Proceeding of the 2nd
RSI/ISM International Conference on Robotics and Mechatronics
October 15-17, 2014, Tehran, Iran

Low Speed Control of AC Servo Motors in No-Load Condition

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***Abstract*— Torque mode control of servo motors in low speed - no load condition requires the applied torques to be as much as dry friction forces which are designed to be as low as possible. Therefore, in these cases amplitude of available noises are comparable to control voltages which deteriorate performance of closed loop system. In this paper a simple but effective method is presented for low speed control of AC servo motors in no load conditions. This method uses a common feature of AC motor drives which enables users to specify torque ramp in torque mode control. By setting this parameter to an appropriate value, first control signal is scaled up to reduce the noise effects. Then, drive will apply the control voltage to motor by internally scaling the signal down to its real value. Since drives are usually well shielded, the noise effects will be negligible during the down scaling process. The effectiveness of the proposed method is demonstrated through some experimental tests.**

Keywords—AC servo motor; Low Speed - no load control; Torque ramp parameter.

I. INTRODUCTION

Speed control of AC servo motors is a highly demanded task [1]-[4] which can be done through two different approaches of velocity control mode and torque control mode [5],[6].

In the first approach, the built-in velocity control mode of motor drives is used. Because of hardware implementation of control loop, this method is simple and fast which makes it the best choice for industrial applications. However, velocity control mode has a major drawback of fixed control algorithm which makes it unsuitable for applications which requires implementation of different control algorithms especially academic researches.

In the second approach, torque control mode of motor drives is used. In this approach an external loop is used to calculate the required torque for reaching the desired velocity. A voltage proportional to the required torque is send to the drive and the drive adjusts motor torque according to the applied voltage. The main advantage of this method is the possibility of implementation of different control algorithms of model free [7] and model based [3], [4] strategies. On the other hand, because of analogue communication between controller and the drive, control signals are more subjected to noises in this method.

Regarding basic physical laws, the torque applied by the motor should counteract friction forces and external loads moreover to providing required inertial torques due to acceleration. If the motor has low linear and rotary inertias, the inertial torques will be negligible in low accelerations. Also when the motor operates with a constant speed, there will not be any inertial effects.

Neglecting the accelerations, if the external loads on the motor are low, the motor torque should only oppose the friction forces which contain dry and viscous terms. Since viscous frictions get smaller as the motor speed decreases, dry friction forces are the only terms to be counteracted by the motor torque in low speed - no load operations. It is also a common trend that for efficiency considerations, servo motors are designed to have low friction forces.

Low speed - no load control of AC servo motors has a wide range of applications. In some usages like micro machining [8] effective inertia and loads are very low and motor is demanded to move very slowly. Moreover, slow motor rotation is an essential part of friction identification process which is largely used in friction compensation algorithms [9], [10]. Such applications, where the motor is required to rotate slowly with low external loads, are commonly called low speed – no load operations which are in the focus of this study.

According to the previous discussion it can be concluded that in low speed – no load operations amplitude of the required control voltage is very low and comparable to available noises which can completely ruin the control signal. Hence, the main difficulty of controlling motor velocity in these conditions is to keep noises as low as possible or to somehow reduce the effect of available noises.

This paper presents a simple but effective method for speed control of AC servo motors in low speed – no load conditions. The proposed method uses adjustable torque ramp option which is mostly offered by AC motor drives (e.g. [11], [12]). In torque control mode, this option specifies for the drive that incoming control voltage corresponds to what percent of nominal torque. By setting this parameter to an appropriate

978-1-4799-6743-8/14/$31.00 ©2014 IEEE

value, controller can send a deliberately scaled up control signal (e.g. by a factor of 10) to the drive. Since the control signal is scaled up while noises have their previous amplitude, noise effects are considerably reduced. The minimally noise affected signal is then scaled down by the drive to regulate the motor torque. Since drives are usually well shielded, the noises can not disturb internal signal of drives and the overall effect of available noises is largely decreased.

Therefore, the main contribution of this paper is to use drive capabilities to propose a simple and effective method for low speed – no load control of AC servo motors.

Some experimental tests are also conducted to show the effectiveness of the proposed method for speed control of a sole AC servo motor without any external loads. The considered motor has a very low rotary inertia and low friction forces which make it a good choice for evaluating the presented method.

This paper is organized as follows: Section II provides a simple dynamic model of a rotating motor shaft. Linear high gain observer which is used for estimation of motor speed is briefly described in section III. Experimental setup is described in section IV and test results are provided in section V. Finally, section VI summarizes the paper.

II. Dynamic Modeling of Rotating Motor Shaft

In order to better understanding the effect of different factors on the speed control of motors, in this section a simple dynamic model of rotating motor shaft is derived using basic physical laws. Dynamic equation of motion of motor shaft can be written as (1),

$$I\ddot{\theta} = \tau_m + \tau_f + \tau_l, \tag{1}$$

in which I is rotary inertia of the motor shaft and $\ddot{\theta}$ is its angular acceleration. τ_m is the motor torque, τ_l represents load torques on the motor and τ_f is friction torque.

Resultant friction force on a motor may include viscous (τ_{fv}) and dry friction (τ_{fc}) effects as indicated in (2).

$$\tau_f = \tau_{fc} + \tau_{fv}. \tag{2}$$

During no load operations, there is not any external loads on the motor shaft and as a result, τ_l can be neglected. Moreover, it is well known that viscous friction forces are functions of velocity in a way that they decrease by reducing the relative speed of contacting surfaces. Therefore, in low speed rotation of motor shaft, which is in the focus of this study, viscous frictions are also negligible. Therefore,

$$I\ddot{\theta} = \tau_m + \tau_{fc}. \tag{3}$$

If the motor is supposed to rotate with a constant speed, its angular acceleration will be zero. Meanwhile, in some applications effective inertia on the motor shaft is very low which also holds for the present work in which an isolated motor shaft is considered. In these cases even if there are some angular accelerations, the inertia term $(I\ddot{\theta})$ will be small and can be neglected.

Summarizing the above discussions, in low speed – no load operations equation (3) can be rewritten as (4) which indicates that the required motor torque is as much as dry friction torque.

$$\tau_m = -\tau_{fc}. \tag{4}$$

In torque control mode of AC servo motors, drive adjusts the motor torque proportional to control voltage (V_c) which is produced by controller.

$$\tau_m = \alpha_{\tau v} V_c. \tag{5}$$

The coefficient $\alpha_{\tau v}$ is commonly called torque ramp parameter which is adjustable in most motor drives (e.g. [11], [12]). Combining (4) and (5) the control voltage can be calculated as,

$$V_c = -(1/\alpha_{\tau v})\tau_{fc}. \tag{6}$$

Regarding (6) and previous discussions, in low speed – no load conditions, if $\alpha_{\tau v}$ has large values the control voltage will be very low and comparable to available noises.

It is evident from (6) that the parameter $\alpha_{\tau v}$ can be employed for scaling up the control voltage in order to reduce the noise effects. Supposing that the control voltage is disturbed by a noise signal, the drive will be fed by a voltage, V_d, which differs from the control voltage as,

$$V_d = V_c + V_n, \tag{7}$$

in which V_n is amplitude of noise signal. The drive will then adjust the motor torque according to (5) in which the control voltage is replaced with the disturbed voltage as,

$$\tau_m = \alpha_{\tau v} V_d, \tag{8}$$

By inserting (8) and (6) into (3) the direct effect of noise signal on the angular acceleration of motor can be better shown through (9).

$$\ddot{\theta} = (\alpha_{\tau v}/I)V_n. \tag{9}$$

Since the motor shafts usually have low rotary inertia, noise signals can lead to high accelerations which can cause large velocity drifts between two sampling steps and before controller gain any information to react suitably. Therefore, always there will be some fluctuations in motor speed. According to (9), Amplitude of these fluctuations is a function of amplitude of available noises, shaft inertia and torque ramp parameter. In low speed operations the amplitude of velocity fluctuations become comparable to the desired speed and the controller performance totally degrades.

A very routine remedy for velocity fluctuations is to reduce the amount of available noises by shielding the system against magnetic and electric fields. This is a very effective way especially for industrial applications where the control system and all the connections are well protected against noises. However, it is not an easy task to completely protect the system and always there will be some noises available. This becomes more important in academic applications in which the control system and connections are required to be substituted occasionally.

Referring to (9), another way to reduce the noise effects is to increase system inertia which is not so practical in real world applications.

This paper proposes another approach of decreasing the torque ramp parameter which is made adjustable in many motor drives. According to (6), the control voltage will be scaled up by reducing the value of $\alpha_{\tau v}$. Consequently, the noise effects are weakened when compared to up scaled control signal. Direct effect of decreasing the torque ramp parameter on reducing the noise induced accelerations is clearly shown in (9).

The proposed method can be readily applied to low speed – no load control of all systems without imposing any physical manipulation of the systems. The only requirement is that the motor derive should support adjustment of the torque ramp parameter.

It should be also noted that $\alpha_{\tau v}$ cannot be arbitrarily decreased to any desired value. If this parameter is excessively reduced, the control voltage may increase over the drive input limit and the drive may saturate. The value of torque ramp parameter should be adjusted such that the control voltage does not exceed the drive input limits in maximum required torques.

III. Speed Observer

In this study the motor position is measured through a high resolution encoder (40000 pulses per revolution) which is susceptible to noise contamination because of its high number of pulses. Therefore, direct differentiation of encoder signal is not a good choice because small amount of noises can lead to high errors in calculated motor speed.

To solve this problem, a linear high gain observer is used which takes in the position signal and estimates its derivative as the motor speed. State space equations of the observer are given in (10) in which α and ε are observer gains that should be adjusted to obtain a desirable balance between observer sensitivity and its estimation delay.

$$\begin{cases} \dot{\hat{x}}_1 = \hat{x}_2 + (\alpha/\varepsilon)(y - \hat{x}_1), \\ \dot{\hat{x}}_2 = (\alpha/\varepsilon^2)(y - \hat{x}_1), \\ y = x_1. \end{cases} \tag{10}$$

In (10), $y = x_1$ is the system output (motor position) and $\hat{x}_2$ is an estimation of the motor speed. For more information about high gain observer refer to [13] and [14].

IV. Experimental Setup

As shown in Fig. 1 and Fig. 2, an experimental setup is prepared to evaluation of the proposed method. The setup includes an ECMA-C2 type 200 W AC servo motor, by Delta electronics, which is enabled to be controlled in torque control mode by means of an ASDA-B2 type Delta AC servo drive. The drive also provides the possibility of adjusting the torque ramp parameter. Angular position of the motor shaft is measured by a rotary encoder which can generate up to 40000 pulses per revolution.

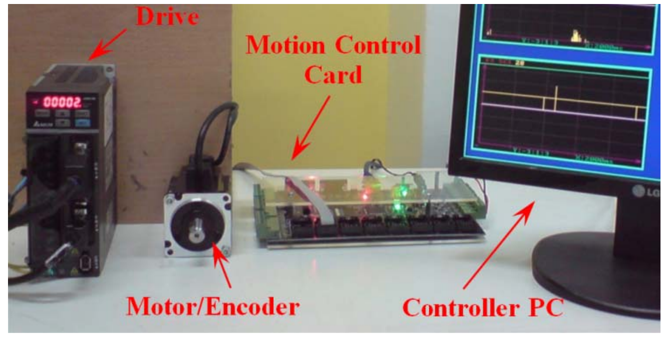

Fig. 1. Experimental setup.

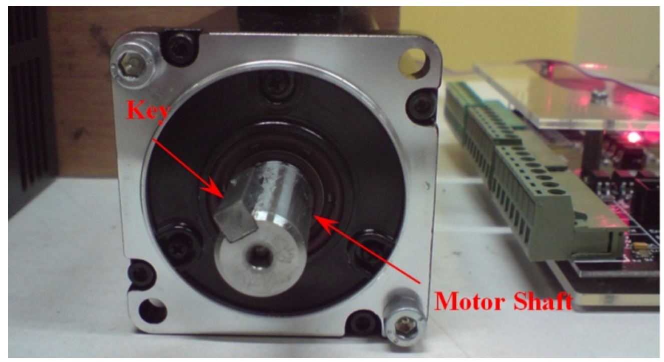

Fig. 2. Motor shaft with key

A simple PID controller is implemented in a PC which sends command signals to the motor, and gets position feedback from motor encoder through a TSP MDI motion control card by tsPishro company. Communication between PC and TSP MDI card is realized through an Ethernet connection.

In the case of ASDA-B2 Delta AC servo drives, the torque ramp parameter can be adjusted by setting the $P1-41$ parameter which can take a value between 0 and 1000. The drive regulates the motor torque according to incoming control voltage and the setting value of $P1-41$ parameter as,

$$\tau_m = \left(\tau_r \times \frac{\{P1-41\}}{100 \times V_{max}}\right) \times V_c. \tag{11}$$

in which $\tau_r = 0.64\, N.m$ is the rated torque of the motor and $V_{max} = 10V$ is the maximum control voltage that can be fed to the drive [12].

For example by setting the value of $P1-41$ parameter to 100, an incoming control voltage of 10V will indicate that the motor torque should be adjusted to 100% of its rated value. If $P1-41$ is set to 50 and the input voltage is changed to 5V, then the motor torque will be adjusted to 25% of the rated torque. Comparing (5) and (11) reveals the following equality,

$$\alpha_{\tau v} = \tau_r \times \frac{\{P1-41\}}{100 \times V_{max}}. \tag{12}$$

V. RESULTS AND DISCUSSION

In this section, results of some experimental test are provided which confirm effectiveness of the proposed method in reducing noise effects.

Conducting some simple tests, the static and kinetic friction torques of the motor are approximated to be $0.028\ N.m$ and $0.030\ N.m$ respectively. Therefore, in low speed - no load operations, the control voltage should be about $0.45\ V$ if $P1-41$ parameter is set to 100. This voltage can be easily affected by a noise signal of a few tenth volts which is typically available in open spaces. If the $P1-41$ parameter is reduced to 10, the control voltage will increase to about $4.5\ V$ which is much stronger against the same noise levels.

For better illustration of effectiveness of the proposed method, a PID control with fixed gains is implemented in conjunction with two different values of 100 and 10 for the torque ramp parameter. After some trial and error, PID gains are set to $K_p = 0.1$, $K_I = 5$ and $K_D = 0.0005$ to obtain the best possible results for speed control with smallest fluctuations in motor velocity. Moreover, the observer gain are set to α=10 and $\varepsilon = 0.05$. The results are depicted in Fig. 3 to Fig. 6. Note that the calculated control voltage is scaled up by a factor of $100/(P1-41)$ in each test.

The effect of the torque ramp parameter is better demonstrated in Fig. 7 which compares motor speed fluctuations for different values of the torque ramp parameter.

The results clearly indicate that by decreasing the torque ramp parameter, the amplitude of velocity fluctuations is effectively reduced which affirms the efficiency of the proposed method.

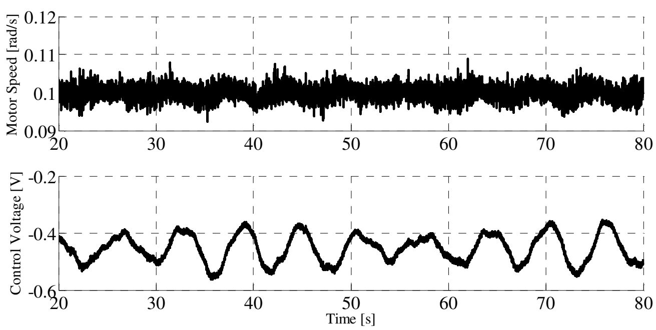

Fig. 3. Controlling motor speed at 0.1 rad/s with P1-41=100.

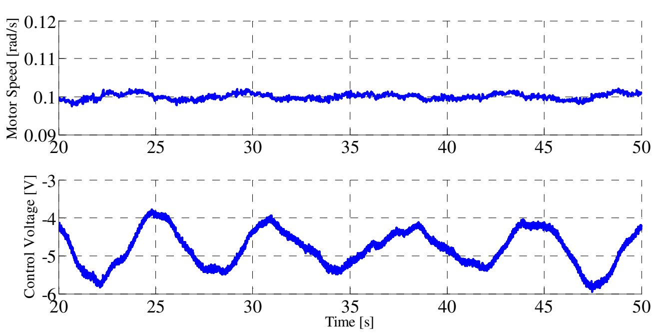

Fig. 4. Controlling motor speed at 0.1 rad/s with P1-41=10.

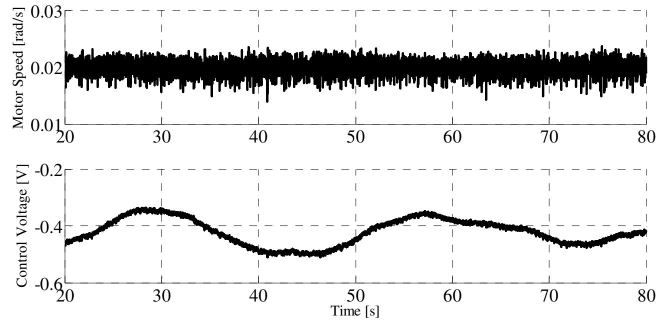

Fig. 5. Controlling motor speed at 0.02 rad/s. with P1-41=100.

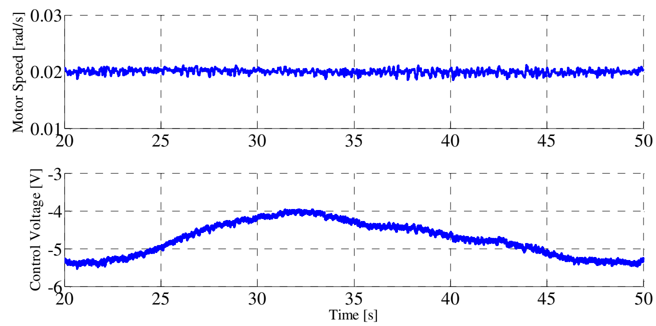

Fig. 6. Controlling motor speed at 0.02 rad/s with P1-41=10.

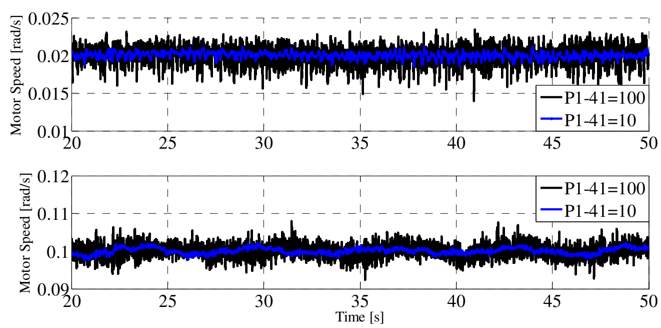

Fig. 7. Effect of torque ramp parameter on motor speed fluctuations

It is also noteworthy that regarding Fig. 3 to Fig. 6, although the motor speed is well regulated at desired values, the control voltages have some fluctuations. This observation can be justified by noticing Fig. 2 which reveals the presence of an eccentric key on the motor shaft. Although the key is very light and small, but in low speed – no load operations the required motor torques are very small such that the torque of the key's weight becomes noticeable. When the key is in horizontal position, the weight torque becomes maximum while it is zero in vertical positions. Therefore, frequency of the torque oscillations should be equal to motor rotation frequency which is evident from test results.

VI. CONCLUSION

In this paper, a simple but effective method is proposed for speed control of AC servo motors in low speed – no load operations. The presented method uses the adjustable torque ramp parameter, which is offered by many AC motor drives. Adjustment of this parameter makes it possible to reduce the noise effects through up scaling the control signal. The presented experimental results clearly confirm the effect of torque ramp values on motor speed fluctuations, or in other words, the speed control accuracy.

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