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A Practical Application of IMC-PID Controller in Unmanned Vehicle

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Abstract

In allusion to unmanned vehicle steering control of the brushless DC motor control system, traditional PID controller parameter adjustment complex, weak ability to adapt to the environment and other issues, on the basis of the analysis of internal model control and classical PID control internal corresponding relationship, comprehensive its advantages, The design uses a brushless DC motor in the steering control system for unmanned vehicles based on the internal model PID controller (IMC-PID) for speed. Based on the build object theoretical model, online simulation controller show that, for the design objects, based on the internal model PID controller whether the system step response or disturbance tracking control effect can reach the classic PID control requirements, also reduces the complexity and randomness of the design parameters.

Keywords: *IMC-PID control, unmanned vehicle, brushless DC motor control system, speed control system*

1. Introduction

Brushless DC Motor is an electromechanical integration product of new generation, the permanent magnetic material used in rotor makes excitation lossless. In addition, no electric sparks produce with the replacement of mechanical brush and mechanical commutator by electrical commutator, no mechanical commutation loss as well [1-5]. Brushless DC Motor is as simple, elegant, reliable, and convenient in maintenance as AC Motor, and high-performance, first-rate in speed control as DC Motor at the same time, still cost-effective. Brushless DC Motor is rapidly gaining ground in many fields [6, 7].

Although traditional PID control technology is mature in motor speed control, it is difficult to keep its ideal performance as designed affected by nonlinear factors of motor load in practice. It is inconvenient to debug in operation as the index parameters need a strictly controlled outer environmental as well [8-11].

IMC (Internal Model Control) is a new control method which can be used in controller design based on Process Mathematical Model proposed by Garcia & Morrari. Compared with traditional PID, IMC has one setting parameter only that makes is clear when debugging the parameter, good dynamical performance and clear robustmess [12-14]. Easy framework, good performance in follow-up control, powerful robustmess, high-denoise quality in immeasurable disturbance are the main advantages of IMC.

By controlling different traits based on IMC, the results indicate that controller is easily designed and wide-used as parameters are easy to set and the designer may consider several parameters at the same time. The corresponding relationship between IMC and PID makes it possible to shift PID design to IMC [15]. IMC is reliable model for sources apportionment and outcomes are in accord with what it is. In this way we can make the requirements of fuzzy PID control with reduced complexity and randomness in parameter design.

In this paper, we analyze the mechanism of PID design based on IMC, finally get the inner mathematical model of controller parameter. Also, be aimed at speed control system of double closed loop Brushless DC Motor, system simulation is conducted via Matlab to make comparisons between designed controller and traditional PID.

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2. A Model of Brushless DC Motor

The model studied in this paper is three-phase Brushless DC Motor which is connected by neutral wireless Y connection, it is a typical model among Brushless DC Motor that can be used in many occasions.

2.1. Equivalent Electric Circuit

Based on the Hypothesis that the three-phase winding is perfectly symmetrical, thus shot effect is neglectful. The shape of air gap magnetic field is square wave, then stator current and rotor flux are symmetrical as well, magnetic saturation, eddy current and hysteresis loss can all be neglectful. We have the potential equitation:

$$U = E + I_{acp} r_{acp} + 2\Delta U \tag{1}$$

Where,

U : Supply voltage;

E : Back emf of armature winding;

I_{acp} : Average current;

r_{acp} : Average electric resistance;

ΔU : Saturation voltage of power tube, which is $2\Delta U$ in bridge commutation circuit. The equivalent electric circuit is shown as Figure 1.

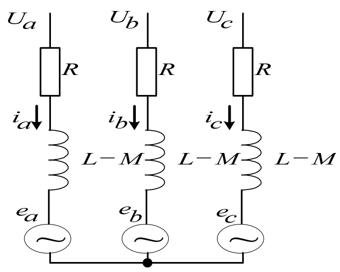

Figure 1. Equivalent Electric Circuit of Three-phase Brushless DC Motor

2.2. Dynamic Structure of Brushless DC Motor

Modeling of Brushless DC Motor based on its characteristics, we have the dynamic structure as Figure 2.

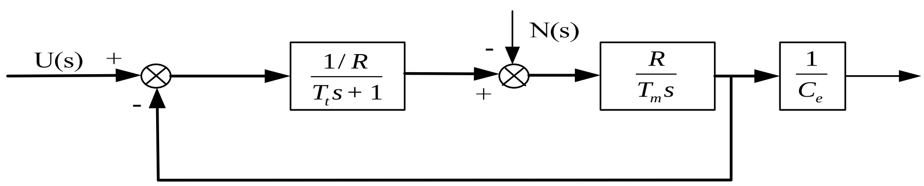

Figure 2. Mathematical Model of Dynamic Structure of Brushless DC Motor

Where:

T_t : The time constant of armature circuit;

T_m : The electromechanical time constant of drive system.

Thus the dynamic structure of double closed loop speed control system is shown below as Figure 3.

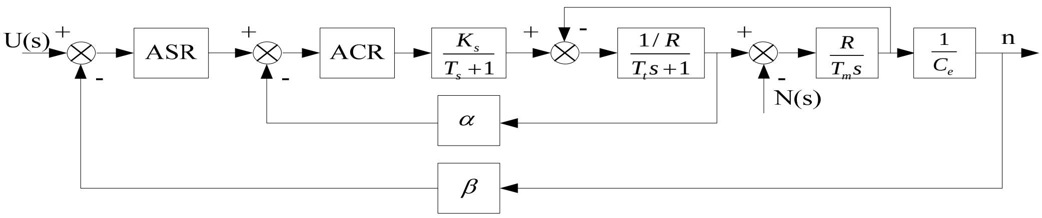

Figure 3. Dynamic Structure of Double Closed Loop Speed Control System

As can be seen in Figure 3, the system is a cascade control system. Thus a simulation method is used by IMC-PID control algorithm based on this cascade controlled controller.

3. Mechanism of IMC

IMC (Internal Model Control) is a new control method which can be used in controller design based on Process Mathematical. IMC is famous in both theoretical field and industry for its advantages, to be more exact, easy framework, good performance in follow-up control, powerful robustmess, high-denoise quality in immeasurable disturbance.

3.1. Typical Structure of Traditional IMC

Typical structure of tradition IMC is shown as Figure 4.

Where:

$G(s)$: Controlled Process;

$M(s)$: Model Process.

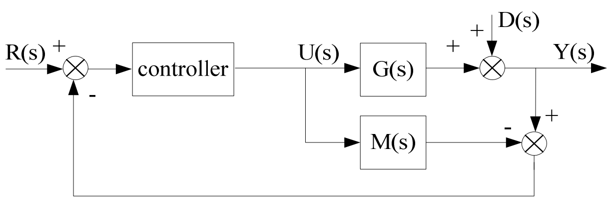

Figure 4. Structure of IMC

Where exactly,

$M(s)$: can be divided in to reversible part $M_-(s)$ and irreversible part $M_+(s)$:

$M(s) = M_-(s)M_+(s)$

$Q(s)$: IMC controller, by means of algorithm for proximate inverse of process model.

$Q(s) = M_-^{-1}(s)R(s)$

Where:

$R(s)$ is an N-order low pass filter: $R(s) = 1/(\lambda s+1)^n$

$U(s)$: Controlled-Output parameter of IMC;

$Y(s)$: Output of the System;

$R(s)$: Input of the System;

$D(s)$: immeasurable disturbance.

3.2. The Influence of λ on Robstmess in IMC

IMC (Internal Model Control) is a control strategy based on inner model by introducing low pass filter and build up inner mathematical model of controller on controlled object or parameter. λ is a setting parameter represents filter constant, which has prominent effect on the performance of system and robustmess, especially in system with time-varying delay.

4. Design of IMC-PID Controller

4.1. The Relationship Between IMC-PID Controller and Traditional One

Equivalent diagram of inner structure of IMC can be derived from Figure 4.

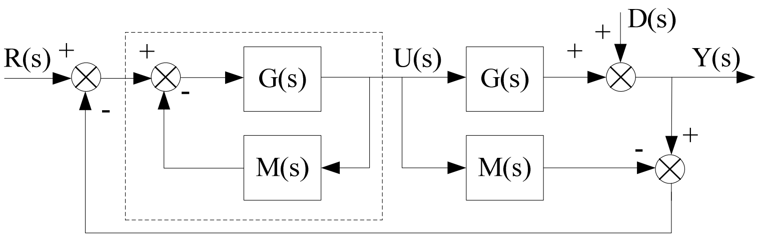

Figure 5. Inner Equivalent Diagram

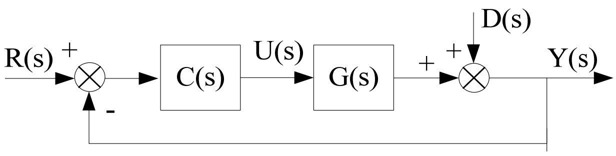

Figure 6. Structure of Traditional PID

IMC controller $Q(s)$ in Figure 4 can be divided into several components around by dotted line in Figure 5. Considering the input and output in Figure 5, two components $M(s)$ can be neutralized. Then Figure 6 is here to show PID feedback control system as an equivalent diagram of Figure 5.

As a result, the relationship between traditional PID feedback control $C(s)$ and IMC-PID $Q(s)$ is:

$$C(s) = \frac{Q(s)}{1 - Q(s)M(s)} \tag{2}$$

By doing equivalence transformation of above equation, we get:

$$Q(s) = \frac{C(s)}{1 + C(s)M(s)}$$

4.2. Design Procedures of IMC-PID Controller

Equation (3) shows the relationship between traditional $C(s)$ and IMC $Q(s)$ in Figure 4. The design concept of IMC-PID controller is finding the equivalent traditional feedback PID control form of $C(s)$, which can be accomplished by dividing IMC into several solutions of PID parameter. In other word, design PID controller from the view of IMC control.

Firstly, Model decomposition:

Divide $M(s)$ into all-pass part $M_+(s)$ and minimum-phase part $M_-(s)$:

$$M(s) = M_-(s)M_+(s) \tag{3}$$

$M_+(s)$ includes the pure time delay and the zero point in right side of plane S .

Secondly, Calculate IMC:

$$Q(s) = M_-^{-1}(s)R(s) \tag{4}$$

Where:

$$R(s) = 1/(\lambda s+1)^n \tag{5}$$

In addition, Transform IMC into appropriate PID controller.
Compare the Equation (3) and $Q(s)$ we get, ideal PID controller has form as follow:

$$C(s) = K_p(1+\frac{1}{T_i s}+T_d s) \tag{6}$$

Based on (3), (4) and (5):

$$C(s) = \frac{M_-^{-1}(s)}{(\lambda s+1)^n - M_+(s)} \tag{7}$$

Based on (6) and (7):

$$K_p(1+\frac{1}{T_i s}+T_d s) = \frac{M_-^{-1}(s)}{(\lambda s+1)^n - M_+(s)} \tag{8}$$

Expand right part of Equation (8) in Taylor series of s, based on the corresponding equivalent principle of polynomial coefficients, the parameter of PID can be calculated easily.

At last, Setting Filter Constant λ .

5. Setting IMC-PID Controller Parameter

As discussed above, the process model of controlled object can be divided into two parts: pure-time-delay part and minimum-phase part. The former one is difficult to analysis. Normally we choose Pade method to approximate analysis.

5.1. Pade Method

Refer to Equation 8, λ is the only parameter that needs being setting in PID controller design based on IMC. The controlled object is a 2-order pure time delay segment, the model structure is as Equation (9).

$$M(s) = \frac{K}{(T_1 s+1)(T_2 s+1)} e^{-\tau s} \tag{9}$$

Pade method is used, which means,

$$e^{-\tau s} = \frac{1-\frac{\tau}{2}s}{1+\frac{\tau}{2}s} \tag{10}$$

So:

$$M(s)=\frac{K}{(T_1 s+1)(T_2 s+1)}\frac{1-\frac{\tau}{2}s}{1+\frac{\tau}{2}s} \tag{11}$$

5.2. Calculate the IMC-PID Control Parameter

From Equation (11):

$$M_-(s)=\frac{K}{(T_1 s+1)(T_2 s+1)(1+\frac{\tau}{2}s)}$$

$$M_+(s)=1-\frac{\tau}{2}s \tag{12}$$

IMC controller is:

$$Q(s)=M_-^{-1}(s)R(s) \tag{13}$$

Based on (11), (12) and (13), IMC-PID feedback controller is:

$$\begin{aligned}
C_{PID}(s) &= \frac{1}{M_{-1}(s)R^{-1}(s)-M_{-1}(s)} \\
&= \frac{M_-^{-1}(s)}{(\lambda s+1)^n-M_+(s)} \\
&= \frac{(T_1 s+1)(T_2 s+1)}{K(\lambda+\frac{\tau}{2})s}(1+\frac{\tau}{2}s) \\
&\approx \frac{1}{K(\lambda+\frac{\tau}{2})}(T_1+T_2+\frac{1}{s}+T_1T_2 s) \\
&= \frac{T_1+T_2}{K(\lambda+\frac{\tau}{2})}(1+\frac{1}{(T_1+T_2)s}+\frac{T_1T_2}{T_1+T_2}s)
\end{aligned} \tag{14}$$

While traditional PID controller is:

$$C(s)=K_p(1+\frac{1}{T_i s}+T_d s) \tag{15}$$

(8), (14) and (15), the parameter of IMC-PID controller:

$$K_p=\frac{T_1+T_2}{K(\lambda+\frac{\tau}{2})}, T_i=T_1+T_2, T_d=\frac{T_1T_2}{T_1+T_2} \tag{16}$$

From Equation (16), we have the conclusion that λ is the only parameter that needs setting when model of control object is known, and T_1 T_2 and K are all known as well.

6. Simulation & Analysis

6.1. Matlab parameter of Brushless DC Motor

Simulink toolbox in Matlab is used to simulate, the mechanism is shown as Figure 7 and Figure 8.

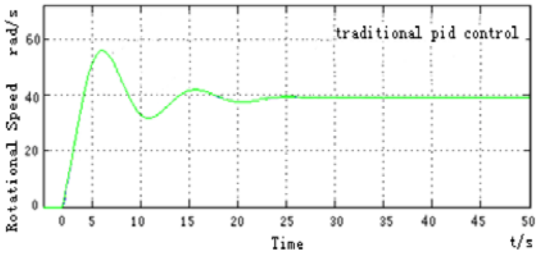

Figure 7. Traditional PID Control System Response Simulation

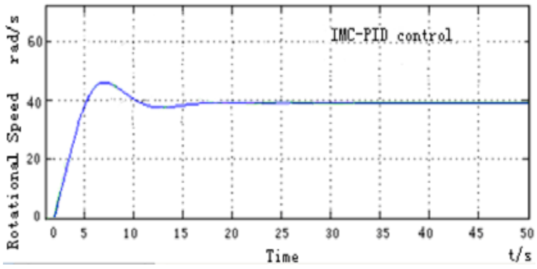

Figure 8. IMC-PID Control System Response Simulation

6.2. Discussion and Analysis of Simulation

We can see from above simulation result, compared with traditional PID controller, IMC-PID method costs less adjusting time, faster responses, lower overshoot, and easier to reach to stable point. IMC-PID improves both dynamical and static performance of controlled object. While on the other hand, there is one setting constant only that makes it much more convenient to regulate the parameters. Last but not least, IMC-PID has great advantages in industrial practice.

7. Conclusion

This design is based on research of control algorithm of steering control on unmanned vehicle. After comparison and simulation of the control effect in speed control systems between Traditional PID controller and IMC-PID controller with double-closed-loop DC motor, the results show that firstly, IMC-PID DC Motor can fulfill the requirements of speed control in double-closed-loop Brushless DC Motor. What's more, IMC-PID controller is more convenient in setting parameters. All in all, IMC-PIC can be used in speed control system of double-closed-loop Brushless DC Motor.

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