



OPERATING PRINCIPALS FOR PRACTISPIN
STEPPER MOTOR MOTION CONTROL

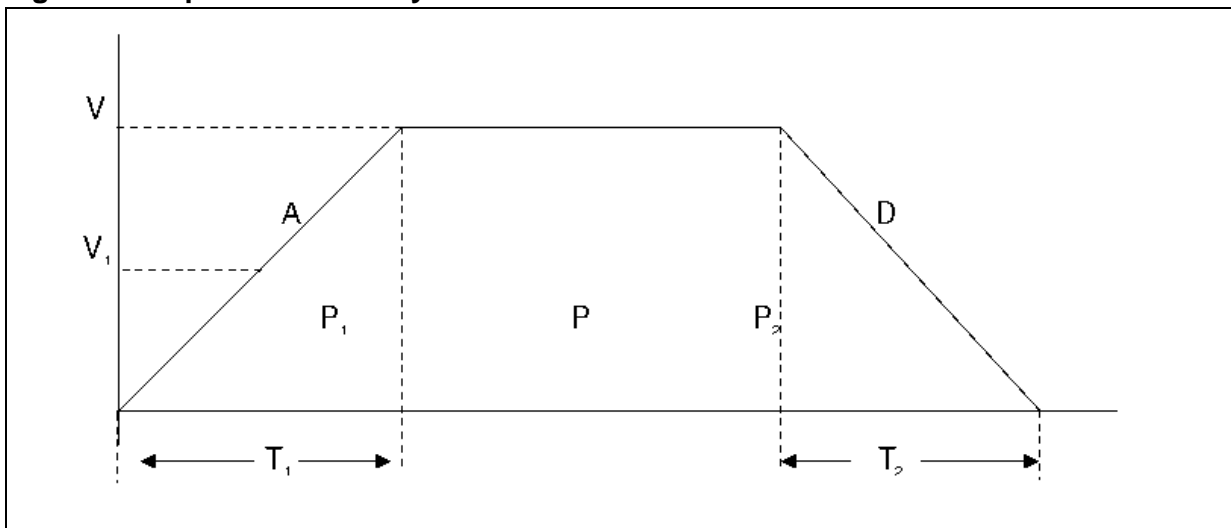
1 REQUIREMENTS

In operating a stepper motor system one of the most common requirements will be to execute a relative move. The move will usually be specified as a fixed number of basic motor steps in the clockwise or counter-clockwise direction. It is common practice to execute this move along a trapezoidal shaped velocity vs. time profile.

This profile is determined by the number of steps to be moved and the required accel, decel, and peak speed. Very often system designers require that a move be made in the shortest time possible and in these cases the accel, decel and peak speed are set to the maximum that the system can achieve.

Given the move distance, accel, decel, and peak speed requirement, a profile can be determined. Since the control structure of the practispin software is designed such that the velocity and accel/decel rate can be changed at will, the task of pre-calculating the velocity profile boils down to determining the position values where operation switches from accel to constant speed and then from constant speed to decel. Since this is a relative move, we can assume that motion starts at position = 0, time = 0, and velocity = 0. Figure 1 shows a typical trapezoidal velocity vs. time profile

Figure 1. Trapezoidal Velocity vs. Time Profile



Let: P = total move distance in steps
P1 = steps required to accel from 0 to V
P2 = steps required to decel from V to 0
V = peak velocity in steps per second (steps/sec)
V1 = average velocity during accel or decel

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- A = required accel rate in steps per second per second (steps/sec²)
- D = required decel rate in steps per second per second (steps/sec²)
- T1 = acceleration time in seconds
- T2 = deceleration time in seconds

2 TRAPEZOIDAL POSITION FORMULAS

If we assume that the velocity will rise from 0 to V at a constant rate of acceleration:

- 1) $T1 = V / A$
- 2) $V1 = V / 2$
- 3) $P1 = V1 T1$

Substituting 1 and 2 into 3 yields:

4) $P1 = V^2 / 2A$

In the same manner we have:

5) $P2 = V^2 / 2D$

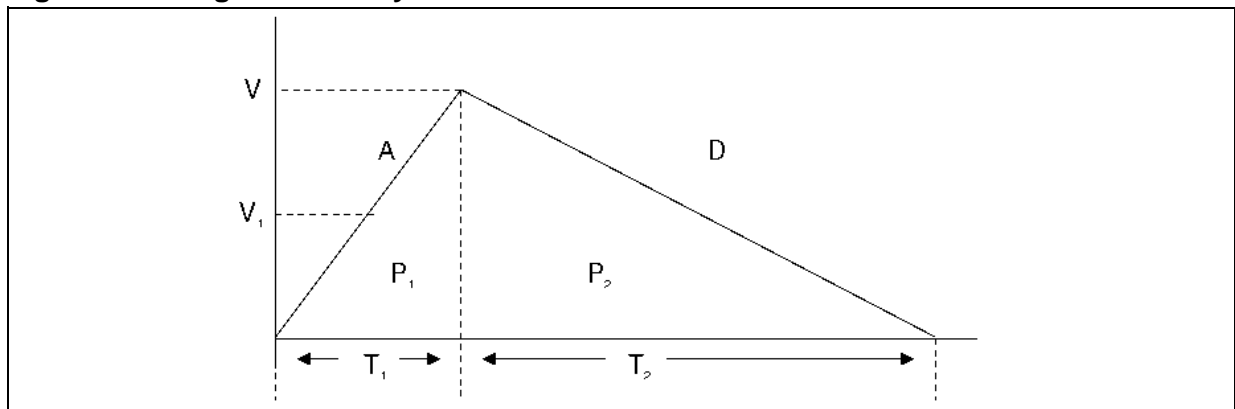
Once P1 and P2 have been calculated a check can be made to determine whether a trapezoidal profile is possible or whether a triangular move must be made instead. If the total number of steps required to accel and decel (P1 + P2) is less than the total move distance, P, then there will be some "room" left for a constant velocity portion of the profile. If, on the other hand, P1 + P2 is greater than P, then the move profile cannot be allowed to get up to the requested speed since just getting up to speed and back down (at the requested accel and decel) would cause a move that would overshoot the target position.

If P1 + P2 is greater than P then a triangular rather than trapezoidal profile must be projected. With a triangular velocity profile there is no constant velocity portion of the move.

The motor will accelerate at A and then abruptly switch to decelerating at D in order to "land" at the desired position at zero speed. In the case of a triangular profile we have only one important parameter to calculate, that being the motor position at which the system must switch from accel to decel mode.

The calculation is, however, somewhat more complicated than the trapezoidal case. Figure 2 shows a typical triangular velocity vs. time profile.

Figure 2. Triangular Velocity vs. Time Profile



3 TRIANGULAR POSITION FORMULAS

In a triangular move, the total distance is the distance to accel plus the distance to decel:

$$6) P = P_1 + P_2$$

Substituting 4 and 5 into 6 yields:

$$7) P = V^2 / 2A + V^2 / 2D$$

Multiplying both sides of 7 by 2AD to clear fractions yields:

$$8) 2ADP = DV^2 + AV^2$$

Extracting the common factor V^2 on the RHS of 8 yields:

$$9) 2ADP = V^2(D + A)$$

Dividing both sides of 9 by $2A(D + A)$ yields:

$$10) DP / (D + A) = V^2 / 2A$$

Substituting 4 into 10 and re-arranging yields:

$$11) P_1 = PD / (D + A)$$

Equation 11 is our final result and is the most convenient form of the formula for calculating the position at which the mode must be switched from accel to decel for a triangular move. Please note also that this formula passes a fundamental "sanity" test.

If the accel and decel rates are equal, then $P_1 = P / 2$.

This is intuitively obvious. The system would have to spend half the total distance accelerating and the other half decelerating.

As the decel rate is increased, we can spend more time accelerating before we have to "put on the brakes" to come to a stop at the required position.

The Practispin stores P, D, and A as unsigned 16 bit variables. A 16 by 16 multiply subroutine is used to get the product PD, which is 32 bit.

A 32 by 16 divide subroutine is used to get the quotient of PD and $(D + A)$. Note: If $(D + A)$ overflows 16 bits then both terms are pre-divided by 2 before the main divide is executed.

The same subroutines are used to calculate formulas 4 and 5 in the trapezoidal case. Please note that execution time for these calculations is not critical since they are done only once per move and are completed before the move begins.

4 PRACTISPIN STEPPER MOTOR CONTROL SCHEME

4.1 20 KHZ INTERRUPT

The heart of the stepper motor control mechanism is the 20KHZ interrupt. This interrupt invokes an Interrupt Service Routine (ISR) which executes repeatedly on a fixed time interval of 50 microseconds. In the subsequent discussion we will call this 50 microsecond interval a TICK and this will serve as our basic time unit.

In order to maintain a consistent system of units we will measure position in steps, velocity in steps/tick, and acceleration/deceleration in steps/tick². The calculation performed by the ISR amount to a real time simulation of the motion system. The ISR calculates real time values for

velocity and position given the commanded acceleration (or decel) and the present values for velocity and position.

4.2 MOTION SIMULATION FORMULAS

It is well known from basic physics that velocity is the time integral of acceleration and position is, in turn, the time integral of velocity. Since the ISR executes once each time TICK it can calculate the system variables in real time by implementing the following equations:

$$\text{SPD} = \text{SPD} + \text{ACC}$$

$$\text{POS} = \text{POS} + \text{SPD}$$

Where:

SPD is motor velocity in steps / tick

ACC is commanded motor acceleration in steps / tick²

POS is motor position in steps

This simulation does a "flat topped" integral approximation. Since the time interval for the simulation is so short (50μSEC) compared to the time scale of the moving system, this crude approximation is sufficiently accurate. Internally these three key variables are represented as multiple precision integers (the ST7 is, after all, an 8 bit processor) with a fixed "binary point". The naming convention used for the memory bytes which make up each variable is to use the basic name (POS, SPD, or ACC) plus a suffix of one digit to show the significance of the byte. 0 for the lsb, 1 for the next, etc. Table1 shows the individual bytes that make up the three variables and their relative scaling. The * represents the "binary point" of each variable.

While the binary weighting of the bits to the left of the binary point are the traditional powers of 2 (1,2,4,8, etc) the weighting of the bits to the right of the binary point are the successive negative powers of 2 (1/2, 1/4, 1/8, etc.).

In the case of the state variable ACC, ACC2 and beyond are not even implemented because we will never encounter acceleration values that large. This is because of the selection of units needed to speed the calculations and provide a uniform system.

An actual value of 1 step/tick² (ACC3 = 1 and the rest set to zero) would be a very great acceleration indeed:

1 step/tick²

$$= 20,000 \text{ steps/tick per second (20,000 ticks in a second)}$$

$$= 400 \times 10^6 \text{ steps/sec}^2$$

$$= 120 \times 10^6 \text{ RPM/sec !! (assuming 200 steps per rotation)}$$

With the scaling as implemented in the Practispin, the smallest accel value (ACC0=1 and ACC1 = 0) is equivalent to 7.153 RPM per second, a much more reasonable value. The maximum value for SPD is 16,777,215 / 16,777,216 (let's call it 1) step / tick which is equal to 20,000 steps / second or 6,000 RPM. Generally speaking, stepper motors just don't go that fast. POS maxes out at 65,535.999985 steps (with a resolution of 1/65536 of a step). This is 327.68 rotations for a 200 step/rot motor.

Table 1. State Variable Representation

POS3	POS2	*	POS1	POS0	
		*	SPD2	SPD1	SPD0
		*		ACC1	ACC0

In its simplest form this system executes a trapezoidal move by the following steps:

- 1) Calculate the motor position values (P1 and P-P2 using the formulas derived above) at which the system should transition from accel to constant speed and then from constant speed to decel.
- 2) Set the POS and SPD variables to zero, set ACC to the required value, and then start up the ISR. The ISR will update SPD by adding ACC0 into SPD0, ACC1 into SPD1 (plus a possible carry from previous), and then inc SPD2 if there was a carry out of ACC1 + SPD1. POS is updated by adding SPD1 into POS0, SPD2 into POS1 (with carry), then inc POS2 if SPD2 + POS1 produced a carry and finally inc POS3 if POS2 rolls over.
- 3) Whenever POS2 increases (it could never increase by more than 1 because of the small time tick), advance the motor by one step.
- 4) When the integer part (POS3: POS2) of POS matches P1, set ACC to zero to enter the constant velocity region. Speed will hold constant but position will continue to increase.
- 5) When POS matches P-P2, change the value in ACC from zero to the required decel setting and start subtracting into SPD instead of adding.
- 6) When POS matches P, set ACC and SPD to zero (SPD should already be there), stop stepping the motor, and hold position.

In step 3 of the procedure for executing a trapezoidal move it was stated that we must "advance the motor by one step". Lets examine the details required to accomplish this. First, let's describe how a bipolar, two phase stepper motor is commutated or stepped.

The motor has two windings (A and B) each of which may be in one of three states: Positive, Negative, or Off based on the direction of current flow, if any, through the coil. The conventional half step commutating sequence is described in figure 4. After step #7 the sequence repeats back from 0. Table 2 presents a graphical display of the current in the motor coils vs. motor step.

Table 2. Half Step Commutating Sequence

STEP #	COIL A	COIL B	IN1A	IN2A	ENA	IN1B	IN2B	ENB
0	POS	NEG	1	0	1	0	1	1
1	POS	ZERO	1	0	1	X	X	0
2	POS	POS	1	0	1	1	0	1
3	ZERO	POS	X	X	0	1	0	1
4	NEG	POS	0	1	1	1	0	1
5	NEG	ZERO	0	1	1	X	X	0
6	NEG	NEG	0	1	1	0	1	1
7	ZERO	NEG	X	X	0	0	1	1

Figure 3. Motor Phase Currents vs. Step Number

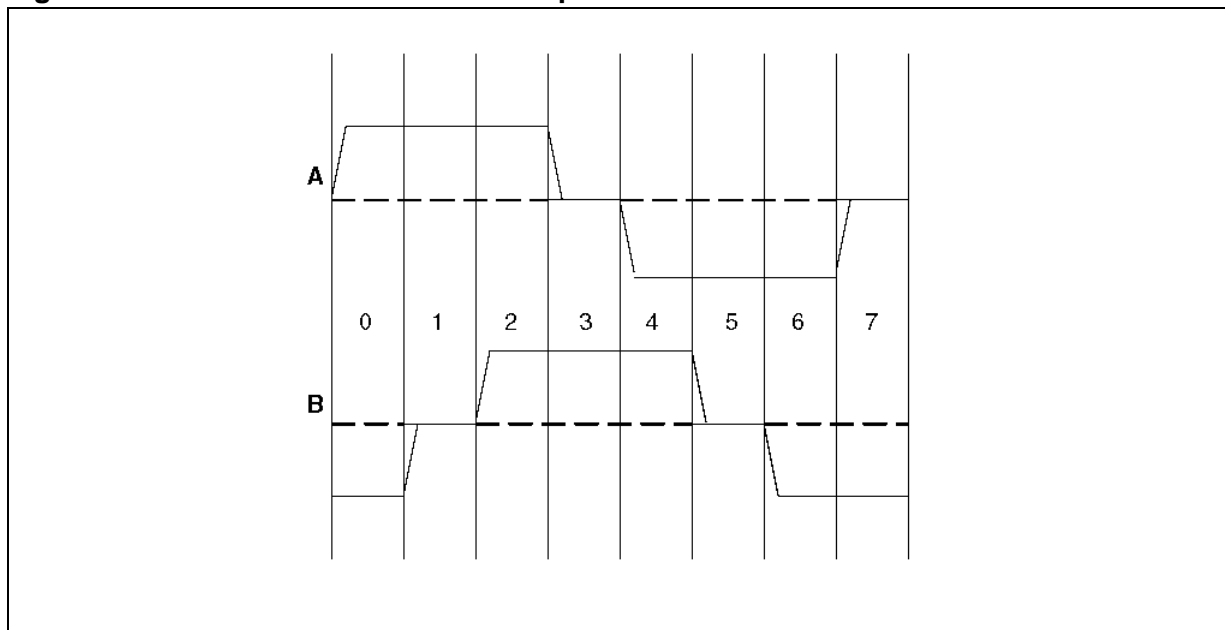


Table 2 also includes the required states for the six logic inputs of the L6207 Stepper Motor Driver. In order to understand the details of this typical driver chip some background on the characteristics of the L6207 are required.

4.3 L6207 DUAL FULL BRIDGE DRIVER

A typical stepper motor driver is the L6207 and we will use this part as an example to illustrate the operation of the Practispin system. The L6207 includes two independent full or H bridges with separate control inputs and current limit functions. The two bridges are designated A and B and their output pins designated as OUT1A, OUT2A, OUT1B, and OUT2B. These outputs are controlled independently by logic inputs IN1A, IN2A, IN1B, and IN2B respectively. A logic high or low on any of these inputs will drive its corresponding output to the positive supply rail or to ground.

Both of the A outputs will be forced to an off (high impedance) state if the ENA pin is taken logic low, as will the B outputs if ENB is taken low.

The L6207 is thus controlled by six logic inputs: IN1A, IN2A, and ENA controlling bridge A and IN1B, IN2B, and ENB controlling bridge B. Each bridge also has an analog control signal, VREFA and VREFB, which control the current limit setting.

4.4 STEP STATE

If we know the state of the stepper motor (a number from 0 to 7) then we can use figure 4 to tell us what logic levels to apply to the control pins of the L6207. The actual state is determined by a byte variable of the Practispin program called stepstate. Stepstate is initialized to zero on power up or whenever the power bridge is disabled. Stepstate is incremented whenever the driving algorithm requires us to "advance the motor". Since eight commutating steps divides evenly into the natural 256 count of a byte variable, stepstate is just continually incremented and allowed to roll over. We only consider the lower three bits to be significant. Now, armed with the stepstate variable, it is a simple matter to construct a lookup table. We will use stepstate (logically anded with a mask to clear all but the low three bits) as the index into a table which will provide the data to be written out to the L6207. Table 3 shows the hardware map-

ping of the port B data bits onto the L6207 control pins. Following Table 3 is the actual lookup table from the ST7 source code.

Table 3. Hardware Mapping of Port B

D7	D6	D5	D4	D3	D2	D1	D0
X	ENA	IN1A	IN2B	IN1B	IN2A	X	ENB

Table 4. halfsteptable

dc.b %	0	1	1	1	0	0	0	1	;0	+ -
dc.b %	0	1	1	1	1	0	0	0	;1	+ 0
dc.b %	0	1	1	0	1	0	0	1	;2	+ +
dc.b %	0	0	1	0	1	1	0	1	;3	0 +
dc.b %	0	1	0	0	1	1	0	1	;4	- +
dc.b %	0	1	0	1	1	1	0	0	;5	- 0
dc.b %	0	1	0	1	0	1	0	1	;6	- -
dc.b %	0	0	1	1	0	1	0	1	;7	0 -

4.5 HALFSTEP, FULLSTEP, REVERSE

In the Practispin program, whenever the stepstate is incremented, a new bit pattern is read from the table and output to port B. If we prefer to full step the motor rather than half step, then we need only to shift the stepstate by one bit left (multiply by 2) immediately before we mask off the three low bits and do the table lookup. This will yield only the values 0, 2, 4, and 6 and these are the only states that will be entered.

Please note as shown in Table 2 that these four states do not include a zero state for either phase as both coils are always energized. If we wish to operate the motor in the other direction it is only necessary to change the increments of stepstate to decrements. We will then run backwards through the commutating table and the motor will follow in the reverse direction.

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Table 5. Revision History

Date	Revision	Description of Changes
September 2004	1	First Issue

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