

Abu Dhabi National Oil Co.

ADNOC Technical Institute

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شركة بنزول أبوظبي الوطنية



INSTRUMENTATION

ADVANCED PROCESS CONTROL FUNDAMENTALS

UNIT 5

PROPORTIONAL PLUS INTEGRAL PLUS DERIVATIVE CONTROL

UNITS IN THIS COURSE

UNIT 1	INTRODUCTION TO PROCESS CONTROL
UNIT 2	MODES OF CONTROL
UNIT 3	PROPORTIONAL CONTROL
UNIT 4	PROPORTIONAL PLUS INTEGRAL CONTROL
UNIT 5	PROPORTIONAL PLUS INTEGRAL PLUS DERIVATIVE CONTROL
UNIT 6	CONTROL LOOP TUNING
UNIT 7	CASCADE CONTROL LOOP TUNING
UNIT 8	RATIO CONTROL LOOP TUNING
UNIT 9	CONTROL LOOP TROUBLESHOOTING

TABLE OF CONTENTS

Paragraph	Page
5.0 INTRODUCTION	4
5.1 PROPORTIONAL PLUS INTEGRAL PLUS DERIVATIVE CONTROL	5
5.2 DERIVATIVE TIME	7
5.3 AMOUNT OF DERIVATIVE ACTION	7
5.4 OPEN LOOP CHARACTERISTICS	8
5.5 SUMMARY	10

5.0 INTRODUCTION

Task 4 discussed the two position control mode in which the controller output is in either the full 'ON' or fully 'OFF' state. When properly applied, the two-position control mode can provide very good process control. However, continuous cycling is an inherent disadvantage. The two-position controller can be viewed as having a 0% proportional band, which is a very high gain. High gain is very useful for controlling the process accurately, but it is the high gain that results in the cyclic nature of this control mode as the controller output change state in response to small changes in the error signal.

Task 5 discussed the proportional control mode in which the gain of the controller is reduced to a moderate level. This provides a fundamental means of returning stability to the control of the process. With a proportional controller, the output signal places the final control element at different positions corresponding to the signal amplitude. For the final control element to remain at a desired position, an undesirable offset error must exist between the control point and the setpoint.

Task 6 discussed the proportional plus integral control mode. With this mode, the proportional section of the controller provides a moderate gain for better control stability, and the integral section increases the gain over a period of time to eliminate offset error. The addition of integral action however, does reduce stability to some degree.

Task 7 discussed the proportional plus integral plus derivative control mode. With this mode, the controller has a high initial gain, due to derivative action, for advancing the output signal. Then, the controller gain returns to the moderate level of the proportional section. The result is that the measured variable overshoots are smaller and that these overshoots have a reduced period. However, an offset error remains.

5.1 PROPORTIONAL PLUS INTEGRAL PLUS DERIVATIVE CONTROL

Derivative or rate control mode can be added to a proportional-plus-integral controller to improve the initial response of the controller and help bring the process variable back to the set point more quickly.

Derivative control mode acts according to the rate at which the process variable is deviating from the set point, not the quantity or size of the deviation. With derivative control, the controller action is similar to an ON/OFF controller during the initial phase of the process change and then returns to normal proportional-plus-integral control. This causes the controller output to begin responding immediately to process changes to correct for the duration and prevent overshoot. This immediate response would not be possible with proportional-plus-integral control.

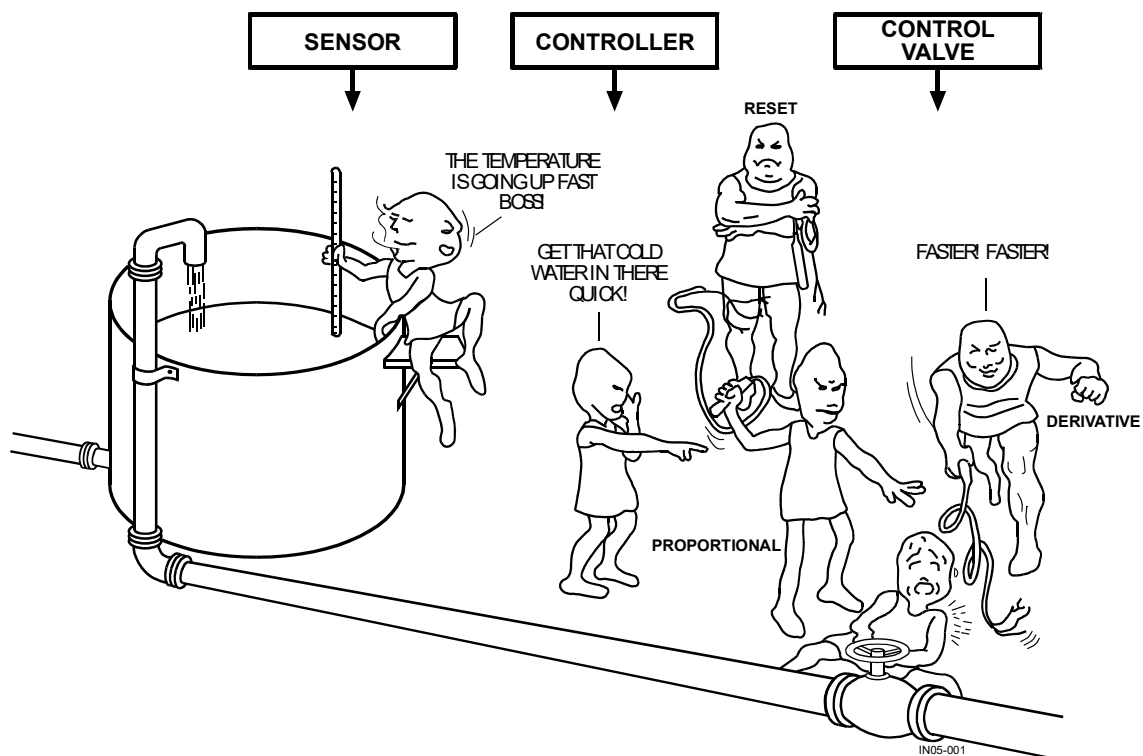


Figure 5.01 – Derivative Action

Illustrates the action of derivative mode in a control loop

Derivative control is most useful in slow-acting process control systems, such as a temperature control loop. Big time lags in a process control system can cause overshoot. In Figure 5.01, as the temperature start to deviate from the set point, derivative and proportional control modes provide an initial response to move the valve. This initial movement of the valve is the correction signal necessary to overcome the effect of the deviation that is about to take place – temperature going up fast. At this point, reset or integral mode provides no action to the controller. Integral mode will take action only if offset conditions occur.

Derivative action is not used alone. It is usually combined with proportional to provide proportional-plus-derivative control or combined proportional-plus-reset to provide proportional-plus-reset-plus-derivative control action. A controller with all these three modes is often called a three-mode controller, or a PID controller.

A PID controller is used in temperature loops only. Also adding derivative control to a fast-acting loop such as a flow loop will only make it unstable. Derivative is not used in flow control loops.

5.2 DERIVATIVE TIME

Derivative control is adjusted in terms of derivative time, usually in minutes. Unlike proportional and integral control modes, this is the only adjustment used by most instrument manufacturers for derivative control. Figure 5.02 shows derivative time adjustment in a controller.

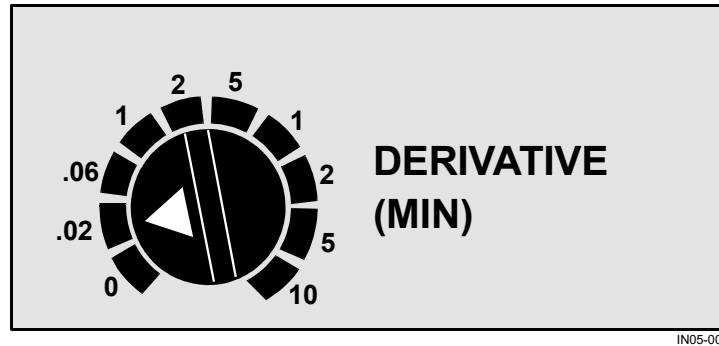


Figure 5.02 – Derivative Time Adjustment

5.3 AMOUNT OF DERIVATIVE ACTION

A three-mode controller (PID) is used to improve control of a slow-acting process variable such as temperature. Improper adjustments of these control modes in the controller will only make the process more unstable instead of bringing it back to the setpoint.

Like proportional and integral control modes, too much or too little derivative action will not help in bringing the process variable to the set point. If the derivative time is set too low, there is too little derivative action in a controller. The initial response of the controller may reduce the size of the overshoot totally. If the derivative time is set too high, there is too much derivative action in a controller. The initial response of the controller may be too much. This can be considered as closing or opening the control valve too soon. With this response, the process variable may not reach the set point.

As with a P+I controller, tuning is also required in a PID controller where the correct adjustments of the three modes combined are derived. Each control system will require controller tuning.

5.4 OPEN LOOP CHARACTERISTICS

A proportional plus integral plus derivative controller would appear to simply combine the three actions as they have already been described. The proportional action positions the final control element in relation to the error amplitude, the integral action eliminates the offset error, and the derivative action improves the stability.

The controller block diagram shown is described as “ideal” because it shows a parallel connection arrangement of the integral and derivative sections. With this arrangement, there is no interaction between the two section. In other words, the integral action does not alter the derivative action and vice-versa. In general, commercially available controllers are not actually constructed in this manner because of the additional component costs involved with providing separate sections. The controllers are actually constructed in a series arrangement, with some components serving more than one purpose. This arrangement results in fewer components, and makes the controller more commercially competitive.

The ideal proportional plus integral plus derivative controller is shown in block diagram from in Figure 5.03.

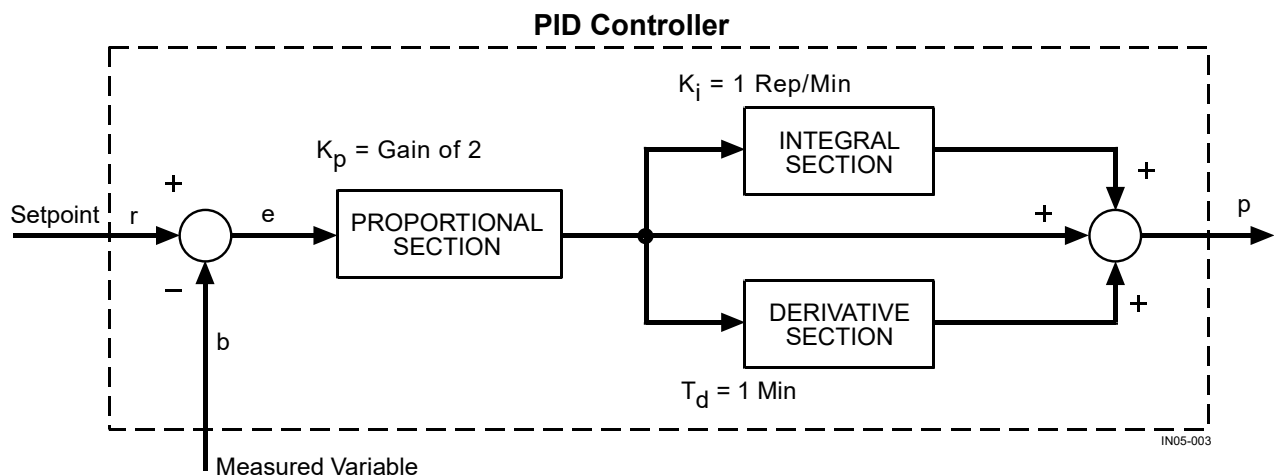


Figure 5.03 – PID Control Block Diagram

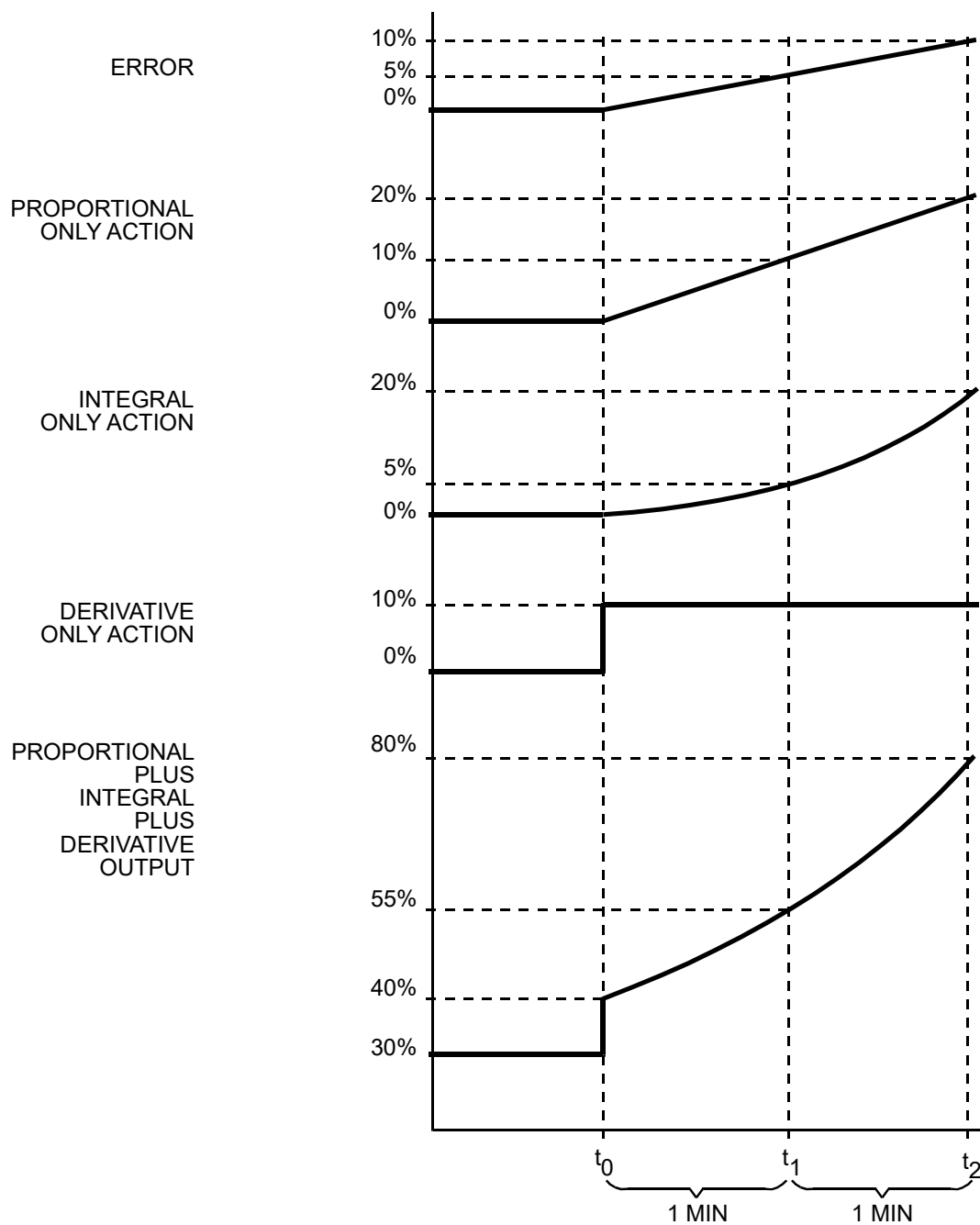


Figure 5.04 – Open Loop Characteristic Waveforms

5.5 SUMMARY

- The main function of rate or derivative control mode is to eliminate overshoot.
- Rate or derivative control mode responds to the rate at which the process variable is deviating from set point.
- Derivative control mode cannot function alone. It is normally combined with proportional or proportional-plus-integral control mode. A controller with these three modes is called a three-mode controller, PID.
- Derivative in a PID controller provides an initial output change as soon as the process variable deviates from the setpoint.
- The amount of derivative action in a controller is adjusted by derivative time in minutes.
- Too little derivative action means that the derivative time is adjusted too low.
- Too much derivative action means that the derivative time is adjusted too high.
- Too little derivative action causes a large initial change in the controller output. This action can be considered as closing or opening the control valve too soon and may prevent the process variable from reaching setpoint.
- As with a P+I controller, a PID controller requires tuning.

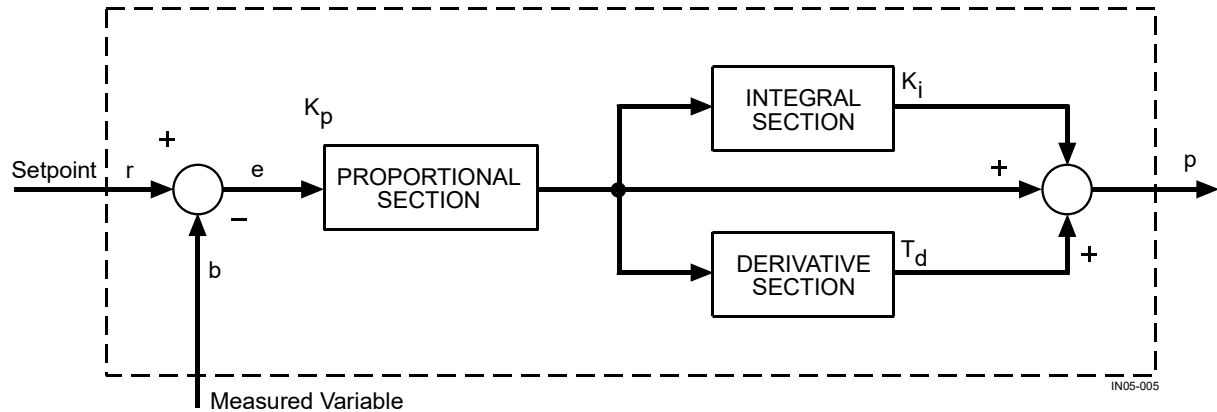


Figure 5.05 - Proportional Plus Integral Plus Derivative
Controller Block Diagram

$$P_{pid(t)} = K_p(\Delta E_p/\Delta t)(t) + 1/2 K_p K_i (\Delta E_p/\Delta t) (t^2) + K_p T_d(\Delta E_p/\Delta t) + P_o$$

Where: $P_{pid(t)}$ = Proportional plus integral plus derivative controller output at a specified time.

$K_p(\Delta E_p/\Delta t)(t)$ = Proportional action to a linear rate of change.

$1/2 K_p K_i (\Delta E_p/\Delta t)(t^2)$ = Integral action to a linear rate of change.

$K_p T_d(\Delta E_p/\Delta t)$ = Derivative action to a linear rate of change.

P_o = Controller output at the start of the time period of change.

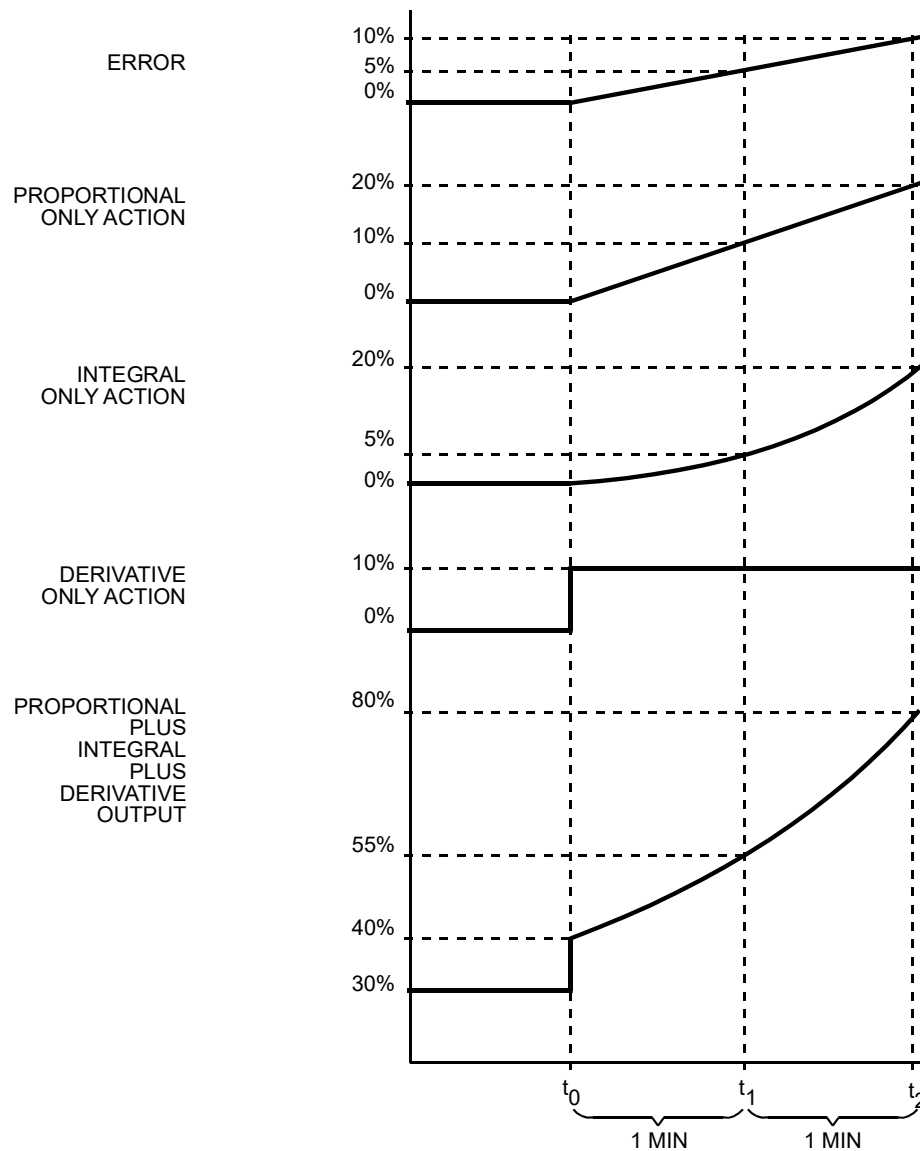
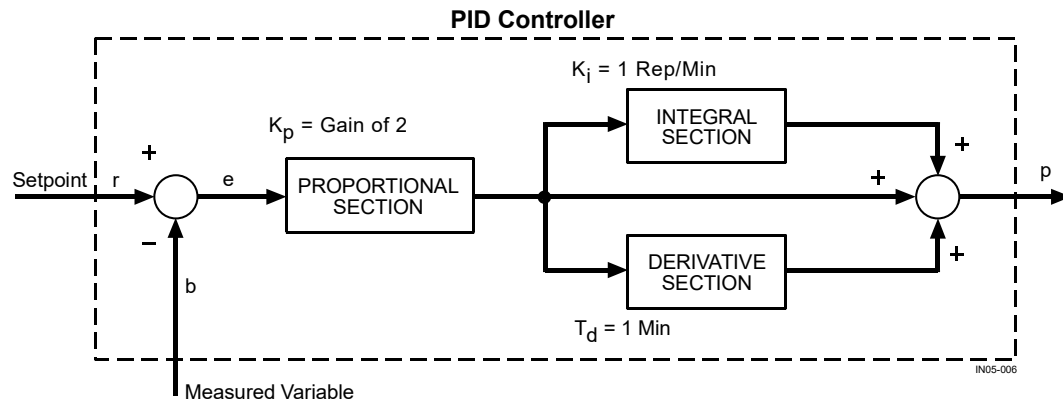


Figure 5.06 – Open Loop Characteristic Waveforms

At time t_0 , the error signal begins a 5% per minutes rate of change. The controller output at time t_0 is:

$$Ppid(t_0) = (2)(5\%/Min)(0 \text{ Min}) + (\frac{1}{2})(2)(1 \text{ Rep/Min})(5\%/Min)(0 \text{ Min})^2 + (2)(1 \text{ Min})(5\%/Min) + (30\%)$$

Therefore:

$$Ppid(t_0) = 40\%$$

This calculation shows that at time t_0 , the proportional and integral sections are just beginning to produce output amplitudes; therefore their outputs at time t_0 are considered to be 0%. The derivative section however provides an output at the instant, the proportional section output has a rate of change. In this example, a 10% derivative section output is produced and added to the 30% initial output for a total controller output of 40% at time t_0 .

After one minute, or at time t_1 , the proportional and integral sections also contribute to the total controller output, or:

$$Ppid(t_1) = (2)(5\%/Min)(1 \text{ Min}) + (\frac{1}{2})(2)(1 \text{ Rep/Min})(5\%/Min)(1 \text{ Min})^2 + (2)(1 \text{ Min})(5\%/Min) + (30\%)$$

Therefore:

$$Ppid(t_1) = 55\%$$

And after a total elapsed time of 2 minutes, or at time t_2 the output is:

$$Ppid(t_2) = (2)(5\%/Min)(2 \text{ Min}) + (\frac{1}{2})(2)(1 \text{ Rep/Min})(5\%/Min)(2 \text{ Min})^2 + (2)(2 \text{ Min})(5\%/Min) + (30\%)$$

Therefore:

$$Ppid(t_2) = 80\%$$