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NEW METHODOLOGY FOR INDENTIFICATION OF THE DEAD ZONE IN PROPORTIONAL DIRECTIONAL HYDRAULIC VALVES

Antonio Carlos Valdiero
UNIJUÍ – Regional University of Northwestern Rio Grande do Sul State
Technology Department – Postal Box 121, Av. Rudi Franke 540, CEP 98280-000, Panambi/RS, Brazil
e-mail: valdiero@unijui.tche.br

Raul Guenther
UFSC - Federal University of Santa Catarina
Mechanichal Engineering Departament - Postal Box 476, CEP 88040-900, Florianópolis/SC, Brazil
e-mail: guenther@emc.ufsc.br

Victor Juliano De Negri
UFSC - Federal University of Santa Catarina
Mechanichal Engineering Departament - Postal Box 476, CEP 88040-900, Florianópolis/SC, Brazil
e-mail: victor@emc.ufsc.br

Abstract. *This work presents a new methodology for indentification of the dead zone nonlinearity in proportional directional hydraulic valves, it is based on observing the dynamic behavior of the pressure in the valve gaps. In the hydraulic valves, the dead zone is common because its spool occludes the orifice with some overlap, so that for a range of spool positions there is no fluid flow. The dead zone nonlinearity is among the key factors limiting both static and dynamic performance of feedback control hydraulic systems. The main idea is to cancel the harmful effects of dead zone by implementing its fixed inverse inside the controller. The inverse is caracterized by a set of parameters that need to be estimated. The classic parameter indentification needs flow transducers that are expensive. In this paper, a new methodology for indentification of the dead zone parameters is proposed that needs only pressure transducers. Experimental results illustrate this methodology that is cheaper and faster.*

Keywords*: dead zone nonlinearity, hydraulic valves, dead zone identification.*

1. Introduction

This work presents a new methodology for identification of dead zone nonlinearity in proportional directional valves, which is based on the study of pressure dynamic behavior in valve gaps. The dead zone nonlinearity is a common imperfection of mechanical system components and mainly of closed center valves when the land width is greater than the port width at neutral spool position (Virvalo, 1997). The presence of dead zone in the system is among the factors that limit the performance of feedback control loops (Sobczyk, 2000; Cunha et al., 2000;Valdiero, 2005), but components without such imperfections are costly to manufacture and their maintenance usually requires specialized personnel (Tao and Kokotovic, 1996). Besides, the dead zone can be desired in some cases, for example hydraulic valve applications in an automotive suspension system, where dead-zone's purpose prevents the leakage and maintains the height when the car is parked and the engine is turned off. However, in this same example, when the suspension is active, the effect of the dead zone is harmful and needs to be "removed" by compensation in control scheme. Therefore, the dead zone nonlinearity requests a methodology for identification of their parameters, and so their degradation effects can be reduced by adequate compensation (Bu and Yao, 2000; Cunha et al., 2002; Valdiero, 2005).

The paper is organized as follows. In section 2, the dead zone model is presented as in Tao and Kokotovic (1996). In section 3 it is shown as dead zone nonlinearity appears in proportional directional valves. In section 4, the new methodology for identification of dead zone in hydraulic valves is described including the test rig used. Conclusions are outlined in section 5.

2. Dead zone model

This section presents the mathematical model for dead zone nonlinearity and its graphical representation that makes it easy to understand. Dead zone is a static input-output relationship which for a range of input values gives no output. Figure 1 shows a graphical representation of the dead zone, when u is the input and u_{zm} is the output. In general, neither the break-points ($zmd \geq 0$, $zme \leq 0$) nor the slopes ($md > 0$, $me > 0$) are equal. The dead zone analytical expression is given by the Eq. 1.

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

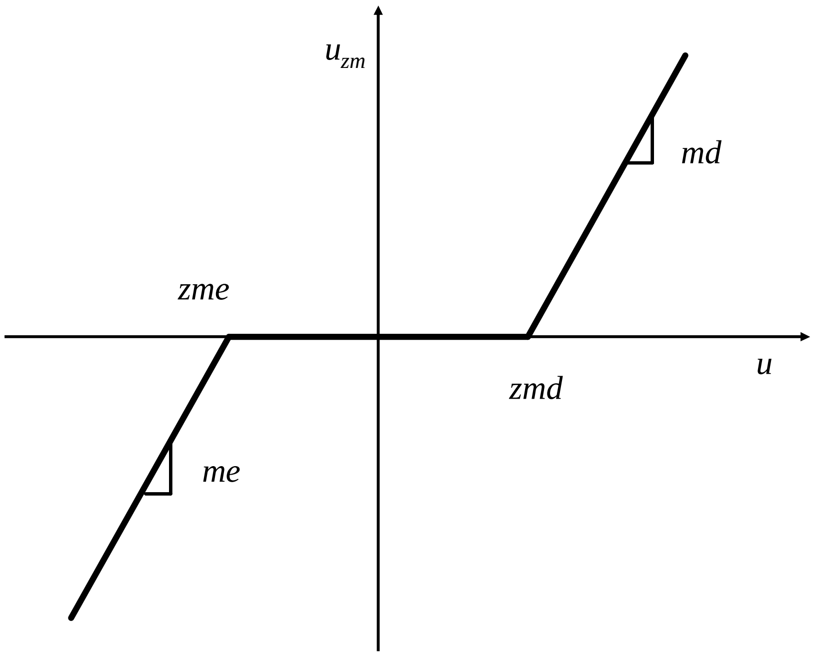

Figure 1. Graphical representation of the dead zone.

3. Dead zone in proportional directional valves

In proportional valves of directional control, dead zone is located at the dynamic system as a block diagram shown in Fig. 2. To understand this phenomenon better, will be presented a detailed depiction of four-land-four-way spool valve components and its working.

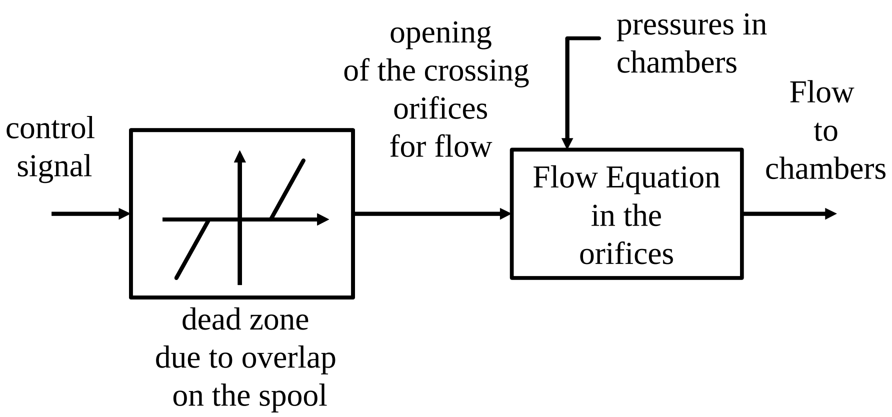

Figure 2. Block diagram of the proportional valve with input dead zone.

Figure 3 shows a sectional view sketch of typical spool valve with main mechanical elements that can be used as a proportional valve. The control signal *u* energizes valve's solenoids that a resulting magnetic force is applied in the valve's spool. If there isn't control signal, centering spring's forces centralize the spool to obtain a null position. An example of commercial four-land-four-way spool proportional valve NG6 BOSCH is shown in Fig. 4.

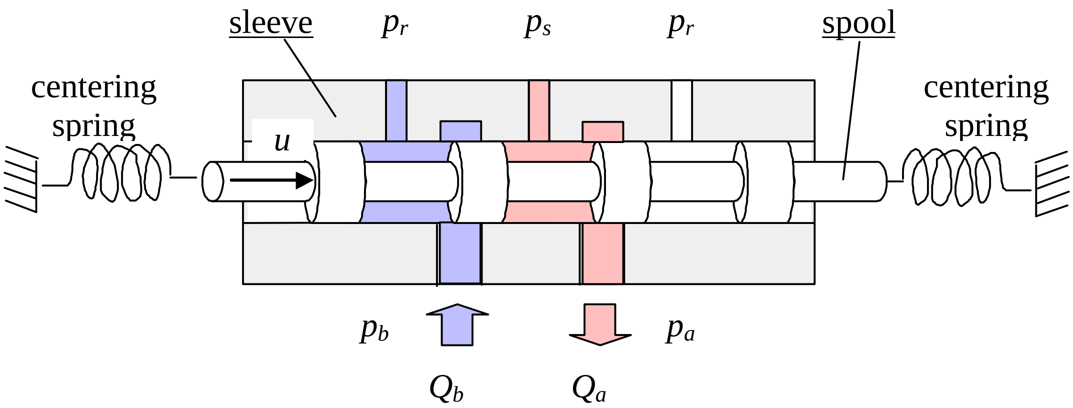

Figure 3. Sectional view sketch of typical spool valve with main mechanical elements.

In closed center or overlapped valves, the land width is greater than the port width when the spool is at null position, resulting the presence of the dead zone nonlinearity (Merrit, 1967). The dead zone nonlinearity is among the key factors causing delay and error in the system's response.

In proportional valves, it is a good idea that the relation between flow rate and control signal is linear. This relation is also damaged by the presence of the dead zone if there isn't compensation. A detailed description of flow rate characteristics and modelling of spool valves can be found in De Negri and Kinceler (2001) and Rodrigues et al. (2003).

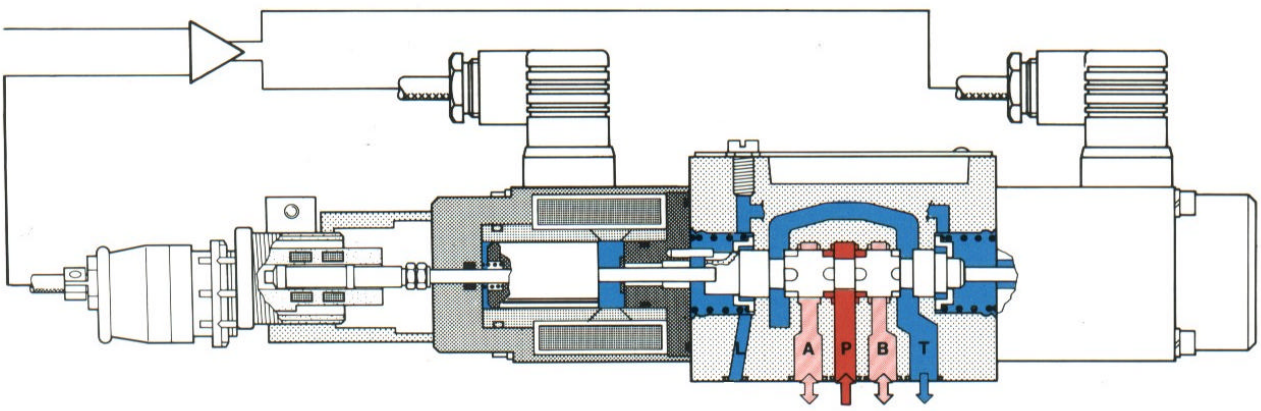

Figure 4. Example of commercial four-land-four-way spool proportional valve NG6 BOSCH.

4. Identification of the dead zone nonlinearity in valves

This section presents a new methodology as an alternative for classical procedure of the dead zone identification in overlapped proportional valves (Iso, 1998). In classical procedure, the dead zone identification in spool valves can be experimentally made in test installation with flow rate transducer, according to Rodrigues et al. (2003). Such flow rate transducer is expensive and these experimental tests can result in unacceptable cost for aspired application.

In this context, it is presented some steps for dead zone identification by dynamic analysis of pressure's behavior in actuator system. Proposed tests can be taken without special test installation or expensive instrumentation, requesting only pressure transducers. Such pressure transducers have a more acceptable price and many times they already are available in feedback control loops.

Experimental tests were taken in Laboratory of Hydraulic and Pneumatic Systems (LASHIP) of the Federal University of Santa Catarina (UFSC), where the test rig is described in section 4.1. The proposed methodology for identification of valve's dead zone is presented in section 4.2. A detailed analysis of pressure's behavior in actuator system is shown in section 4.3.

4.1. Test rig

Figure 5 presents the main components of experimental setup. It consists of a double acting cylinder (2), a proportional valve NG6 BOSCH (4) and its electronic card, position transducer (3), pressure transducers (5 and 6), an acquisition and controller board dSPACE (1), and a hydraulic power unit (7). The dSPACE board is assembled in a PC microcomputer and composed by 4 analog inputs (ADCs) and 4 analog outputs (DACs) as shown in Dspace (1996) . Sensors permit to measure actuator chamber pressures (p_a nd p_b), actuator position and spool position.

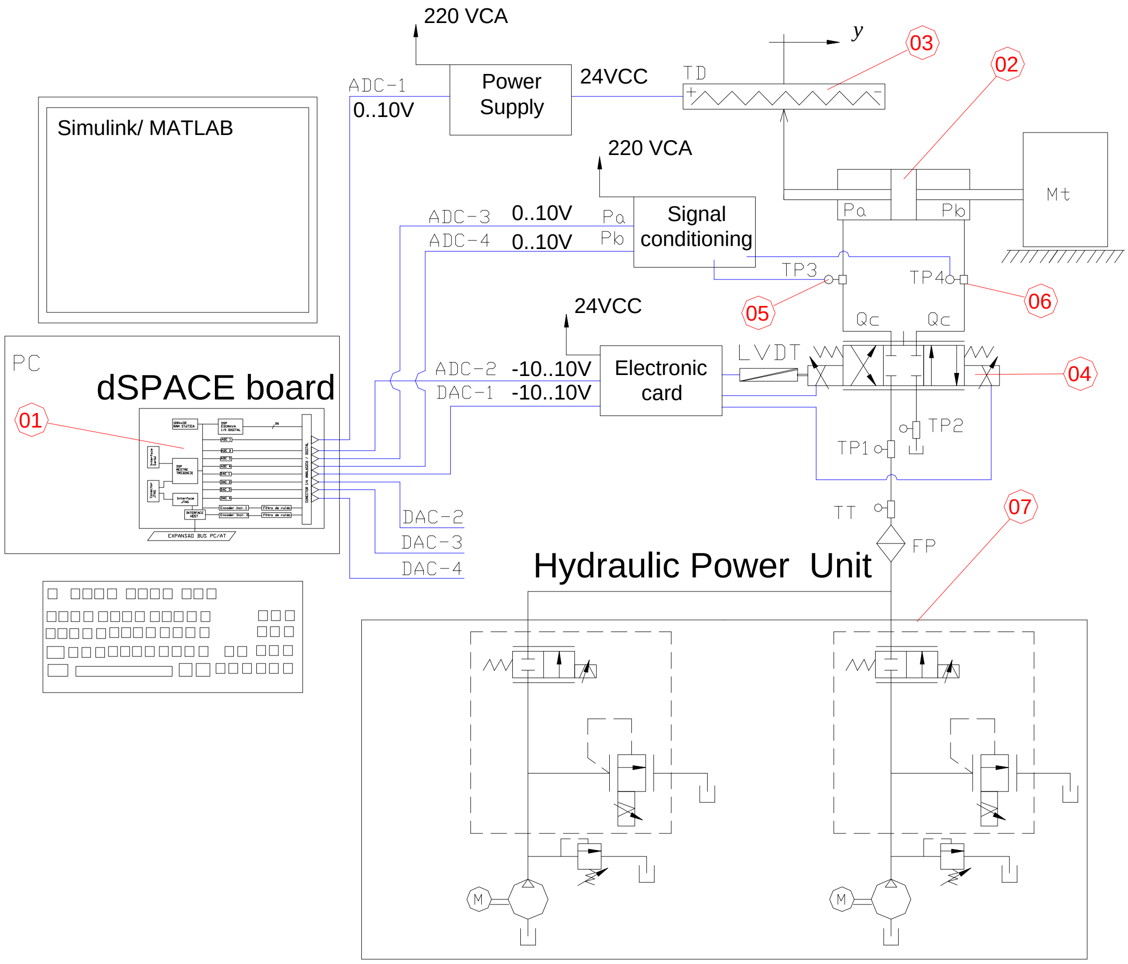

Figure 5. Experimental setup with main components.

4.2. New identification methodology

The proposed methodology is composed by open-loop's tests of actuator system (valve and hydraulic actuator) with a slow sine control signal (10 volts amplitude and 100 seconds period), as for example it is shown in Eq. 2, pressure's measurements and analysis of their behavior as a function of the control signal.

$$u(t) = 10\sin(2p\, t/100) \quad (2)$$

The slopes of dead zone (*md* and *me* as show in Fig. 1) can be regulated such as $md = me = 1$ in electronic card of the proportional valves. Such slopes are a relation between control signal and spool displacement.

Using such open-loop's tests, the steps below are followed.

At the first moment, it is observed the p_a pressure graphical in the valve gap for the *u* control signal range from -10 to 10 Volts (Fig. 6), as it is shown in Fig. 7. In this graphical, it is possible to estimate the right dead zone value (right break-point) with the knowledge of the pressure's dynamic behavior.

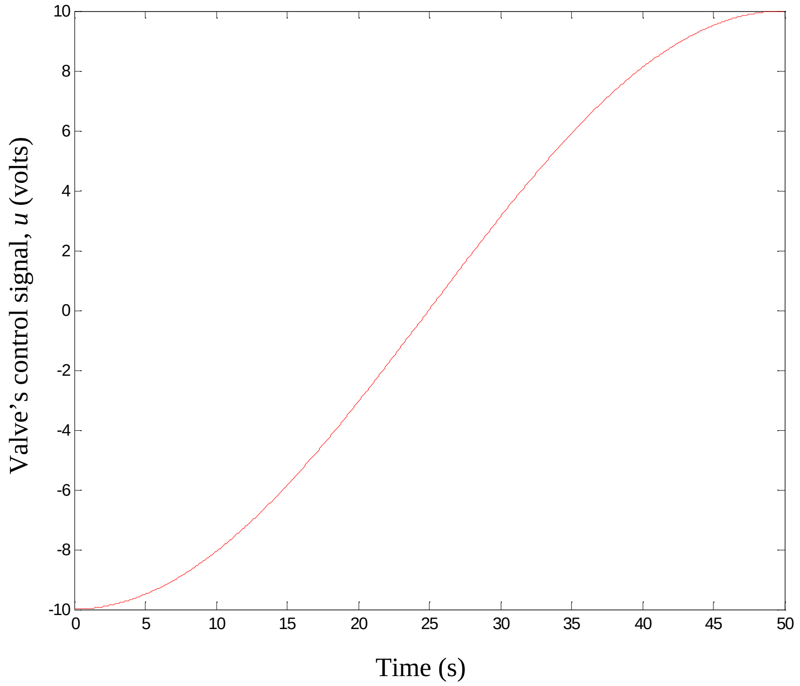

Figure 6. Interval of valve's control signal used to estimate the right dead zone value (right break-point).

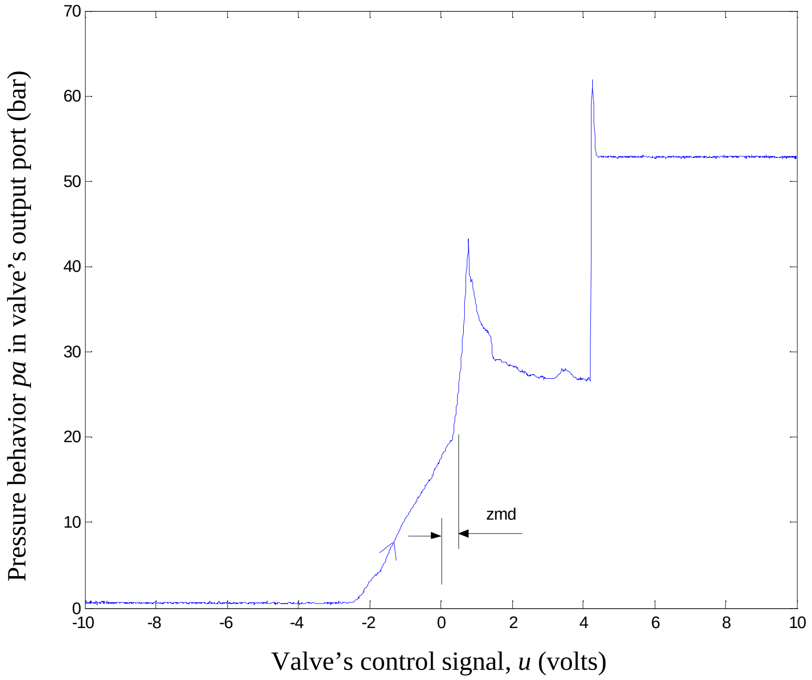

Figure 7. Pressure behavior p_a in valve's output port and the evidence of the right dead zone value.

In the range that consists of the control signal from -10 to -2 Volts, the valve is opened so that flow issues from the "*a*" port to the tank, the pressure in this port leans to tank's pressure and there isn't piston's movement when in retracting position. When the valve begins to blockade the control orifices and the control signal is next to null value, the valve's leakages are considerable and they have smooth influence in pressure's variation. At the moment that control signal crosses the right dead zone value (right break-point, *zmd*), there is a sudden pressure's variation as it is shown in Fig. 7. A detailed study of flow rates in control orifices is presented in De Negri and Kinceler (2001).

In the next step, the graphical of the p_b pressure is analysed in the valve gap for the u control signal range from 10 to -10 Volts (Fig. 8), as it is shown in Fig. 9. The same thought previously described can be used when the control signal crosses the left dead zone value (left break-point, *zme*). In this case, there is a sudden pressure's variation as it is shown in Fig. 9.

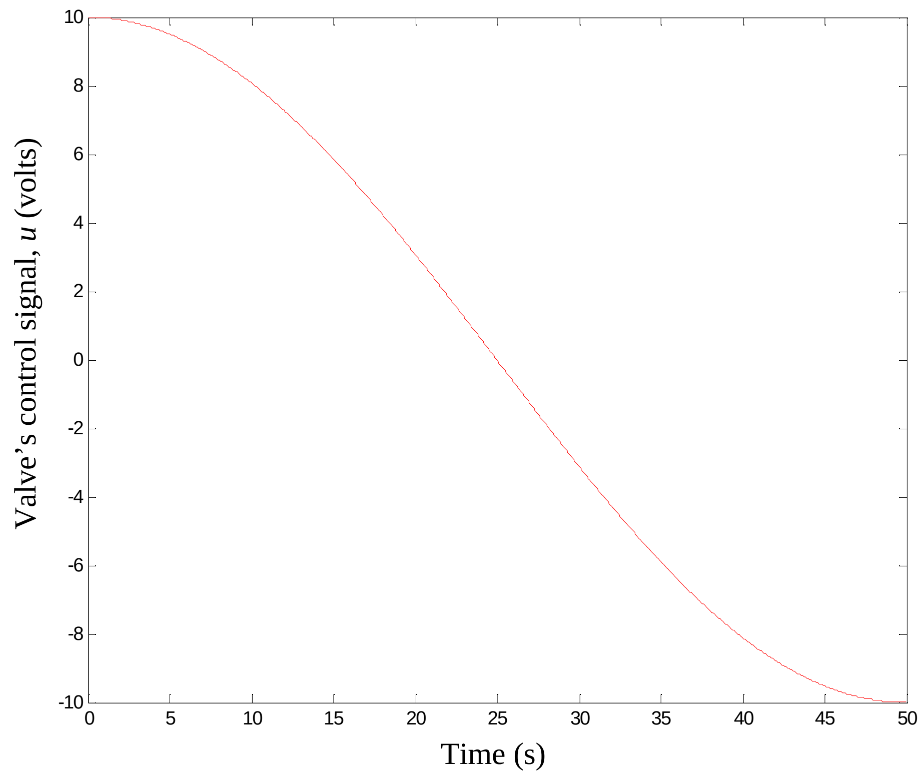

Figure 8. Interval of valve's control signal used to estimate the left dead zone value (left break-point).

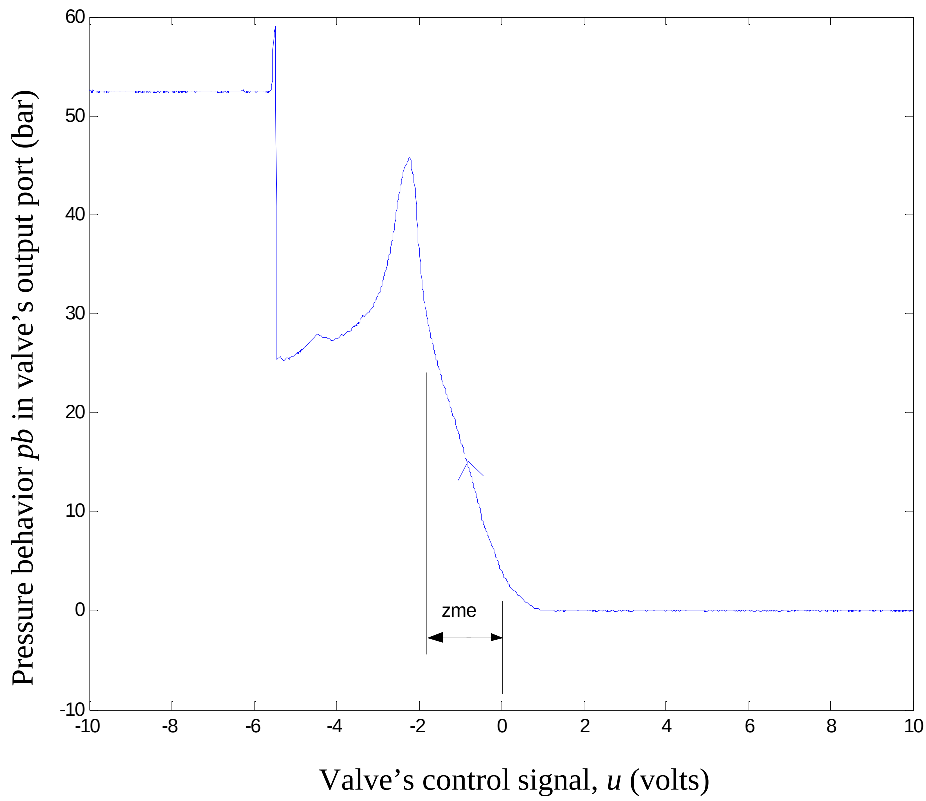

Figure 9. Pressure behavior p_b in valve's output port and the evidence of the left dead zone value.

4.2. Analysis of pressure's behavior in actuator system

Both pressures behaviors as a function of control signal can be represented in only figure as in Fig. 10. In this graphical representation, the control signal value was added with the constant offset value such that the dead zone values (*zmd* and *zme*) are identical. The offset value can be important in some control applications.

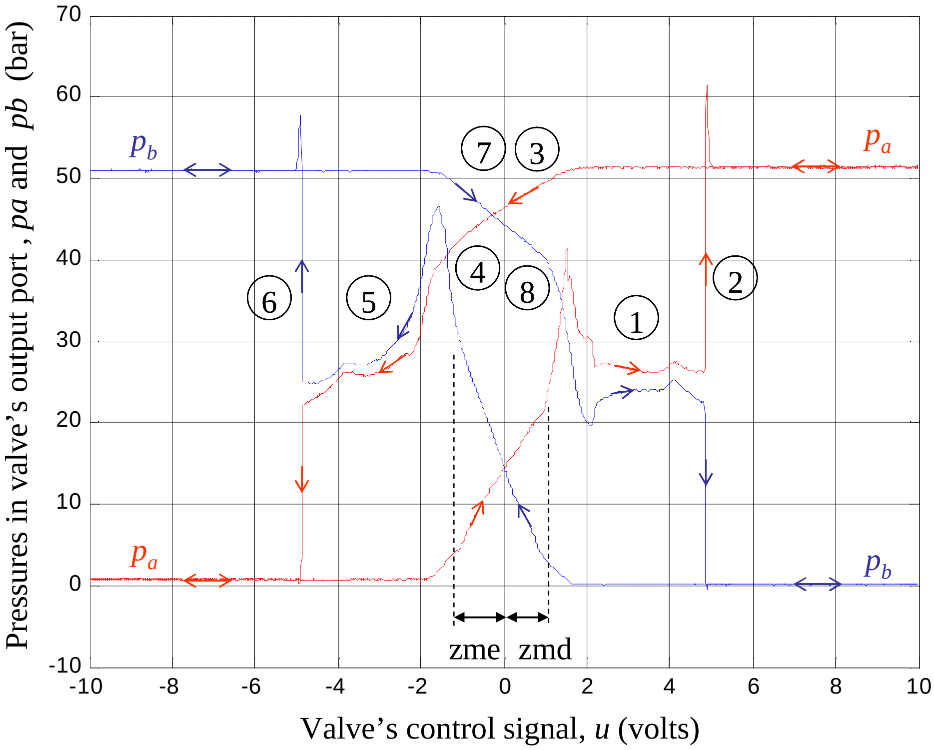

Figure 10. Graphical representation of the dead zone values (break-points) and the enumeration of the pressure behavior branches.

For the best comprehension of Fig. 10, some pressure behavior branches are enumerated and commented in Tab. 1. This table describes the behavior of the hydraulic system's elements during experimental tests.

Table 1. Behavior description of the hydraulic system's elements for the enumerated pressure branches in Fig. 10.

Branches	Control signal	Flow rates	Pressures	Cylinder's piston
(1)	$zmd < u < 4.85$	Cross cylinder chambers	Maintain necessary difference to movement	Travel to positive position
(2)	$4.85 \le u \le 10$ and $10 > u \ge 2$	There aren't flow rates to the chambers and the leakages aren't considerable.	Become quickly equal to tank's pressure and supply's pressure	Remain stopped at the end of its stroke.
(3) and (4)	$zmd > u > zme$	Leakages are considerable	Vary due to the leakages	Remain stopped
(5)	$zme > u > -4.85$	Cross cylinder chambers	Maintain necessary difference to movement	Travel to negative position
(6)	$-4.85 \ge u \ge -10$ and $-10 < u \le -2$	There aren't flow rates to the chambers and the leakages aren't considerable.	Become quickly equal to tank's pressure and supply's pressure	Remain stopped at the end of its stroke.
(7) and (8)	$zme < u < zmd$	Leakages are considerable	Vary due to the leakages	Remain stopped

5. Conclusions and future work

This paper presents a new methodology that addresses the experimental dead zone identification, based on the pressure dynamic behavior in the valve gaps. Dead zone is a typical nonlinearity in proportional directional hydraulic valves and it is treated as imperfection of mechanical components.

The dead zone analytical model is characterized by set of parameters and the main aspect considered is its identification. The results of this paper show that is possible to obtain the parameters to dead zone model, in a simpler and easier way, based on observing the dynamic behavior of the pressure in the valve gaps.

This methodology is cheaper than the conventional ones because it needs only pressure transducers. With this paper, the authors intend to contribute in the study and research of advances in proportional hydraulic control to open the doors to new industrial applications for these systems.

In future works, the authors intend to apply this methodology in the case of non-symmetrical proportional valves.

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