Optimal Speed Profile Design of Stepping Motors for an Inkjet Printer

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Abstract

This paper proposes a procedure in designing of an optimal speed profile for stepping motors used in a inkjet printer. The design procedure starts with a curve-fitting technique for the motor torque-speed characteristics. The torque-speed curve is taken as the input of the speed profile design program to generate the optimal speed profile by solving the equation of motion of the motor driving system. On the basis of this procedure, optimal profile of minimal acceleration steps for a given motor can be achieved. In order to achieve smooth operation of the motor from the acceleration stage to the constant speed stage, the torque-speed curve is modified based on the steady state load and the operating speed. Then the same procedure is applied to generate the profile. Experimental results are presented to verify the effectiveness of this design approach.

Introduction

The open-loop stepping motor can follow a variable pulse train, providing the change of rate is within the torque available for holding synchronism. That is, for each step pulse the motor must move one step and be able to accept the next winding change of state. A commonly used open-loop trajectory is a linear speed profile, which starts from a specific pulse frequency and ramps linearly up to the operating pulse frequency. Other known speed profiles are exponential curve and S-curve. These predetermined speed profiles are good in design for acceleration of stepping motors, but they cannot ensure min-imal accel-erating distance of the object driven, thus the torque capacity of the stepping motors are not fully developed.

This paper provides a new design procedure contrary to those old methodology. The design procedure starts from the torque capacity of the stepping motors, then generates optimal speed profile which ensures minimal acceleration distance of the print head carriage. This procedure also can generate out optimal speed profiles to obtain the smooth operation of the stepping motors.

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New Design Procedure

Curve-Fitting Technique

The design procedure started with a curve-fitting technique for the motor torque-speed characteristics. We sampled data pairs from the motor pull-out torque-speed characteristics. Let N be the number of data pairs, then there existed a N-1 degree polynomial which passed exactly through each point on the X - Y plot of the data pairs. The N coefficients of such a N-1 degree polynomial could be calculated uniquely from the N sets of data pairs by the method of least square fitting. In order to achieve smooth operation of the motor from the acceleration stage to the constant speed stage, we modified the data pairs to make the N-1 degree polynomial curve smoothly connect the steady state load at the operating speed. This procedure was taken into design application for the stepping motor MITSUMI M42SP-7(77Ω). The steady state load was 100 g-cm and the operating speed was 600 PPS. We sampled 6 data pairs from the motor pull-out torque-speed characteristics, the 5 degree polynomial which passed exactly through every data pair was plotted in Figure 1 in line 1, and the modified polynomial which fit modified data pairs was plotted in line 2.

The Law of Motion

The translational motion of the inkjet print head carriage is driven by the stepping motor through a rotary-to-linear motion control system (belt and pulley). The mass, friction and speed of the translational motion of the inkjet print head carriage can be converted into equivalent rotational inertia, load torque with respect to the stepping motor shaft, and the required angular speed for the stepping motor shaft respectively. Then the torque equation of the stepping motor with load can be obtained according to Newton's Law of Motion.

Optimal Speed Profile Design

Once the torque-speed curve has been worked out through curve-fitting technique, the discrete step time sequence can be obtained for stepping motor control unit through solving the equation of motion. The speed at specific step equals the inverse of the step time interval before that step. And the time at that step is the sum of all step time intervals from start. The key to find the discrete speed-time relation is by solving the equation of motion inversely from the final operating speed along with the motor torque at that speed. The adjacent discrete speed just before the final speed can be found by using the torque equation which relates these two speed values and the torque value. All discrete speed values can be found similarly using a recursive computer subroutine. The set of computed nonnegative speed values is the design output.

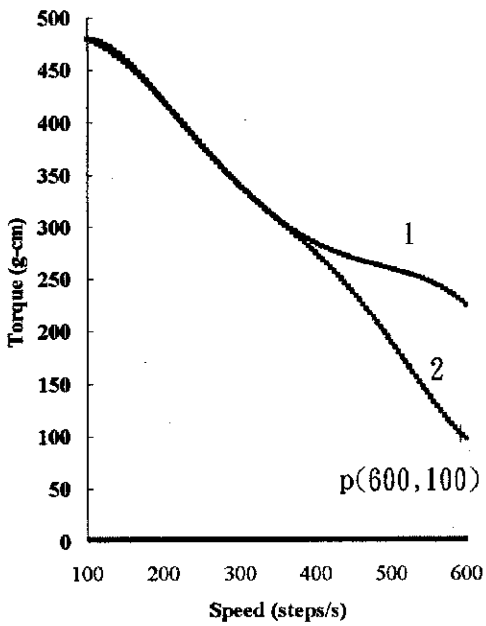

Figure 1. Curve-fitting for original and modified torque-speed characteristics of the motor M42SP-7

The set of discrete speed values are calculated on the basis of motor torque capability at those speed values, so the speed profile has maximal speed ramping and thus minimal acceleration steps.

In inkjet printing process, the print head fires ink drops within the constant speed stage, so the print head carriage should move steadily in the constant speed stage with very small oscillation. The optimal speed profile of minimal acceleration steps may cause large oscillation in the transition stage between acceleration stage and constant speed stage. In order to achieve smooth operation of the motor, the torque-speed curve is modified based on the steady state load and the operation speed. If the motor torque near the operating speed is set to approach the steady state load, the jerk of driving force will be minimum, and smoother operation of the motor will be accomplished. Based on this idea, the torque-speed curve is modified to smoothly connect the steady state load at the operating speed, and the modified optimal speed profile is worked out through the same procedure stated above by using the modified torque-speed curve. As shown in Table 1 and Table 2, the optimal speed profile only needs 6 steps and the modified optimal speed profile needs 16 steps.

Experimental Results

The designed speed profiles were transfered into step times, then the sequence of step times were downloaded to the control unit to drive the stepping motors step by step. In the experiment process, the inkjet print head did not print until the step time sequence reached the constant speed stage form the acceleration stage. The print pattern during the constant speed translational motion of the print head carriage were set to be one dot per motor step. By inspecting the intervals of every two adjacent dots, the motion behavior of the print carriage driven by the stepping motor at the constant speed stage could be investigated. As shown in Figure 2 and Figure 3, the modified optimal speed profile got smoother operation than the original optimal speed profile.

Table 1. Discrete Optimal Speed Profile

Step No.	Time(ms)	Speed(steps/s)
0	0.0000000	0.0000000
1	3.7037037	270.00000
2	6.2791226	388.28635
3	8.4387570	463.04133
4	10.351651	522.76808
5	12.099068	572.27344
6	13.765735	600.00000

Table 2. Discrete Modified Optimal Speed Profile

Step No.	Time(ms)	Speed(steps/s)
0	0.0000000	0.0000000
1	3.6630037	273.00000
2	6.2064100	393.17352
3	8.3600008	464.34075
4	10.217490	509.74943
5	12.179880	538.17510
6	13.977460	556.30355
7	15.736835	568.38352
8	17.470501	576.81265
9	19.185964	582.93274
10	20.888028	587.52218
11	22.579920	591.05405
12	24.263907	593.82912
13	25.941628	596.04647
14	27.614309	597.84262
15	29.282883	599.31403
16	30.949550	600.00000

Summary

A new design procedure of optimal speed profile for stepping motors used in a inkjet printer has been presented.

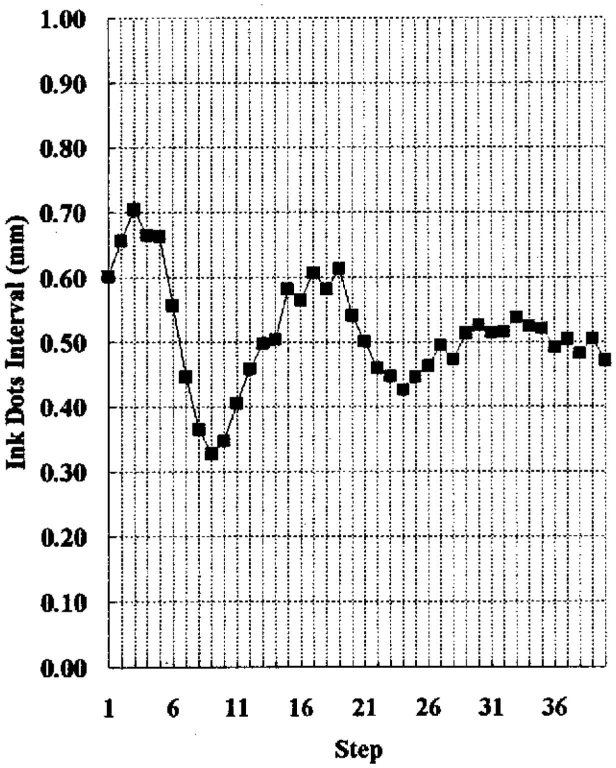

Figure 2. The motion behavior of the print head carriage using the original optimal speed profile

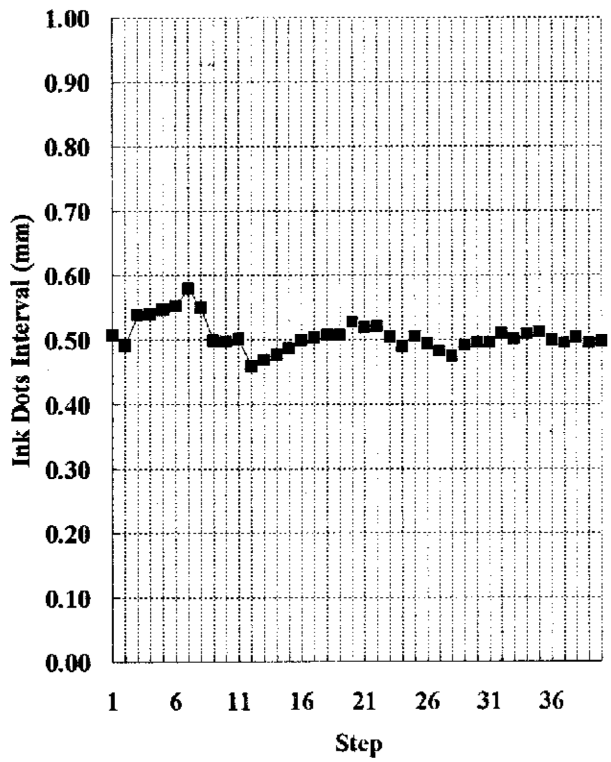

Figure 3. The motion behavior of the print head carriage using the modified optimal speed profile

It provides computerized optimal design and quick modification of speed profiles for different stepping motors. The optimal design ensures minimal acceleration steps for a given motor. Another modified speed profile con cerning smooth operation of the print head carriage driven by the given stepping motor also can be designed through this design program. The experimental results show excellent constant printing alignment by using the modified optimal speed profile.

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