Introduction:

In this summary, we present the results of simulations for the controllers developed. These results have been compared to those given by the old controller (PID) in an aim to show the improvements introduced by each controller. We make the note that some numeric values are intentionally hidden conformably to the internship contract terms.

4.1. Simulation parameters:

4.1.1. Servo-valve:

- ✓ Pressure supply: 206 Bar.
- ✓ Saturation current: Ir=20mA.
  - ✓ Flow max correspondent: Q= 160L/min.
  - ✓ Pressure drop correspondent :
    - Ps-Pa=35 bar.
    - Pa-T= 35 bar.
    - Ps-Pb= 35 bar.
    - Pb-T=35 bar.

4.1.2. Jack's parameters:

- ✓ Stick length: 0.8m.
- ✓ Initial position: 0.4m.
- ✓ Viscosity coefficient: 1000 N/(m/s).

4.1.3. Effort reference signal:

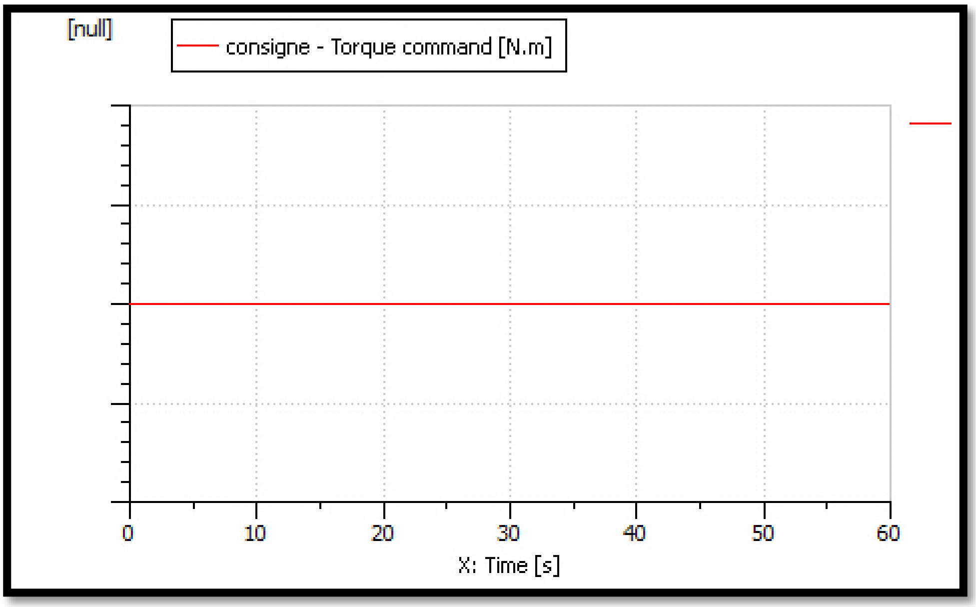

Fig.IV.1 effort reference signal

4.1.4. Angular velocity reference signal:

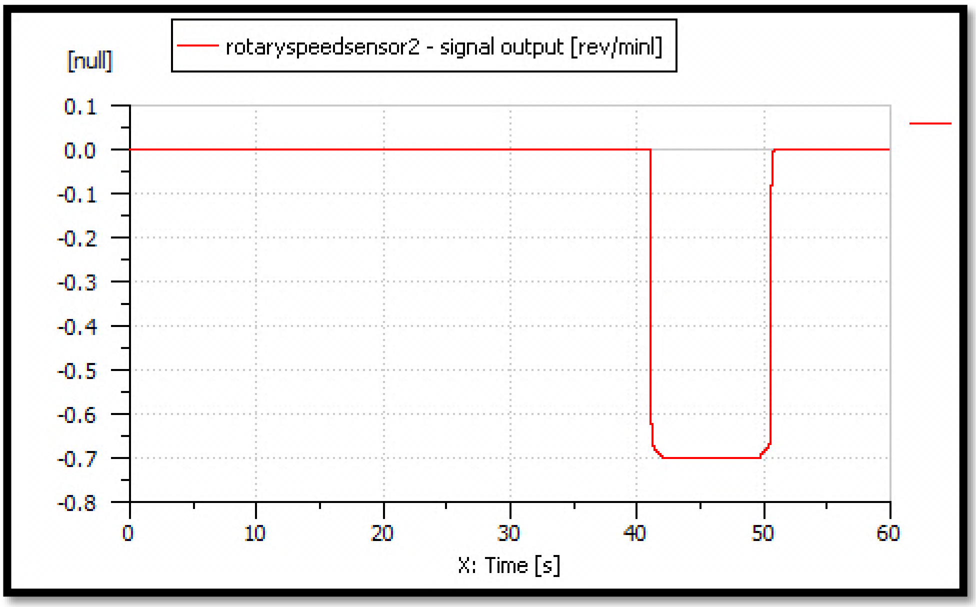

Fig. IV.2 angular velocity reference signal.

4.1.5. Temporal parameters:

- ✓ Simulation interval: 60 s.
- ✓ Interpolation step: h=0.001s.
- ✓ Integration Step: variable (tolerance 10^{-5}).

4.2. The Fuzzy controller:

To perform the analysis of performances for the fuzzy controller, we observe the system's output compared to that produced by the PID controller.

We mainly focus on three parts of the temporal evolution of the two responses during the transitory regime, the angular velocity transitions, and the permanent regime.

In order to ensure that the fuzzy controller respects other practical requirements, we also observe the evolution of the pressure inside the actuator chambers as well as the control signal sent to the Servo-valve:

4.2.1. The system's response during the transitory regime:

Figure IV.3 illustrates the responses during the transitory regime obtained by both the PID and fuzzy controllers:

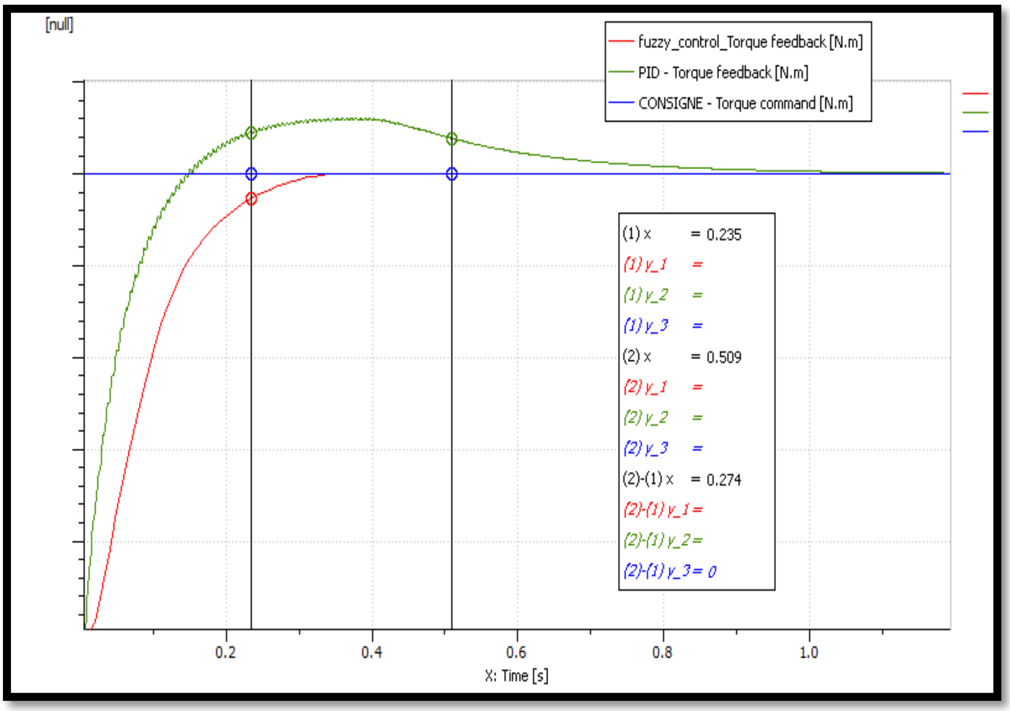

Fig. IV.3 comparison between responses during the transitory regime.

4.2.2. Robustness against the angular velocity transitions

Figure IV.4 shows responses for the PID and Fuzzy controllers during the transitions in the angular velocity signal:

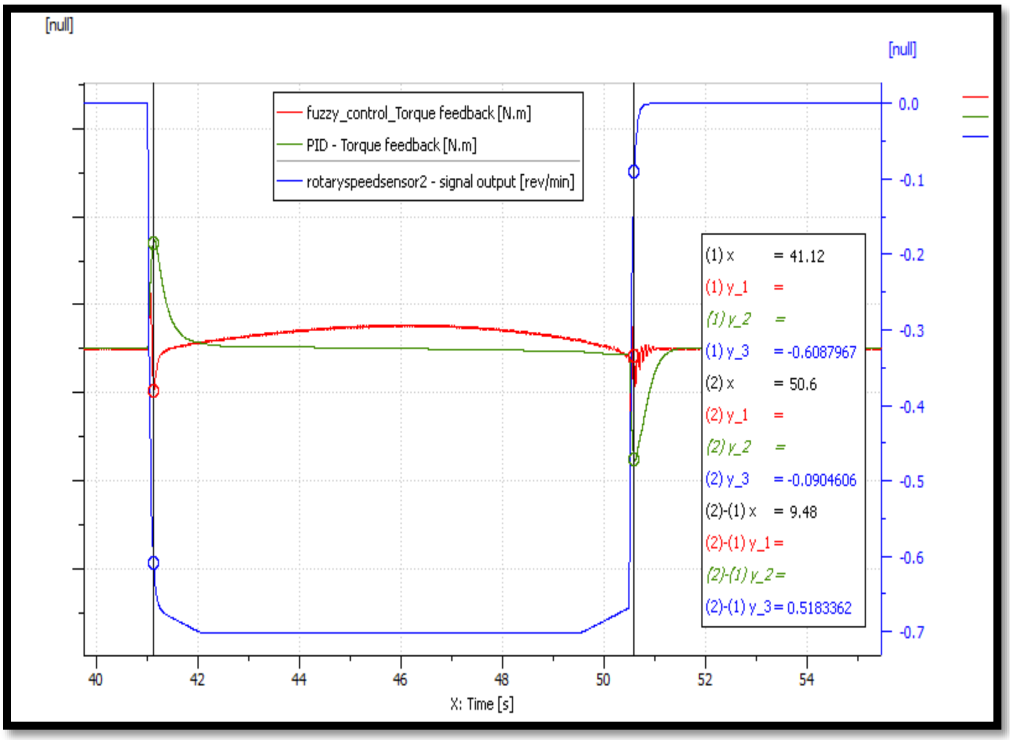

Fig. IV.4 comparison between responses during the angular velocity transitions.

4.2.3. Response during the permanent regime:

Figure IV.5 demonstrates the responses for the PID and fuzzy controllers during the permanent regime:

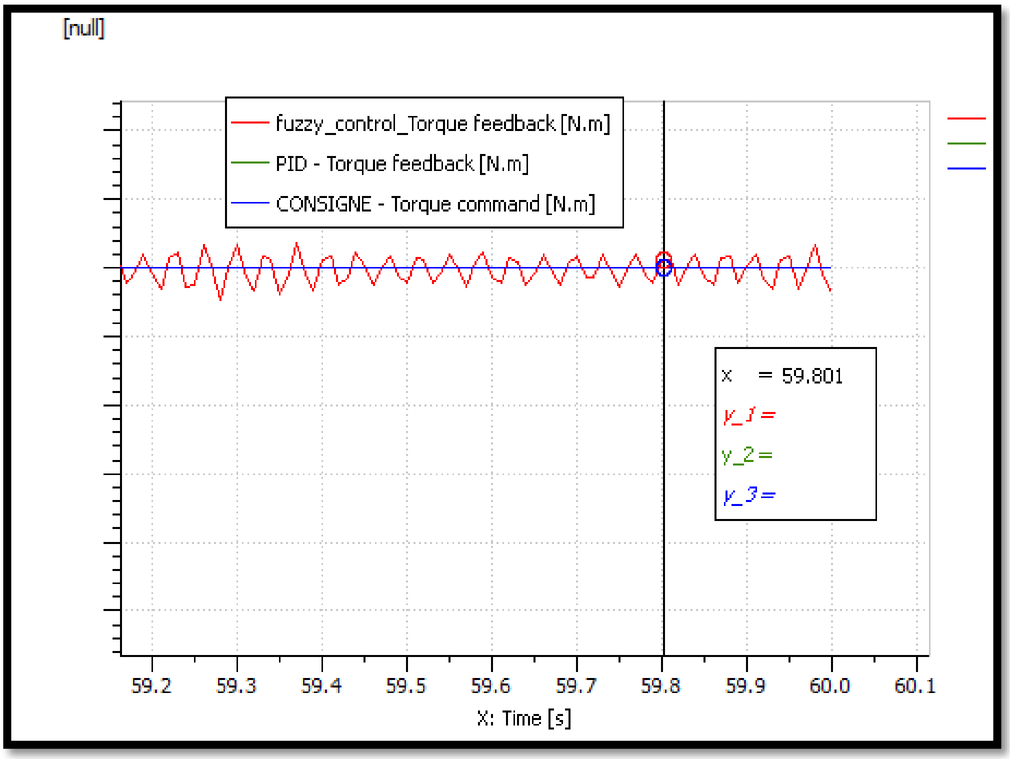

Fig. IV .5 comparison between responses during the permanent regime.

4.2.4. Internal variables:

4.2.4.1. control current for the servo-valve:

Figures IV.6 and IV.7 shows the curves of the servo-valve's current signals for each control scheme:

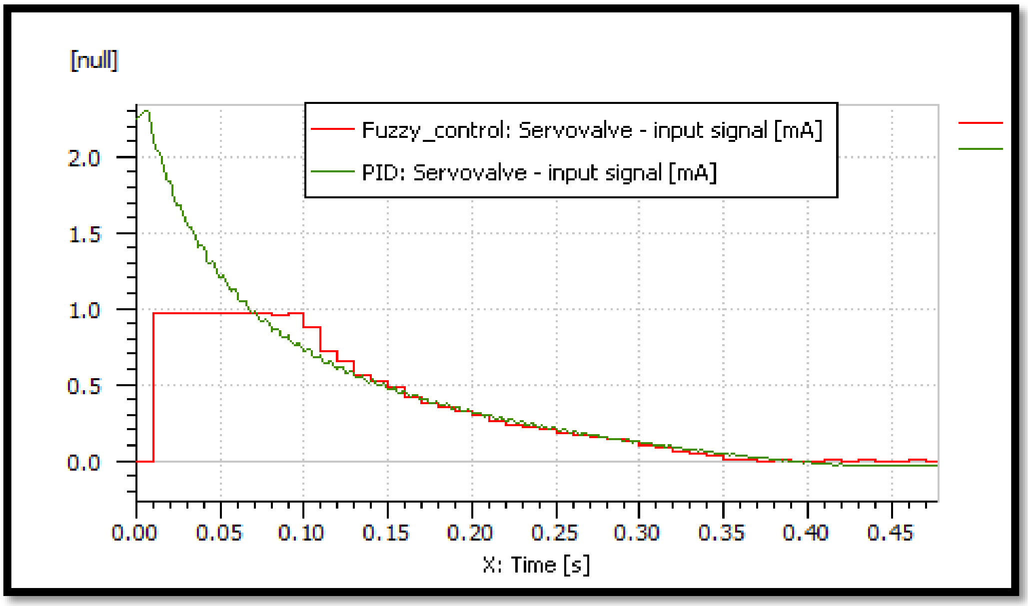

Fig. IV.6 evolution of the control signals during the transitory regime

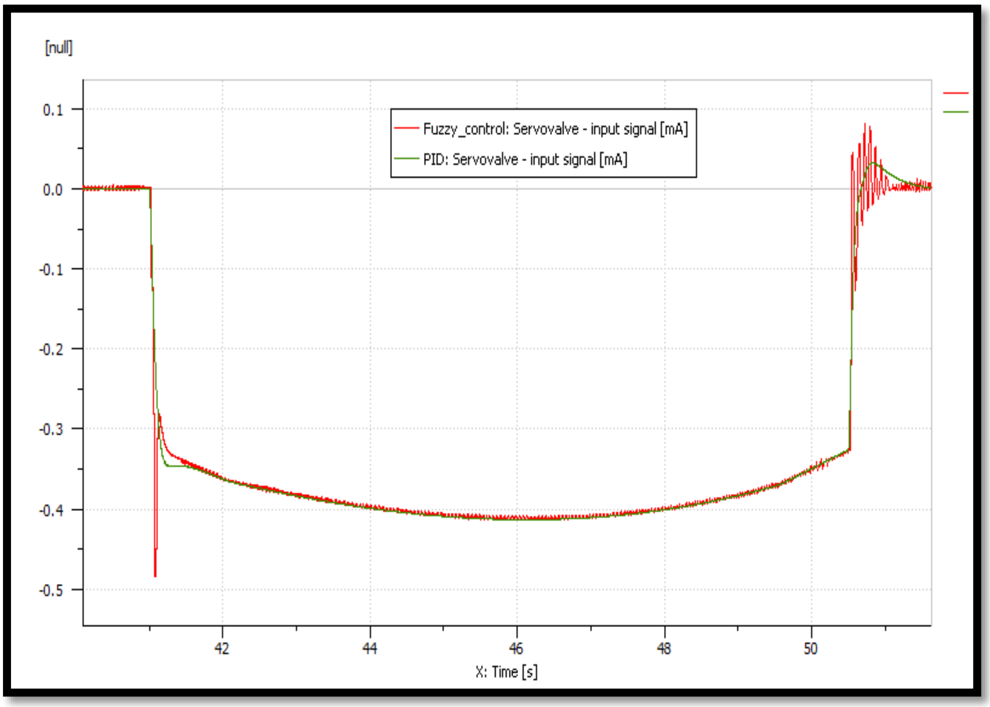

Fig. IV.7 evolution of the control signals during transitions in angular velocity.

4.2.4.2. Jack's pressure:

Figure IV.8 shows the pressure variations inside the actuator for the two control schemes:

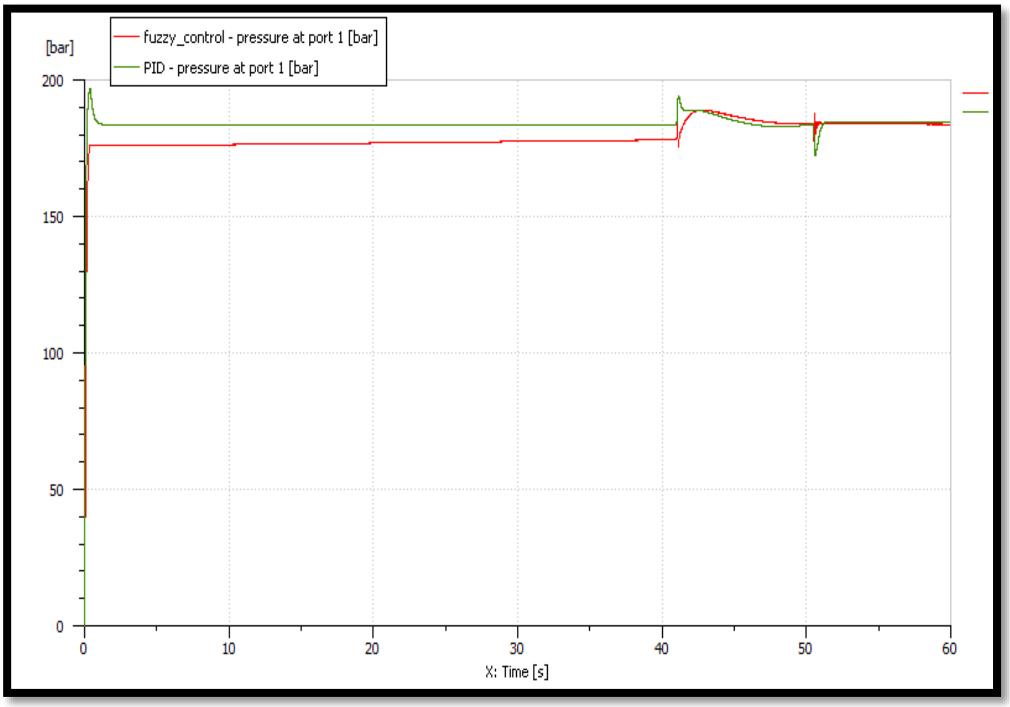

Fig.IV.8 pressure variations inside the actuator for both controllers: PID (red curve) and the Fuzzy controller (red curve).

4.2.5. Result analysis and comments:

4.2.5.1. Rapidity:

The duration for the transitory regime has been diminished, from t1=0.509s for the PID to t2= 0.23s for the fuzzy controller. Hence, the rapidity of the system has been ameliorated with 256%.

4.2.5.2. overshoot

The output response for the PID control presents an overshoot of 11.93%, whereas the fuzzy controller allowed us to cancel this overshoot. That indicate a notable improvement of the stability margin.

4.2.5.3. Robustness against the angular velocity transitions:

- We can clearly see that the PID controller doesn't ensure a robust behavior for the system during the transitions of the angular velocity signal. Indeed, the output presents two peaks with the lengths (9.71%, 10.08%) and the widths (1.78s, 1.476s) respectively.
- The robustness of the system has been improved by the fuzzy controller, in fact, the lengths of the two peaks have been lessened to 4.99% and 7.38% respectively. Furthermore, the static error has been restricted at 2.18%.

4.2.5.4. Precision of the control schemes during the permanent regime

During the permanent regime, we can see that the precision has been tolerably affected, actually, the PID controller ensure a null static error, while the fuzzy controller introduced an error of ±0.0072%.

4.2.5.5. Internal variables:

The pressure variations inside the actuator, as well as the control signal sent to the servo-valve input don't still have an acceptable pace and don't induce any unsafe functioning mode. Thus, we conclude that the practical requirements are still respected.

4.3. Our control approach:

To perform the analysis of performances for our control scheme, we observe the system's output compared to that produced by the PID controller. We mainly focus on three parts of the temporal evolution of the two responses during the transitory regime, the angular velocity transitions, and the permanent regime.

In order to ensure that our control scheme respects other practical requirements, we also observe the evolution of the pressure inside the actuator chambers as well as the control signal sent to the Servo-valve:

4.3.1. The system's response during the transitory regime:

Figure IV.9 illustrates the responses obtained by both the PID and our control scheme during the transitory regime:

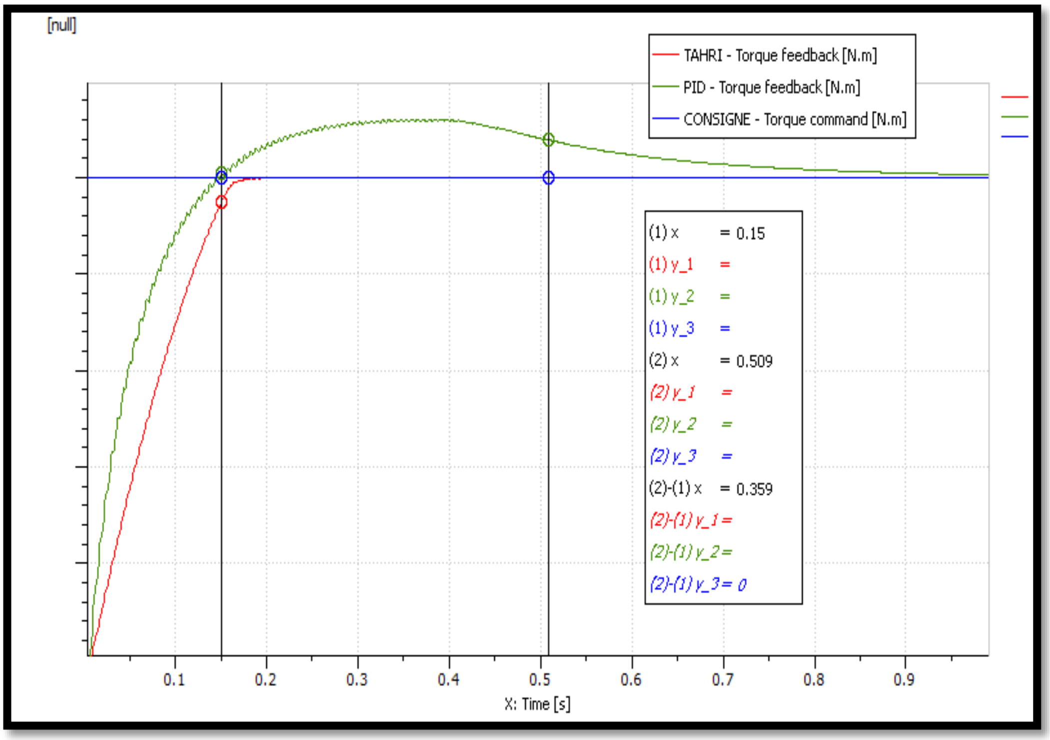

Fig. IV.9 comparison between responses during the transitory regime.

4.3.2. Robustness against the angular velocity transitions

Figure IV.10 shows responses for obtained by the PID controller (green curve) and our controller (red curve) during the transitions in the angular velocity signal:

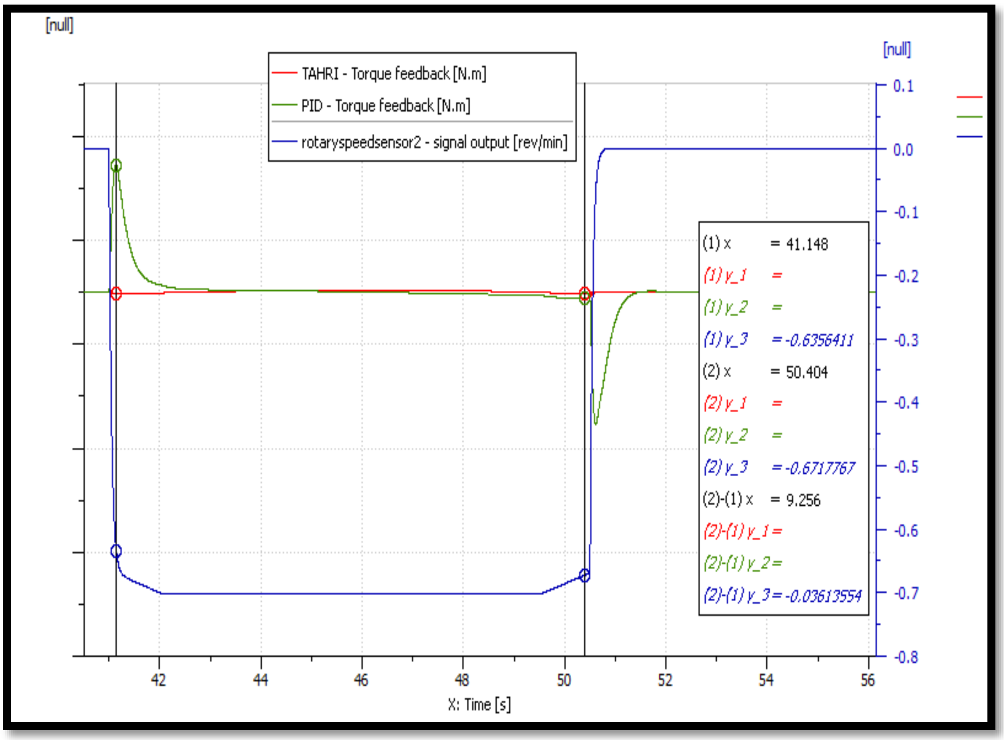

Fig. IV.10 comparison between responses during the angular velocity transitions.

4.3.3. Response during the permanent regime:

Figure IV.11 demonstrates the responses for the PID controller and our control scheme during the permanent regime:

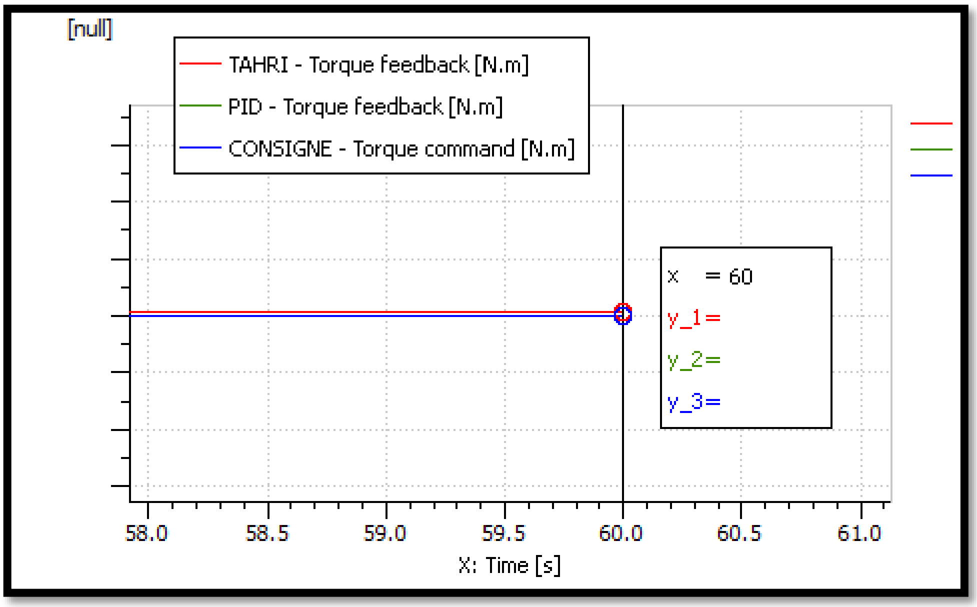

Fig. IV.11 comparison between responses during the permanent regime.

4.3.4. internal variables:

4.3.4.1. Servo-valve control current:

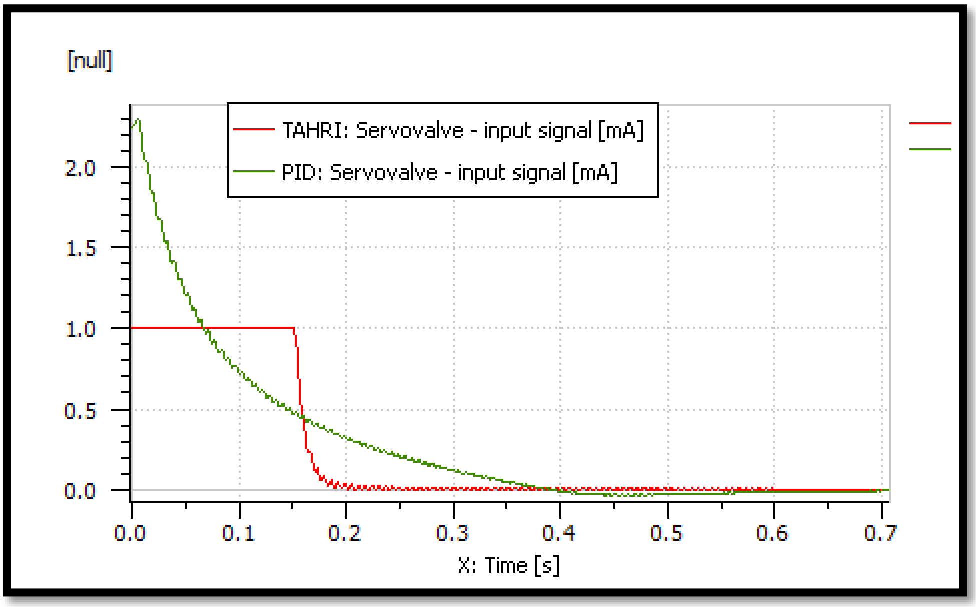

Fig. IV.12 7 evolution of the control signals during the transitory regime.

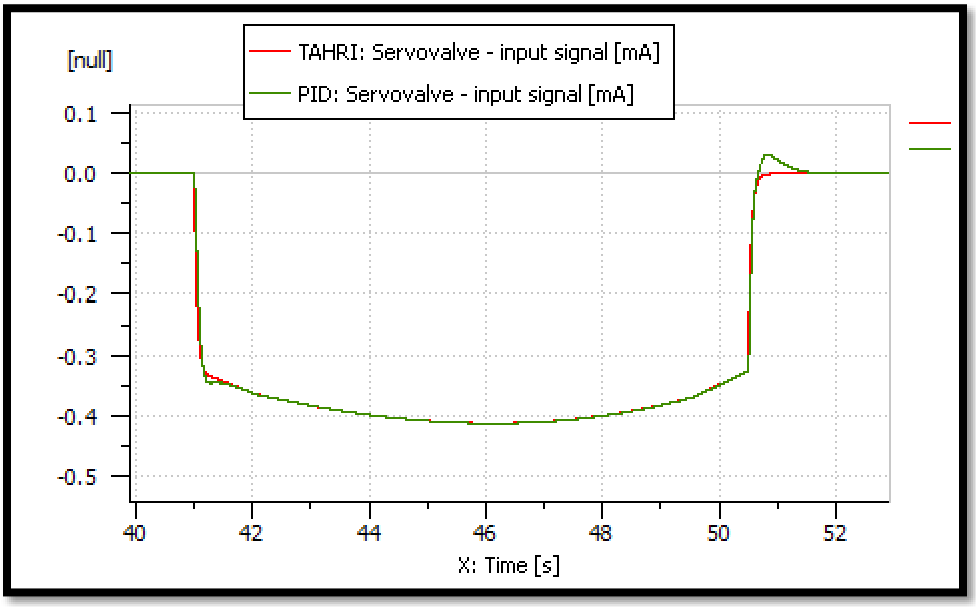

Fig.IV.13 7 evolution of the control signals during transitions in angular velocity.

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4.3.4.2. Pressure variations

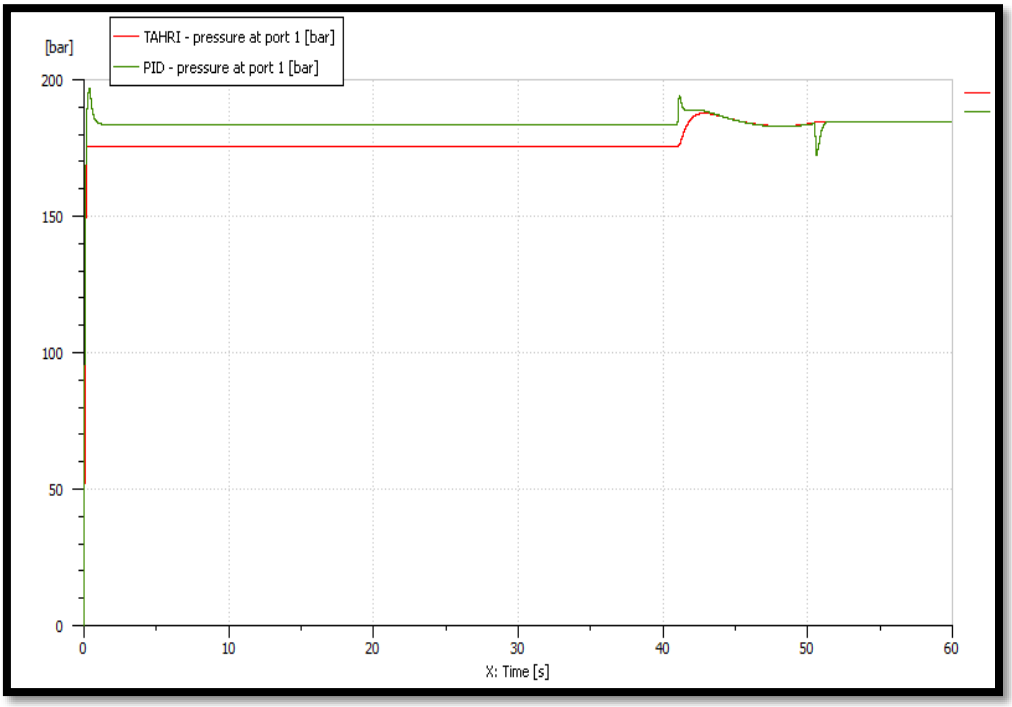

Fig. IV.14 variations of the pressure inside the actuator, green curve: system controlled by the PID controller , red curve: system controlled by our control scheme.

4.3.5. Results analysis and comments:

Considering the results shown above, we note a considerable improvement of the control loop performances, in terms of rapidity, stability, and robustness against the transitions of the angular velocity signal:

4.3.5.1. The rapidity of the control loop:

The transitory regime duration is reduced, it has been lessened from 0.509s in the case of the PID controller to 0.1505s for our control scheme. Therefore, the new control loop is 3 times faster comparing to the old one.

4.3.5.2. The overshoot:

The response of the system controlled by the PID controller shows an overshoot of 11.93%; whilst, our control scheme allows to cancel it. Thus, the stability margin has been extended.

4.3.5.3. Robustness facing angular velocity transitions:

- For the PID control: we can see that the output presents two peaks during the transitions of the angular velocity signal, with the lengths (9.71%, 10.08%) and the widths (1.78s, 1.476s) respectively
- In the other hand, the response obtained by our control scheme is considerably ameliorated. Actually, the two pics presented in the case of the PID control are almost eliminated, their dimensions became 0.22% (for 0.036s) and 0.012% (for 0.1s).

4.3.5.4. The precision of the control schemes:

Concerning the permanent regime, we can see a degradation of the system's precision, indeed the PID controller ensures a null static error, whereas, our controller introduced an error of 0.0006%.

4.4. Summary of performances for the control schemes:

4.4.1 control performances

Table IV.1 summarize the different simulations' values quantifying the performances of the control schemes (rapidity, precision, and stability margin):

	Response delay(s)	**Overshoot (%)**	**Static error (%)**
The new control scheme	**0.1505**	**/**	**0.0006**
Fuzzy controller	**0.235**	**/**	**0.0072**
PID	**0.509**	11.93	**0**

Table IV.1: summary for the control values for the three control schemes

4.4.2. Robustness against of angular velocity transitions:

We note that our control scheme ensured a very good robustness against the transitions of the angular velocity.

Comparing to the PID controller, the fuzzy controller has considerably improved the robustness of the system.

Conclusion

The results of simulations are widely satisfying regarding the goals of our project. Indeed, the new control scheme developed allowed to ensure an optimal control in terms of performances, notably the robustness against the transitions of the angular velocity, while improving the other exigencies of the control loop.

Regarding the improvement approved by the Fuzzy controller, the latter presents an eventual solution to ensure the Robustness needed for the system.

Motivated by the results obtained, we have decided to incorporate our new control scheme into another effort/velocity control loop. So, the next chapter is devoted.