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Fractionalized PID Control in Multi-model Approach: A New Tool for Detection and Diagnosis Faults of DC Motor

Abstract. *A new approach for the detection and diagnosis of faults DC-motor using the fractionalized PID in multi-model controllers is presented in this paper. We propose to use the hysteresis algorithm switching law which allows adapting these regulators to the plant model in real time. Eight models corresponding to the healthy motor and seven faults were considered. Thus, a bank of eight controllers was designed by using an fractionalized controller. To detect and identify a fault, the response of the DC-motor is compared with each of response model and the supervisors select the adequate controller corresponding to the minimal index of the performance. A simulation results illustrates the efficiency of the proposed control approach (Fractionalized PID) comparing with integer and fractional PID controllers. This approach can also be generalized to others fractional and integer systems in order to improve their performances and noise rejection.*

Streszczenie. *W artykule przedstawiono nowe podejście do wykrywania i diagnozowania usterek silnika prądu stałego z wykorzystaniem frakcjonowanego PID w regulatorach wielomodelowych. Proponujemy zastosowanie prawa przełączania algorytmu histerezy, które pozwala na dostosowanie tych regulatorów do modelu instalacji w czasie rzeczywistym. Rozważono osiem modeli odpowiadających zdrowemu silnikowi i siedem usterek. W ten sposób zaprojektowano bank ośmiu kontrolerów przy użyciu kontrolera podzielonego na części. Aby wykryć i zidentyfikować uszkodzenie, odpowiedź silnika prądu stałego jest porównywana z każdym z modeli odpowiedzi, a nadzorcy wybierają odpowiedni sterownik odpowiadający minimalnemu wskaźnikowi wydajności. Wyniki symulacji ilustrują efektywność proponowanego podejścia do regulacji (frakcjonowany PID) w porównaniu z regulatorami całkowitoliczbowymi i ułamkowymi PID. To podejście można również uogólnić na inne systemy ułamkowe i całkowite w celu poprawy ich wydajności i tłumienia szumów.* (***Ułamkowa regulacja PID w podejściu wielomodelowym: nowe narzędzie do wykrywania i diagnozowania usterek silnika prądu stałego***)

Keywords: Fractional Multi-models control, Detection and Diagnosis of Faults, Supervision, Large model variation, Magnet DC-Motors.
Słowa kluczowe: Ułamkowe sterowanie wieloma modelami, Wykrywanie i diagnozowanie usterek, Nadzór, Duży model zmienności,

Introduction

The applications of fractional order differentiation have attracted the attention of researchers from vide variety of science disciplines especially from the fields of applied sciences [1,2].

In 1997, Podlubny put up the idea of FOPID controllers. In comparison to the conventional PID controller, he also showed how this sort of controller responds more quickly, when used for the control of fractional order systems [3,4].

Eight models corresponding to the DC motor and seven faults were considered [5]. Then a bank of eight controllers was designed by using a technique of Fractionalized PID , Fractional PID and Integer PID control [6-7] . To detect and identify a fault, the response of the motor is compared with each preset model. What makes it possible to the supervisor at every moment to select the adequate controller corresponding to the minimal index of performance [8-9].

The paper is organized as follows: firstly we have discussed the State Modeling of DC-Motor followed by various models of the DC-motor schemes. . Afterwards, the Fractionalized PID , Fractional PID and Integer PID control methods are presented followed by The multi-model DC-motor architecture with a simulation results. Lastly, the conclusion along with future perspectives of the study is given.

State modeling of DC-Motor

A model of the DC-motor with applied voltage u(t), which is the manipulated variable, used to control the angular velocity ω(t) [5]

The state model of speed DC-motor is given by:

$$(1)\quad \begin{bmatrix} \dot{X}_1 \\ \dot{X}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -a_0 & -a_1 \end{bmatrix} . \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} 0 \\ b_0 \end{bmatrix} . u(t)$$

where:

$$a_0 = \frac{\mathrm{Ra.fr} + \mathrm{K_T} . \mathrm{K_e}}{\mathrm{L.J_1}}, \quad a_1 = \frac{\mathrm{Ra.J_1} + L . \mathrm{fr}}{\mathrm{L.J_1}},$$

$$b_0 = \frac{K_T}{L.J_1} \; b_1 = \frac{K_T}{L}$$

where: Ke: Back-EMF constant, Kt : Torque Constant, Ra: Terminal Resistance, La : Armature Inductance, J : moment of inertia of the rotor, fr: Viscous Friction.

The following table shows the use of nominal parameters of the DC motor with permanent magnet [5].

Table 1. Nominal Parameters of DC-Motor with Permanent Magnet

Nominal power p	120 [W]	F.E.M Coefficient [kg]	$3.57*10^{-2}$ (Tr/min)
Nominal voltage	24 [V]	Inertia constant	$1.42*10^{-3}$N.M.S
Armature resistance *Ra*	1.21 [*Ω]*	Rubbing Coefficient	$2.45*10^{-3}$N.M/(Tr/min)
Armature inductance L	$5.34*10^{3}$ [H]	Nominal speed *ω*	2688 Tr/min

The equations of state of the healthy model (speed and torque) of the permanent magnet DC-motor is obtained when we replace the preceding parameters in the speed and torque equations.

Various Models of Faults

With an aim of obtaining the various models of faults, the authors in [5] injected the various faults in the DC-motor with permanent magnet by thinking its parameters each time.

Table 2. Various Faults

N° of Faults	Faults
1	Healthy motor
2	Increased of armature resistance *Ra* by 0.5Ω
3	Increased of armature resistance *Ra* by 1,4 Ω
4	Wear of brushes
5	Cut of the rotor winding
6	Short-circuit between two adjacent blades
7	Disconnection of the winding of the collector

The estimated parameters of the DC-motor with the presence of various preceding faults are mentioned in the table 3.

Table 3. Parameters of the Various Models of Faults

N° of Fault	R_a (Ω)	L$\times10^{-3}$ (*H*)	K_e x10^{-3}	J x10^{-5}	fr x10^{-5}
1	1,203	5,584	8,574	1,416	2,450
2	1,703	5,5837	8.399	1,3949	2,489
3	2,03	6,4942	8,490	1,519	2,020
4	1,769	6,0798	9,124	1,567	2,468
5	1,794	5,7591	8,639	1,568	2,453
6	1,174	4,405	7,340	1,221	4,014
7	1,436	8,755	8,065	1,485	4,323

Integer, Fractional and Fractionalized PID controllers

We can approach the design of a controller in two manners [10-11]:

- To assign a controller for a group of models, i.e., a controller who can control a beam of models, which is similar to the robust design.
- To assign a controller for each model.

The Integer integer-order PID controller to be designed is in the following form [1,10]:

$$C_{fz}(s) = K_p\left(1 + \frac{1}{T_i s} + T_d s\right) \tag{2}$$

The Fractional of the integer-order PID controller $C_f(s)$ is given by the following form [1]:

$$C_f(s) = K_p\left(1 + \frac{1}{T_i s^{\alpha}} + T_d\, s^{\beta}\right) \tag{3}$$

The Fractionalized of the integer-order PID controller $C_{fz}(s)$ is given by the following form [1,10]:

$$\begin{aligned} C_{fz}(s) &= K_p\left(1 + \frac{1}{T_i s} + T_d s\right) \\ &= \frac{1}{s}\left(\frac{(k_p T_d s^2 + k_p T_i s + k_p}{T_i}\right) \\ &= \frac{1}{s^{\alpha}}\frac{1}{s^{(1-\alpha)}}\left(\frac{(k_p T_d s^2 + k_p T_i s + k_p}{T_i}\right) \end{aligned} \tag{4}$$

Were, $0 < \alpha < 1$

Structure of the multi-model system

The supervisor architecture is illustrated by figure 1:

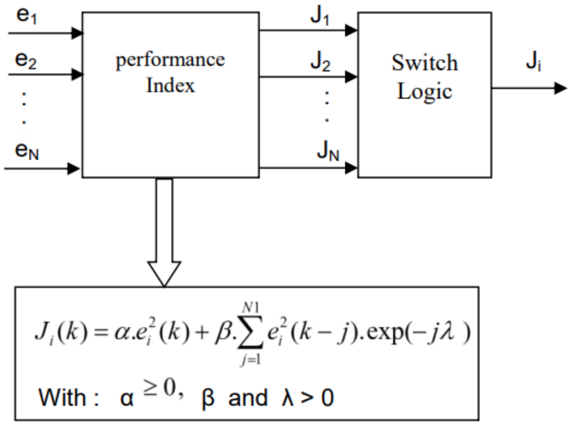

Fig 1 Supervisor Architecture

The multi-model DC-motor architecture control is illustrated by figure 2 [5-9].We associated the process eight models in parallel; a healthy model and seven models of faults. We designed for each model its adequate controller.

The objective of our study is to bring back the real system has its operating mode of reference, it is has to say: Speed (281.37 rad/s), torque (0.066 N.m) and that whatever the influence of the one of the faults on the system.

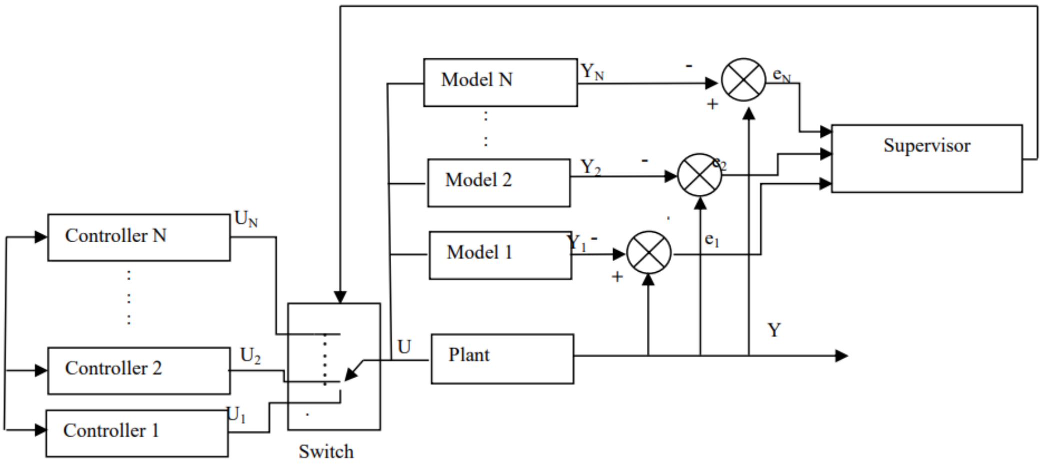

Fig 2 Multi-model Architecture control

After the detection of fault, the service of maintenance must deal with the equipment (repair or change). Thus, normally, we should be interested only in the transition from operation from the healthy model towards a fault. The case multi-faults were not considered [20]. However, to test the effectiveness of the supervisor, one allows oneself to carry out commutations between the various models. But this does not correspond to the real operation of the motor. The appearance of a new fault never implies the disappearance of old. The Commutations between the various models are useful only for the test of the stage of supervision during the study of simulation.

Results and Discussion

We used the index of performance for the commutation given by [10,14]:

$$(5)\quad J_i(k) = \alpha . e_i^2(k) + \beta . \sum_{j=1}^{N1} e_i^2(k-j) . \exp(-j\lambda)$$

The adequate values of the parameters are as follows: N1=1000, $\alpha = 0.45$; λ=10.5; β =0.06.

Such as: N1 is the number of sample.

The speed of the DC motor obtained after the application of the multi-model approach using the Integer, Fractional and

the fractionalized controllers is shown in figure 3 and figure 4.The parameters of various PID controllers are given in table4.

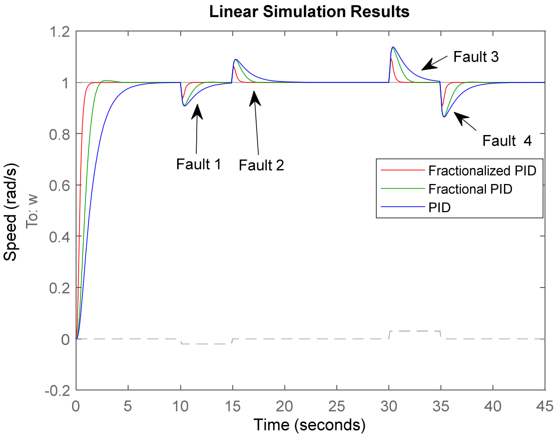

Fig 3 Speed DC-motor with the Multi-model control with an Integer, Fractional and Fractionalized PID controllers

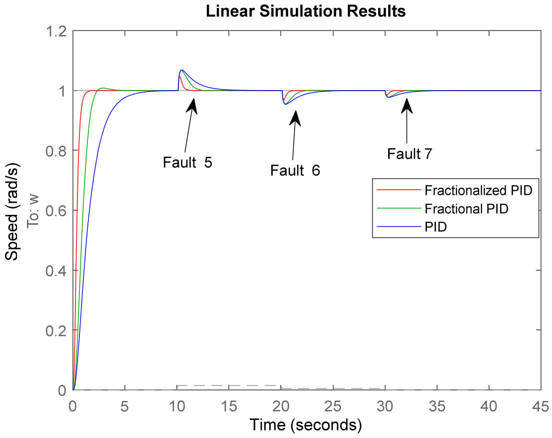

Fig 4 Speed DC-motor with the Multi-model control with an Integer, Fractional and Fractionalized PID controllers

With each time the system is subjected to a fault, the supervisor acts on one of the controllers (to vary the control signal) to make bring back the desired system to the reference.

The Transient Response Stability Parameters of DC motor using multi-model Approach is given by table 4 and the parameters are obtained using the oustloup approximation méthods [7-13].

Table 4. Transient Response Stability Parameters of DC motor using multi-model Approach

Controllers	Overshoot [%]	Setting time [s]	Rise time [s]	Mean Absolute Error (Rad/s)
Fractionalized PID (kp=5,Ti=0.4, Td=1.3,α=0.6)	0.00	0.94	0.41	0.00012
Fractional PID (kp=7,Ti=0.7, Td=2.7,α=0.6)	0.01	1.75	0.98	0.0045
PID (kp=15,Ti=1.2, Td=13.51)	0.00	4.02	1.63	0.0081

we remark that the fractionalized PID give a good performance (overshoot, Rise time, setting time and mean absolute error) then an Integer and a fractional PID controllers

Conclusion

In this work, the multi-model technique using the Fractionalized PID controllers approach is proposed to detect and diagnose the faults that may occur in a Maintenance of DC-motor system. The principle of this method consists in generating residues making it possible to detect the faults and to diagnose them.

To prepare our study, we started with the modeling of DC-motor with its various faults and we applied the multi-model approach for the supervision of the complete system. Our main goal is to find a control which leads the system to a desired objective in spite of the existence of a fault. The simulation results confirmed the advantages of the multi-model control using the Fractionalized PID controllers approach such as the good follow-up of the instruction and the maintenance of stability in spite of the occurrence of the fault.

The simulation studies show good performances of the proposed approach (Fractionalized PID) and confirm its superiority over Integer PID and Fractional PID Controllers.

In future work, we will investigate the generalization of the fractionalized control approach to others systems in order to improve their robustness and noise rejection.

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