PID675 Users Manual

PortRail

April 2005

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1 Introduction

Thank you for purchasing the PID675 Model Railway Controller. This is quite simply the finest analog controller available today, and yet it is quite economical thanks to modern microcontroller technology.

Features of the PID675 include:

- Precise speed control delivered by a full “proportional-integral-differential” feedback system;
- Small size;
- Modest cost;
- Adjustable simulated inertia;
- Automatic stopping at stations or at the touch of a button;
- Full overload protection;
- Overload and loss-of-control warnings;
- Timeout mode to switch off unattended trains;
- Factory and user presets for control and inertia settings.

If you have a version of the controller that includes a power transformer, you can skip at once to section 3 and read about how to use your new controller. If you have a controller that is to be wired into a layout, this is discussed in the next section.

2 Connecting the Controller

There are 5 connections to the PID675 controller. Two are required to bring DC power. The controller requires 16–26 volts to function properly. Two are required to deliver current to the track. Finally, one further optional connection is available to carry a signal to the controller to trigger automatic station stops.

2.1 DC Input Power

The controller expects filtered DC power in the range 16–26V. The controller will not be harmed by either reverse polarity or the application of up to 35V, but may not function properly if the supply is less than 16 or more than 26V.

The controller will work if the supply is not filtered, but operation can be less effective or even erratic.

If you are correcting directly to the PCB, the positive supply is indicated by the symbols “V+” and the zero volts or negative connection is marked ”GND”.

2.2 Output to Rails

The output to the track consists of two wires. On the PCB these are labelled "T". If you have a PID675 mounted in an enclosure (either with or without a transformer) there is a reversing switch included. In this case there is no explicity polarity in the track connection.

2.3 InStation Trigger Line

The PID675 has a connection that can be used to cause automatic stopping of the train. This is called the "Stationing" signal line. When this line is connected to ground (the negative supply input connection), the train will slow to a stop, wait, and then automatically resume its journey.

This line is normally pulled up to 5V. When the line is pulled low (below about 2.5V) the signal is considered active. The input line will not be harmed even if levels as high as 10V are applied. The line will normally be connected to ground via a relay contact or a wired-or logic line with TTL levels.

On the PCB, this connection is labelled "DET".

3 Using the Controller

The PID675 has a control knob, a press button, and an indicator LED. When first turned on, the indicator flashes quickly for about two seconds to show the the controller has started correctly. The controller then loads the same settings that were in use when it was last turned off.

After the two seconds starting up, the controller goes into its "standby" mode. This is signalled by a slow (1Hz) even flashing of the indicator LED. In this mode, the train does not run, even if the speed knob is set to a high speed. Touching either the button or the knob will reset the controller into its "active" mode. In normal, active operation the knob sets the speed of the train, and the LED shows a "heartbeat" signal, consisting of a one-sixteenth second flash every second. Turning up the knob makes the train go faster and turning it down makes it go slower.

The controller starts in the standby mode as a safety precaution, so that locomotives do not take off as soon as power is applied if the control knob has been left turned up. In normal usage, starting with the control turned down, the controller commences operation as soon as the knob is turned up, and the initial standby is not even noticed.

Pressing the button while the train is in motion causes it to stop for 16 seconds. During this interval the indicator LED flashes quickly, 8 times per second, to indicate that the controller is in its "stationing" mode.

3.1 Auto Mode

The controller has a mode, called “Auto”. When it is in Auto, the controller will respond to a logic signal applied to the “InStation” input by stopping the train for a period between 8 and 16 seconds. The interval is selected in this range at random. If the controller’s speed knob is turned up past half-way when power is applied, the controller will enter Auto mode. Otherwise it is in manual mode, and the “InStation” input will be ignored.

The controller shows a slightly different “heartbeat” signal when it is in Auto mode. Instead of a single flash of 65ms duration every second, the heartbeat signal becomes two short flashes every second. The two short flashes are 65ms each, and are separated by 65ms, so that a pattern of the form “blip-blip-pause, blip-blip-pause” appears.

The “InStation” line will typically be connected to the logic signal from a block detector at the entry point to a station. Thus, the train stops at the station by itself if Auto mode is enabled through turning up the speed knob before applying power. The “InStation” line triggers a pause, as described above, with a random duration. The pause interval is “non-retriggerable”, meaning that the “InStation” line is not able to extend the pause period, so it does not matter if a train continues to trigger the block detector after it has stopped. Further, there is a 10 second period after the train restarts during which the “InStation” line cannot trigger another halt. This blackout period helps prevent retriggering if passing carriages continue to trigger and release the block detector.

Auto mode is most useful for demonstration layouts.

3.2 Factory Reset of PID Coefficients

The PID675 holds five sets of PID coefficients in its memory. The first set is the “working” set. The other four contain “typical” sets of coefficients that can be called up to overwrite the working set, to take the user back to a known starting place or to set up for the four most common situations.

The sets are:

1. Basic proportional-only mode with no inertia. This is the kind of performance expected from a conventional analog feedback controller.
2. Proportional, integral & differential coefficients set to modest values, no inertia. This gives more precise operation, especially at low speeds.
3. Proportional, integral & differential coefficients set to modest values, medium simulated inertia. This gives the precise low-speed operation, as well as smooth stops and starts.
4. Relaxed P-I-D coefficients and mild inertia. This set is only slightly better than a conventional feedback controller, and has only just enough inertia to prevent jerky actions. This set might be better for “learners”.

The factory reset states are invoked by holding down the press button while applying power. If the button is pressed at the end of the initial, 2-second startup period, the speed control is read, and a factory set is used to overwrite the working set. The factory set that is called up is chosen according to the position of the speed control. The control range is divided into four equal areas. If the control is at zero, set 1 is used. If it is at full power, set 4 is used. In between these, sets 2 and then 3 are selected. For example, if zero is at the 7-O'clock position and full speed is at the 5-O'clock position, set 2 would be selected if the control is in the 10-O'clock to 11-O'clock range, and set 3 for the case of the control set to the 1-O'clock to 2-O'clock region.

3.3 Adjusting PID Coefficients

The most performance is obtained from your controller if you adjust the P-I-D coefficients to suit your scale of locomotives and the inertia setting to suit your own personal taste. Changed coefficients are stored in non-volatile memory and will thus remain in place once you have tuned them. This section explains how to set the coefficients, both the mechanics of making the change in the PID675, and some rules of thumb for choosing the values themselves.

There are four coefficients that control the feel and action of the controller: The constant of proportionality, K_p, the integral constant, K_i, the differential constant, K_d and the inertia constant, K_j. These setting sequence is started by holding the push button down for a period of more than 2 seconds.

Upon the release of the push button, provided it was held down for two seconds or more, the controller enters "set K_p mode". This is signalled by the indicator led giving one 187ms dash every 1 second. This appears a bit like the manual heartbeat signal, but is clearly a dash (187ms) rather than a dot (65ms). The speed control (sometimes called a potentiometer, or pot) can then be used not to adjust loco speed, but the value of K_p. The maximum value corresponds to the control turned up to full speed, fully clockwise, the minimum or zero to the full counter-clockwise position. Using the clockface analogy again, with 7 O'clock at zero and 5 O'clock as full, a typical value corresponding to a conventional controller will be about 40position. If you do not wish to change the value of K_p, leave the control untouched. The value of K_p will not be altered no matter the position of the knob.

When satisfied with the K_p setting, press the button again. The controller will advance to setting K_i. The signal becomes two dashes of 187ms duration, spaced 65ms, every second. Again adjust the control if you wish to change K_i, make no adjustment to leave it unaltered. When finished, press the button again.

Next K_d will be set. The signal becomes three dashes of 187ms duration, spaced 65ms, every second. In a conventional feedback controller, there is no differential action, so the equivalent value of K_d is zero. When finished, press the button again.

Finally, K_j is available for setting. The signal is four dashes of 187ms duration, spaced 65ms, so that it appears as if there are 4 short dark blinks per second. This control sets the amount of simulated inertia. Roughly, the full-up position corresponds to about 10 or 15 seconds required to bring a train to a halt, the lowest position corresponds to a sudden stop as if the power had been removed. When finished setting the inertia, press the button again. This time the controller returns to normal operation, the signal to the heartbeat.

3.3.1 Rules of Thumb for Tuning

The process of selecting the coefficients of a PID controller is called “tuning”. This process can be a mathematically daunting exercise, but for the less-demanding purpose of a model train controller it is better thought of as an art and you can get the hang of it in a few minutes or an hour.

The first thing to realise is that there is a great deal of interaction between the four values that the PID675 allows you to set. It is best to get each right in turn. The first and most important rule of thumb is this: Start by setting $K_i = 0$, $K_d = 0$, and $K_j = 0$, and getting K_p correct first, then adjust K_i until you are satisfied, then K_d and only at the end allow K_j to advance from zero. After a lot of practice, you can usefully iterate between the first two steps to get the cleanest, sharpest operation, but any more complicated approach will probably not get you much advantage.

So, let’s go through a tuning procedure. First, reset the controller to a known state; turn off the power, set the pot to the minimum setting, hold down the press button, apply power, and wait until the flashing falls to the slow rate to indicate timeout. Now $K_i = 0$, $K_d = 0$, and $K_j = 0$.

Connect the controller to a test track, a short one with a hill and a curve is best. Select a locomotive and rail it. Use no carriages on the locomotive. Adjust the controller to get the locomotive running around the track at modest speed. Press and hold the button down for about 3 seconds, then release it. You should see that the indictar LED swaps from a single “dot” flash to a single “dash” flash once per second. Adjust the control. You should find that turning it down stops the locomotive and turnig it up makes it go faster, but only to a certain point. There is a place where advancing the control does not increase the speed. It may be that turning the control higher causes the loco to travel jerkily. The best position is just at the point where turning up the control has a noticeably reduced effect upon speed.

In fact, you can make no further adjustments on the controller, and you have performance equal to the best “analog” feedback controller that your locomotive could ever get. If you are happy with this, press the button three times and be done with tuning.

If you want some improvement, let us carry on. Press the button again, and observe that the LED now shows two “dashes”. We are now adjusting the Integral Coefficient, K_i. Turn the pot to zero, and advance it slowly. You should see nothing at first. The main effect upon train operation of K_i is to maintain speed constant as the load on the train runs. If you were *very* observant and your test track has a *steep* grade, you might see the train slow a bit as it climbed. This would be more pronounced if it carried carriages. (If you really want to spend the time fooling around, you could let your loco pick up a heavy consist and watch carefully with different settings of this K_i value as it climbs.) If you continue to increase the control setting, your loco will in all possibility start to move in jerks. This mean you have too much K_i! Turn the control back down.

It is possible to compromise between the first setting of K_p and this one of K_i, if you wish to take the trouble. In practice, if you have turned the control up past about one-quarter of its travel, you have enough without more work. Beware that the instability and jerking that arises with too much Integral term can start at different settings with heavier and lighter trains; it is better to be well clear of where this effect occurs.

Done with K_i, press the button again. Now you will see three “dashes” on the indicator LED. If this is your second time through these steps, you might want to exit here with two more pushes, and just try a few different trains, get the feel. If not, let us press on.

The next adjustment is of K_d. Start at the lowest setting. As you turn up the control you should see that the loco gets “nervous”, and eventually seems to jitter. If the loco has lights, and especially LED-based ones, you may see the lights flickering before the body of the train jitters. You may hear some irregular buzz from the motor. Once you see the jittering, back off some. What you are observing is moment-to-moment respones to dirt and electrical noise getting out of hand. The Differential Coefficient changes the electrical equivalent of a young driver’s tendency to overcompensate or respond too quickly to minor events. It can smooth out disturbances that affect models, particularly smaller-scale models that have very little real weight to bring to bear. The setting should be no higher than makes the jitters visible; have the effect present, but unobserved in normal running. It will come into play when shunting into trucks or crossing dirt.

Finally, press the button again and adjust inertia. This setting should be purely to taste. It is easy to set it too high, and get a train that starts very slowly, stos slowly, and is hard to shunt. One-third to one-half of full adjustment is recommended.

Now try driving the train. You may not like some aspect of its motion. See how relaibly it will travel *very* slowly. If you wish to adjust a parameter by itself, this is easy. Start with the initial long press, then advance through the four setting states, watching the dashes on the indicator, until you are at the one you want to change. Remember that if you do not adjust the speed knob the parameter will remain uchanged, irrespective of the position of the knob.

3.4 Timeout Mode

The PID675 has a final function installed to help the longevity of your locomotives. This is the “timeout” mode. After an hour of inactivity, the controller turns off the track power. This is similar to the “station” mode, but remains in place until a control is adjusted. The signal LED flashes evenly at 1Hz (500ms on and 500ms off) when the controller is in this mode.

4 How Speed-Regulating Controllers Work

Model train motors are small, permanent-magnet motors with brush commutators. This kind of engine has a very useful property: it acts equally well as a generator as a motor (ignoring minor losses). In practice, this means that if it is being driven with a pulsed electrical signal, in the moments between voltage being applied by the controller, the motor is acting as a generator, and it produces a voltage. This voltage is the so-called "back EMF" of the motor, and it is proportional to the speed of rotation of the motor shaft.

Feedback contollers measure the speed using the back EMF, and try to adjust their operation moment by moment to maintain constant speed in the motor. This is the basic principle of industrial control, applied to motor speed. When operating properly, the controller ensures that the setting you have on your control knob is the speed of the train, not the amount of power applied, as in the case of, say, the accelerator pedal of your car. The controller acts like a kind of cruise control.

A cruise control makes it easy to drive on the freeway. The feedback controller makes the drivers life easier by keeping a train running at a known speed, even as it climbs hills. However, a cruise control is not useful for low-speed work... not much call for shunting with an automobile. Why then, is a feedback controller so popular for shunting?

The answer lies in the fact that when you scale things down and make a four-inch model act like a 40' locomotive, it goes wrong. There is very little weight in a model compared to the original, no wind resistance, very different running fricton yet vastly more stiction, and very little immunity to small pieces of dirt on the track, etc. Feedback controllers, and particularly the PID series, help to negate the nastier of these.

Low-speed running is vastly improved in a feedback controller. A good-quality analog-feedback PWM controller will give you improvement, a full proportional-integral-differential feedback system can do wonders. The difference (apart from the complexity) lies in the precision with which the feedback can regulate the speed, and the range of problems with which it can deal smartly.

4.1 Pulse Control and Motor Heating

Many enthusiasts believe that pulse controllers overheat locomotives and are responsible for burnouts and excessive brush and commutator wear. On the other hand, some authors have suggested that PWM controllers do not increase the stress on motors significantly. Who is right?

Theory aside, there is no doubt that motors run hotter when driven by a PWM controller. A 10 minute comparison test will show this clearly without any more accurate measurements than the temperature sensing of your upper lip. However, such tests also make it hard to believe that the heating could be bad enough to burn out a locomotive. The excess heating is less pronounced at higher speeds (actually at levels closer to 100% duty cycle of the controller, meaning with its control turned up higher). So the situation is worse if you are using a controller designed for higher voltages than your loco requires, for instance running a Z-scale locomotive with a PWM controller designed to handle G-scale models.

Simple theory based on resistive losses says that the heat generated with pulsed drive will be higher than the constant-dc case by a factor of the duty cycle. In other words, if the PWM must use a 50% duty cycle to achieve the desired speed, resistive losses will be double what they would have been with a proportional analog controller, and if it has to use a 10% duty cycle, the losses will be 10 times greater. In practice, a small locomotive, N-scale say, will run fast with 11 volts applied, and might shunt with 3 volts applied. If a PWM controller applies 15 volts, it will run a duty cycle of between 20one third to five times. Note that the 5 times loss only occurs when the power delivered to the locomotive is less than one-tenth of its full-power load, so that it still represents half the power dissipation of full load. On this basis one might feel safe to disregard the additional dissipation of a PWM controller.

The “resistive loss” case discussd above is somewhat naïve. In fact, motors are quite complex magnetic systems. They present inductive reactance and exhibit magnetic loss mechanisms. Together with a PWM signal, these decrease efficiency and cause heating of the motor.

Much of the energy in a pulsed signal is contained in frequencies above dc. A squarewave signal corresponding to PWM with 50% duty cycle puts half of its energy into frequencies above dc; this fraction increases as the duty cycle falls, as does the content at higher harmonics of the pulse frequency. Above a certain frequency of operation, perhaps as low as a few hundred Hertz, the energy is simply lost as eddy current losses in the magnetic circuit. Efficiency would be improved if the frequency of operation, the pulse repetition rate or PRR, was to be lowered. However, below a few tens of Hertz the locomotive vibrates. This high-frequency loss accounts for much of the excess heating in a locomotive driven with PWM.

A rule of thumb for electric motors is that their life is halved for every 10C rise in the armature temperature. If your locomotive feels warm to the touch on the outside, this suggests an external temperature in the region of 40C (Luke warm is 38C, the limit of what you can touch comfortably is in the region of 55C). The armature temperature could be much higher, perhaps 80C, especially in light of the fact that locomotives do not generally have a cooling fan on the drive shaft, as do the motors of cordless power tools, for instance. Locomotive motors tend to rely on having an open casing and a draft created by the armature itself. This means that it is “wearing out”—approaching burnout—32 or 64 times faster than if you had left it on the shelf. If that sounds scary, remember that shelf life is very long, and the duty cycle of usage is usually quite low, unless the locomotive is used somewhere like a shop window. These considerations promoted the inclusion of the timeout function, as described in section 3.4.

5 Technical Information

5.1 Circuit Diagram