16 Apr 1992

Implementation of T1545 in Air Pressure Control

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ABSTRACT

The Texas Instruments Model 545 programmable logic controller is used to control the air pressure in a heating/ventilation simulator designed and built for a classroom experiment station. Through the use of the PLC's built-in PID algorithm, the pressure in the duct was controlled to within a 2% tolerance and over 72% of the sensor range for a load setting of 10%. The theory of PID controllers and their application to this problem are discussed. Also, the configuration of the simulator, and plans for future work are described.

THEORY

The Proportional-Integral-Derivative (PID) controller, because of its simplicity and effectiveness, is one of the most widely used control schemes in industry. Fundamentally, the PID is a feedback loop with three terms in the feedback transfer function: proportional, integral, and derivative. The proportional term responds to changes in the process variable, but a P controller settles at an offset value that is different from the process set-point. The integral term remedies this problem by responding to the integral of the difference between set-point and process variable values. However, in some circumstances, the integral term can saturate the controller and render it useless. The use of an integral reset coefficient can fix this problem. The derivative term is added in some situations for faster response and better damping characteristics.

SYSTEM DESCRIPTION

The heating/ventilation simulator (see Figure 1) consists of a piece of ordinary air ducting with a 3-phase blower on one end, a heating element inside, and a variable opening on the other end to simulate varying loads on the H/V system. The blower is driven by an Allen Bradley variable-frequency motor drive, with a range of 0.5 to

60 Hertz. The drive frequency is controlled by a 0-10 Volt analog signal from the PLC. An Omega pressure sensor with a range of 0-1" H_2O is located close to the opening and sends a 4-20 mA analog signal to the PLC.

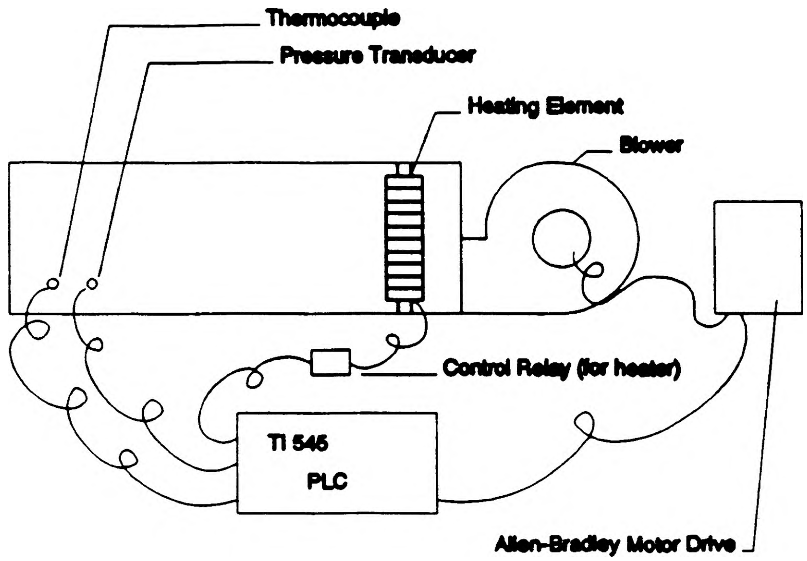


Figure 1

CONTROL

There are three primary parameters which affect the pressure inside the duct: (1) the speed of the blower, (2) the load setting, and (3) the temperature in the duct. To simplify the investigation, the load was considered to be a system disturbance and not controllable by the PLC. Also, the effect of temperature on the pressure was neglected. In essence, the duct air pressure was considered to be a direct function of only the speed of the blower. The block diagram of this simplified system is shown in Figure 2.

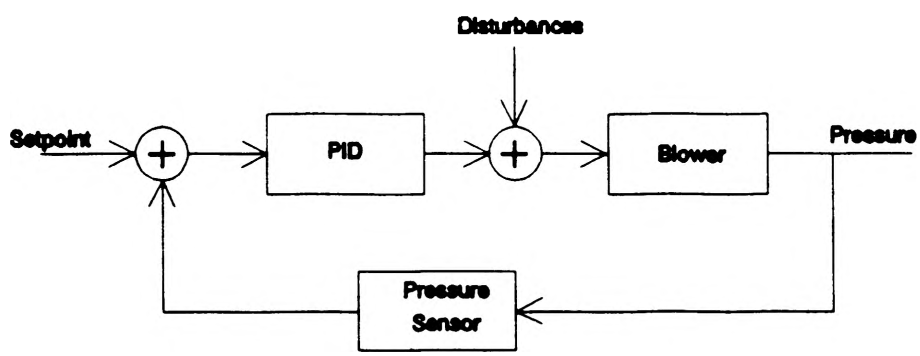


Figure 2

The Laplace transform of the PID loop is given by equation 1.

$$M = K_c (E + E/(T_i s) + C T_d s) + M_x/s \quad (1)$$

Where:

- M = PID loop output
- E = Set point - process variable
- C = Process variable (pressure in duct)
- M_x = Loop output when $E=0$
- K_c = Proportional Gain
- T_i = Reset coefficient
- T_d = Derivative coefficient

As was mentioned before, the PLC has a pre-programmed PID algorithm so that the application engineer has only to "fill in the blanks" to set up and tune the controller. The set-point is held in a special dedicated variable called LSPX (where X is the loop number, 1-64.) In this case, the process variable (C) is contained in WX49, which is the address of the analog pressure sensor value after A-D conversion. The parameters K_c, T_i, and T_d are directly entered into the PID loop table (Appendix A.) It was found that values of 0.75, 0.09, and 0, respectively, gave the best performance. T_d was set to zero because taking the derivative of the inherently noisy pressure signal puts wild swings into the loop output. This effectively classifies this control as a PI control rather than a PID.

PERFORMANCE

The PI controller is not aggressively tuned and the settling time equals the rise time. There is no sinusoidal "bouncing" around the set point, so once it is within tolerance, it stays within tolerance. Table 1 shows the 95% rise times when the set point was changed in a step from 10% to another value. For each measurement, the system was allowed to settle at the 10% point before input of the new set-point value. The control was able to hold the process variable to within 1.3% of the set point. In the table, t_r is given in seconds, set-points are given in hundredths of an inch of water (which corresponds to percent of sensor range.)

TABLE 1: RISE TIMES

New Set Point	t_r
15	14
20	22
25	27
30	29
40	29
50	30
60	30
72	30

PROGRAMMING

The basic programming tools of the PLC logic are discrete and analog inputs and outputs, control relays, timers, counters, math special functions, and various bit and word manipulation functions. Most of the programming of this project was accomplished in math special functions. The ladder listing and special function listing are in Appendix A.

The basic operation of the system is to use a selector switch (X3, X4, X5, X6) to choose one of two pressure set-points (or one of two temperature set-points in the future.) Then using momentary push buttons (X7-up,X8-down,) the set point is incremented up or down by one percent. The value is displayed on an LED readout (Y17-Y24.) When the START button (X1) is pressed the value from the display is loaded into LSP1 (the PID algorithm's dedicated set-point address,) the loop is set to automatic mode, and the control relay (Y29) for the frequency drive is turned on. The set point may be changed at any time with no effect on the loop until the START button is pressed. Pressing the STOP button (X2) turns off the freq. drive relay and takes the PID loop out of automatic mode. The two lamps (Y26, Y28) are turned on and off by the control loop flag (C106) which shows the sign of the E in the loop. For example, if the system is stepped to 60 from a value of 20, the Error (set-point - process variable) will be positive until the process variable becomes greater than the set-point. This was handy for tuning, since one could see the system was settled when the two lights began blinking back and forth rapidly.

FUTURE WORK

Plans for future experimentation consist mainly of developing a temperature control loop, a better user interface, and perhaps implementing a fuzzy controller to replace the PID algorithm. All three of these will be totally software changes, as the temperature control hardware is already in place.

The most immediate of these projects will be the temperature control loop. It will be almost identical in structure to the pressure control loop except that the heating element (driven by a relay) is either off or on. There is no analog control of the heating hardware. Therefore a proportional time control scheme will be implemented, where the output from the PID will go to a math function which will calculate a duty cycle for the heating element. One of the issues to be resolved in this problem will be finding the optimum period of the off/on total cycle.

CONCLUSION

By holding the pressure to within 1.3% of the set point, PLC PID controller has proven its viability to an HVAC application. The ease with which the application engineer is able to assemble a working system highlights the flexibility and explains the popularity of the industrial programmable logic controller.

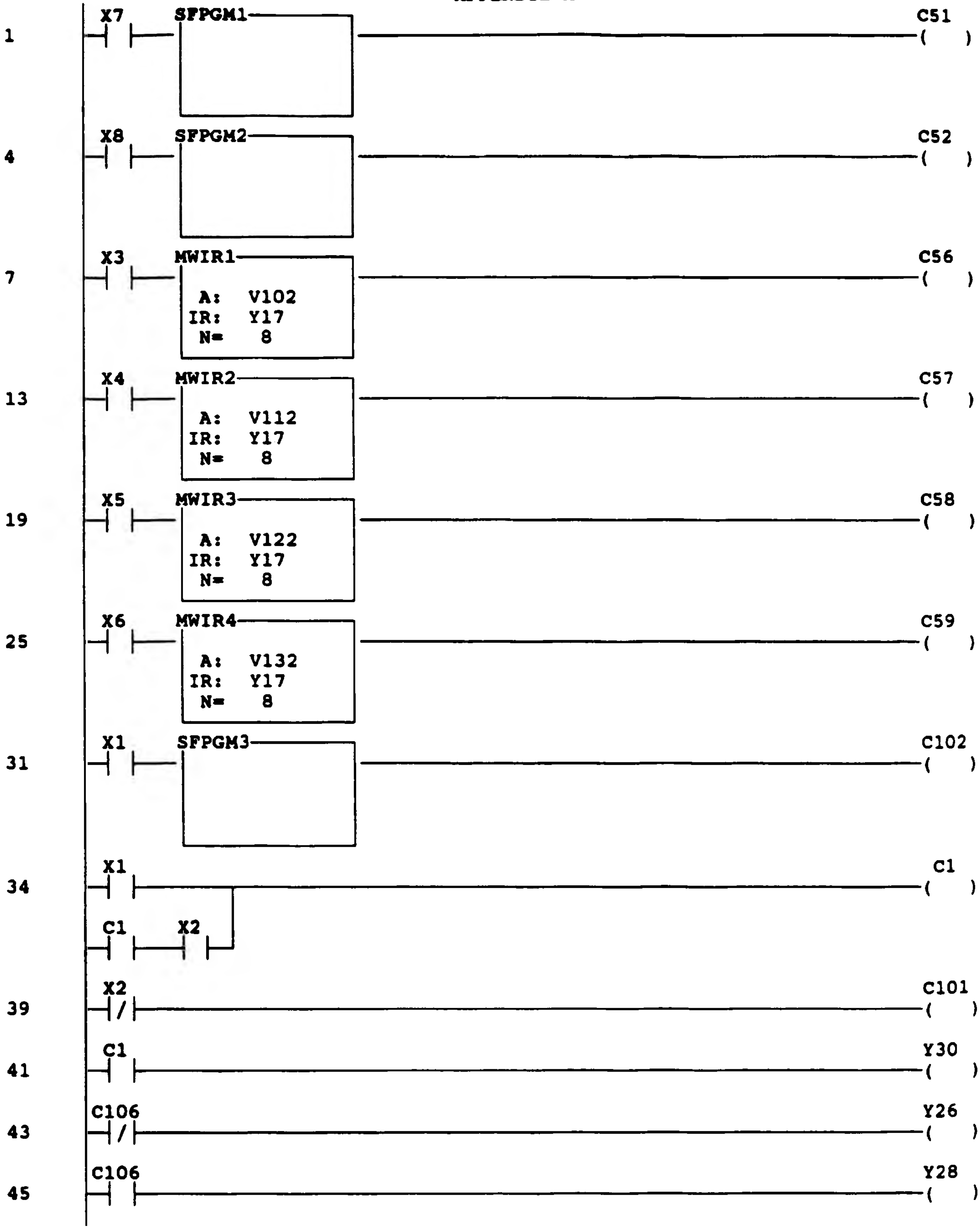
ACKNOWLEDGMENTS

I would like to thank those whose help has made this project possible:

Dr. Kelvin Erickson -- Faculty Advisor

Marvin "Eddie" Light and Donald "Frosty" Foster for building the platform

APPENDIX A


1 X7 SFPGM1 C51
4 X8 SFPGM2 C52
7 X3 MWIR1 A: V102 IR: Y17 N= 8 C56
13 X4 MWIR2 A: V112 IR: Y17 N= 8 C57
19 X5 MWIR3 A: V122 IR: Y17 N= 8 C58
25 X6 MWIR4 A: V132 IR: Y17 N= 8 C59
31 X1 SFPGM3 C102
34 X1 C1 X2 C1
39 X2 C101
41 C1 Y30
43 C106 Y26
45 C106 Y28

```
    PID LOOP   1  TITLE: PRESSURE

   POS/VEL PID ALGORITHM: POS
      LOOP VFLAG ADDRESS: C101
      SAMPLE RATE (SECS): +0.10000

PROCESS VARIABLE ADDRESS: WX49
          PV RANGE:  LOW = +20.0000
                    HIGH = +100.000

           PV IS BIPOLAR: NO
         SQUARE ROOT OF PV: NO
        20% OFFSET ON PV: YES

     LOOP OUTPUT ADDRESS: WY57
       OUTPUT IS BIPOLAR: NO
    20% OFFSET ON OUTPUT: NO

    RAMP/SOAK PROGRAMMED: NO
       RAMP/SOAK FOR SP: NO

         ALARM DEADBAND: +2.00000

   MONITOR LOW-LOW/HI-HI: NO
       MONITOR LOW/HIGH: NO
   PV ALARMS:    LOW-LOW = +41.0000
                     LOW = +45.0000
                    HIGH = +55.0000
               HIGH-HIGH = +59.0000
```

```
              REMOTE SETPOINT: NONE
     CLAMP SP LIMITS:  LOW = +20.0000
                      HIGH = +100.000

                    LOOP GAIN: +0.75000
      RESET (INTEGRAL TIME): +0.09000
     RATE (DERIVATIVE TIME): +0.00000
                  FREEZE BIAS: NO

   DERIVATIVE GAIN LIMITING: NO
      LIMITING COEFFICIENT: +10.0000

    SPECIAL CALCULATION ON: NONE
          SPECIAL FUNCTION: NONE

               LOCK SETPOINT: NO
            LOCK AUTO/MANUAL: NO
                LOCK CASCADE: NO

             ERROR OPERATION: NONE
              REVERSE ACTING: NO

           MONITOR DEVIATION: NO
   DEVIATION ALARM: YELLOW = +3.00000
                    ORANGE = +5.00000

     MONITOR RATE OF CHANGE: NO
       RATE OF CHANGE ALARM: +0.00000

     MONITOR BROKEN XMITTER: NO
```

```
TITLE: SETPT.UP                                                       SF PROGRAM     1
                    CONTINUE ON ERROR (Y,N): NO
                 ERROR STATUS ADDR (Y,C,WY,V): V50 - V52
                      PROGRAM TYPE (N,P,C,R): PRIORITY
                          CYCLE TIME (SEC): 0.0
--------------------------------------------------------------------------------------
00001 *         INCREMENTS HIGH TEMP SET-POINT WITH
                ACTIVATION OF UP/DOWN SWITCHES
00002 IF        X3
00003 MATH      V101 := V101 + 1
00004 ENDIF
00005 IF        V101 > 99
00006 MATH      V101 := 99
00007 ENDIF
00008 BINBCD     BINARY INPUT..: V101               BCD RESULT....: V102
00009 IF        X4
00010 MATH      V111 := V111 + 1
00011 ENDIF
00012 IF        V111 > 99
00013 MATH      V111 := 99
00014 ENDIF
00015 BINBCD     BINARY INPUT..: V111               BCD RESULT....: V112
00016 IF        X5
00017 MATH      V121 := V121 + 1
00018 ENDIF
00019 IF        V121 > 99
00020 MATH      V121 := 99
00021 ENDIF
00022 BINBCD     BINARY INPUT..: V121               BCD RESULT....: V122
00023 IF        X6
00024 MATH      V131 := V131 + 1
00025 ENDIF
00026 IF        V131 > 99
00027 MATH      V131 := 99
00028 ENDIF
00029 BINBCD     BINARY INPUT..: V131               BCD RESULT....: V132
****  END ****
```

```
TITLE: SETPT.DN                                                  SF PROGRAM     2
                    CONTINUE ON ERROR (Y,N): NO
                ERROR STATUS ADDR (Y,C,WY,V): V53 - V55
                     PROGRAM TYPE (N,P,C,R): PRIORITY
                          CYCLE TIME (SEC): 0.0
```

```
00001 *         INCREMENTS HIGH TEMP SET-POINT WITH
                ACTIVATION OF UP/DOWN SWITCHES
00002 IF        X3
00003 MATH      V101 := V101 - 1
00004 ENDIF
00005 IF        V101 < 10
00006 MATH      V101 := 10
00007 ENDIF
00008 BINBCD     BINARY INPUT..: V101             BCD RESULT....: V102
00009 IF        X4
00010 MATH      V111 := V111 - 1
00011 ENDIF
00012 IF        V111 < 10
00013 MATH      V111 := 10
00014 ENDIF
00015 BINBCD     BINARY INPUT..: V111             BCD RESULT....: V112
00016 IF        X5
00017 MATH      V121 := V121 - 1
00018 ENDIF
00019 IF        V121 < 10
00020 MATH      V121 := 10
00021 ENDIF
00022 BINBCD     BINARY INPUT..: V121             BCD RESULT....: V122
00023 IF        X6
00024 MATH      V131 := V131 - 1
00025 ENDIF
00026 IF        V131 < 10
00027 MATH      V131 := 10
00028 ENDIF
00029 BINBCD     BINARY INPUT..: V131             BCD RESULT....: V132
****  END ****
```

```
TITLE: LOOPS.ON                                                         SF PROGRAM      3
                        CONTINUE ON ERROR (Y,N): NO
                   ERROR STATUS ADDR (Y,C,WY,V): V56 - V58
                        PROGRAM TYPE (N,P,C,R): PRIORITY
                             CYCLE TIME (SEC): 0.0
```

```
00001 *         SETS LOOPS' REMOTE SET-POINTS TO THE
                VALUES CORRESPONDING TO POSITION OF THE
                ROTARY SWITCH
00002 IF        X3
00003 MATH      V210 := V101
00004 ENDIF
00005 IF        X4
00006 MATH      V210 := V111
00007 ENDIF
00008 IF        X5
00009 UNSCALE    SCALED INPUT..: V121             BINARY RESULT.: LSP1
                 LOW LIMIT.....: 0.0              HIGH LIMIT....: 100.0
                 20% OFFSET....: NO               BIPOLAR.......: NO
00010 ENDIF
00011 IF        X6
00012 UNSCALE    SCALED INPUT..: V131             BINARY RESULT.: LSP1
                 LOW LIMIT.....: 0.0              HIGH LIMIT....: 100.0
                 20% OFFSET....: NO               BIPOLAR.......: NO
00013 ENDIF
****  END ****
```