Appendix: PID Control Tuning Tips

When tuning the PID on your system, at times the values that you are entering may seem very high but below you will see the reason for this.

First it is important to determine what output voltage setting you will be running your system at. If you will be running the system with a 0-10V full-scale voltage then you will be using P values that seem normal 35-100. However, if you are going to be running the system with a limited voltage such as 5 or even 2.5 there is one thing to remember. For each factor that you decrease the output voltage you have to multiply the PID by that same factor. For example if you were running 35 for a P value at 10V you will now be running 70 for a P value at 5V.

When setting the PID up on your system you do not have to go through the long process for each material. If you select a material that you know runs like most other organics or metals then you can tune for that material and then you will have the ball park values for tuning of the other materials.

PID is most difficult to set up with these evaporative systems because of the delay that occurs due to the way that the systems work. As power is applied the response in temperature is not instantaneous as the boat and material has to physically heat up. In the same manor it will not cool instantly either. With this in mind you have to remember that there will be a minimum 5-20 second delay in response depending on the size of boat and amount of material used.

For the above reason a material that requires higher power to run is easier to tune the PID for. This is because the source will be running a lot hotter and therefore will respond to change a lot faster as the temperature changes will be greater with each power change either up or down. Generally materials such as Aluminum and Lithium Fluoride will use a higher P value and a lower I value.

PID will not always react the way that you think it will. This means that dropping the I term by one will sometimes quicken the response but other times it may make the response slower. This is because the P and the I work together. The P determines how much drive the source will have and the I determines how fast it will allow the P to react and drive. In essence the I works to slow down the P. Remember that simply removing P to limit overshoot may not work as it may not have enough drive to push the power back down in this situation. You have to remember that the P not only drives the power up but also has to drive the power back down.

Setting up PID is a trial and error process. There are no values that will work all of the time for every material and every system. The following pointers are designed to be a set of guidelines to follow to help you to narrow down the settings faster and with a minimal waste of material.

However, keep in mind that this will be time consuming and patience and a clear mind is needed to make this successful.

If possible try to do the PID tuning when you will have few or no interruptions as you can get into the PID train of thought and go with it until it has been set up.

As a general rule setup tuning of PID values could take around 4 hours and about 25 runs for the first material if starting with unknown values.

Below are the steps and thoughts that have been found useful in setting up PID on a system. The values that were arrived at may work very well on your own system and it is my advice that you try them before changing any variables.

The following values were used successfully with Organic materials, including TPD, NPB and ALQ3.

These steps are required when starting a run from 0 with no pre-condition. Although it is not Angstrom Engineering's recommendation to do this, these steps should help you to tune the PID to allow you to do so.

"*Angstrom Engineering recommends that for the best system function you should pre-condition your runs so that you come in to the deposit phase on or near the desired rate*".

A precondition with zero for the time and a power of just below the required power to start the material depositing would help with the initial dead band when the system is just ramping up the power.

However, initially tuning PID to work from a zero start will ensure that your system will respond very quickly and accurately when running with a pre-condition in later runs.

<u>Step 1:</u>Select a source and fill the boat so that you will be confident that you will not run out of material during this setup. In setting up PID you may go through thousands of Angstroms of material before you get it right. (If you have some older material that you are not planning on using for devices now would be a good time to use it.)

<u>Step 2:</u> Set your ramp times and percent powers to 0 and also turn off the Shutter delay. This will ensure that you will be starting your run in deposition mode. Also set your final thickness to a high number so that the Inficon software will not end the run before you have seen the results of your tuning. Set your rate for the rate that you will normally run the material. This is not critical but you may see more overshoot if you tune the PID for a rate of 1A/s and then run it at 3A/s. This is because the Drive will be a lot further to get

it to the desired rate. (Note: it is not necessary to watch a whole run when tuning your PID settings as after a couple of oscillations you will be able to see a pattern and get an idea of what setting you want to try next.)

Step 3: If you are using new material (One that has not been melted or heated to deposition yet) you should do a run in manual first to deposit at least 200 Angstroms so that you can be sure that the material will react nicely to the PID control. (Note: Once you have the PID set up this will not be necessary every time you change materials. However, with unused material you may see more overshoot on your first PID controlled run)

Step 4: If you are comfortable with trying the values that have been determined before on another customers system then put in P 400, I 12 and D 0 with a power output voltage of 2.5. Then start the run and watch to see what happens.

a) Initially you should see the power climb rather quickly as the amount of deviation from the setpoint is very big.
b) It will start to deposit within 20 – 50 seconds. When this happens it will appear to be shooting up way to fast. However, if you watch the power should be drastically dropping. It will overshoot, but should not deviate from the setpoint by more than 50 – 60%. (It will shoot up a lot faster than it falls back down.)
c) Once this initial overshoot starts to happen you should now see the output power dropping very quickly as the deviation from the setpoint is now getting smaller. It may even drop to 0.
d) With this drop you will see the rate start to fall.
e) As the rate gets closer to the desired rate you will now see the power start to rise as it is getting closer to the rate again.
f) You should have no undershoot and the rate should now be stable.
g) This whole process should take about 50 – 80 seconds from the time you hit start to the time it is stable.

Step 5: If this run has been satisfactory then you now have to try it on your other sources and see how it reacts.

Possible Results:

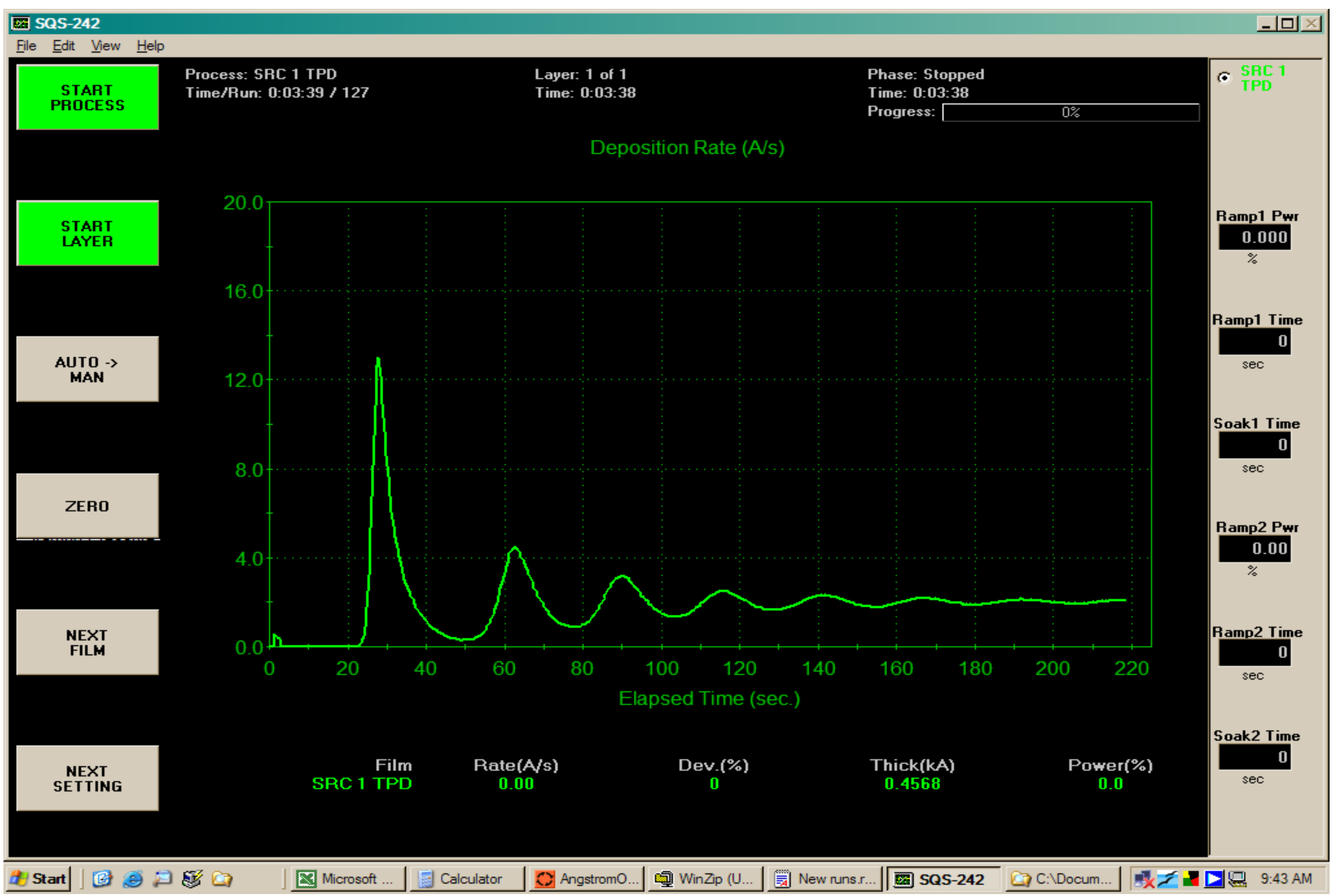
Changing any of the values in these PID settings may make the source run differently than is outlined here. If a change does not do what the possible result said it would then refer to other possible results to determine what type of change may now be required.

1 – If you did the run and you saw that it took more than 1 oscillation to level off then you will have to increase both the P and the I. If you started with P 400 and I 12 then try P500 and I 15. See what this does and then determine whether it was better or worse. If it was worse then try increasing only the P and leaving the I or vice versa.

Below is a run that was done that yielded these results and the values that were used.
<u>TPD in Source location 1 Test run</u>

This is a run to see if the PID can control the source from a 0 start. With no ramp or soak.

Starting Pressure 5.2x10-8
Sensor 1 only used
Z-stage at 0"
Tooling factor 27.2 (chart)
Source to substrate distance 10.104" (chart)
Ran in auto
PID 96,2, 0
All output voltages are at 2.5.
Period 0.5 and filter 3
Angstrom Thurs Test 1 SRC1 TPD.log
Run #: 125
Ran at 2Å/s /500Å
Pressure at the end of the run was 6.8 x10-7

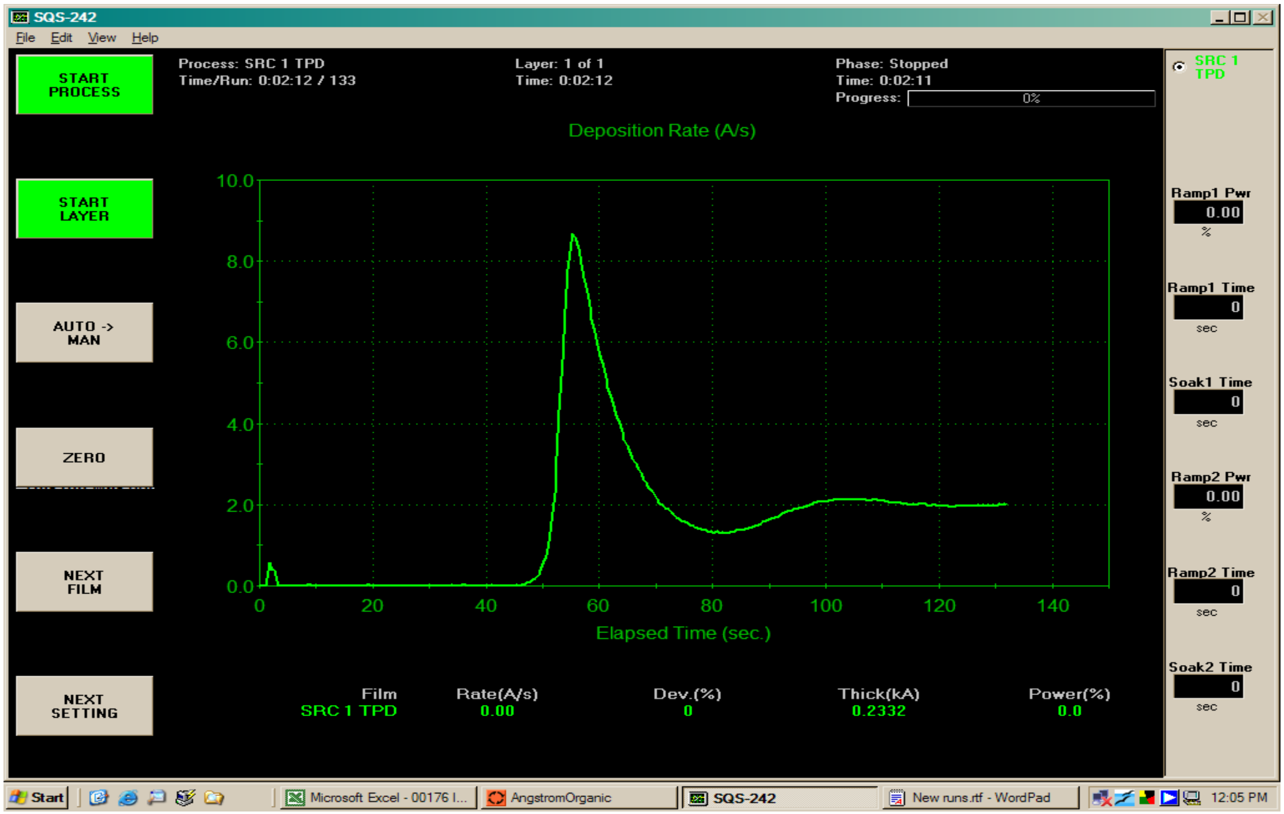


2 - If you did the run and you saw that the power rose at a good speed but the overshoot was more than 50 or 60% and then it fell back down quickly but also had some undershoot and then leveled off this means that the P is allowed to drive the power too hard. You should leave the P and raise the I. You could try raising I from 12 to 13. Then do the run again and see if you have fixed the overshoot. If it does the same thing but to less of an extent then try raising the I again. Note that raising the I may result in the system being too slow. If this occurs then the P will have to be raised to compensate.

<u>TPD in Source location 1 Test run</u>

This is a run to see if the PID can control the source from a 0 start. With no ramp or soak.

Starting Pressure 5.7x10-8
Sensor 1 only used
Z-stage at 0"
Tooling factor 27.2 (chart)
Source to substrate distance 10.104" (chart)
Ran in auto
PID 96,5, 0
Output voltage is set to 2.5
Period 0.5 and filter 3
Angstrom Test 1 SRC1 new wire TPD.log
Run #: 125
Ran at 2Å/s /500Å



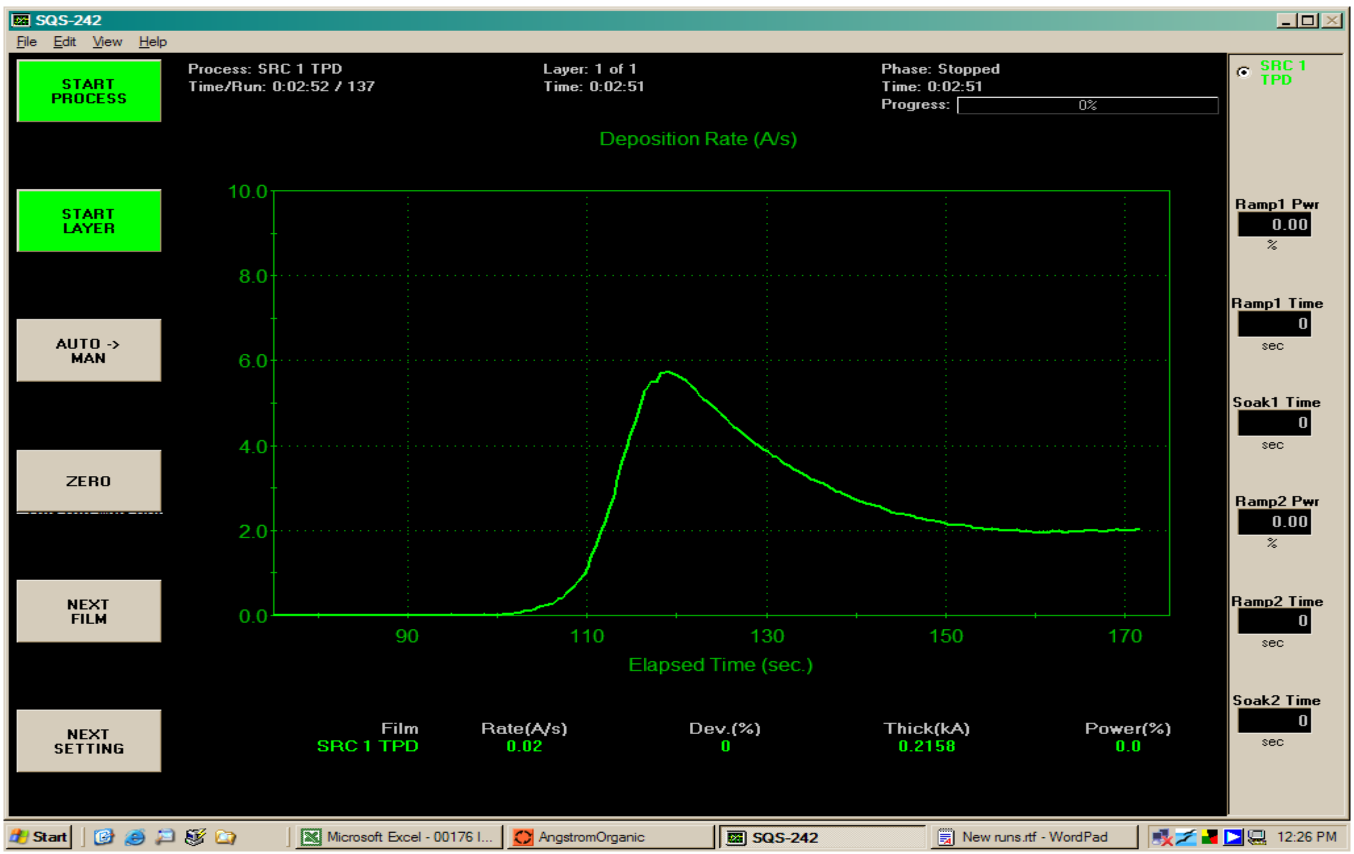
3 – If you ran it and the power rose very slowly and then overshot more than 50 – 60% and then took a long time to level out (i.e. The power didn't fall very quickly or at all) but did not undershoot then you have to lower the I. This is because you are allowing the P to drive it hard but are also not allowing the I to react fast enough for it to realize that it is above the setpoint. In this case you could start with an I value of 10. Do the run again and see if it is fixed. If it now rises quickly and then overshoots the right amount and then has no undershoot and then levels off nicely but seems to take a long time to start to deposit and also get back to the required rate then you should try lowering the I more and see if it gets faster. Lower it only 1 at a time as changing the I term can make the system very unstable. If lowering the I stops making a positive difference then try leaving the I as it is and increasing the P by 25 at a time. This will allow you to see a change right away.

<u>Run 10 - TPD in Source location 1 Test run</u>
This is a run to see if the PID can control the source from a 0 start. With no ramp or soak.

Starting Pressure 6.4x10-8
Sensor 1 only used
Z-stage at 0"
Tooling factor 27.2 (chart)

Source to substrate distance 10.104" (chart)
Ran in auto
PID 80,12, 0
Output voltage is set to 10
Period 0.5 and filter 3
Angstrom Test 1 SRC1 new wire TPD.log
Run #: 125
Ran at 2Å/s /500Å

It got slower but the I was too high so it was too slow to react on the way up.



4 – If the power rose at a good speed and then the rate overshot more than 50-60% and then came back down at a good speed then your I value is most likely very close to being right. You then have to increase the P value to drive the system both up and down faster to reduce the overshoot.

<u>TPD in Source location 1 Test run</u>
This is a run to see if the PID can control the source from a 0 start. With no ramp or soak.

Starting Pressure 7.8x10-8

Sensor 1 only used
Z-stage at 0"
Tooling factor 27.2 (chart)
Source to substrate distance 10.104" (chart)
Ran in auto
PID 130,12, 0
Output voltage is set to 2.5
Period 0.5 and filter 3
Angstrom Test 1 SRC1 new wire TPD.log
Run #: 125
Ran at 2Å/s /500Å

Less overshoot because the I is controlling it. The I slows it down but you still need the P to drive it.