CONTROL OF A PNEUMATIC SERVOSYSTEM USING FUZZY LOGIC

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The servodrive analyzed here consists on a large stroke actuator of 2 meters, activated by a flow proportional valve. The aim of the Ph.D. is to achieve a successful control of the actuator despite it having big chambers, which has a big influence on the system response, owing to the air compressibility. For the experimental study, a test bench has been built and a magnetorrestrictive sensor of displacement is used in order to close the loop. Before starting the control of the system and in order to know how the pneumatic servo drive reacts, the interaction of the actuator and valve set has been studied by means of Bond Graph technique.

At first, the PID control was applied in pneumatic servodrives, after seeing its several problems, state control algorithm started to be applied. The state loop control algorithm reaches a good result, however in cases where a system parameter changes it is necessary to retune the state variable gains (position, velocity and acceleration), above all in this particular case. It is here where Fuzzy Logic reasoning could be used.

Key words: Servo pneumatic drive, bond graph, state loop control, fuzzy controller.

1 INTRODUCTION

The electro-pneumatic control systems are widely applied in the industrial automation technology, especially, when action is controlled by using programmable logic controllers.

Conventionally, when a control must be optimised, we have to build up a mathematical model, Astrom (1999) and Ogata (1996, 1998). The control performance of a traditional controller fully depends on the accuracy of a known system dynamic model. The complex pneumatic servodrive positioning process has non-linear and time varying behaviours; thus it is difficult to derive and identify an appropriate dynamic model for traditional controllers, Ming (1992, 1995, 1998). Then the control system should be analysed and a controller can be designed. It is very difficult to get an accurate and linearised mathematical model; therefore the fuzzy control technology is applied.

As it is well known, Zadeh, Zimmermann (1991), originates the fuzzy theory in 1965. In recent years, the control technology has been well developed and has become one of the most successful tools in the industry. In fact, nowadays, there are several programmable logic controller dealers who offer fuzzy control tools in their products..

This kind of control has been applied in the industrial world (process and automation) giving an optimal effect, Klein (1993). The results of this application have demonstrated that the fuzzy control shows better benefits in comparison with that those offered by other PID controllers. The main advantages of the fuzzy controller are these, Sorli (1998, 1999):

- It is not necessary to build a detailed mathematical model. Despite this, in the present work, this point is considered by means of Bond Graph Technique.
- The fuzzy controllers have a high strength and a high adjustment.
- They can operate with a high input number.
- They can be adapted easily into non-linear systems.
- The human knowledge can be easily applied.
- The process development time is relatively lower.

The essence of fuzzy logic control is that appropriate linguistic fuzzy rules are chosen, using some decision-making process, from a rule table constructed using human control experience and databases. In the present work the fuzzy rules are established by trial and error with the concept of symmetry. Fuzzy set theory is employed to simulate the logic reasoning of human beings.

Fuzzy control has been demonstrated to provide highly satisfactory results in terms of accuracy, repeatability and insensitivity to changes in operating conditions, Ferraresi (1990). Classic controls satisfies the requirements for stability, accuracy and rapid response; providing that there is an optimal match between the real values of the system's physical parameters and the values used for control design, and there is no external interference (change in load). Advanced control techniques (e.g. optimum, robust, self tuning) requires highly sophisticated and complex control algorithms if they are to be any effective use.

Applying fuzzy control to a continuous pneumatic positioning system is particularly advantageous in terms of simplicity of design and implementation, and thus significantly reduces the time required to develop the entire system, Ferraresi (1989, 1994). Experience shows that the success of a fuzzy control depends on the level of knowledge concerning the positioner's physical behaviour.

2 LAYOUT OF THE EXPERIMENTAL DEVICES

The functional pneumatic positioning system with fuzzy control is shown in figure 1. The actuation element consists of a double-acting pneumatic rodless cylinder with bore of 40 mm, and a stroke of 2000 mm. The cylinder is a Heavy Duty model of Norgren - Herion. The cylinder chambers are connected to a flow rate proportional valve, the ISO 1 Isotron model of Norgren (1000 Nl/min). The flow proportional valve has an internal position closed loop, an a cutoff frequency of 80 Hz.. The system incorporates provision for varying the inertial load acting on the actuator bore.

A magneto restrictive analog sensor of displacement closes the loop in terms of position; this sensor can give the speed signal also offering a high resolution. The Fuzzy Controller generates valve control signals by processing the resident program on the basis of measured magnitudes. The fuzzy system consists of a National Instruments Data Acquisition Card (model PCI 1200), the control program is run under Labview, and Labview Fuzzy Toolbox is also used. For the control system, an electrical cupboard has been built. This rack and the pneumatic system are shown in figures 2a and 2b.

The rule sets and the membership functions for input and output variables are transferred to the fuzzy processor. Rules and functions are written using the National Instruments Fuzzy Logic Toolbox. The fuzzy inference process used by the controller is the min-max-center of gravity method.

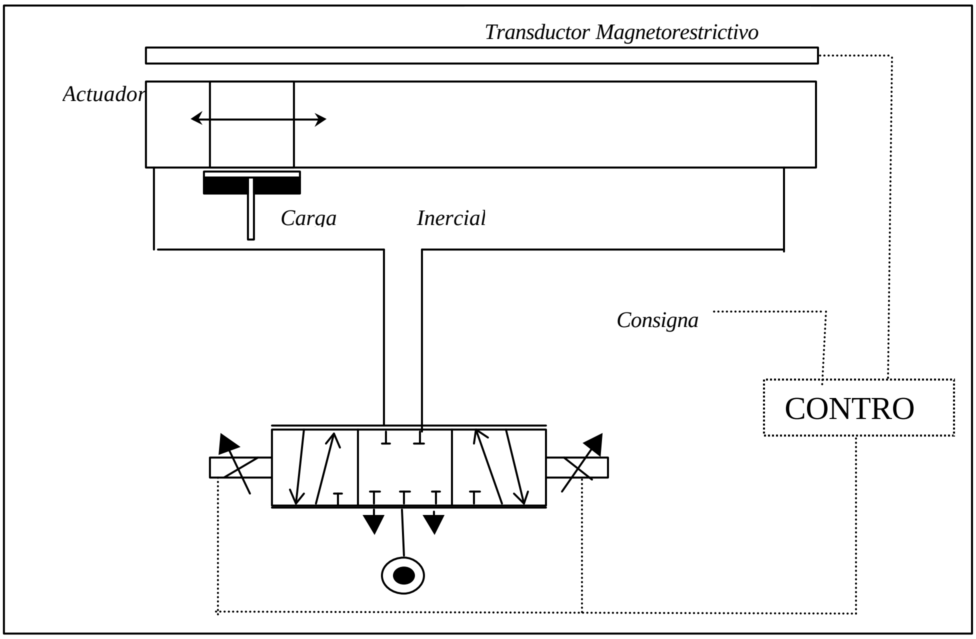

Figure 1.- Positioning System.

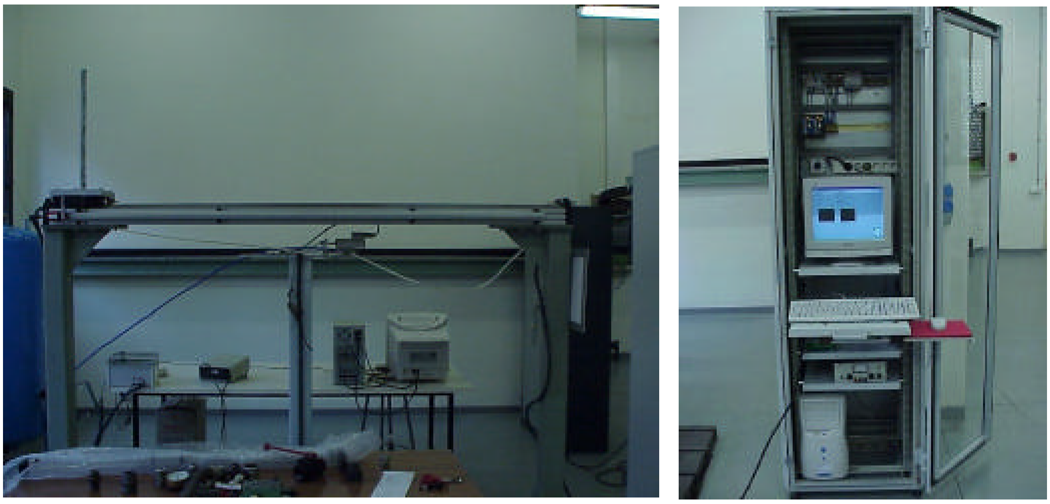

Figure 2a. 2b.- Pictures of the pneumatic positioning system.

3 SYSTEM CHARACTERISATION

As explained before, the positioning system basically consists of a pneumatic actuator operated by a servovalve with a position closed-loop. Pneumatic actuator performance can be determined at first approximation by steady state tests. The real working conditions including coupling between actuator and proportional valve, cannot be completely achieved if the design specifications require reduced motion times. Coupled system characteristics can only be evaluated by performing a dynamic analysis of the system, specially dealing with short stroke heavy loaded actuator or long stroke low loaded actuator.

Assuming the type of actuator, single or double acting, with stiff or flexible wall and supposing that the power regulation element has been chosen, the parameters that influence the dynamics of the actuator are:

- The sizes and geometry of the chambers, defined by the linear or rotary stroke, bore and rod, in the linear actuators.
- The type of seals and the mobile support, which exert a strong influence on friction forces.
- The size of the regulation valve.
- The length and dimension of feeding pipes.
- The magnitude to be controlled by the actuator (force, position or velocity).
- The level of supply pressures.
- The entity of disturbances related to the controlled magnitude.

The above mentioned parameters interact in a very strong non-linear way. The servo system performances also strongly depends on the control strategy.

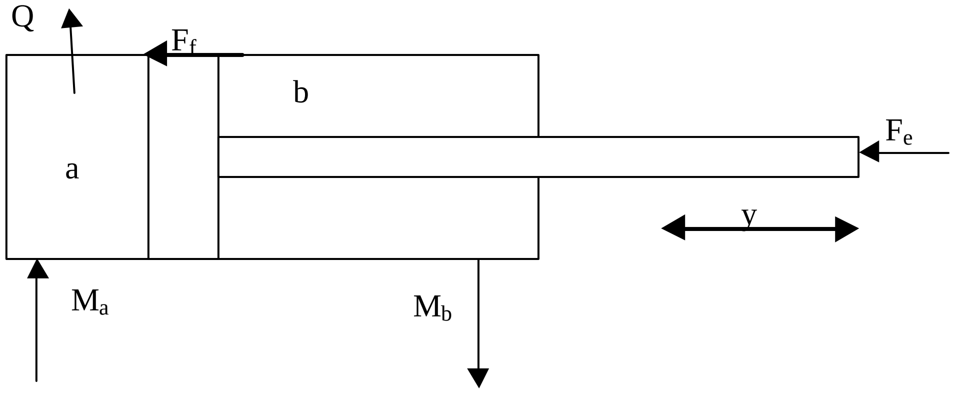

Figure 3. - Drive parameters.

One of the first researchers to model the pneumatic system was Burrows (1968). In the research work, the author suggested to feedback the state variables. Applying the first principle of thermodynamics, and the equilibrium forces, the pneumatic system is characterised as follows:

$$\frac{dP_a}{dt} = grT_s \frac{\dot{M}_a}{V_a} - gP_a \frac{\dot{V}_a}{V_a} \qquad [1]$$

$$\frac{dP_b}{dt} = grT_s \frac{\dot{M}_b}{V_b} - gP_b \frac{\dot{V}_b}{V_b} \qquad [2]$$

$$(p_a - p_b)S - b_{vis}\dot{y} - F_f - F_e = M\ddot{y} \qquad [3]$$

The heat transfer in the actuator models has been disdained.

Then we can express the state equations,

$$\frac{dy}{dt} = \dot{y} \qquad [4]$$

$$\frac{d\dot{y}}{dt} = \frac{S}{M}(P_a - P_b) - \frac{b_{vis}}{M}\dot{y} - \frac{F_f}{M} - \frac{F_e}{M} \qquad [5]$$

In the model taken by Backé and Ohligschläger (1990) the same formulae as Burrows, has been taken into account considered but the heat transfer is considered. This results in the following state equations are given:

$$\frac{dP}{dt} = \frac{g}{V}\left(R(\dot{m}_a T_a - \dot{m}_b T_b) - p\frac{dV}{dt} + \frac{g-1}{g}\dot{Q} \right) \qquad [6]$$

$$\frac{d\dot{y}}{dt} = \frac{1}{M}\left(A(P_a - P_b) - b_{vis}\dot{y} - F_f - F_e \right) \qquad [7]$$

In the research center of INSA, Tolouse (France), Prof. Scavarda (1993, 1998), bases his state equations by considering the control signal or manipulated variable, u. Using this way, it is possible to take a non-lineal model from Burrows'. Consequently, the state equations would be:

$$\dot{x} = f(x,u) \qquad [8]$$

$$\frac{dP_a}{dt} = \frac{grT_s}{V_a(y)}\left[m_a(u,P_a) - \frac{P_a A_1}{rT_s}\dot{y}\right] \qquad [9]$$

$$\frac{dP_b}{dt} = \frac{grT_s}{V_b(y)}\left[m_b(u,P_b) - \frac{P_b A_2}{rT_s}\dot{y}\right] \qquad [10]$$

$$\frac{dy}{dt} = \dot{y} \qquad [11]$$

$$\frac{d\dot{y}}{dt} = \frac{S_a}{M}P_a - \frac{S_b}{M}P_b - \frac{b_{vis}}{M}\dot{y} - \frac{F_{\sec}}{M} - \frac{F_e}{M} \qquad [12]$$

The hypotheses considered for the construction of these models are:

- take air as a perfect gas
- homogeneous pressure and temperature in both drive chambers
- supply temperature and pressure variation, T_s, P_s, are not considered.
- kinetic energy is neglected
- valve dynamics is not considered
- air losses are not considered
- external force, F_e, is constant.

Another way to modelise the pneumatic system to obtain transfer function, is by Virvalo (1989, 1991), considering the theoretical dynamics of the drive-valve set.

A common function transfer would be:

$$G(s) = \frac{K_{qa} w_n^2}{s(s^2 + 2dw_n s + w_n^2)} \qquad [13]$$

$$K_{qa} = \frac{3Q_N P_a \sqrt{\dfrac{P_s - 1}{3\Delta P_n}}}{2P_s u_{\max} A} \qquad [14]$$

Where the second order function represents the valve and the drive dynamic interaction and the integrator is used to obtain the response in terms of position.

The natural frequency is calculated just considering the analogy to hydraulic systems.

$$w_n = \sqrt{\frac{2.8 \cdot p_s}{3 \cdot M} \cdot \left(\frac{A_1^2}{A_1 \cdot y + V_{10}} + \frac{A_2^2}{A_2 \cdot (l - y) \cdot V_{20}}\right)} \qquad [15]$$

It is noticed that the natural frequency depends on the bore position.

The models explained previously do not consider the high non-linearity system. The unidirectional mechanics of the system is easily recognized in bond graph, see figure 3. Prof. de las

Heras has developed the Bond Graph used in this work, de las Heras (1997, 1999). In this bond graph scheme three sub model have been created: the actuator, the servo valve, and the controller. This Bond Graph is calculated by means of the 20 Sim program.

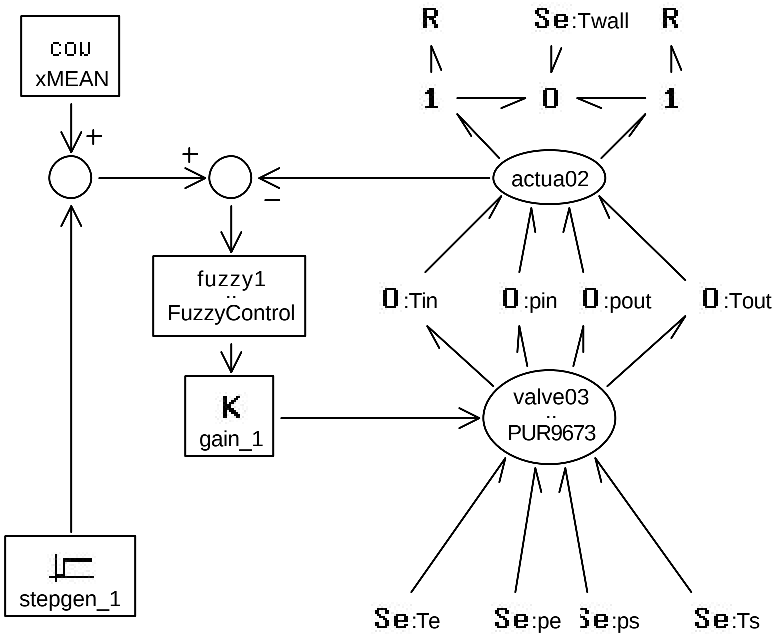

Figure 3. - Modelization of the pneumatic positioning system in Bond Graph technique.

The actuator model considers the thermal dynamics; hence the bond graph identifies two C-fields and two R-fields in conductance form inside the actuator model. The actuator model considers also the behaviour of the real gases (at will), the total energy transmitted at the ports, the stick-slip and friction forces. The simulations of the system as an open loop or and closed loop can be acquired. For the first case, it will give response in terms of velocity and in the other case in terms of position if a position sensor is used

The valve model considers its internal position closed loop, the hysteresis of the proportional coil and its internal friction.

The controller model, here showed is a typical error and change in time error control. Having one input, the position error, and one output, the control valve voltage. The linguistic variables are the position error and the error change.

Upon the completion of the physical model of the system, it is now to make some theoretical tests. Then one of the aims of the thesis will be to contrast these results with real experiences. The data used in the model is the real data that configures the real test bench system. In that case a load of 5.4 kg is applied.

With this model the pneumatic system response has been studied. If a sinusoidal signal with a variable frequency input (chirp pattern) is introduced to the system, the results given in figure

4 are obtained. For this simulation it is considered that the system is an open loop and an input is introduced to the flow proportional valve. The response is in terms of velocity, and the stick-slip is also considered.

As it is easy to see, the model response is not linear, because the applied model is non linear neither. The sinusoidal input is a chirp pattern, which generates a sample according to the following formula:

$$y_i = A\cdot\sin((a/2 \quad i+b)i), \qquad \text{for} \qquad i = 0,\, 1,\, 2,\, \dots,\, n-1 \qquad [16]$$

where A is amplitude, $a = 2\pi\ (f_2\text{-}f_1)/n$, $b = 2\pi\ f_1$, f_1 is the beginning frequency in normalised units, f_2 is the ending frequency and n is the number of samples.

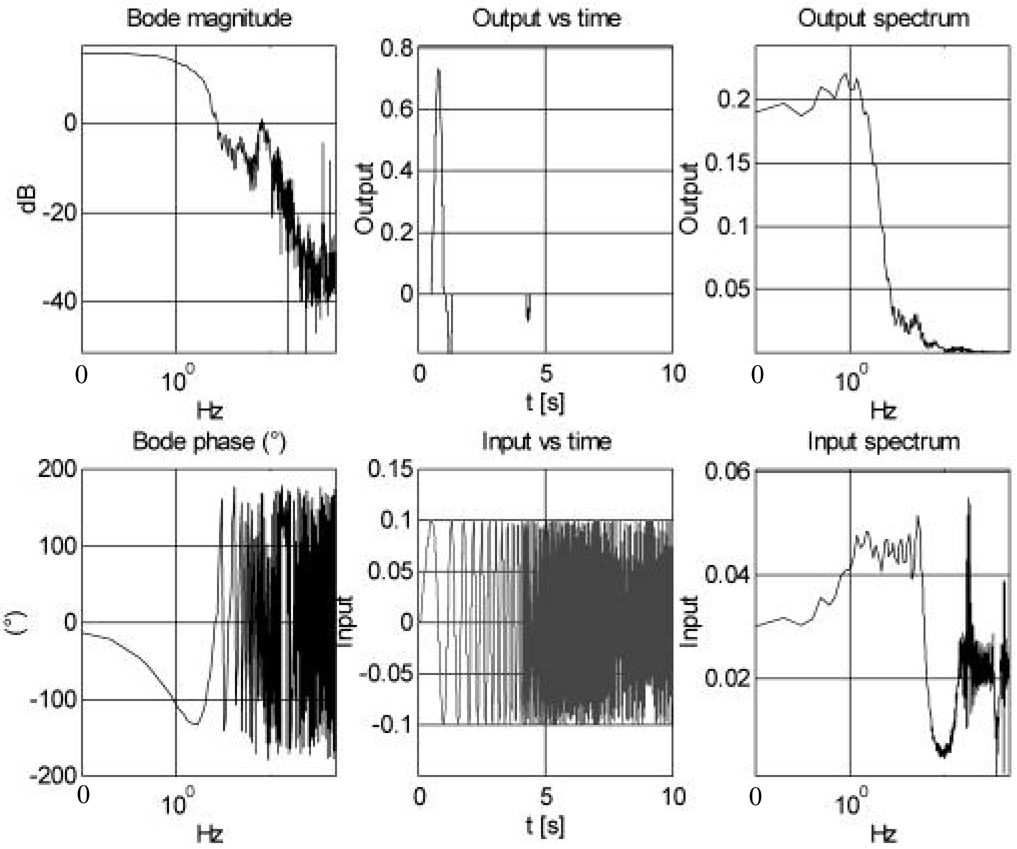

Figure 4. - Response obtained in the Bond Graph simulation with a chirp pattern Input.

One of the aims of the Ph. D. work is to obtain a real response of the pneumatic system when a chirp pattern is introduced, in order to compare the simulation and the reality. The important thing to determine is in which sense the non linearity of the servo drive in the Bond Graph model, can be adjusted. The Labview software will generate this chirp pattern signal.

4 PRIMARIY TESTING.

Nowadays, the experimentation done in the Ph. D. thesis compromises of PID control, as well as the state observer and the Fuzzy Control. In the case of the PID experiences, the tests were done with an industrial PID of OMRON, model ES100. However, the trials made with this controller did not give suitable results, they presented a high unsteadiness to the system variations, and the positioning was slow, in term of severals seconds. It has to be considered that the case explained in this work consists of a long stroke drive.

After this experimentation, the state observer was studied. In figure 5, the control scheme used in order to close the loop in terms of positions can be seen. The Position (SP) is introduced by the means of a Labview control icon, to this value the position lecture (PV) is substracted, by this way the regulation error (e) is obtained. From here, this error is treated, the state variables (x, v, a) are feedbacked with their respective gains. By these means, the flow proportional valve is commanded (MV).

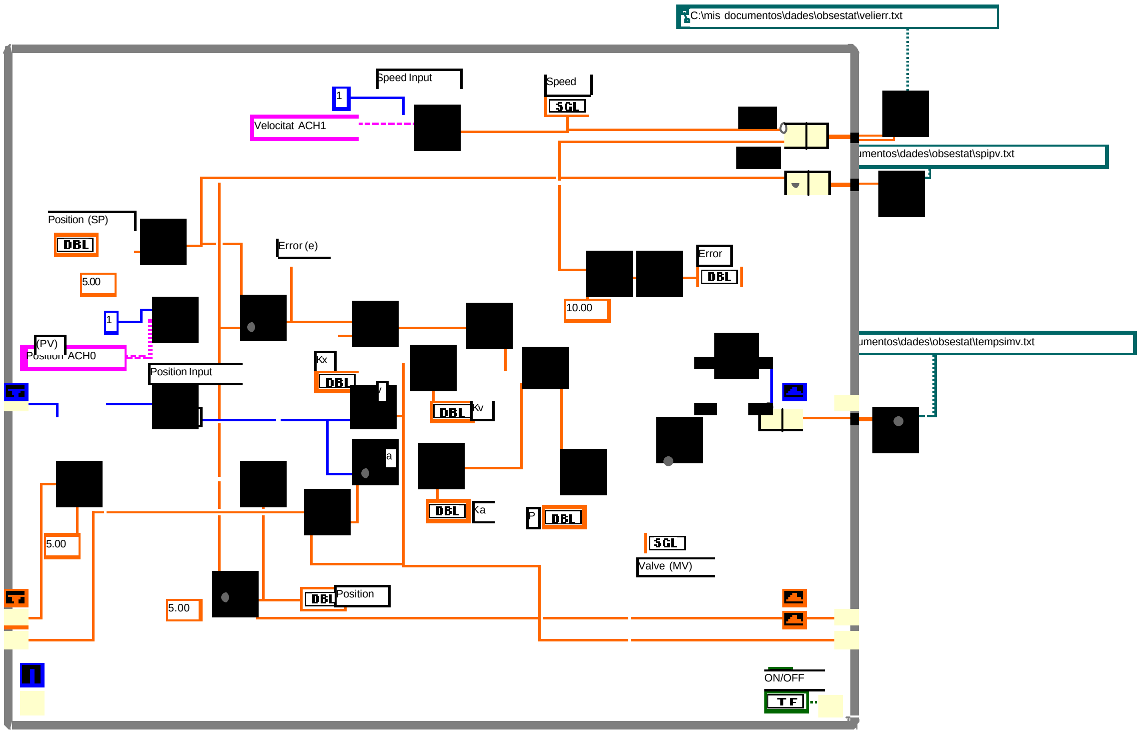

Figure 5.- State control diagram in Labview.

The control algorithm presents a high and a precise response, the difficulty in this case is that the state variable gains depends on the setpoint and the system parameters. This influence has also been studied in order to increase the system knowledge, by this way it will be possible to integrate the fuzzy logic in this control algorithm. The state variable gains could be scheduled by means of a fuzzy system, in order to take the correct values for the desired positioning.

Before reaching this point, the fuzzy control has been studied, taking as fuzzy variables the error (e) and the change in time error (de). The controller structure is the usual in fuzzy controllers, in figure 6 it is reflected how it is controlled in the Labview program. For this controller the Labview fuzzy control toolbox has been used.

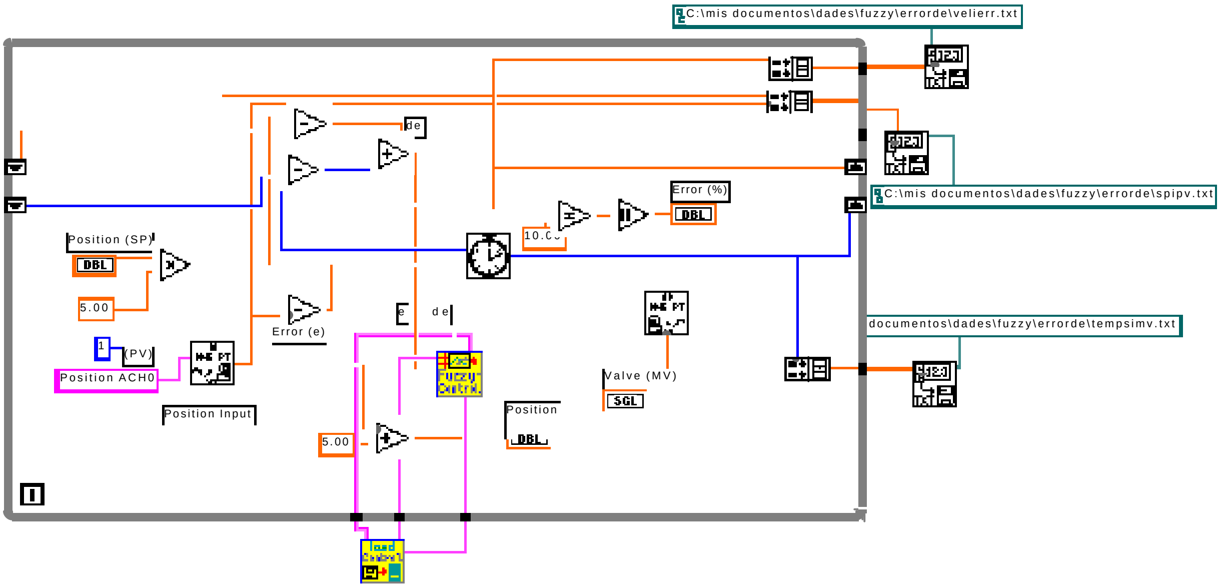

Figure 6. - Fuzzy e, de control in Labview.

For this control a response for a 5 V step is shown in figure 7. This step corresponds to 50% of the pneumatic drive stroke; in this case it is 1 meter. In the figure it is possible to see the process variable (PV) evolution and the manipulated variable (MV) faced with the setpoint signal. From this result the response time can be observed, next to a 1 second. It can be appreciated that the speed is almost constant, seeing that the PV presents an evolution that corresponds to a straight with a constant slope. The average speed in the case shown is 1 meter per second.

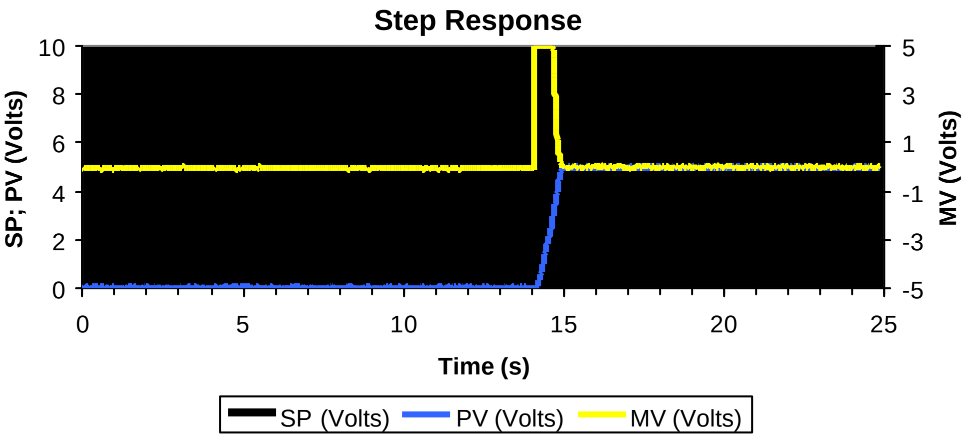

Figure 7. - Step Response of Fuzzy e, de control.

At present, it is proceeded to the realisation of a system control by the means of the state observer. The structure used corresponds to that of the figure 5, but in the actual case a fuzzy algorithm parameterises the state variable gains. With this, the steadiness of the state observer controller with a high response along with the fuzzy logic adaptation is competed for. The control algorithm final structure is shown in figure 8, for this controller it has not been possible to obtain good results up to this moment, as it is necessary to increase the system knowledge for this kind of control structure.

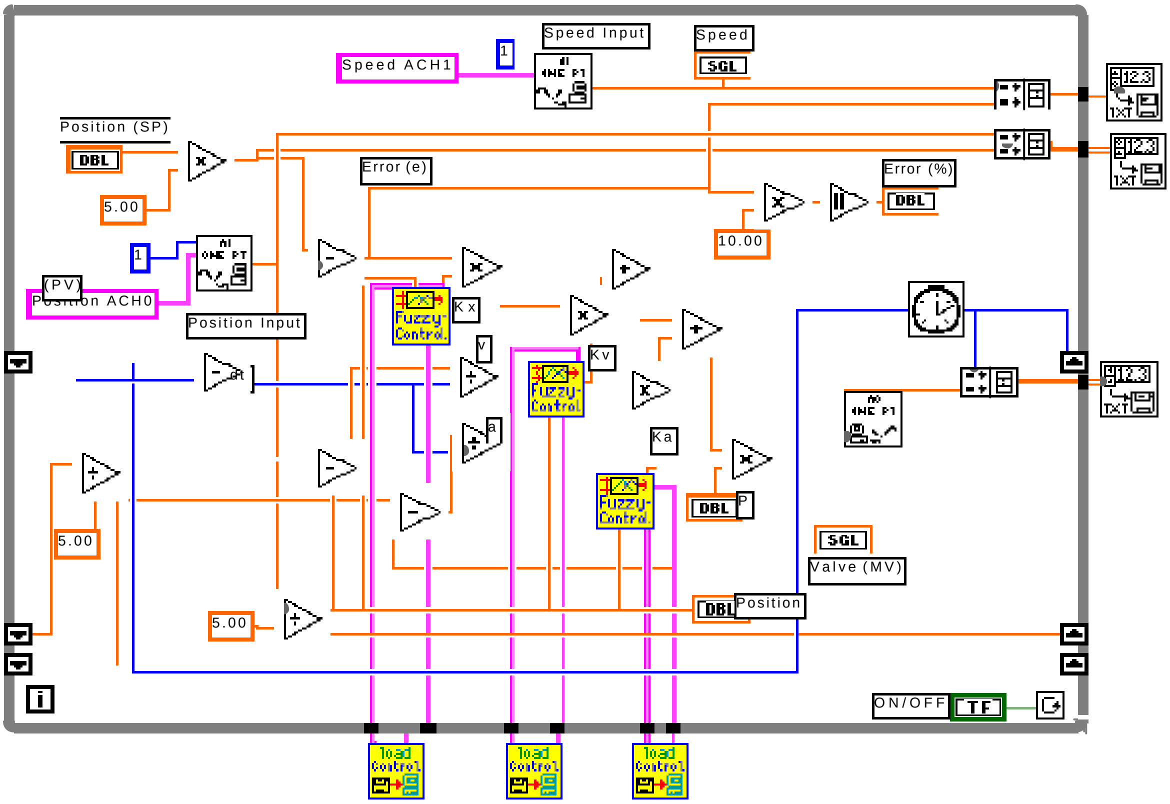

Figure 8. - State Fuzzy control diagram in Labview.

5 CONCLUSIONS AND FURTHER STUDIES

In conclusion, it is important to make evident the great potential that fuzzy logic has to offer, such as the need for the mathematical model. However high system knowledge is necessary to improve the performance of the controlled servodrive. Another point to consider is also the easy integration of the fuzzy logic in traditional control algorithm, as it is shown in this work.

Another advantage that the fuzzy logic offers is that an autotuning algorithm can be applied to the system, by the means of this reasoning. In this way, the system can learn the control parameters to take, Backé and Klein (1990). With this point it is possible to save the experimentation for the controller tuning.

Considering these the further studies of the thesis will be the experimental characterisation of the pneumatic servodrive. After this the results will be compared with those of the Bond Graph. With this, the influence of the control to the closed loop will be seen and studied.

6 ACKNOWLEDGEMENTS

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