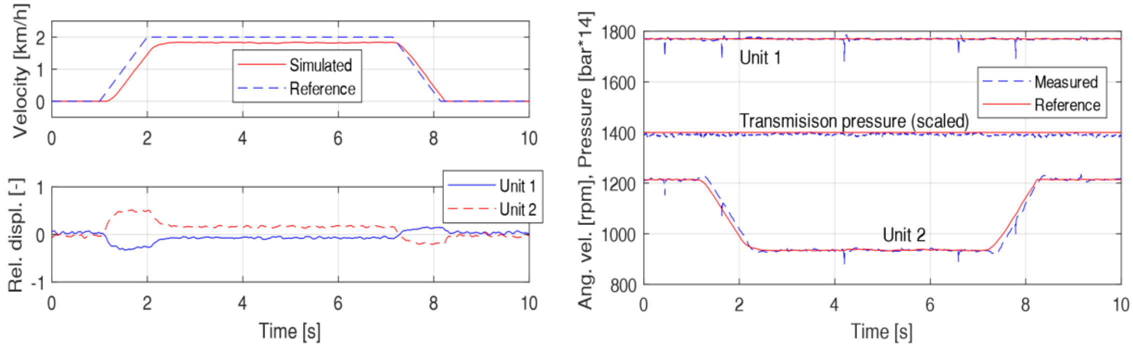

Figure 14 - Tentative HWIL-simulations of an example vehicle. Left: Vehicle speed and relative unit displacements. Right: Transmission units shaft speeds and transmission pressure (scaled).

CONCLUSION

This paper presents preliminary results of a study on HardWare-In-the-Loop simulations of heavy complex hydraulic hybrid transmissions. A test rig suitable for the topic is presented and a structure and control strategy for the HWIL-simulations are proposed. The results show the importance of decoupling the torque and speeds in the interface between the hardware and the software in the simulation, to maximise the reliability of the results. Furthermore, the bandwidth of the rig controllers cannot be ignored, as they set the limit of the testable system dynamics. For a simple test case of a mid-sized wheel loader equipped with an input-coupled power-split hydraulic hybrid transmission, the proposed set-up performed satisfactory results that may be used as validation of the transmission control strategy. Future work will primarily involve testing of more realistic drive cycles for the example vehicle.

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