S-CURVE MOTION PROFILES GENERATOR FOR HYDRAULIC ACTUATORS

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Abstract: *Position control is usually achieved using a position controller and a profile generator. The profile generator establishes the desired trajectory based on reference position and predefined profiles, and the position controller forces the actual position to traces the generated position trajectory. The proposed profile generator allows control for maximum values of speed, acceleration and jerk, using S-curve motion, it uses an original solution of point to point movement with feedback. When profile position value reaches the value of final point position, the generator sends a signal to the set-point generator to move on to next desired point of motion profile, and so on. This motion profile generator will be implemented as a software sequence on a PLC.*

Keywords: *S-curve motion, profile generator, hydraulic actuator*

1. Introduction

The motion profiles generator, used in hydraulic actuator, allows the load movement from point A to point B in minimum time, while controlling the maximum values imposed for speed, acceleration and jerk. These values are imposed by the hydraulic actuation limitations regarding the flow rate, the response to the step signal or because the payload may be damaged when exceeding the critical acceleration and jerk values.
The material aims to analyze the motion profile for the hydraulic actuator that simultaneously controls: speed *v[m/s],* acceleration $a[m/s^2]$ and jerk $J[m/s^3]$. The paper presents an original S-curve motion profile generator of "point to point motion profile" type. There are presented some principles of design of the hydraulic actuators proportional to the limitation of speed, acceleration and shock. The generator implementation on *PLC* hardware support is realized using Ladder Diagram programming language.

2. Theoretical assumptions

The equations describing the rectilinear motion (straight-line motion), for which velocity, acceleration and jerk are controlled, are the following (S-curve profile) [1]

$$J[\tfrac{m}{s^3}] = constant \tag{1}$$
$$a(t)\left[\frac{m}{s^2}\right] = \int_0^t J\,dt = a_0 + Jt \tag{2}$$
$$v(t)\left[\frac{m}{s}\right] = \int_0^t a(t)dt = v_0 + a_0\,t + Jt^2/2 \tag{3}$$
$$p(t)[m] = \int_0^t v(t)dt = p_0 + v_0 t + a_0\,t^2/2 + Jt^3/6 \tag{4}$$

where *p(t)* is the actuator position, *v(t)* is speed, *a(t)* is acceleration and *J* is jerk.
Determining the value of the flow required for a linear hydraulic actuator is done according to the considerations presented below.

- Calculation of the actuator cylinder area [2]

$$A[m^2] = 1.3F_R[N]/p_s[Pa] \tag{5}$$

where A is the cylinder area, F_R is the load force in cylinder rod and p_s the supply pressure of the hydraulic drive.
In order to compensate for the unknown forces that may occur at the level of the hydraulic cylinder rod, is chosen a factor of 1.3 (30% more than the desired force).

- Calculation of the flow required to reach a required speed of actuation of the load [2].

$$Q_L[\frac{m^3}{s}] = A[m^2]V_L[\frac{m}{s}] \tag{6}$$

$$p_L[Pa] = F_R[N]/A[m^2] \tag{7}$$

where Q_L is the flow required to reach a required speed V_L maximum velocity of the rod, and p_L the pressure drop required by the load.

- The maximum actuation speed (velocity) V_{max} of the hydraulic cylinder rod is

$$V_{max}[\frac{m}{s}] = Q_R[\frac{m^3}{s}]/A[m^2] \tag{8}$$

where Q_R is the nominal flow rate of the proportional electro-hydraulic device, servo valve or proportional valve.

- The maximum acceleration a_{max} of the hydraulic cylinder rod can be estimated by knowing the response time at the step signal t_{SR}, jump from zero to maximum flow rate, of the electrohydraulic device, such:

$$a_{max}\left[\frac{m}{s^2}\right] = V_{max}\left[\frac{m}{s}\right]/t_{SR}[s] \tag{9}$$

3. Implementation of the motion profiles generator

The motion profiles generator in the functional block diagram of the proportional hydraulic actuation, fig. 1, is placed between the input of the position set-point (desired position) and the input of the hydraulic actuator controller. The generator adapts the reference position signal to the hydraulic limitations, regarding the maximum speed and maximum acceleration of the hydraulic cylinder rod. These limitations are imposed by the maximum rated flow and the response time at the step signal, specific to the proportional electro-hydraulic device with which the hydraulic drive is built.

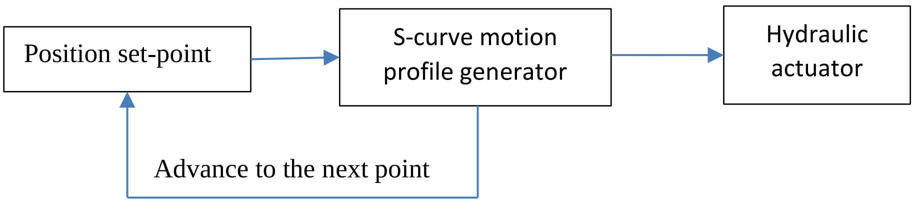

Fig. 1. Hydraulic unit with generator of motion profiles

The motion profiles generator is "point to point motion profile" type. Its operation is as follows, see fig. 1:

- „Position set-point” generates a value of the position set-point, the current point in the motion profile;

- „S-curve motion profile generator” generates a motion profile, from the previous point to the actual value of the position set-point, according to the equations of motion (1)…(4);

- Reaching value of set-point position, the current point in the motion profile, trigger the control block "Position set-point " to advance to the next point in motion profile;

- The operating sequence is repeated.

Motion profile generator can be implemented as a software module running on PLC program that controls hydraulic drive. The signals processed by the motion profile generator are processed numerically according to equations (1), (2), (3) and (4) with the limitations of the speed and acceleration values given by the equations (8) and (9).

The numerical processing of the signals involves the writing of equations (1) ... (4) in the discrete form as:

$$J_T = J = constant \tag{10}$$
$$A_T = A_T + J \tag{11}$$
$$V_T = V_T + A_T + J/2 \tag{12}$$
$$P_T = P_T + V_T + A_T/2 + J/6 \tag{13}$$

where P_T , V_T , A_T , J_T are the values of position, speed of acceleration and shock at time T.
Given the limitation of speed and acceleration values, the equations of the motion profile will become

$$J_T = J = constant \tag{10}$$
$$A_T = \min\left(A_T + J, a_{max}\right) \tag{11}$$
$$V_T = \min\left(V_T + A_T + J/2, V_{max}\right) \tag{12}$$
$$P_T = P_T + V_T + A_T/2 + J/6 \tag{13}$$

Figure 2 shows the S-curve motion profiles for position, speed, acceleration and jerk [3], and in figure 3 are presented the formulas that define the motion parameters for the time intervals that compose the motion profile.

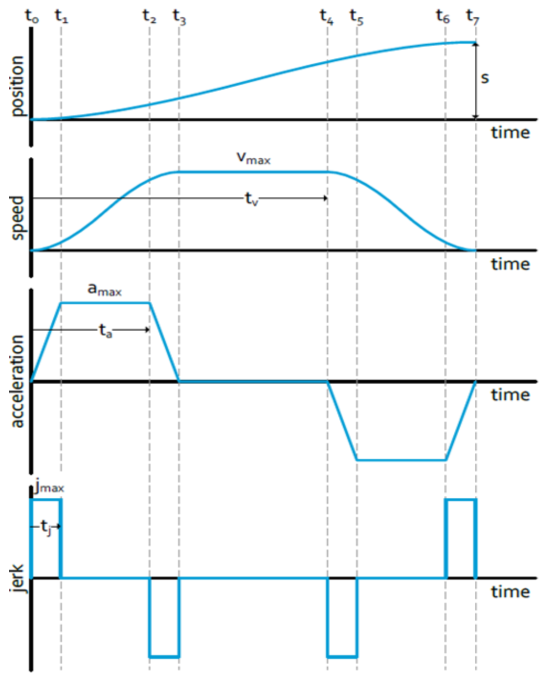

Fig. 2. S-curve motion profiles – motion parameters variation

The implementation of the S-curve motion profile generator for hydraulic actuators using the PLC „M221 Logic Controller” [4] will be exemplified. It will set an execution as "Periodic tasks" at a time of *1ms* or a thousand times per second, thus the time for integration and derivation is *Δt = 1ms*. Formulas (10) ... (13) written using the "Ladder Diagram" are shown in figure 4.

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Motion parameters	jerk	acceleration	velocity	position
$t_0 \ldots t_1$	j_{max}	$j_{max} \cdot (t - t_0)$	$\frac{1}{2} \cdot j_{max} \cdot (t - t_0)^2$	$\frac{1}{6} \cdot j_{max} \cdot (t - t_0)^3$
$t_1 \ldots t_2$	0	$a_1 = a_2$	$v_1 + a_1 \cdot (t - t_1)$	$p_1 + v_1 \cdot (t - t_1) + \frac{1}{2} \cdot a_1 \cdot (t - t_1)^2$
$t_2 \ldots t_3$	$-j_{max}$	$a_2 - j_{max} \cdot (t - t_2)$	$v_2 + a_2 \cdot (t - t_2) + \frac{1}{2} \cdot -j_{max} \cdot (t - t_2)^2$	$p_2 + v_2 \cdot (t - t_2) + \frac{1}{2} \cdot a_2 \cdot (t - t_2)^2 + \frac{1}{6} \cdot -j_{max} \cdot (t - t_2)^3$
$t_3 \ldots t_4$	0	0	$v_3 = v_4$	$p_3 + v_3 \cdot (t - t_3)$
$t_4 \ldots t_5$	$-j_{max}$	$-j_{max} \cdot (t - t_4)$	$v_4 + \frac{1}{2} \cdot -j_{max} \cdot (t - t_4)^2$	$p_4 + v_4 \cdot (t - t_4) + \frac{1}{6} \cdot -j_{max} \cdot (t - t_4)^3$
$t_5 \ldots t_6$	0	$a_5 = a_6$	$v_5 - a_{max} \cdot (t - t_5)$	$p_5 + v_5 \cdot (t - t_5) + \frac{1}{2} \cdot a_5 \cdot (t - t_5)^2$
$t_6 \ldots t_7$	j_{max}	$a_6 + j_{max} \cdot (t - t_6)$	$v_6 + a_6 \cdot (t - t_6) + \frac{1}{2} \cdot j_{max} \cdot (t - t_6)^2$	$p_6 + v_6 \cdot (t - t_6) + \frac{1}{2} \cdot a_6 \cdot (t - t_6)^2 + \frac{1}{6} \cdot j_{max} \cdot (t - t_6)^3$

$t_1 = t_j$	$t_2 = t_a$	$t_3 = t_a + t_j$	$t_4 = t_v$	$t_5 = t_v + t_j$	$t_6 = t_v + t_a$	$t_7 = t_v + t_j + t_a$

Fig. 3. S-curve motion profiles – motion parameters formula’s over time

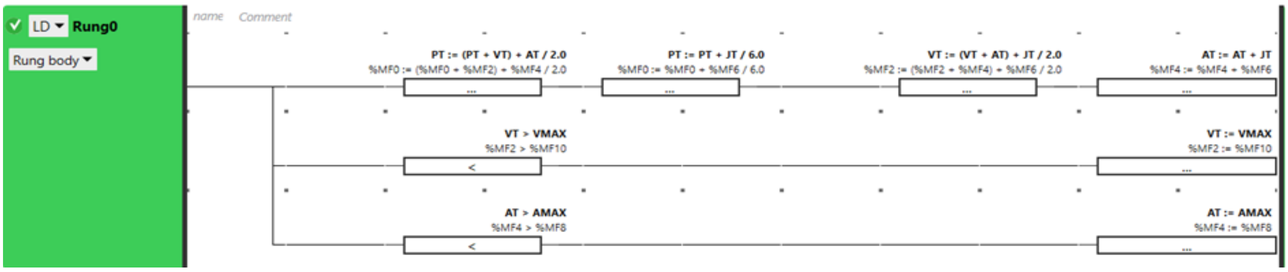

Fig. 4. Implementation example of S-curve motion profiles in language „Ladder Diagram”

4. Conclusions

The design of an optimal motion profile generator for hydraulic actuators, to achieve a "point to point" movement in a minimum time, taking into account the limitations imposed by the hydraulic actuation parameters, allows to obtain a more efficient actuator.

There were presented some considerations for the design of the hydraulic drive in order to ensure an imposed motion profile; thus the choice of the proportional electro-hydraulic device with which the actuation is equipped is made according to the value of the maximum speed and the value of the maximum acceleration that is desired to be obtained in the actuating rod.

An S-curve type motion profile generator was presented having an original conception in the sense that the event of ending a movement between two points triggers a new movement between next two points. This type of generator allows the realization of a movement profile, described by successive points, which is executed in minimum time, respecting the limitations regarding the maximum values imposed for speed, acceleration and jerk.

Finally, the generator implementation principles were presented as the software module written in the programming language specific to the programmable controller.

References

[1] www.pmdcorp.com.
[2] www.moog.com.
[3] Mu, Haihua, Yunfei Zhou, Sijie Yan, and Aiguo Han. "Third-order trajectory planning for high accuracy point-to-point motion.” *Frontiers of Electrical and Electronic Engineering in China* 4, no.1 (March 2009): 83–87.
[4] www.schneider-electric.com.