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Adaptive Control of Velocity Profile of an Alternating Current Motor

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1. Introduction

In the recent years, many control techniques have been developed for motor drives to yield a good performance. Dynamic advancement of drive systems has benefited from the progress in power electronics, intelligent controllers, and informatics. Many problems are solved by making the control structure digital and applying sophisticated DSP control [3, 4, 5]

The typical motion control system consists in controlling a motor, which has to move or displace an object over some time reference. Traditionally three-loop systems are used to control simultaneously the main motor parameters: position, velocity, and torque/current. Commonly applied for position/velocity control in different electro mechanic configurations are servo and step motors. Tachogenerators and optical encoders are usually used to detect the rotor velocity.

The most general types of a move involves three periods – acceleration period, slewing at a desired target velocity for some time and deceleration to reach the end position. The easiest for program realization is the trapezoidal move, which is characterized by poor quality of control, because of large and sudden discontinuities. The goal is to achieve smooth acceleration and deceleration curves with continuous and constrained derivative. For creation of the velocity profile different logarithmic, exponential and mostly S-curves are used [1, 9].

To control all axes in a single control system is a very complex task, for that reason, some leading motion developers have chosen distributed control architectures over centralized control. This type of motion systems has the advantage that as the number of axes increases or motion requirements increase, peak performance and synchronization of the system do not degrade [7].

2. Creation of velocity profile using s-curves

In this paper an approach is proposed for velocity profile control of an AC motor. The dynamic control algorithms for calculation and estimation of the S-curve profile adapt in real time to variations in system behavior to improve their performance.

The S-curve velocity profile is similar to trapezoidal, and in this case, trapezium sides are replaced by S-curves, which enables smoother velocity transitions in acceleration and deceleration periods [1, 9].

The first order trapezoidal velocity profile is a typical point-to-point move. An axis accelerates from rest to a given velocity at a constant rate. Then traverses, or slews, to a certain point where it decelerates at a constant rate until finally, the end position is reached and the axis will come to a rest. Sometimes the slew velocity and the end position can be changed on the fly. The S-curve velocity profile can be represented as a second-order polynomial in velocity. We have an extra term here – jerk (jerk is a derivative of acceleration and a measure of impact). The second order S-curve provides complete flexibility in the control of profiles for smoothing motion and eliminating jerk from mechanical systems. The degree of S-curve on a motion profile is controlled by separate acceleration and deceleration smoothing (jerk-limit) factors.

The following polynomials define an S-curve motion [1]:

(1) $$j = j_{\max} = \text{const} ,$$

(2) $$a = a_0 + j_0 t ,$$

(3) $$v = v_0 + a_0 t + \frac{1}{2} j_0 t^2 ,$$

(4) $$p = p_0 + v_0 t + \frac{1}{2} a_0 t^2 + \frac{1}{6} j_0 t^3 ,$$

where

p, v, a, j are the current position, velocity, acceleration, jerk (jerk is a derivative of acceleration and a measure of impact);

p_0, v_0, a_0, j_0 – the previous position, velocity, acceleration, jerk;

t – the sample time period.

A typical S-curve velocity profile is illustrated in Fig. 1. The S-curve has an intermediate constant acceleration (linear zone) to reduce the time to transition to the slew velocity. We assume that the acceleration and deceleration periods are symmetrical, and therefore, the times (t_a and t_d) and distances traveled for each (p_a and p_d) will be equal. The three-deceleration zones are symmetrical with acceleration as well.

From equations (1)-(4) we can find simple expressions for slew velocity, acceleration and jerk:

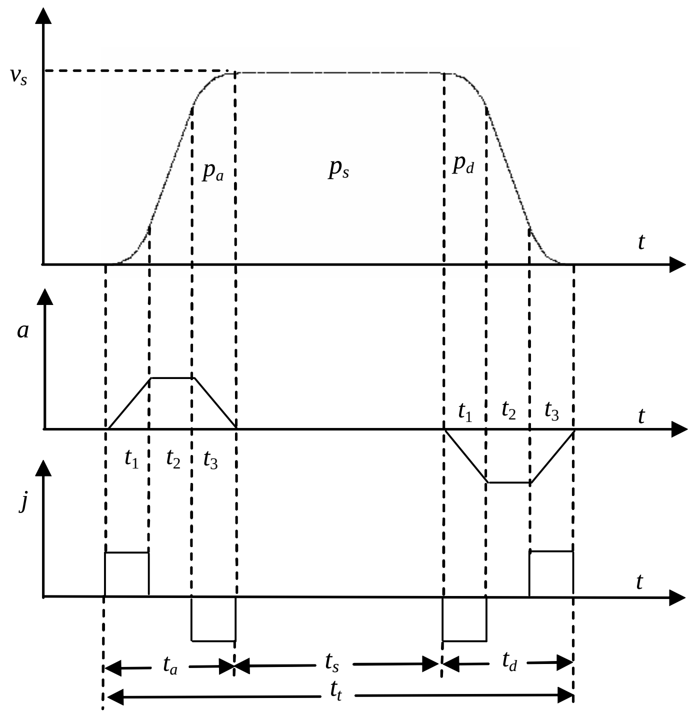

Fig. 1. S-curve profile with symmetrical acceleration and deceleration periods

(5) $$v_s = \frac{p_t}{t_s + t_a},$$

(6) $$a = \frac{v_s}{t_a},$$

(7) $$j = \frac{a}{t_1}.$$

Our task here is to accelerate from the rest (initial position), then traverse within a given target velocity v_s, and decelerate until the end position is reached. Therefore this is a modified assignment – we will know the total distance p_t that we have to move and the time t_t it takes to move to there, but also that distance must be achieved with a given velocity.

3. Adaptive control of velocity profile of an AC motor using DSP

A powerful processor such as a DSP controller provides an efficient control in all velocity range implying right dimensioning of power device circuits. The computing power of a DSP allows to exploit software modeling to implement closed-loop motor control and shifting from hardware to software. In practice, it is the best-suited solution

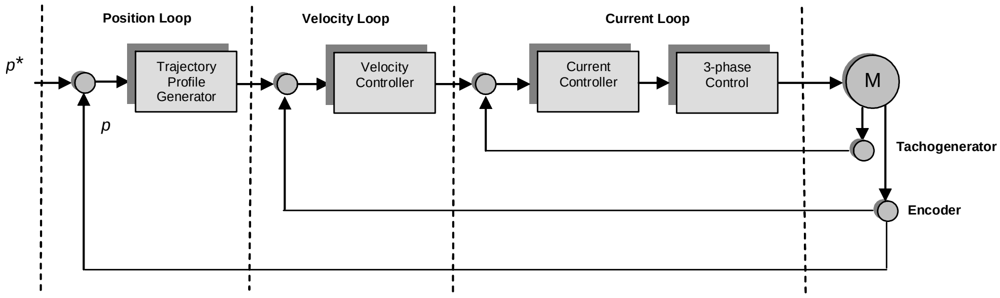

Fig. 2. A block diagram of 3-loop control scheme of an AC motor

for real world signals and algorithms processing. For our task here we will use an ADSP-2181 from Analog Devices to generate in real-time a smooth reference profiles and move trajectories, which yield a good performance [2, 8].

A three loops system is used to control the rotor position, velocity, torque/current. The trajectory profile generator has to produce a typical point-to-point move with an S-curve velocity profile. There is also a loop for velocity control – a PID controller with an optical encoder feedback, and a current controller.

Each motion on the predefined trajectory could be represented as a sequence of local point-to-point moves. The special case is to control move between two neighboring points following the desired velocity profile and the goal is to provide a smoothing motion and eliminating jerk from mechanical systems using of S-curve velocity profile.

The motor control system has to satisfy certain conditions, which impose some constraints in the creation of S-curves:

$$v \le v_{max},\quad a \le a_{max},\quad j = j_{max}. \tag{8}$$

Even if we take into consideration the above-mentioned assumptions that acceleration and deceleration periods are symmetrical, further simplification is possible after considering more constraints. We suppose that declination of the linear zone in acceleration and deceleration periods are equal and the transition zone has to be symmetrical with same curve radius. These parameters can be used in estimation of the velocity profile in a purpose of its eventual adaptation to the dynamic characteristics of the system. The change of these parameters is given as a set of rules (strategies), which could be defined, for instance by fuzzy logic formalism.

The process of adaptation of the S-curves could be presented as a sequence of procedures, realized in the software – in trajectory profile-generator. To summarize, the loop algorithm consists of the following steps:

1) setting the model of ideal (desired) S-curve velocity profile;

2) measuring the rotor position using an encoder feedback and create the real S-curve velocity profile;

3) calculating and estimating the current error by comparing real with the ideal velocity profile;

4) creation of strategy for correction and adaptation of the S-curve in the following movements.

Adaptation based on estimation could be done in one of the two blocks – profile-generator and velocity (PID) controller. When the error is small, the adaptation could be done changing PID parameters, without the need of intervention of the profile-generator. When the error gets too large there for instance, if the given target velocity is not reached, the profile-generator could be used in changing the strategy (declination or curve radius). The subjective nature of the estimation for small and large errors makes useful the fuzzy logic decision making. In this way, doing consecutive iterations and improving the velocity profile and PID parameters could lead to optimization of the system control. These parameters stored in energy independent memory are then used for the realization of consecutive moves.

4. Conclusion

This paper discusses the main aspects related to the use of S-curves in motion control systems. The approach proposed is convenient in applications that can take advantage of a distributed motion control architecture for realization of complex trajectories. DSP control allows producing real-time generation of smooth velocity profiles and move trajectories and adaptation to variations in dynamic properties of the load. The additional advantages of this approach are the possibilities for high-level supervisor system control.

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Адаптивное управление профиля скорости двигателей промепливого тока

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В статье представлено DSP управление профиля скорости двигателей переменного тока, которое позволяет генерирование в реальном времени траектории движения и адаптирование к переменам динамических характеристик систем.

В работе описывается базисная постановка управления движением и представлен метод адаптивного управления профилем скорости переменно-токового двигателя. Управляющий алгоритм оценки и вычисления профиля S-кривой (S-curve) дает потребителю возможность легкой настройки и диагностики работы.