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**OPTIMIZATION OF THE PID PARAMETERS FOR CONTROL SPEED OF A DC**  
**MACHINE:**

**A COMPARATIVE STUDY**

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**ABSTRACT**

Most of the current industrial devices use the controllers of the type Proportional Integral and Derivative for the numerical regulation from certain physical magnitude such as speed, current, voltage, temperature... etc. The realization of analogical controller based on operational amplifiers cheaper is an interesting alternative provided that their performances are not too distant from those of their numerical counterparts. The robustness or the effectiveness of this type of controller depends on the compromise of the constants  $K_p$ ,  $K_i$  and  $K_d$  which are the parameters of the PID controller. This paper concerns the optimization of the parameters of PID controller applied for the speed control of a D.C machine. So we initially studied the PID controller and some methods of optimization of its parameters ( $K_p$ ,  $K_i$  and  $K_p$ ). Thereafter, we implemented various methods of optimization of the parameters of the PID controller (Ziegler-Nichols open loop, Ziegler-Nichols closed loop, Chien-Hrones-Reswick 0% and 20%, Particle Swarm Optimisation (PSO)) to control the speed of a DC machine.

**Keywords:** PID controller, Operational amplifier, optimization, DC machine.

**ABBREVIATION**

u(t) : Input voltage  
R : Résistance of DC machine  
L : Inductance of DC machine  
e(t) : Electromotrice force  
i(t) : Current flow  
 $\theta(t)$  : Rotor position  
 $\Omega(t)$  : Speed  
Ke : Constante of e.m.f  
Cp : Losses torque  
Cu : Rate torque  
Cr : Torque of the load  
f : Friction coefficient  
J : Inertie of the rotor  
Kc : Torque Constant

**I. INTRODUCTION**

Nowadays, the physical systems animated by an automatic control are very widespread in industry. The recent development of average data processing, the processors and consequently the power of computing amplified considerably the use of the auto adjustment technics more sophisticated and reinforce the interest for PID controller in the numerical control of processes [1]. Taking into account new technological projections, the regulation is done

automatically in a numerical way. However, it is always interesting to analyse such analog circuits in order to understand direct implementation of certain theoretical concepts. Moreover, the manual adjustment of the parameters of analogical PID controller is a work which depends considerably on the knowledge of the system and the experiment of the operator [4]. On the other hand the components of the numerical controller use advanced technologies. Several work carried out by many authors reports that on more than 2000 control loops, 95 % of those used structures of the type PID [ 2 ], [ 3 ], [ 4 ]. Regulator PID thus seems the best strategy of regulation in various industrial fields [5]. The uncontested prevalence of this type of order comes not only from its extreme simplicity, but also from the performances which it can offer to the loop closed systems. Owing to the fact that the majority of controllers being of PID type, one notes that 20 % of these control loops function correctly [3]. One of the major causes of these weak performances would be due to the bad choice of the parameters of the PID controller [6] [1], [7], [5]. The possibility of perceiving PID controller under several radically different angles comes owing to the fact that the literature abounds in methods of synthesis which takes account of the complexity and the very variable performances of various encountered problems. PID controller can be seen, very intuitively, as a tool whose adjustment can be accomplished by independently considering the effect produced by each one of its parameters [8-9]. Also, it can be perceived like a using tool of the rules and the relations. Lastly, it can thus be regarded as a robust tool of order one can optimize the performances. In the past, the controllers of the type PID were controlled in an empirical way thanks to the methods described by Ziegler and Nichols (1942) [10]. These methods were based on the determination of some characteristics of dynamics of the system. The parameters of the controller were then expressed according to these characteristics by simple relations. These methods, in their use, although requiring few information on the system, presents a disadvantage such as the loop closed system presents a very low damping coefficient [3], [11]. Within sight of all that above one can raise the question to know how to find out a robust method allowing of controller the speed of a DC machine? The principal goal of this study consists in optimizing the parameters of analog PID controller so as to answer the criteria of robustness of the numerical PID controller applied to the control the speed of a D.C machine by using 05 methods. This article is articulate as follows, firstly, the presentation of materials and methods which show in detail a comparative study of five (05) various methods of optimization (Ziegler-Nichols open loop, Ziegler-Nichols closed loop, Chien-Hrones-Reswick 0%, Chien-Hrones-Reswick 20% and particle swarm optimization) of the parameters of PID controller applied to the control speed of a DC machine, thereafter the results and discussion and finally the conclusion.

## II. MATERIEL AND METHODS

### Material

Within the framework of this paper, we had used a computer of mark HP (2GHz, 4Go, HD 750 Go) and the software MATLAB 2014b for the simulations

### Methods

#### *Characteristic Equations Of A Dc Machine*

The operation of the D.C. machine is controlled by the following physical equations which rise from its electric, mechanical and magnetic characteristics combined with the law of Newton and Kirchhoff in the temporal field:

$$u(t) = Ri(t) + L \frac{di(t)}{dt} + e(t) \quad (1)$$

$$e(t) = K_e \Omega(t) \quad (2)$$

$$J \frac{d\Omega(t)}{dt} = C_u - C_r \quad (3)$$

$$C_u = K_c i(t) - C_p \quad (4)$$

$$C_r = f\Omega(t) \quad (5)$$

$$\Omega(t) = \frac{d\theta(t)}{dt} \quad (6)$$

### State Space Representation Of The Dc Machine

In the circuit of D.C. machine, we count three state variables, among which are current ( $i$ ) the position ( $\theta$ ) and speed ( $\Omega$ ).

By changing variables, we have:

$$i(t) = x_1(t); \quad \theta(t) = x_2(t); \quad \Omega(t) = x_3(t); \quad (7)$$

Equations (1), (2) and (3) can be written in the form of the following system equation:

$$\begin{cases} \dot{x}_1(t) = -\left(\frac{R}{L}\right)x_1(t) - \left(\frac{K_e}{L}\right)x_3(t) + \left(\frac{1}{L_a}\right)u(t) \\ \dot{x}_2(t) = x_3(t) \\ \dot{x}_3(t) = -\left(\frac{f}{J}\right)x_3(t) + \left(\frac{K_c}{J}\right)x_1(t) \\ y(t) = x_3(t) \end{cases} \quad (8)$$

Equation 8 can be put in the following matrix form:

$$\dot{x}(t) = Ax(t) + Bu(t) \quad (9)$$

$$y(t) = Cx(t) + Du(t) \quad (10)$$

We have:

$$\begin{pmatrix} \dot{x}_1(t) \\ \dot{x}_2(t) \\ \dot{x}_3(t) \end{pmatrix} = \begin{pmatrix} -R/L & 0 & -K_e/L \\ 0 & 0 & 1 \\ K_c/J & 0 & -f/J \end{pmatrix} \begin{pmatrix} x_1(t) \\ x_2(t) \\ x_3(t) \end{pmatrix} + \begin{pmatrix} 1/L \\ 0 \\ 0 \end{pmatrix} u(t) \quad (11)$$

$$y(t) = (0 \quad 1 \quad 0) \begin{pmatrix} x_1(t) \\ x_2(t) \\ x_3(t) \end{pmatrix} \quad (12)$$

By identification we obtain:

$$A = \begin{pmatrix} -R/L & 0 & -K_e/L_a \\ 0 & 0 & 1 \\ K_c/J & 0 & -f/J \end{pmatrix}$$

$$B = \begin{pmatrix} 1/L \\ 0 \\ 0 \end{pmatrix}$$

$$C = (0 \quad 1 \quad 0)$$

$$D = 0$$

### Optimization Methods Of The Parameters Of The Pid Controller

#### Method Of Ziegler - Nichols

The experimental traditional methods of determination and fast adjustment of the parameters of regulators PID presented by Ziegler and Nichols are based on the determination of certain characteristics of dynamics of the processes [17], [10]. The parameters of the PID controller are then expressed in terms of functionalities by simple formulas.

#### Ziegler – Nichols Open Loop Method

The temporal method of Ziegler-Nichols is based on the step response of the process in open loop, design by a transfer function, which is characterized by two essential parameters. These parameters are determined by using the step response of the process. The intersection of the tangent with the two axes gives the parameters  $a$  and  $L$ . Ziegler and Nichols gave the parameters directly according to  $a$  and  $L$ . The parameters of the PID controller are given in Table 1.

Table 1. PID parameters, obtained by the method of Ziegler-Nichols open loop

controller	$k_p$	$T_i$	$T_d$
PID	$1.2/a$	$2L$	$L/2$

with  $k_i = k_p/T_i$  and  $k_d = k_p T_d$ .

#### Ziegler-Nichols Close Loop Method

The frequential method developed by Ziegler and Nichols is based on certain characteristics  $K_U$  and  $T_U$  with knowing the ultimate profit and the ultimate period of the dynamic process of the system in a regulation loop. In order to determine these parameters, one proceeds in the following way:

- Connect the PID controller to the plant to be controlled, fixe the integral gain  $K_i$  and the derivative gain  $K_d$  at 0 ( $T_i = \infty$  and  $T_d = 0$ ).
- Increase  $K_p$  until to obtain the value which leads to the oscillation of the output of the process. We can now take this value as  $K_U$  corresponding to the gain and  $T_U$ , the period of the oscillation.

The parameters of the PID controller obtained by the Ziegler -Nichols closed loop method are presented in Table 2.

Table 2. Parameters of the PID controller obtain by the Ziegler-Nichols close loop method

Régulateur	$K_p$	$T_i$	$T_d$
PID	$0.6K_u$	$0.5T_u$	$0.125T_u$

#### Method Of Dog - Hrones - Reswick

The method of Chien, Hrones and Reswick appeared in 1952 represents an improvement of the temporal method of Ziegler-Nichols, making it possible to obtain systems more deadened in closed loop (the criterion being an overshoot of 0% or 20%) [14]. The parameters of the controller are calculated separately according to the desired overshoot. The tables 3 and 4 below present the parameters of PID controller obtained by the method of Chien-Hrones-Reswick (CHR) (for an overshoot of 0% and 20%) where  $a$  and  $L$  are parameters obtained in the method of Ziegler-Nichols open loop.

Table 3. Parameters of the PID controller obtained by CHR<sub>0</sub> method

Controller	$K_p$	$T_i$	$T_d$
PID	$0.95/a$	$2.4L$	$0.42L$

Table 4. Parameters of the PID controller obtained by  $CHR_0$  method

Controller	$K_p$	$T_i$	$T_d$
PID	$1.2/a$	$2L$	$0.42L$

#### Particle Swarm Optimization Method

The algorithm of optimization by swarm of particles PSO (Particle Swarm Optimization) belonged to the stochastic methods of evolutionary type. This method takes as a starting point the behaviour of the groups by animals in nature and its principle is based on collaboration between the individuals to explore a precise field. Each individual being part of the population (swarm) contributes with his experiment to the evolution of the group and it uses the total experiment of the group for its own evolution. Thus, information passes in the two directions, from the group towards the individual and the individual towards the group [22]. The algorithm by swarm of particle is an iterative algorithm; with each step of calculation, the values of the individuals are compared according to the fixed objective function and then, the new guides are selected. During its execution, the steps of the PSO algorithm are gathered in the flow chart of the following figure 1.

The update the speed and position of each particle is carried out by application of the following equations:

$$V_{i+1} = \gamma_1 V_i + \gamma_2 (x_{ip} - x_i) + \gamma_p (x_g - x_i)$$

$$x_{i+1} = x_i + V_{i+1}$$

With  $\gamma_1, \gamma_2, \gamma_p$  are values chose between 0 and 1 in random way;  $x_{ip}$  and  $x_g$  respectively the best position of the particle  $i$  since the first iteration, and the best global position of the swarm.

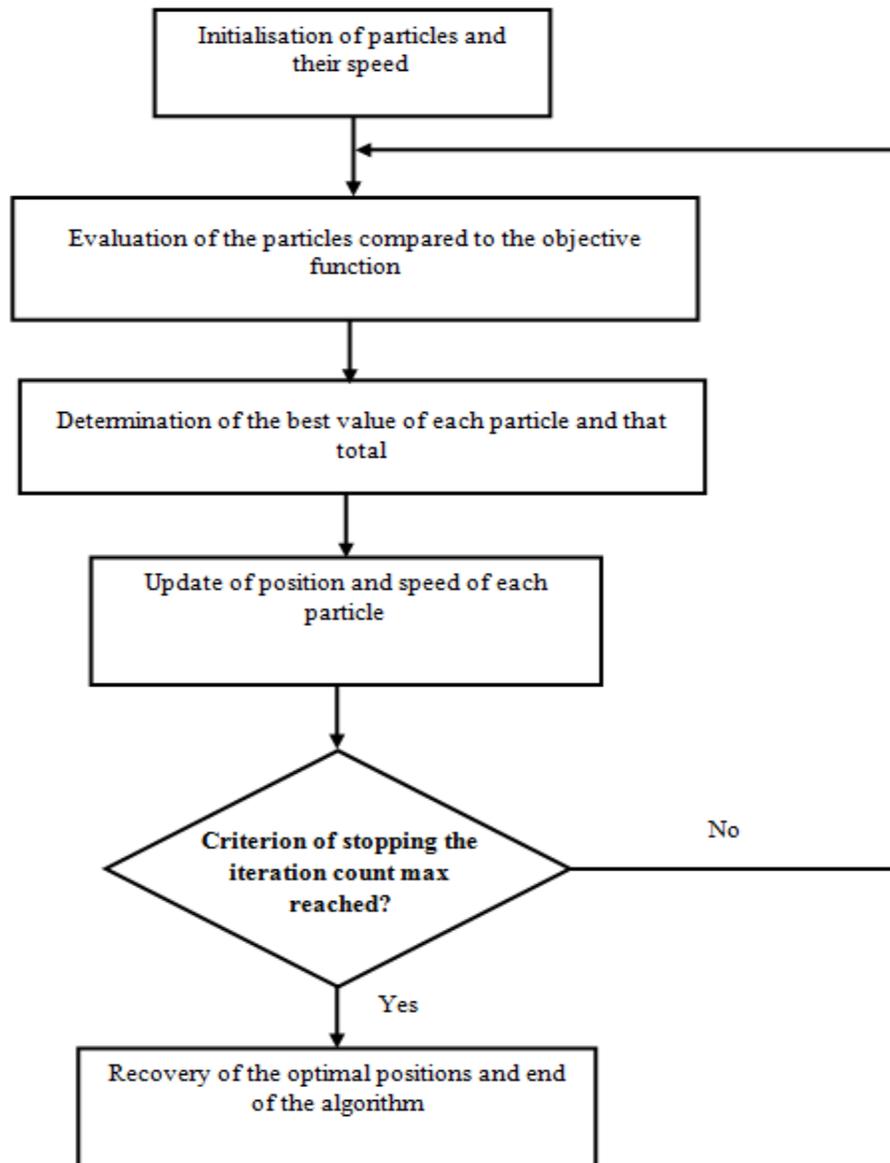


Figure 1. Flow Chart for the PSO algorithm

### The Optimal Parameters

Generally, there are four kinds of performance criteria [1], such as the integral absolute error, the integral of squared error (ISE), the integral of time weighted squared error, and the integral of time weighted absolute error (ITAE). Since ITAE performance criterion provides fastest response with small overshoot for a class of optimisation techniques [2], hence ITAE fitness has been chosen as a fitness function in this simulation study and is represented by

$$ITAE_{fitness} = \int_0^{\tau} t|e(t)|dt$$

Where, the upper limit  $\tau$  is chosen as steady-state value.

III. RESULTS AND DISCUSSIONS

The parameters of the PID controller obtained by using those five methods which minimize the fitness function is found in table 5.

Table 5. Summary of the PID parameters obtained by the various methods

Methods \ Parameters	Ziegler–Nichols OL	Ziegler–Nichols CL	Chien–Hrones–Reswick 0%	Chien–Hrones–Reswick 20%	PSO
$K_p$	12.90	189.443	10.21	12.90	450
$K_i$	21.16	378888.8	13.96	42.32	5000
$K_d$	0.00196	0.02368	0.0013	0.00165	0.03
$D$ (%)	4.65	19.3	5.25	6.75	0
$T_m$ (s)	0.00075	0.0002	0.00082	7 e-4	1.7e-4
$Tr$ (s)	0.00225	0.00171	0.00339	2.2e-3	2e-4
$J_{ITAE}$	0.0028	1.9241e-05	0.0037	0.0025	1.3825e-04

The curves of the figures 2 to 3 show the results of the simulation of the Speed control of DC machine by using optimized PID

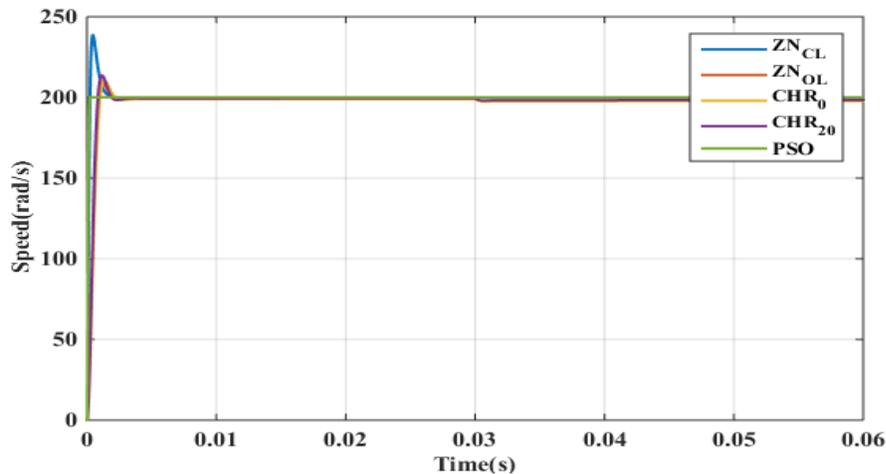


Figure 2. Output response of the system by using five tuning methods

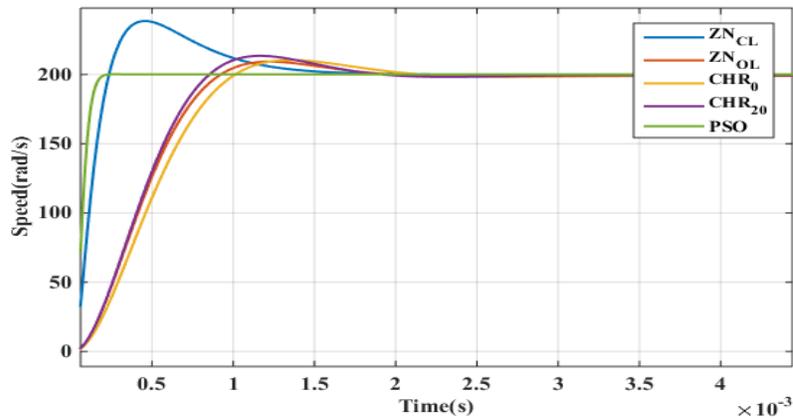


Figure 3. Zoom attransitory zone

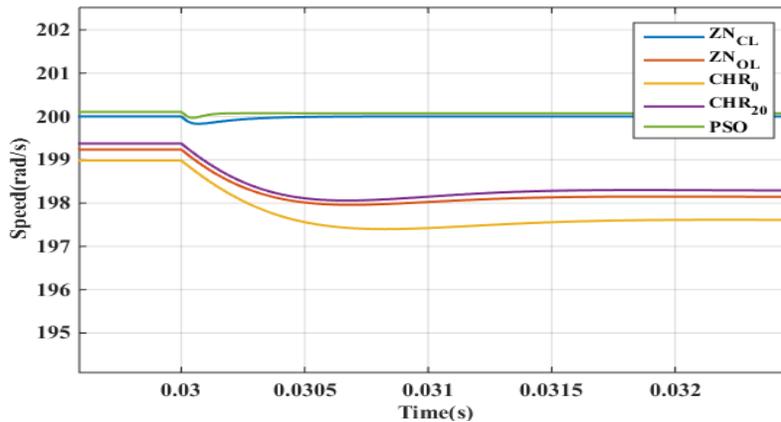


Figure 4. Zoom at the perturbation zone

The observation of the last figures (2, 3 and 4) shows clearly that, the robustness of the stochastic method of particles swarm optimization in the following set reference. In the presence of a disturbance of **0.45N.m** of load torque (approximately 100% of rate torque) applied at **t=0.03s**, we can notice it on the method of particles optimization swarm is less sensitive to the disturbance i.e. more quickly rejects the disturbance compared to the other methods. With regard to the response time, method PSO records a better response time of **0.0002s**. However, the steady error by using the method of ZN closed loop gives an error of **1.9241e-05** while PSO method records an error of **1.382e-04** what explains the values of the integral of the absolute error. This means that ZNcl method is more precise in the permanent mode compared to PSO method. Nevertheless PSO method remains the best in terms of rapidity, stability and the rejection of the disturbances.

#### IV. CONCLUSION

The objective of this work was to optimize the parameters of the PID controller with an aim of controlling the speed of a D.C machine. To achieve our goal we applied the numerical approach by the intermediary of the software of MATLAB. By applying 05 various methods of optimization (Ziegler-Nichols open loop, Ziegler-Nichols closed loop, Chien-Hrones-Reswick 0%, Dog-Hrones-Reswick 20% and Particle Swarm Optimization), only method PSO gives us the best result. This method is better owing to the fact that the result the simulation of the system provided by this method gave us a very weak response time (0.0002s), without overshoot (0%) and one better precision compared to the other methods. Its system is stable for a disturbance of 0.45N (100% of the rate torque). What

means that the system very quickly rejects the disturbance with method PSO. However the results of this work are confined in the theoretical analysis and of simulation, and should be checked by an experimental analysis. As perspectives, we can test other stochastic methods such as the method of the Genetic Algorithm (GA), method of biogeography and finally the method of Ants colonies on this same system in order to compare them with the result obtained by method PSO

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