OPERATING INSTRUCTION MANUAL

Model 63 PID Controller
Supplemental Manual

(for use with Model P63 pH Analyzer)

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HELPFUL IDENTIFIERS

In addition to information on Model 63 PID controller operation, this instruction manual may contain WARNINGS pertaining to user safety, CAUTIONS regarding possible instrument malfunction, and NOTES on important, useful operating guidelines.

A WARNING LOOKS LIKE THIS. ITS PURPOSE IS TO WARN THE USER OF THIS ANALYZER OF THE POTENTIAL FOR PERSONAL INJURY.

A CAUTION LOOKS LIKE THIS. ITS PURPOSE IS TO ALERT THE USER OF THIS ANALYZER TO POSSIBLE INSTRUMENT MALFUNCTION OR DAMAGE.

☞ ***NOTE:*** *A note looks like this. Its purpose is to alert the user of this analyzer to important operating information.*

TABLE OF CONTENTS

PART ONE - GENERAL INFORMATION

PART TWO - TUNING GUIDELINES

ILLUSTRATIONS

PART ONE - GENERAL INFORMATION

SECTION 1

THE PID CONTROLLER

A PID (Proportional-Integral-Derivative) controller is one whose output is a sum of these three terms derived from operations on the difference between the measured process pH and the desired value at which you want to control the process (setpoint). The controller output drives a final control element, such as a modulating valve, that can act to bring the process pH to the setpoint value.

The following equation defines the relationship between controller functions:

$$m = P\left[(pv - r) + I\int (pv - r)\,dt + D\,(dpv \div dt)\right]$$

where:

- m = controller output
- P = proportional gain
- pv = measured process pH
- r = setpoint
- I = integral gain
- D = derivative gain

SECTION 2

GAIN FACTORS

PROPORTIONAL GAIN SETTING:

(Entry range: -99.99 to + 99.99)

The proportional gain factor increases or decreases the controller output in direct proportion to the control error (pv - r, in the preceding equation). A positive value proportional gain entry provides direct control action (increasing error increases the controller output). Conversely, a negative value proportional gain entry provides reverse control action (decreasing error increases the controller output).

INTEGRAL GAIN SETTING:

(Entry range: 0.00 to 50.00 repeats per minute)

The integral gain factor increases or decreases the controller output in direct proportion to the time integral of the error. If the error is constant, the correction increases with time. It is an inherent property of proportional control that it does not bring the process to the setpoint all of the time. Integral action forces the process to the setpoint (unless the controller is improperly tuned).

The action of the controller varies with the integral gain value. If integral gain is set to a non-zero value, then the integral action is automatic. If integral gain is set to “0.00 /min”, the controller has “manual reset”, enabling a fixed offset to be added to the controller output.

DERIVATIVE GAIN SETTING:

(Entry range: 0.00 to 10.00 seconds)

The derivative gain factor increases or decreases the controller output in direct proportion to the rate of change of the process value. The derivative gain is used to compensate for second order effects in the process. Most processes have one dominant response time, such as the response to mixing in a tank. If there are two response times in the process, derivative gain helps compensate for the second response time. If a process has only one dominant response time, derivative gain will not help. It is best to start tuning the controller without any derivative gain.

SECTION 3

AUTO/MANUAL OPERATION

The Model 63 PID controller can be transferred between an automatic mode in which the PID routine calculates the output, and a manual mode in which the output is manually adjusted. To select the controller operating mode:

1. Press the **MAINT** key, select “Manual PID” from the menu, and press **ENTER**.
2. Select the desired mode (AUTO or MAN).
3. Depending on the selected controller operating mode, do one of the following:
   - **For AUTO Mode:** Press the **ENTER** key.
   - **For MAN Mode:** Select the value at the right and jog it up or down using the ⇧ or ⇩ keys until the desired controller output is displayed. The adjusted output is provided while the controller remains in the MAN mode. The value can be further adjusted at any time.

When the controller is returned to the AUTO mode, its output is derived by the PID routine. The AUTO mode output begins at the last MAN mode output value and then changes according to controller calculations. This provides bumpless transfer between the MAN and AUTO modes of operation. The output changes smoothly without abrupt jumps that could damage a final control element.

SECTION 4

CONTROLLER OUTPUT TERMINALS

The “4-20 mA” terminals for analog output #1 are always used as the PID controller output. (Disregard the “analog output” terminal designation on the analyzer since this output cannot be used for this purpose.) When an analog output signal is needed to represent the measured pH or temperature, analog output #2 must be used.

PART TWO - TUNING GUIDELINES

SECTION 1

INTRODUCTION

Most controllers are actually tuned by setting only the proportional gain and integral gain factors to some initial, arbitrary values. These settings are then readjusted, one at a time, by experimentation based on observed response.

Excessive process noise may require the controller to be detuned somewhat (proportional gain increased and derivative gain decreased). Successful control relies on proper selection of the control element and the controller range. For self-regulating processes, a full-scale stroke should provide a full-scale change in the measurement signal. pH applications typically have an integrating response. Avoid using integral gain unless the derivative gain can also be used. Neither of these gains are needed if the proportional gain setting is more than 90.00.

After setting the controller range and setpoint, and controlling the process manually, use the Ultimate Oscillation Tuning Method to tune the controller.

SECTION 2

ALGORITHM TYPE (ISA OR VELOCITY?)

The Model 63 PID controller can be selected to use an ISA (Instrument Society of America) or velocity algorithm. Both algorithms have “anti-reset windup” which prevents the output from remaining at its minimum or maximum value when the process is recovering from an upset condition.

The velocity algorithm, with its transit time setting, is intended for use on pH control processes with more than 5 seconds of dead time in the control loop. Do not use the velocity algorithm if the typical process pH changes very slowly. When process deadtime is less than 5 seconds, or the pH tends to change very slowly, select the ISA algorithm. To select the algorithm type:

1. Press the **CONFIG** key, select “PID Operation” from the menu, and press **ENTER**.
2. With the “PID OPERATION” screen displayed, select “PID Mode” and press **ENTER**.
3. With the “PID MODE” screen displayed, select the desired algorithm.

SECTION 3

FULL SCALE/ZERO SCALE SETTINGS

The “Full Scale” and “Zero Scale” fields on the “PID MODE” screen define the range of inputs over which the controller will act. **Recommendation:** For normal pH control, leave these settings at their factory defaults of “14.00” and “0.00” respectively. To change these settings:

1. With the “PID MODE” screen displayed, select the “Full Scale” value and adjust it using the ⇧ and ⇩ keys.
2. Select the “Zero Scale” value and adjust it using the ⇧ and ⇩ keys.

SECTION 4

SETPOINT SETTING

The controller setpoint is the pH value to which the controller should bring the process. To set the setpoint:

1. With the “PID MODE” screen displayed, select the “Set Pt” field.
2. Use the ⇧ and ⇩ keys to adjust the displayed value to be the desired setpoint, and press **ENTER**. This simultaneously enters all of the items on this screen (type, full scale, zero scale, and set pt).

SECTION 5

MANUAL RESET SETTING

The “Man Reset” value should always be “0.0%” whenever the controller’s integral gain is set to a non-zero value. When the integral gain is set to “0.00 /min.”, the controller becomes a PD (proportional + derivative) controller. In this case, select “Man Reset” and adjust the value using the ⇧ and ⇩ keys to establish a desired controller output that will be provided when the process value is at the setpoint.

SECTION 6

DIRECT/REVERSE CONTROL ACTION

Direct or reverse control action is set by the sign of the proportional gain setting. A positive or “+” gain value provides direct action. That is, <u>increasing</u> error causes increasing output. (Use a positive gain factor for acid addition.) Conversely, a negative or “-” gain value provides reverse action. That is, <u>decreasing</u> error causes increasing output). (Use a negative gain factor for caustic addition.)

SECTION 7

TRANSIT TIME SETTING

☞ ***NOTE:*** *Set a transit time only when the velocity algorithm has been selected, and only when there is more than 5 seconds of process dead time.*

Transit time is the time it takes for the sensor to “see” a change in the process pH that was caused by a change from the connected control element. Transit time compensates for the process dead time by establishing an amount of time the controller “holds” before it “acts” to change the output as needed. The sequence of “hold” and “act” times continues automatically while the controller is in the AUTO mode of operation.

To determine the transit time, control the process manually. This also enables you to get a sense of control system capability, and to check for proper control element sizing.

1. **Recommendation:** Use a strip chart recorder to observe the effect of the control element on the process pH.

   NOTE: *Since analog output #1 is dedicated as the controller output, connect the recorder to appropriate analog output #2 terminals. Make sure that output #2 is configured to represent the measured pH.*

2. Place the controller in the MAN operating mode. See Part One, Section 3 for details.
3. Manually jog the controller output to control the process in a safe direction towards the setpoint.
4. Time how long it takes for a change to affect the measured pH value. Note this transit time.
5. Press the **CONFIG** key, select “PID Tuning” from the menu, and press **ENTER**.
6. With the “PID TUNING” screen displayed, select the “Transit” value and, using the ⇧ and ⇩ keys, adjust it to match the time noted in step 4.
7. Press **ENTER** to enter the transit time.

SECTION 8

ULTIMATE OSCILLATION TUNING METHOD

This method requires that the measuring loop response develops undamped oscillations that may be undesirable from an operational or safety viewpoint. Preventing these oscillations from growing or reaching some physical limit may be difficult.

8.1 Proportional Gain Effect on Response

By increasing proportional gain, the setpoint offset (sustained error) decreases but response becomes more oscillatory. The following diagrams illustrate this effect, with proportional gain settings of +75.00 for Curve 1, +65.00 for Curve 2, and +50.00 for Curve 3. A proportional gain entry of "0.00" disables the controller.

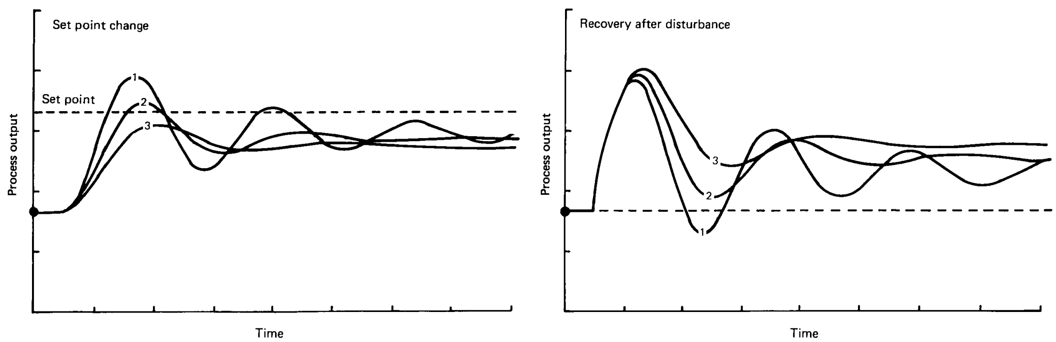

FIGURE 2-1 Proportional Gain Effect on Response

8.2 Integral Gain Effect on Response

By increasing integral gain, the setpoint offset is eliminated faster but the response becomes more oscillatory. If integral gain is increased too much, oscillations develop into a reset cycle whose period is much longer than the "ultimate" period. The following diagrams illustrate this effect, with integral gain settings of 0.02 repeats/minute for Curve 1, 0.05 for Curve 2, and 0.10 for Curve 3. An integral gain entry of "0.00" disables integral response, but provides manual reset, enabling a fixed offset to be added to the controller output.

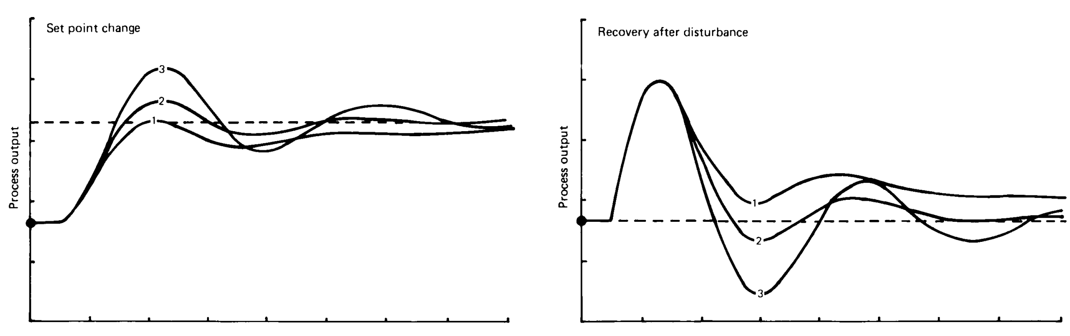

FIGURE 2-2 Integral Gain Effects on Response

8.3 Derivative Gain Effect on Response

By increasing derivative gain, the overshoot for setpoint changes and the peak error for load disturbances reduces, but response becomes more oscillatory. If response turns back as the pH approaches the setpoint before actually crossing the setpoint, the derivative time is longer than normal. If derivative gain is increased too much, oscillations develop into a rate cycle whose period is shorter than the "ultimate" period. The following diagrams illustrate this effect, with derivative gain settings of 2.00 seconds for Curve 1, 5.00 for Curve 2, 10.00 for Curve 3, and 20.00 for Curve 4. A derivative gain entry of "0.00" disables the derivative response.

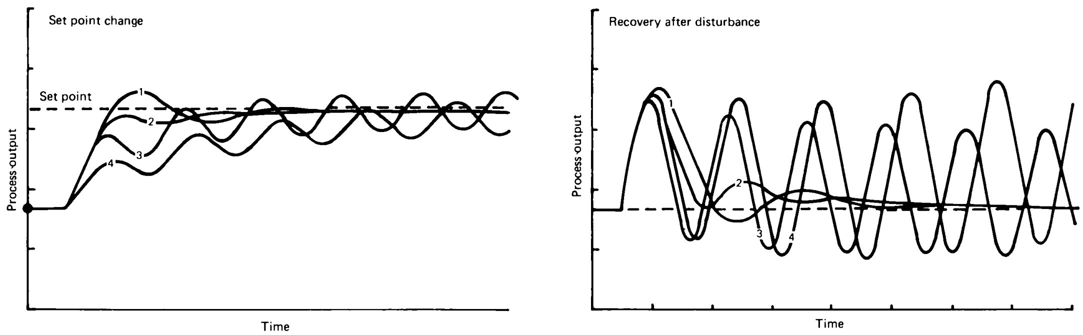

FIGURE 2-3 Derivative Gain Effect on Response

8.4 Tuning Procedure

1. Use a strip chart recorder to monitor the process. It must be connected to analog output #2 terminals, since output #1 is the controller output. Make sure output #2 is configured to represent the measured pH.
2. Display the "PID TUNING" screen by pressing **CONFIG**, selecting "PID Operation" from the menu, and pressing **ENTER**. Then enter the following gains:
   - Proportional gain: "0.00"
   - Integral Gain: "0.00 repeats/minute"
   - Derivative Gain: "0.00 seconds"
3. Place the controller in the MAN operating mode by pressing **MAINT**, selecting "Manual PID" from the menu, and pressing **ENTER**.
4. Select "MAN" and manually adjust the controller output as needed to drive the measured pH as close as possible to mid-scale.
5. Now transfer the controller to the AUTO operating mode.

6. Display the "PID TUNING" screen again, and increase the proportional gain setting in 5.00 increments until the observed oscillations neither grow nor diminish in amplitude. Note this proportional gain setting, referred to as PG_U (ultimate proportional gain) for this tuning method. If the oscillations saturate at either extreme, repeat steps 3 and 4 to stabilize the response. If there are not enough disturbances to start the oscillations, jog the setpoint.

   NOTE: *Oscillations only need to be approximately, not exactly, equal in amplitude.*

7. At this PG_U setting, time the period between oscillations. This time is referred to as T_U (ultimate time). If the recorder chart speed is too slow, time the interval between the first and third measurement trace past the controller setpoint.

8. Depending on the gains you intend to apply, use one of the following sets of equations, and the PG_U setting and T_U time period noted in steps 6 and 7 to calculate the estimated settings for the controller gains:

   - When using only proportional gain:

     Estimated proportional gain = 0.55 x PG_U

   - When using proportional + integral gains:

     Estimated proportional gain = 0.45 x PG_U
     Estimated integral gain = 0.83 x T_U

   - When using proportional + integral + derivative gains:

     Estimated proportional gain = 0.6 x PG_U
     Estimated integral gain = 0.5 x T_U
     Estimated derivative gain = 0.125 x T_U

9. Enter each of the estimated gains calculated in step 8.

SECTION 9

FINAL TUNING

The typical procedure for testing the gain settings is to observe the performance of the controller when the output is upset. With the process being sucessfully controlled, manually jog the controller output up or down by a safe amount, return the controller to AUTO operation, and observe the control action as the controller brings the process back to setpoint. If the process value becomes unstable, oscillates, or does not return to setpoint in a reasonable amount of time, individually readjust the gains in small increments and observe the response.