Direct PID Tuning For Spindle Motor Systems

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Abstract— **This paper presents a direct PID tuning method suitable for Spindle Motor Test and Measurement Systems. In these systems, the electrical parameters (the armature resistance, the armature inductance, the electromotive force constant) as well as the mechanical parameters (inertia and viscous constants) will be measured or extracted. Based on these parameters, the controller can automatically be designed either in simulation packages or analytically. The latter approach is recommended as these systems typically run on a firmware environment, utilizing either HDL or C. Utilizing this method will greatly minimize any laborious and time consuming tuning. The validity of the proposed method is demonstrated through simulation.**

Index Terms— **BDCM, PID, PMSM, Spindle Motor and Ziegler-Nichols.**

I. Introduction

Rapid progress in computer technologies and widespread adoption of consumer appliances have expanded the application for mass data storage devices. These remarkable progress has been made possible due to a combination of developments in some key technologies in areas of materials for heads and media, electronics for data communications, head-positioning systems and innovative designs for spindle motor.

In a manufacturing environment, the electrical parameters (the armature resistance, the armature inductance, the electromotive force constant) as well as the mechanical parameters (inertia and viscous constants of the bearings) are controlled within certain limits and have to be accurately measured. Apart from these, other parameter such as run-out, resonance, starting torque and operating current have to be acquired. These parameters require stable rotational operation for measurement and hence necessitate the need for a speed controller.

PID is widely used in the area of motor drives because of its robustness over a wide range of operating conditions. It has been experimentally validated in [1] that traditional PID controller is generally better than fuzzy controller in the rate of response. To determine the PID parameter gains, Ziegler-Nichols method has been widely known as a fairly accurate heuristic method. However, this manual tuning method is not often applied in practice because it is laborious and time consuming. Nevertheless, due to the uniqueness of spindle motor structure, it is feasible and straightforward to derive a set of mathematical equations in the controller parameters based on the Ziegler-Nichols method.

In this paper, PID controller is designed from the motor specifications by direct calculation based on the Ziegler-Nichols step response method.

II. Mathematical Model Of Spindle Motor

Spindle motors are classified as Brushless DC Motors (BDCM) and broadly, as Permanent Magnet Synchronous Motor (PMSM). Compared to PMSMs, BDCM has several unique features. The rotor of BDCMs has got surface-mounted permanent magnet constructing a smooth-air-gap machine. As such, reluctance torque contributed by inductance variations can be neglected. In addition, the rotor utilizes fractional-slots which in turn make the cogging torque negligible. These, together with other features, such as sinusoidal Back-EMF and well symmetrized three-phase structure, create an unique PMSM or a BDCM. Assuming a wye-connected 120^0 conduction drive, the BDCM can be represented as follows [2]:

$$V = IR + L\frac{dI}{dt} + K_e\omega \tag{1}$$

$$T = K_t I = J\frac{d\omega}{dt} + B\omega \tag{2}$$

where R= 2 x armature resistance, L= 2 x armature inductance, $K_e = K_t = 3\sqrt{3}/\pi$ x backemf constant, J=inertia and B=viscous constant.

III. PID Controller

PID control is a proportional integral plus derivative controller whose control action is characterized by the transfer function [3] below:

$$G_{pid}(s) = K_p\left(1 + \frac{1}{T_i s} + T_d s\right) \tag{3}$$

IV. Ziegler-Nichols Step Response Method

For the Ziegler-Nichols step response method, it approximates the system by a first-order lag plus a time delay as

$$G_p(s) = \frac{Ke^{-L_o s}}{T_o s + 1} \tag{4}$$

where T_o and L_o can be determined from the step response of the plant [3] as seen in Fig. 1.

V. Direct Calculation

Solving (1) and (2), the step response can be expressed as

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$$\omega(t)=\frac{\gamma}{\alpha\beta}+\frac{\gamma}{\alpha(\alpha-\beta)}e^{-\alpha t}+\frac{\gamma}{\beta(\beta-\alpha)}e^{-\beta t} \tag{5}$$

where

$$\gamma=\frac{K_e}{JL} \tag{6}$$

and α, β are the negative roots to the equation

$$(s+\alpha)(s+\beta)=s^2+\frac{JR+LB}{JL}s+\frac{RB+K_e^2}{JL} \tag{7}$$

With the step response mathematically defined, in order to obtain T_o and L_o directly, the inflection point $(\omega(t_1), t_1)$ must be obtained. And t_1 is derived to be

$$t_1=\frac{1}{\alpha-\beta}\ln\frac{\alpha}{\beta} \tag{8}$$

Consequently,

$$L_o=t_1-\frac{\omega(t_1)}{\omega'(t_1)} \tag{9}$$

$$T_o=\frac{\gamma}{\alpha\beta}\times\frac{1}{\omega'(t_1)} \tag{10}$$

Following the determination of these two parameters, the gains parameters are derived using the following equations.

$$K_p=1.2\frac{T_o}{L_o},\qquad T_I=2L_o,\qquad T_D=0.5L_o \tag{11}$$

VI. SIMULATION RESULTS

To verify the validity of the derivation, a simulation of a spindle system with the PID gains calculated using the derived equations was performed using MATLAB. The parameters of the motor used for simulation is measured from a HDD using FDB Motor. The values for these parameters are provided in Table 1 and the calculated gains are provided in Table 2.

The speed response is shown in Figure 2. It can be seen that the response using the direct tuning method is good with overshoot of 0.36%.

VII. CONCLUSION

In this paper, a direct method based on the Ziegler-Nichols step response method for PID tuning is presented. This method is feasible due to the unique and simplified structure of a spindle motor. With the spindle motor parameters measured, the PID gains can be calculated. The PID controller designed has been simulated and observed to have good performance.

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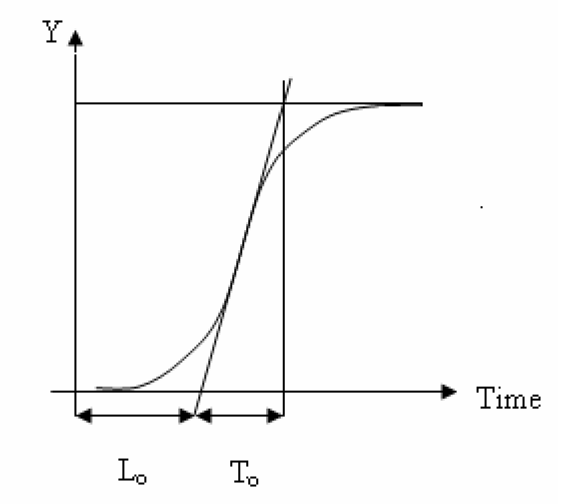

Figure 1. Open loop spindle motor step response

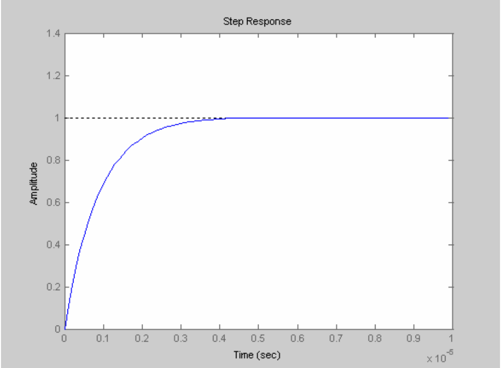

Figure 2. PID Controlled Spindle Motor

Table 1. PID Controlled Spindle Motor

MOTOR PARAMETERS	Values
Pole Pairs	4
Armature Resistance (Ω)	2.40
Armature Inductance (mH)	0.562
BackEmf Constant (V/krpm)	0.753
Inertia (gcm^2)	33.14

Table 2. Calculated PID Gains

PID GAINS	Values
K_p	6.498e+03
T_I	4.677e-04
T_D	1.169e-04