

Pump Programming

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FTÅ systems with stepper motor driven syringe pumps can be programmed to generate complex volume or surface area waveforms in time. This note illustrates two waveforms.

Square Wave

The screenshot shows the 'Pump Program' dialog box in the FTÅ software. The dialog box has a title bar 'Pump Program' and a close button. Below the title bar, there is a text area with instructions: 'Enter dispense times and volumes for 1 to 12 steps. Positive volumes dispense, negative volumes pick up. Enter number of times to repeat pattern in program. Program begins on Run if enabled in Movie Setup.' Below the text area, there are two radio buttons: 'Syringe' (selected) and 'Piezo Pump'. Below the radio buttons, there is a table with 12 rows and 2 columns: 'Time (s)' and 'Volume (ul)'. The table contains the following data:

Step	Time (s)	Volume (ul)
Step 1:	4	4
Step 2:	2	0
Step 3:	1.25	2.5
Step 4:	8.75	0
Step 5:	1.25	-2.5
Step 6:	8.75	0
Step 7:	0	0
Step 8:	0	0
Step 9:	0	0
Step 10:	0	0
Step 11:	0	0
Step 12:	0	0

Below the table, there are three input fields: 'Repeat Times (1...1000): 10', 'Loops to go', 'After First Loop, Start @: 3', and 'Stepper Motor Delay (s): 0'. Below these fields, there is a 'Dispense time for this step (0 skips step)' field with a value of 0.033s. At the bottom of the dialog box, there are 'Run' and 'Close' buttons. The background of the screenshot shows the main software interface with a contact angle measurement window and a data results table.

A simple square wave program.

Step 1. forms initial drop. This presumes no droplet present before beginning. Depending on how you clear the previous drop, the 4 μ l volume will require tweaking. The goal was to start with a 4 μ l drop, something slightly more than your "small" drop. This drop is formed at 1 μ l per second; we may be able to go faster, but this is affected by needle size and fluid characteristics (tendency to run up needle, viscosity, etc.).

Step 2. wait for drop to settle. This time can be adjusted or set to zero for no wait.

Step 3. expand drop to 6.5 μ l total (increment = 2.5 μ l.). We have requested 2 μ l per second rate. May be able to go faster (see note in Step 1).

Step 4. rest for 8.75 seconds at expanded state.

Step 5. retract back to 4 μ l at 2 μ l per second.

Step 6. rest for 8.75 seconds at retracted state. This gives a total period of 20 seconds.

Subsequent steps, down to 12, are skipped because they have zero time. Upon hitting Step12, the program loops back to Step 3 and does this 10 times.

Sine Wave

The screenshot shows the FTA 4000 software interface. The main window displays a contact angle measurement of a drop. Two data result windows are visible, showing surface tension and volume measurements. A 'Pump Program' dialog box is open, showing a table of 12 steps with time and volume values. The program is set to repeat 10 times.

Step	Time (s)	Volume (μ l)
Step 1:	4	4
Step 2:	2	0
Step 3:	2.5	.293
Step 4:	2.5	.707
Step 5:	2.5	.707
Step 6:	2.5	.293
Step 7:	2.5	-.293
Step 8:	2.5	-.707
Step 9:	2.5	-.707
Step 10:	2.5	-.293
Step 11:	0	0
Step 12:	0	0

Repeat Times (1...1000): 10
Loops to go
After First Loop, Start @: 3
Stepper Motor Delay (s): 0

The sine wave program is setup to mimic the square wave. It will have a 20 second cycle. The sine wave is synthesized by a piecewise linear approximation in steps 3-10. There are more efficient approximations, but this one is easiest to understand and does well in practice. We use

equal time divisions ($8 \times 2.5\text{s} = 20\text{s}$). Each time division represents $360 / 8 = 45^\circ$. The sine of $45^\circ = .707$. For simplicity, we set the peak amplitude of the sine wave = 1 and the peak-to-peak = $2\mu\text{l}$. So the volume at 45° is $.707\mu\text{l}$. Since the peak is $1\mu\text{l}$, the increments are $1 - .707 = .293\mu\text{l}$ and $.707\mu\text{l}$.

Because we are starting at the *minimum* volume in Step 3, the increment for Step 3 is $+.293\mu\text{l}$. The minimum volume occurs at 270° , where the sine = -1. Step 3 corresponds to 270° .

Step 1. expand initial drop, as before.

Step 2. wait for stabilization, if desired.

Step 3. starts at 270° , sine = -1. Increment towards $270 + 45 = 315^\circ$ where sine = $-.707$.

Step 4. starts at 315° , sine = $-.707$. Increment towards $315 + 45 = 360 = 0^\circ$ where sine = 0. This gets us to 4 (initial volume) + $1 = 5\mu\text{l}$.

Steps 5-8. covers 0 to 180° .

Steps 9-10. covers 180 to 270° , the beginning at sine = -1.

Understanding this, you can see that Steps 4 and 5 and Steps 8 and 9 could be combined into $+1.414$ and $-1.414\mu\text{l}$'s, respectively, over 5 seconds each, for a simpler and smoother running program.

Triangle Wave

As you desire to run faster, you will find that a triangle wave is a satisfactory approximation to a sine wave when fluid viscosity starts to "smooth" the flows. The triangle that would correspond to the above example is

3:	10s	$2\mu\text{l}$
4:	10s	$-2\mu\text{l}$

Notice it has only two steps. This runs fast because the pump is not being reprogrammed as often (each reprogramming takes some fraction of a second, hence some dead time).

Finally, since we *measure* the actual drop volume and surface area, any imperfections in the excitation do not really hurt us.