

Trouble shooting on Extrusion Temperature Control Equipment

Arthur Holland. Holland Technical Skills

Know your Machine

Label with its Function or Zone, the various controls, indicators and parts, such as: Temperature controllers, thermocouples plugs and sockets, heaters, heater contactors, ammeters, cooling solenoid valves. Melt pressure transducers and indicators, motor drive controls, their meters, switches and push-buttons. Electrical disconnects, fuses, blowers and their contactors and indicator lights.

This includes terminal and wiring identification inside the control panel.

Write down or use a marker to denote normal reading or settings on gauges, indicators and adjustable valves.

For controllers, list settings that vary with different jobs; e.g. temperature, speed, amps. Record adjustable parameters like proportional band, integral time and derivative time. These do not normally need resetting for different jobs except for when you change a controller or a die.

Know what to expect of any change or adjustment you make.

Know where to find the wiring and piping drawings; keep them up to date after changes.

Know how to open enclosures. If you cheat a door-latch disconnect be aware of live and dangerous parts inside the panel.

Put a permanent sticker on the control cabinet showing names and phone numbers of contractors and parts suppliers who can help with parts or trouble shooting advice.

Identify spares. For any suspect parts that come off the machine attach a **what's wrong** label and put in for repair right away. This way you keep only good parts on the spares shelf. Separate heat-only from heat-cool temperature controllers. If you plug a heat-only (e.g. die controller) into a heat-cool (barrel) zone you will be unable to bring the temperature down when screw shear heat overheats the zone.

NORMAL BEHAVIOUR OF TEMPERATURE CONTROLLED ZONES

For observing the process in action, ammeters permanently fitted on every heater are a great help. Otherwise check heater currents with a clamp-on ammeter. Lights showing ON/OFF state of cool solenoids or blowers are a useful aid. So are coolant flow indicators.

If temperature is well below set point, the heater current will be on steady at its maximum value and not pulsing. Cooling will be off

If temperature is well above set point, heater current will be off. Cooling will be full-on (barrel zones).

If temperature is around set point (a few degrees either way), heater current could be coming on and off typically every 10 sec or so (faster with solid-state contactors) ; or the cooling

solenoid valve (or blower) could be cycling equally slowly.

It looks illogical sometimes when you see pulses of heat coming on when temperature is a little above set point or cool coming on a bit below set point. The controller will slowly work it out and settle down delivering just enough heat or cool to hold the correct temperature. The amount of heat or cool to expect around set point is not easy to predict because of the complexities of PID control.

PROBLEM : Temperature well below set point and heater current off.

Check for loss of line voltage, blown heater fuses or heater open circuit. If the contactor coil is energised, usually at 120V ac (though some solid-state contactors are switched by a DC signal around 10V), check that its contacts have closed. If not, change the contactor. If the contactor coil is not energised, voltage could be failing to get to the controller's internal relay or that relay (or triac) could be failing to close.

TRAP Triac switches inside controllers need an AC voltage on them and at least a 50 mA load to check their operation. DC continuity tests do not work, but they do on magnetic relays.

ANOTHER TRAP Let's say you disconnect the contactor coil and use a voltmeter to check whether a controller's internal relay or triac is switching voltage through. You will probably find a voltage there all the time. Reason? a snubber (spark suppressor) is often fitted internally across the triac or the relay or contacts. This can pass a tiny current, enough to show full line voltage on your meter when the relay or triac is open but nowhere near enough to pull in a contactor coil. Even without the snubber a triac switch could leak enough current to show on the voltmeter. A 120V 5W filament lamp works well as a tester.

TRAP AND SERIOUS HAZARD. In place of the commonly used mercury or magnetic contactors for heater control, more machines are now using solid-state relays (SSRs). They come mostly in two versions designed for either low voltage, typically 10V dc logic or 120V ac logic at the input terminals (the terminals that correspond to the coil on a magnetic contactor). The 120V ac version from most manufacturers has an input impedance of some 120Kohm. The result is that a controller with a triac or relay output with a snubber fitted will fail to turn the SSR off and your process will overheat.

If you cannot convert to low voltage dc logic a work-around solution is to connect a 0.47 microfarad 400V capacitor (not electrolytic) across the 120V input terminals of the SSR. It will divert enough current to ensure that the controller can switch the SSR off.

Some SSR manufacturers recognise this problem and make the input impedance low enough to defeat this hazard.

A much better solution is to use an SSR designed for low dc voltage operation and use a controller that has a matching DC logic output. This ensures reliable turn off.

PROBLEM: Temperature abnormally high, heater current on.

Check for voltage on the contactor coil or SSR logic input. If absent, the contactor is locked on or welded to a short circuit condition, change it.

If coil voltage or logic input voltage is present, change the controller, its internal relay or logic signal is on when it should be off. Or check for **TRAP AND SERIOUS HAZARD** above if you are using SSRs.

PROBLEM: Temperature persists a few degrees above set point, heater current off.

Upstream or adjacent zones are set hotter and pass heat across. Don't set a temperature that

adjacent heat sources can overcome.

PROBLEM: Temperature indication extremely high, zone doesn't feel over hot, current off. The controller may show broken sensor message.

Check the thermocouple and wiring continuity all the way back from the thermocouple to the controller's thermocouple terminals. The most probable cause is open circuit thermocouple or wiring. The resistance measured from the controller input terminals should normally be under about 20 Ohms. If the controller is good it will indicate around room temperature if you connect a wire link or double alligator clip across its thermocouple terminals. If the thermocouple and wiring are good, change the controller.

PROBLEM: Heater current on, temperature indication stays abnormally low but zone is clearly over heated.

Check for 1. thermocouple pulled out of its hole and sitting at room temperature 2. stray wire strands bridging the thermocouple connector or wiring.

If temperature indication goes below room temperature check for crossed thermocouple wires.

TRAP On North American Type J thermocouple wires, white is positive and red is negative. It is understandable but wrong here, to connect the red wire to the positive input terminal.

Thermocouple wiring errors are common when installing or rewiring imported machines.

Note: on plastics machines, thermocouples are almost invariably type J (Iron/Constantan) and the iron wire is positive so if you don't trust wire colours you can identify the + wire with a magnet.

The internationally agreed colour code standard for thermocouple wire is IEC 584-3 but up to now (2001) few users have adopted it or even heard of it.

Note that the small pin on the thermocouple plug is positive and the plastic body on type J is black.

PROBLEM: Zone temperature comes up normally at start-up but after a few hours the zone overheats. The controller indication stays normal.

Reason 1. The run between the thermocouple head and controller is wired in copper instead of thermocouple extension wire. As the head warms up, being close to the heat, the presence of copper wire causes a shortfall of temperature signal. The controller receives a signal lower than true temperature and turns up the heat until it makes up the shortfall.

The result is a zone running hotter than indicated, by an amount equal to the head-to-controller temperature difference.

Reason 2. The run between the thermocouple head and controller has the correct thermocouple extension wire but it is crossed at both ends. Even worse than reason 1. The controller receives a signal lower than the true temperature by **twice** the head-to-controller difference. This is because the thermocouple extension wire subtracts instead of adding its signal to the controller. Again the controller turns up the heat to compensate for the shortfall and the indication looks normal.

This error can vary during the day from not noticeable to some 50 deg C too hot; depending on

how near the thermocouple head is to the hot zone and how long the zone has been on.

HEATER PROBLEMS AND PRECAUTIONS.

Heat Transfer. Ensure clean heater mating surfaces, well clamped down (snugly inserted in the case of cartridge heaters) for good heat transfer. Poor thermal contact or air gaps can cause hot areas on the heater and premature local burnout.

Use the largest contact-area heater you can get into the space. Lower watts/sq inch longer the life. Tighten down occasionally.

Infra-red or thermocouple contact thermometers can help locate too hot or too cold areas on a heater surface.

You will always see disagreement between your contact thermometer on the heater, barrel or die surface, and the controlled temperature from the thermocouple deep in the barrel or die. This is to be expected due to deep-to-surface temperature differences in the zone. With thermocouple contact probes another error comes from incomplete transfer of all the surface heat to the probe tip. Measurements taken on the surface are of limited use in knowing the polymer processing temperature.

Damage and Corrosion

Wires that are frequently bent or moved (maintenance or die changes) can break or disconnect. Corroded or dirty studs, nuts and washers spark, buzz and lose contact. Keep them tight and replace with bright new hardware if needed at maintenance time when you have the barrel covers off.

Use high temperature connecting cable. Unplated copper cable oxidises badly.

Bad connections, loose fuse clips and oxidation can appear anywhere in the heater wiring. These points behave like an electric arc welder and fire hazard. Fuses do not protect against bad connections.

Watch for polymer or oil dripping onto connections or between segments of ceramic band heaters. It will decompose into conductive carbon and flash over.

WATER COOLING

PROBLEM Heat off, cool on but temperature will not come down to set point

1. No water- pressure or pump stopped.
2. Pipe or solenoid valve clogged. Cooling water should be closed-loop and de-mineralised.
3. Manual volume-adjusting valve turned off
2. Solenoid valve fails to open. Check if its coil is energised. If not, the controller cool output relay or power feed to it is at fault. If the coil is energised and the valve does not allow flow, change it. If you feel the valve; you will sense a click as the controller switches it on or off.

PROBLEM Heat on but temperature will not come up to set point

Look for the solenoid valve stuck open or held open by a defective controller relay failing to switch it off.

FAN COOLING

PROBLEM. Temperature below set point and fan will not turn off

Check for fan contactor welded up or locked on or controller relay locked on due to a faulty controller.

PROBLEM. No air flow and temperature well over set point

Check for faulty controller, controller relay or fan contactor. Check for motor failure or air path blockage.

CONTROL PRINCIPLES

Fig 1. Shows an example of easy to control process. A well-stirred water bath with a light gauge electric heater, a fast, bare thermocouple and an **on/off** controller with a very small dead band. As soon as the temperature rises to set point the control relay opens and the temperature stops climbing. When the temperature falls slightly say 0.1deg C, the controller switches the heater on again. The temperature graph is virtually a straight line.

Why so easy? There is not enough mass and heat capacity in the heater wire to make the temperature overshoot after switch off. Also the thermocouple senses the water temperature immediately and there is no delay in the control action. This is not a practical process.

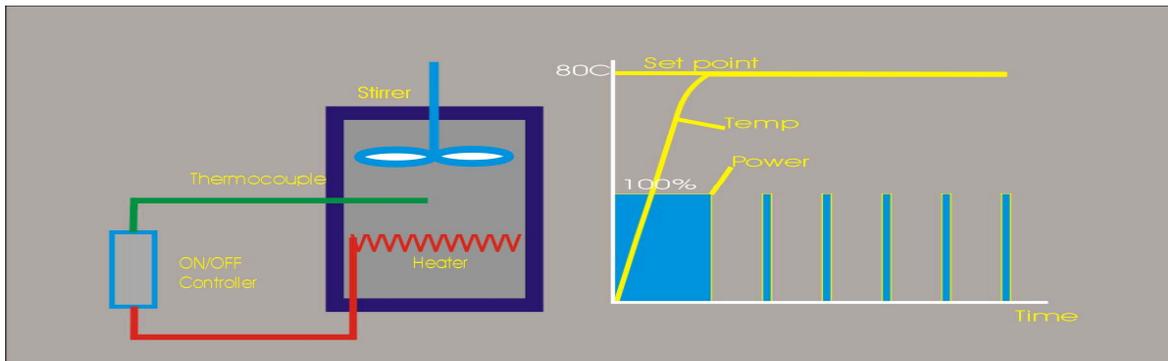


Fig 1. Easy to control process-Well stirred water bath

A REAL WATER BATH. NOT SO EASY.

A practical heater will be metal sheathed, heavy and could run one or two hundred degrees C higher than the water temperature. Controller switch-off does not stop the heater delivering heat into the water; overshoot is inevitable. Worse yet; the thermocouple will be insulated and in a protection tube so it is late telling the controller that the water has come up to the set point and time to switch off.

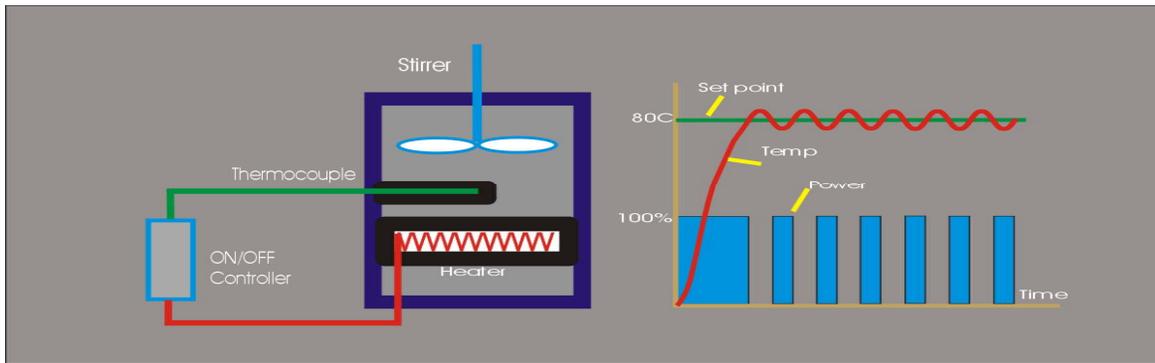
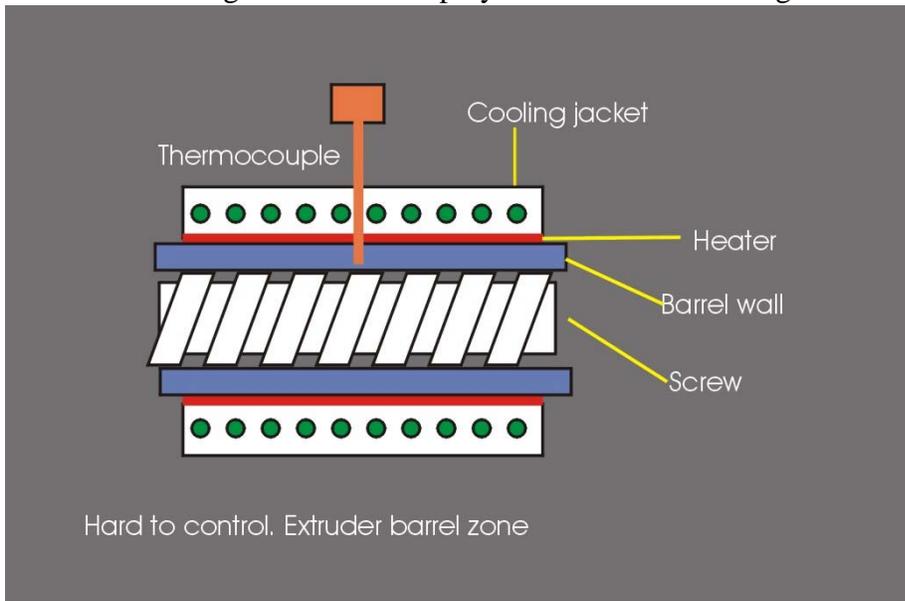


Fig 2. Practical water bath

The result is that the temperature cycles continually above and below set point even though the controller is very precise in switching on and off exactly at set point. Dead band in the controller makes the cycles larger.

ANOTHER HARD TO CONTROL EXAMPLE, AN EXTRUDER BARREL ZONE.

An extruder barrel zone would also overshoot and cycle because there is a massive heater and barrel wall running hotter than the polymer when heat is being demanded. Also the thermocouple



is set deep because you have to sense and control the polymer temperature. This makes it late in responding to changes in heat input and reporting back to the controller. You need a controller that can throttle back the power well ahead of the temperature reaching set point. This provides a way to defeat temperature overshoot and

cycling.

Fig 3 Extruder Barrel

Fig 4. shows the elements of a controller that would achieve this, along with a thermocouple and a controlled load.

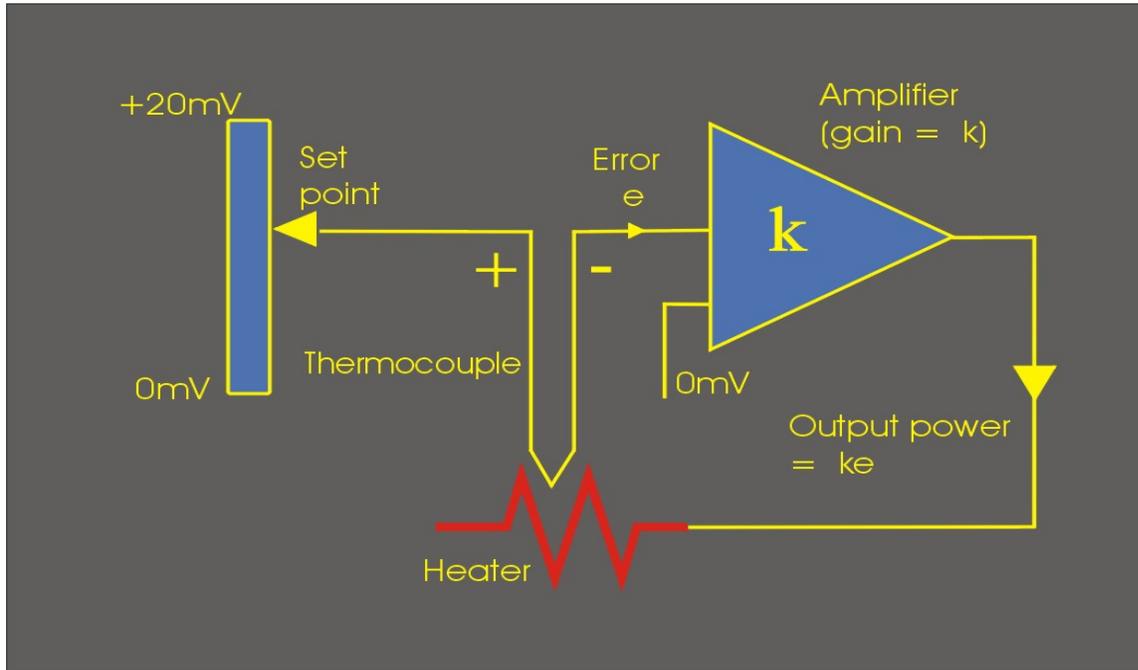


Fig 4. Simple controller circuit with thermocouple and load

PROPORTIONAL CONTROL How it works (Refer to Figs 4 and 5)

On the circuit on Fig 4 you adjust the set point by setting a dc millivolt signal representing desired temperature. You read this on a scale or on a digital readout. Your control thermocouple (feedback) will match this value when the process comes up to the desired temperature.

The back-to-back (subtractive) connection of set point millivolts and thermocouple millivolts puts the difference (called the error signal e) into the amplifier.

As connected here, the amplifier's objective is to deliver enough power to the heater to bring the thermocouple temperature (therefore millivolts) up to match the set point.

If the amplifier gain is very high, the slightest error signal, minus or plus at its input gives full heater power or no heater power. You are now back to **on/off** control; power does not go off until the temperature has reached set point. Result, large overshoot and temperature swings.

Solution. reduce the amplifier gain k so that it takes an error e of say 40 deg to give full heater power at the output. Being a linear amplifier in terms of power, a 20 deg error gives 50% power, 10 deg gives 25% power and so on.

The controller is now delivering corrective action (i.e. power) in proportion to deviation of temperature from set point This is **proportional control**. Power $P = ke$ (that is, amplifier gain \times error)

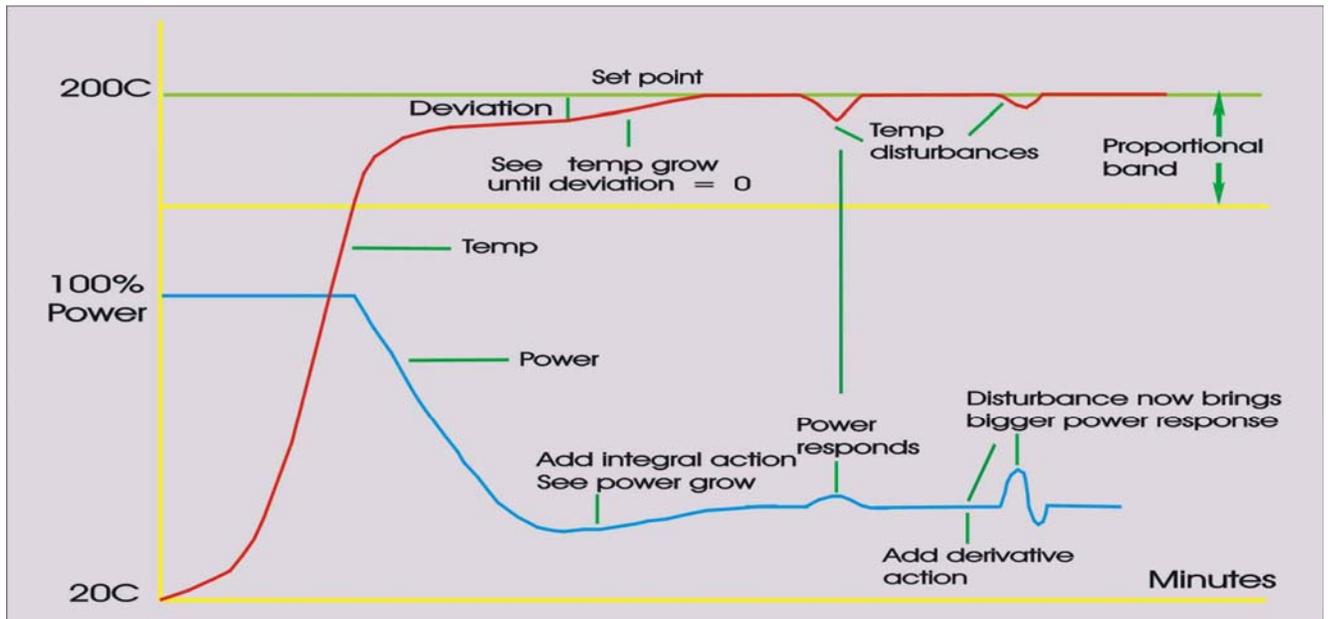


Fig 5. Start up Graph of a Temperature Control Loop

The size of error needed to make the amplifier deliver 100% power is called **proportional band** (40 deg in this example). It is sometimes expressed as a percentage of controller temperature range. So if this controller has a range of say 0 to 1000 deg, 40 deg represents a 4% proportional band. The gain k is defined as $100 / \% \text{prop band}$ ($100 / 4 = 25$ in this example)

HOW TO AVOID OVERSHOOT AND TEMPERATURE SWINGS

If you make the proportional band large enough as shown in Fig 5, the power will throttle back in good time to avoid overshoot and the temperature swings that come with it.

If the temperature could reach set point (giving zero deviation), the amplifier input would reach zero therefore so would the power. This does not happen. The temperature settles out some way below set point and some intermediate level of power is delivered.

This shortfall of temperature below set point is called **offset**.

It is no use reducing the proportional band to get more power and try to reduce the offset. You would soon break into temperature and power swings again, (called control loop instability).

HOW TO ELIMINATE OFFSET

Say the temperature settles at 180C, i.e. 20 deg below your set point of 200.

You could reset the set point 20 deg up at 220 to get the controlled temperature close to 200.

Some controllers have a small knob called **manual reset** that achieves this without showing it as an extra 20 deg on the set point display.

So this 20 degree deviation is amplified into enough power to heat the zone to about 200 deg. There may be times when the zone needs say, twice that power to hold 200 deg, For example when you have a higher material throughput or a very cold material and environment.

To put out twice the power, the amplifier needs twice the input, i.e. a 40 deg offset. This would

take the temperature down again towards 180 deg.

So are you going to keep resetting the set point and waiting around every time the heat demand changes?

No, you need an automatic and continuous watch on the temperature and gentle corrections of the power aimed at keeping the deviation at zero.

INTEGRAL ACTION, SOMETIMES CALLED AUTOMATIC RESET

So you give the amplifier a second job. Let it watch the deviation and so long as it persists, make the amplifier put out a gently increasing contribution until there is enough power to reach set point, making the deviation e equal to 0.

The amplifier is designed to make the rate of power growth proportional to deviation. So when temperature is close to set point, the power is changing very slowly. When the temperature reaches set point the power stops growing and holds at just the level needed to hold the temperature at set point.

This is called **integral action**. You now have a PI (proportional + integral) controller.

HOW TO DEFINE INTEGRAL TIME

If the deviation = one proportional band, the contribution of integral action will grow to 100% power in one **integral time**, T_i .

DERIVATIVE ACTION, SOMETIMES CALLED RATE ACTION

Now give the amplifier a third job. Let it watch for **changes** of temperature and put out a contribution of power proportional to **rate of change**. E.g. fast dive, big boost, slow dive gentle boost. Fast rise big throttle back etc. The purpose here is to resist and damp out unwanted changes and to speed up recovery from temperature disturbances.

HOW TO DEFINE DERIVATIVE TIME

If the temperature dives at a rate of one proportional band in one **derivative time**, T_d , the contribution of derivative action is 100% power (and minus 100% power for temperature climbing)

You now have a **PID** (proportional + integral + derivative) controller. Also called a **3-term or 3 mode** controller.

Among the parameters that you adjust to optimise (= tune) your controller are **proportional band, integral time and derivative time**.

Start up overshoot

Say that a 10deg proportional band gives you the tight, stable control that you want after the process has settled down but power throttles back too late to avoid overshoot on start up. You could increase proportional band and that would work; but then you would lose some of that tight control.

Low cutback. You could design the controller introduce a pause at say 20 deg before set point. That is, move the proportional band temporarily downwards 20 deg. The controller now throttles back the power that much earlier, then slowly takes the proportional band upwards to its normal position. This gives you a new adjustable parameter called **low cutback**, set to 20 deg in this

example.

Analogy. When you drive to a junction, ease up 200 ft away (low cutback) then brake for the last 100 ft (proportional band).

If you notice a start up overshoot try a **low cutback** setting equal to the amount of overshoot. Note that this parameter name and means of implementation will vary with manufacturer.

TUNING THE CONTROLLER

Self tuning

Many controllers have a feature called self-tune or automatic tune. Upon initiation of self-tune, the controller typically gives a controlled dose of heat to the process and from the temperature response back from the process, calculates optimum settings for the PID parameters and sometimes other parameters. You should record these after a successful self-tune because they could be different for different zones on the same process.

Self tuning can take anything from a minute or two in the case of say a fast tungsten lamp applying heat to a low mass material, to one hour or more with a slow, large mass process. It is advisable to start

self-tune when the process is at or a bit lower than its normal working temperature. Watch the temperature at this stage and be ready to intervene if the initial heat dose threatens to overheat your material or equipment. You must make your own judgement of optimum control. E.g. if your processed material takes no harm from a certain overshoot you might accept that in exchange for a faster time to settle at set temperature.

HOW THE CONTROLLER VARIES POWER TO THE HEATER

We referred to the controller amplifier putting out power. The final stage of this sometimes uses silicon controlled rectifiers (SCRs), which deliver heater power by smooth variation of ac voltage (like a lamp dimmer). This is done in some processes but is not usually necessary or economical on extruder heaters.

The power curve in Fig 5. looks like a continuous modulation of power but the usual method is to pulse the heat contactor typically once every 10 seconds (called **cycle time** and not to be confused with the temperature cycling of an unstable control loop). See Fig 6.

The controller delivers long pulses for high power and short pulses for low power while keeping the same time (10 seconds) between the start of successive pulses. The same idea works on a stove ring. Turn the knob half way round (to No 5) and the contact closes for 5 sec then opens for 5 sec continually. This makes your 2 kW ring deliver an average power of 1kW.

The temperature controller determines the duration of the pulses. Although it can only turn the power **on** or **off**, it is called a **time-proportioning** not an **on/off** controller.

It turns the power progressively lower by ever shorter ON pulses as the temperature gets closer to the set point. The pulses then have just the right duration to hold the temperature at set point.

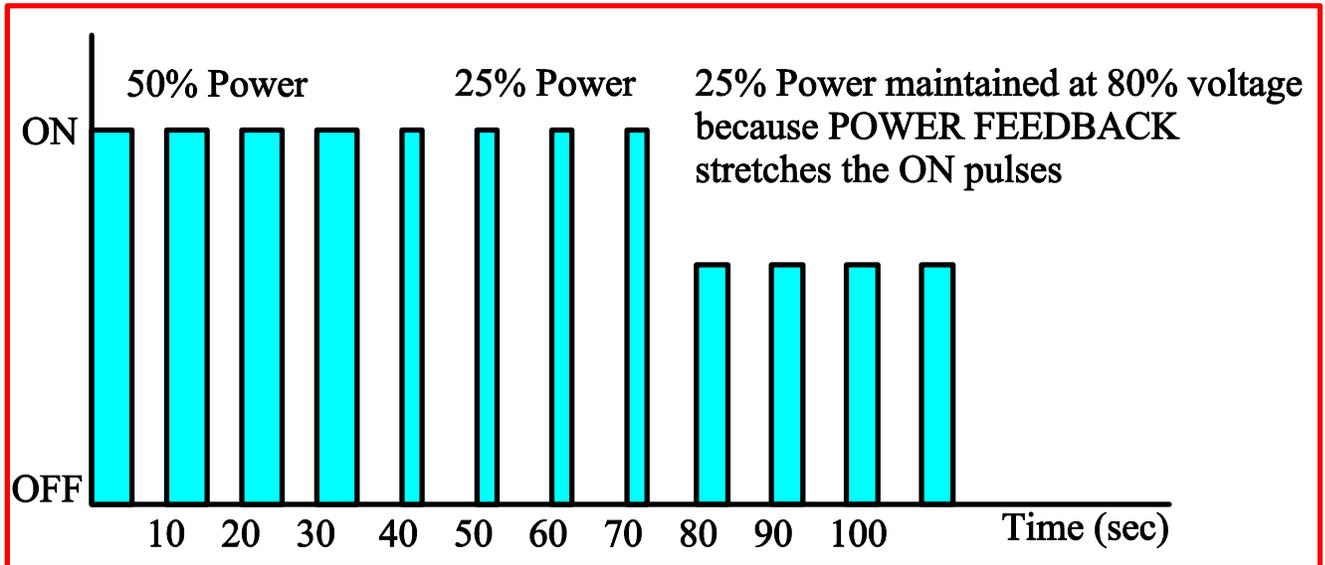


Fig 6. Modulation of power by pulse width variation

POWER FEEDBACK

Say your zone is running at 25% power and the temperature is right on set point.

Line voltage falls say 20%. This results in a heater power drop of 36% because of the square law dependence of power on voltage. Sooner or later the temperature falls.

After a time the thermocouple and controller would sense this fall and increase the **on-time** of the contactor just enough to bring the temperature back to set point. Meanwhile the material is running a bit cooler than optimum and may show some imperfection in the product.

A smart controller would watch line voltage continuously and increase or decrease contactor % **on-time** to compensate right away. In this way the zone need never suffer a temperature disturbance caused by a line voltage change. See Fig 6.

Note that the feature **power feedback** is only applicable to electric heaters. Disable it if you have some other heating medium such as water, steam or heat transfer oil.

In process-control terminology the same idea; heading off the effect of a disturbance as soon as it happens is called **feedforward**.

For example you might vary the base heater power on a conveyer furnace automatically in proportion to material throughput and leave the controller to do only fine trimming and correction of other disturbances.

CHOICE OF HEAT CYCLE TIME

This is a controller parameter with a range adjustable typically between 0.1 and 100 sec. A 0.1 sec time (10 operations per second) would soon destroy a magnetic contactor, so in this case you would select typically 20 sec. On most extruder zones there is so much metal mass that the temperature would not rise and fall noticeably in sympathy with these slow on and off pulses.

On the other hand consider a fast responding application like radiant heating of moving sheet.

You would need a cycle time say 0.2 sec to avoid the alternate under and overheated sections of sheet that slow cycling gives. A 10 second cycle would show large temperature swings.

On any fast control loop be on the alert to recognise this as too long **cycle time** not **control loop instability**.

If you are using tungsten lamp heaters, even on a slow loop, you would not use magnetic contactors; you will need **silicon controlled rectifiers** (SCRs) with phase-angle control in the manner of a lamp dimmer.

CHOICE OF COOL CYCLE TIME

If you are switching a solenoid valve or blower motor with a magnetic contactor, a cycle time of 10 or 20 seconds would be suitable, because of the mass and slow response of a typical cooled zone.

Some machines have blowers, switched by fast solid-state contactors (e.g. 0.1sec cycle-time). Instead of stopping and starting every cycle, the blower, because of its inertia, will assume some intermediate speed at which the controller is satisfied that the temperature is correct.

BALANCING HEAT AND COOL DELIVERY

It is rare to find an extruder zone whose cooling capacity is equal to its heating capacity. You can see this if you switch on the heater band and record the rate of temperature increase; then switch on full cooling and record the rate of fall. If the rate of fall is say 5 times the climb rate then the cooling capacity is 5 times the heater capacity.

In this example a temperature rise would bring a dose of cooling 5 times as strong as the heater would deliver for the same under-temperature and you would see a severe drop of temperature, then a recovery and continual repetition of this **temperature cycling**.

The solution? Run in the heat only mode and tune the control loop i.e. find the PID settings that give stable control.

Now make the cooling proportional band 5 times that for the heat mode. This translates to setting a **cool gain** of 0.2. The parameter for this is sometimes called **relative-cool**. The mnemonic (abbreviation) in the controller parameter list depends on the brand of controller.

Fig 7A shows a balanced heat/cool zone.

Fig 7B shows cool gain 2 times too large but maximum heat and cool capacities balanced

Fig 7C shows cool capacity twice that of the heater and cool gain in need of adjustment

Fig 7D shows the correct balance of proportional bands by making the cool gain equal to 0.5

Heating capacity is easily defined (= the kW rating stamped on the heater band). However cooling device capacity is not easy to define or to keep constant.

WATER COOLING

Cooling capacity with water depends on inlet water temperature, working temperature of the zone, flow rate and heat transfer of the cooling jacket.

Inlet temperature can change during the day, dependent on other loads on the cooling water system. Flow-rate is often changed by a throttling valve according to the judgement or experimentation of the operator.

Unless you know the machine design the quickest way is, after tuning in the heating mode, to find a setting for **cool gain** setting that gives temperature stability when that zone is running in the cooling mode.

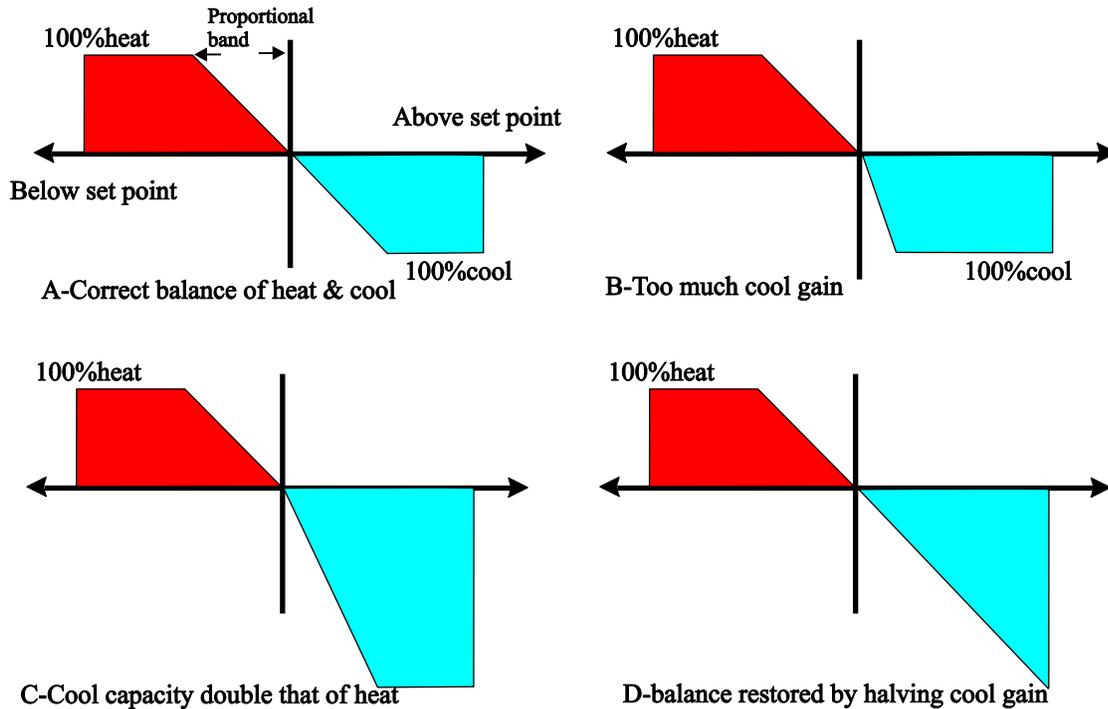


Fig 7. Balancing heat and cool delivery

Another complication with water-cooling comes if the zone is running well above 100 deg C. Usually the first few pulses of water will flash off into steam giving a greatly increased cooling capacity due to the **latent heat of evaporation**.

When the zone settles down, less or even no evaporation is a possibility and the cooling is less severe.

To handle evaporative cooling you would choose the **water cool** mode from the controller parameter list.

This technique delivers much shortened pulses of water for the first few percent of the cooling range, when the water is likely to be flashing off into steam. This compensates for the transition out of the initial strong evaporative cooling.

FAN COOLING

This is much gentler than water cooling and not so immediate or decisive because of the long heat transfer path through the finned aluminum cooler and barrel.

Again, capacity is hard to predict but you can get a rough idea if you can feel the outgoing air from that zone with your hand and compare it with how a 1500W hair drier feels.

With fan cooling, a cool gain setting of 3 upwards would be typical and delivery of pulses to the blower would be linear, i.e. the on time would increase proportionally with percentage cool demand determined by the controller.

OIL COOLING

Being non-evaporative, oil cooling is also pulsed in a linear manner. It is deep and more direct and will not need such a high cool gain as fan cooling. Again its capacity varies with oil inlet temperature and flow rate.