INVESTIGATION OF SLIDING MODE POSITION SERVODRIVE CONTROL

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Abstract. The theoretical and experimental investigation of servo drives with a sliding mode position control is given. The sliding mode control (SMC) prescribes the position, speed and acceleration (deceleration) time functions and the quality of the drive transient phenomena as well. The control surface is performed by given four sliding mode errors: position, speed, acceleration and deceleration errors. It is shown that the smooth control is insured. The simulation and experimental results of the sliding mode controlled dc chopper drive verify the theoretical results.

Keywords: Sliding mode control, Servo drives, DC machines, Microcontrollers.

1. INTRODUCTION

In motion control systems the robustness against parameter changes and disturbance rejection are of main importance. It is well known that the sliding mode control, which belongs to the group of variable structure control, has the following features:
• Insensitivity to parameter variations and disturbances,
• No requirement of the accurate model of the controlled system,
• Simple realization of the control algorithm.

In this paper the application of sliding mode control to permanent magnet DC servomotors is presented.

2. THEORETICAL CONSIDERATIONS

The synthesis of sliding mode control (SMC) can be broken into three parts. The first part is the design of the sliding surfaces, the second part is the design of the control, which holds the system trajectory on the sliding surface and the third part is the chattering-free implementation.

Sliding mode position control

The sliding mode control should be investigated by the limitation of the current, the speed and the acceleration (deceleration) of the drive.

The sliding surfaces at this restricted mode are determined by the sliding surface equation of the position control [7] (1) and by the additional equations (2-4), which take into account the possible restrictions:

\[ s_\alpha = \Delta \alpha + \lambda_1 \frac{d\Delta \alpha}{dt} + \lambda_2 \frac{d^2 \Delta \alpha}{dt^2} , \]

(1)

\[ s_\omega = \Delta \omega + \lambda_\omega \frac{d\Delta \omega}{dt} , \]

(2)

\[ s_d = \epsilon_d - \frac{d\alpha}{dt} , \]

(3)

\[ s_d = -\epsilon_d - \frac{d\alpha}{dt} , \]

(4)

where \( \Delta \alpha = \alpha_\text{ref} - \alpha \) is the position error, \( \alpha_\text{ref} \) is the position reference signal, \( \alpha \) is the position, \( \lambda_1 \) and \( \lambda_2 \) are parameters and \( \Delta \omega = \omega_\text{max} - \omega \),

\( \omega_\text{max} \) is the prescribed limit of the speed,

\( \epsilon_d \) is the limit of the acceleration,

\( \epsilon_d \) is the absolute value of the deceleration limit.

The solution of a second order differential equation

\[ \Delta \alpha + \lambda_1 \frac{d\Delta \alpha}{dt} + \lambda_2 \frac{d^2 \Delta \alpha}{dt^2} = 0 \]

with \( \lambda_1 = 2\sqrt{\lambda_2} \) (damping factor \( \xi = 1 \)) are:

\[ \Delta \alpha(t) = [\Delta \alpha_0 + (\Delta \alpha_0 \Omega - \omega_0) t] e^{-\Omega t} , \]

(5)

where \( \Omega = 2 / \lambda_1 \) and \( \omega_0 \) is the speed when the SMC switches the system to the position surface according to (1), providing the smooth setting of the drive.

For small position reference the system from beginning to end stays on the position surface thus \( \Delta \alpha_0 = \alpha_\text{ref} \) and \( \omega_0 = 0 \). Then the solution is as follows:

\[ \Delta \alpha(t) = \alpha_\text{ref} (1 + \Omega t) e^{-\Omega t} , \]

(6)

\[ \Delta \alpha(t) = -\alpha_\text{ref} \Omega^2 t e^{-\Omega t} , \]

(7)

\[ \Delta \alpha(t) = -\alpha_\text{ref} \Omega^2 (1 - \Omega t) e^{-\Omega t} . \]

(8)
In this case neither speed nor acceleration (deceleration) are limited as it can be seen in Fig. 1a-b where the theoretical transient time functions and the projections of sliding curves in phase plain are shown. The selection of the damping factor $\xi = 1$ ensures the motion performance without overshoot. 

The projections of sliding curves on phase plain and transient time functions for restricted modes of operations are presented in Fig. 1c-d. If in Fig. 1c-d the operation region is in dashed region the (+U) motor voltage, in opposite case the (-U) voltage is switched to the motor. The acceleration and deceleration limits prescribe the motor current limits therefore the maximal acceleration (deceleration) is limited by current limit. 

In the first part of the motion in Fig. 1.-d the system space trajectory is performed in $\xi = \xi = \text{const}$ plane. In the second part the speed limitation according to (2) - beginning from the speed $\omega = \omega_{\text{max}} - \Delta \alpha$ leads smoothly the system speed to the prescribed maximal speed $\omega_{\text{max}} = \text{const}$ .

Further the system trajectory stays in the plane $\Delta \alpha - \omega$ since the acceleration $\varepsilon = 0$ . The third part of the trajectory is lying in the deceleration plane $\varepsilon = -\varepsilon_d = \text{const}$ . When this trajectory reaches the plane determined by (1) the last part of motion starts, namely the position control with a smooth stop of the system, that is the system trajectory reaches the origin of the coordinate system.

Realization of SMC
The system motion is performed according to sliding performance (1)-(4) as it was shown above. But there is some freedom in the selection of the braking start time. According to (5) the last part of the trajectory will be realized without position overshooting if

$$\Delta \alpha_0 \Omega - \omega_0 > 0,$$

that is $\Delta \alpha > \omega_0 / \Omega$. If the condition of (9) is fulfilled one can prescribe the initial value of the last trajectory part speed $\omega_0$ . Then the position error in this point will be:

$$0^2 \Delta \alpha_0^2 + \Delta \alpha_0^2 = \omega_{\text{max}}^2 - \omega_0^2, \quad (11)$$

and in the instant when $\Delta \alpha = \Delta \alpha_0$ the transition to the sliding surface (1) must start.
Fig. 1. c, d. Transient time functions and sliding curves for SMC with restrictions of speed, acceleration and deceleration

Fig. 2. Results of simulations
The SMC simulation of a permanent magnet dc motor drive was performed. The motor dates that have been used for both simulation and experimental investigations are: $U = 63V$, $I = 13A$, $\omega = 262rad/s$. Motor electric time constant is $3ms$, the starting time constant is $161ms$.

The results of SMC simulation for a small reference signal $\alpha_{ref} = 2$ and a relatively big one $\alpha_{ref} = 10$ are presented in Fig. 2. In Fig. 2b, the scale of the speed is increased by 10 times and $\omega_{max} = 0.5$. Due to no-load motor operation and $e_d = e_d$ there is $I_{max} = I_{max} = 5I_{rated}$. The dc voltage of the chopper drive is 2.5p.u. (157.5V). The chopper frequency was 20kHz.

**Chattering free implementation**

SMC laws present discontinuities on the sliding line which cause chattering and a strong control activity which are amplified by the effect of time delays (limited switching frequency and computation time) and of unmodelled small time constants. Usually, all state variables are not measurable (for instance the acceleration), the system parameters are not known and the unmodelled dynamics may cause chattering.

To solve this problems the asymptotic state observer has been proposed [6]. Even if the real states are measurable, the switching surfaces and the control are calculated from the observer states. Since the observer structure and all the observer parameters are exactly known, an ideal sliding mode might occur in the observer-controller loop. According to the theory of singular perturbation, the small time constants of the real system can be ignored in the observer model.

### 3. HARDWARE REALIZATION

The experimental results are obtained using two identical permanent magnet DC motors, which are joined together by a clutch as it is shown in Fig. 3. One of them is used as a motor whose position is controlled and the other is used as a load. Both of the DC motors are driven separately by two identical servo drivers containing a four-quadrant chopper amplifier.

The sliding mode controller is implemented on a DSP (TMS320) equipped with the counter for the encoder, digital-analogue converters (DAC) and analogue-digital converters (ADC). The armature current given by the servo amplifier is converted by ADC in every $T_2=100\mu s$ which is the sampling period of the sliding mode controller. The output of the sliding mode controller is the voltage reference for the motor.

### 4. EXPERIMENTAL RESULTS

The experiences show that the sliding mode control suggested in this paper works without overshooting and chattering. Though the method SMC requires a longer calculation period it is less sensible to the variations of parameters. The position, speed and current time-functions are shown in Fig. 4. for no-load motor operations, In Fig. 4a. these functions are given for a small reference signal $\alpha_{ref} = \pi$, while in Fig. 4b. they are given for a considerable signal $\alpha_{ref} = 4\pi$. In the first case the motor speed doesn't reach the maximal speed, while in the second case there is a part of motion with the constant restricted speed. In both cases the SMC provides the acceptable time functions and a good quality of the position control with smooth setting.

### 5. CONCLUSIONS

This paper presents the theoretical and experimental investigation of servo drives with sliding mode position control. The control surfaces are performed by given four
sliding mode errors: position, speed, acceleration and deceleration errors. The simulations and experimental results demonstrate that the proposed sliding mode control is a promising tool to control the servo drives and it is shown that the smooth and accurate control is insured.

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7. REFERENCES


Fig. 4a. Experimental results for small reference signal

Fig. 4b. Experimental results for big reference signal


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