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# MICROCOMPUTER IMPLEMENTATION OF PROPORTIONAL-INTEGRAL-DERIVATIVE (PID) TEMPERATURE CONTROLLER FOR AN ELECTRIC KETTLE

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## ABSTRACT

This paper presents a practical implementation of a microcomputer based temperature controller for an electric kettle. The controller is built around AT89S52 microcontroller. A custom electric kettle was constructed on which an open-loop experiment was carried out to obtain its transfer function model. PID control algorithm was then developed as compensator for the system.A printed circuit board was itched, on which the circuit was soldered. assembled and tested. The PID gains (1161, 1210, and 1 respectively) developed from the open-loop ultimate gain method made the system highly unstable. Accordingly, the gains were tuned by trial and error. PID gains of 172.58, 0.0053 and 6.29 respectively were obtained. The responses of the closed-loop system these gains show rise time of 86.30s, settling time of 526s. Over the temperature set points measured, the controller demonstrated an overall steady-state error of 2.02%.

***Keywords***: *Microcontroller, Temperature, PID, Closed-loop, Response, Gain*

## I. INTRODUCTION

Few devices at home and industries have control systems more than that which is related to temperature. Thus from simple domestic appliances like pressing iron to complex industrial processes, there is one form of temperature control or the other [1-2]. When temperature is critical, its loss of control results in catastrophic failure with attendant damage and loss of life.

Before the advent of microcomputers, most of the Proportional-Integral-Derivative (PID) temperature controllers were of the analog type. Their implementation entails the use of operational amplifiers or comparators. For many applications, the analog PID controllers havedemonstrated fast response characteristics, low overshoot and minimal steady-state gain [3]. The down part of such controllers is the impossibility of changing the controller parameters at an instance except through jumpers using capacitors and resistors.

Advances in electronics have greatly enhanced temperature control by corresponding development of digital electronics. Considerable number of scholars describes these contributions, many of which have been motivated by availability of the ubiquitous large scale digital computer and the more recent microcontrollers [4-8]. These works have shown considerable improvement in terms of efficiency and accuracy of temperature control. It is even argued that temperature control is no longer a challenging problem in many applications [9]. However, significant number of devices at home and in industries still utilize simple on-off control algorithm.Key among these vital domestic appliances is the electric kettle. Though relatively cheap, their inaccuracyin temperature control such as large overshoot and cycling constitutes a serious drawback in contemporary energy economy and hence elicits further studies.

The main thrust of this paper is to describe a microcomputer based temperature controller implemented on an electric kettle using Proportional-Integral-Derivative (PID) control algorithm.It is built around the AT89S52

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microcontroller. The design requirement is that the system should be stable, have low overshoot, fast response and zero steady-state error.

## II. METHOD AND MATERIAL

The first step in this study was to build a physical model of the plant (electric kettle). This was necessary so as to derive the mathematical model of its thermal system. The open-loop reaction curve was obtained using MATLAB. A schematic of the circuit is then drawn using Eagle 4.12 light edition. PID algorithm is then developed according to the instruction sets of the Atmel 89S52 microcontroller. A custom printed circuit board (PCB) was also designed and etched on a copper board. The system was then assembled and tested. The PID gains were tuned while the response of the system as measured was recorded against the values of the desired set points as shown in Table 1.

*Process Modeland Control Algorithm*

A custom electric kettle (plant) was constructed with sheet metals. Asensor (thermistor) and an immersion heater were fixed inside it. The cylindrical kettle was lagged to minimize energy loss from the kettle to the environment. It was also coated with Aluminum paint to minimize corrosion. A simple open-loop response experiment was carried out on the reactor by switching on the heater while the temperature of the water inside was measured and recorded with a digital multi-meter (MAS-345) connected to a laptop computer. This was necessary so as to determine the open-loop response characteristics of the plant. Equation (1) implies that this is a first order system.

$$F(s) = \frac{K}{\tau s + 1} \qquad (1)$$

where:

$\tau = R_T C_T$ : Time constant of the process

$K = R_T$ : Steady-state or static gain

$s$ = frequency.

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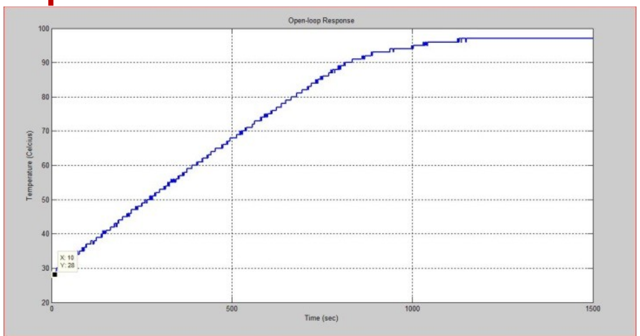


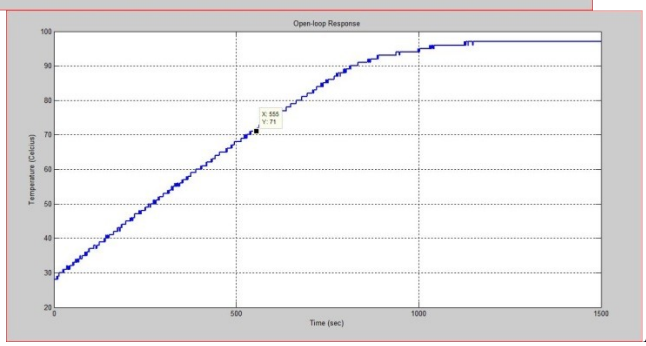


***Figure 1: Open-loop reaction curve (dead time)***

***Figure 2: Open-loop reaction curve (time constant)***

The time constant, τ, of the process is a measure of the time necessary for the process to adjust to a change in its input. The value of the response reaches 63.2% of its final value when the time elapsed equals 1τ. From the experimental results in Figures 1 and 2, dead time,

$t_d = 10s.$

Step-input (power input to the plant) $\approx 1181W$;

Steady-state change in output = $97^oC - 28^oC = 69^oC$;

Process gain,

$$K = \frac{69^OC}{1181W} = 0.058^oC/W \approx 0.06$$

The temperature corresponding to the time constant of the process is, thus:

$$63.21\% \times (97-28)^oC + 28^oC = 71^oC$$

from which (Figure 2),

$\tau = 555s$

Since the response of the process is not instantaneous, the system will have a dead time. It follows that [10-11]:

$$G(s) = \frac{Ke^{-st_d}}{\tau s + 1} \qquad (2)$$

Thus, equation (1) becomes,

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$$G(s)=\frac{0.06e^{-10s}}{555s+1} \tag{3}$$

The overall control of the process is substantially improved by using a correcting signal whose value, and hence the control action has been determined by a Proportional-Integral-Derivative (PID) control algorithm. This three term control is given as [9],

$$U(t)=K_p e(t)+K_i\int e(t)dt+K_d\frac{de(t)}{dt}=K_p\left(e(t)+\frac{k_i}{k_p}\int e(t)dt+K_d\frac{de(t)}{dt}\right)$$

$$U(t)=K_P\left(e(t)+\frac{1}{T_I}\int e(t)dt+T_d\frac{de(t)}{dt}\right) \tag{4}$$

where U(t) is the manipulated variable.
To implement equqtion(4) on a microcomputer for the nth sample, it is first represented in descrete form:

$$U_n=K_p\left[e_n+\frac{1}{T_I}\sum_{i=1}^{n}e_i t_s+T_d\frac{(e_n-e_{n-1})}{t_s}\right] \tag{5}$$

Equation (5) is called position algorithm. This implies that all the values of the errors on the RHS at all instances of time have to be stored by the microcomputer; a better option is to employ the velocity algorithm [12].
For (n-1)th sample,

$$U_{n-1}=K_p\left[e_{n-1}+\frac{t_s}{T_I}\sum_{i=1}^{n-1}e_i+\frac{T_d}{t_s}(e_{n-1}-e_{n-2})\right] \tag{6}$$

Subtracting (6) from (5),

$$U_n-U_{n-1}=K_p\left[(e_n-e_{n-1})+\frac{t_s}{T_I}e_n+\frac{T_d}{t_s}(e_n-2e_{n-1}+e_{n-2})\right]$$

$$=K_p\left[\left(1+\frac{t_s}{T_I}+\frac{T_d}{t_s}\right)e_n-\left(1+2\frac{T_d}{t_s}\right)e_{n-1}+\frac{T_d}{t_s}e_{n-2}\right]$$

$$=K_P\left(1+\frac{t_s}{T_I}+\frac{T_d}{t_s}\right)e_n-K_p\left(1+2\frac{T_d}{t_s}\right)e_{n-1}+K_P\frac{T_d}{t_s}e_{n-2}$$

$$\therefore U_n-U_{n-1}=A_o e_n-A_1 e_{n-1}+A_2 e_{n-2} \tag{7}$$

To determine the control action after the nth sample,

$$U_n=U_{n-1}+A_o e_n-A_1 e_{n-1}+A_2 e_{n-2} \tag{8}$$

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Microcontroller

Triac and its Firing Circuit

The PID gains were tuned using the Ziegler and Nichols ultimate gain method as[13]

$$K_p = \frac{1.2\tau}{Kt_d} = \frac{1.2 \times 555}{0.06 \times 10} = 1161$$

$$K_i = \frac{1}{2t_d} = \frac{1}{2 \times 10} = 0.05$$

$$K_d = 0.5t_d = 0.5 \times 10 = 5$$

Heater

$$T_I = \frac{K_p}{K_i} \qquad T_d = \frac{K_d}{K_p}$$

But and

$$A_o = K_p\left(1 + \frac{t_s}{T_I} + \frac{T_d}{t_s}\right) \approx 1161$$

$$A_1 = K_p\left(1 + 2\frac{T_d}{t_s}\right) \approx 1210$$

$$A_2 = K_P \frac{T_d}{t_s} = 0.5 \approx 1$$

Keypads

A/D Converter

$$U_n = U_{n-1} + 1161\, e_n - 1210\, e_{n-1} + e_{n-2}$$

and in Hexadecimal,

$$U_n = U_{n-1} + 489\, e_n - 4BAe_{n-1} + e_{n-2} \qquad (9)$$

Equation (9) is the PID velocity algorithm in hexadecimal form. The advantage of this algorithm is that the microcomputer need only store three previous values of the change in errors, $e_n$, $e_{n-1}$, and $e_{n-2}$.A microcomputer with its peripherals was designed for the implementation of the controller.

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*Power Supply and Microcontroller*

The system power requirement is 3.5 A. It was estimated by summing the current requirement of all the components of the circuit. However, a 5.0 A, 15 V transformer was used instead. An LM338 was then used to regulate the rectified voltage to supply the system with nominal 5 V.

The microcontroller is a computer on a single chip. The AT89S52 used in this work is an Atmel 40-pin chip designed in Harvard architecture which is compatible with the ubiquitous Intel 8051 processor. Its classic application namely simple sensor interfacing, keypad reading, display and closed-loop control were incorporated in this work. External devices to the microcontroller are analog/digital converter (ADC0804), keyboard controller (Intel* 8279), TRIAC (MOC3022) and alarm circuits. The block diagram is shown in Figure 3.

*Signal Conditioning and Analog/Digital Conversion*

The thermistor (NTP-15WB333 NTC) is the temperature sensor used for this work. It was connected in voltage divider configuration. Its voltage/temperature sensitivity was experimentally determined by measuring the changes across the voltage divider and the corresponding change in temperature using MAS-35 digital multi-meter. This was necessary so as to guide on the design of the signal conditioning circuit and its interface to the A/D converter. The voltage signal across the sensor was adequate to drive the inputs of the ADC0804. The A/D converter input voltage was adjusted through the variable resistor in the voltage divider circuit from the reference voltage output of the chip. A voltage reference of 5.0 V which corresponding digital number is $255_D$was kept. It was supplied to drive the data inputs of the microcontroller.

*Keyboard/control and Display/drivers*

The keyboard was designed to enable entries to be made to the microcontroller. The Intel* 8279 is a general purpose programmable keyboard and display I/O interface device. The keyboard ports were interfaced to 8×2, 16−contact key matrix (OSRAM switches). It was designed to operate on scanned keyboard, right entry mode and 8−character multiplexed display. The microcontroller decodes the keyboard entries from the keypads scan and return lines through a built-in look-up table. Since this is a digital system, it was necessary to build a digital display. The display was built for set point and actual temperatures using 7-segment LED displays driven by a 3-8 line decoder (74LS138). The decoder was interfaced to the microcontroller through the 8279 keyboard controller.

*TRIAC and its firing Circuit*

MOC3022 was used as the opto-coupler. It serves as a trigger device only. The hot side of the line is switched ON while the load is connected to the cold or ground side. Through this circuit, pulse width modulated signal from the microcontroller supplies appropriate excitation to the heater. TRIAC (T410−600B) was used to switch this high current excitation according to the command signal from the microcontroller. Its period is kept constant except for the width which is varied in accordance with the power requirement of the plant by the source code ADC0804.

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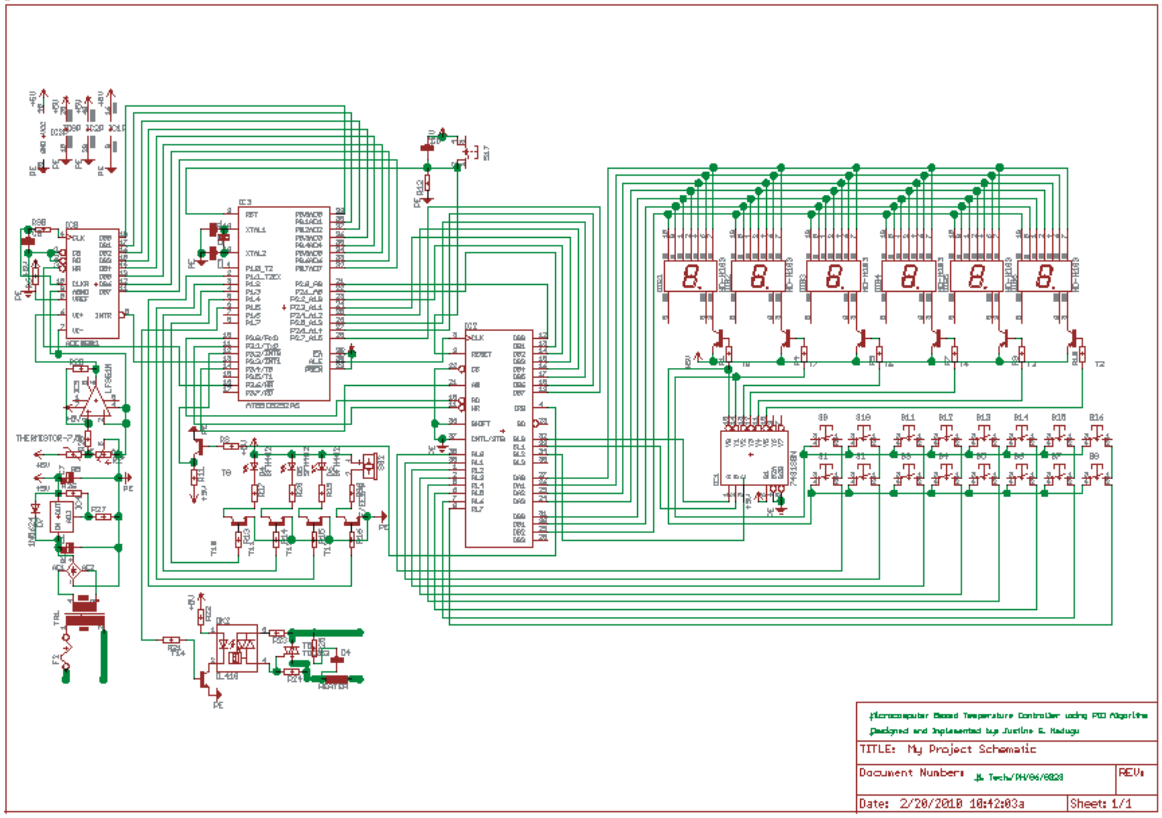


*Figure 4: Circuit Schematics*

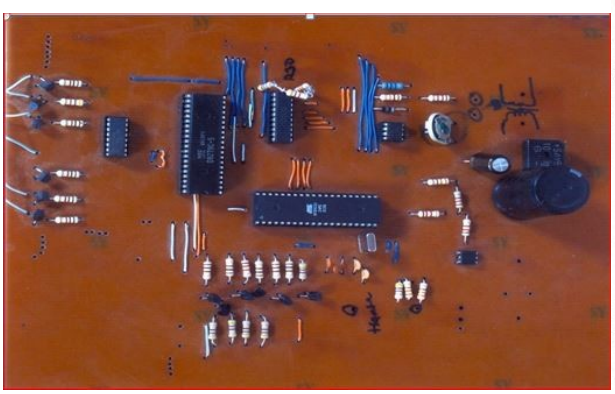

*Figure 5: Main Circuit Board of the system*

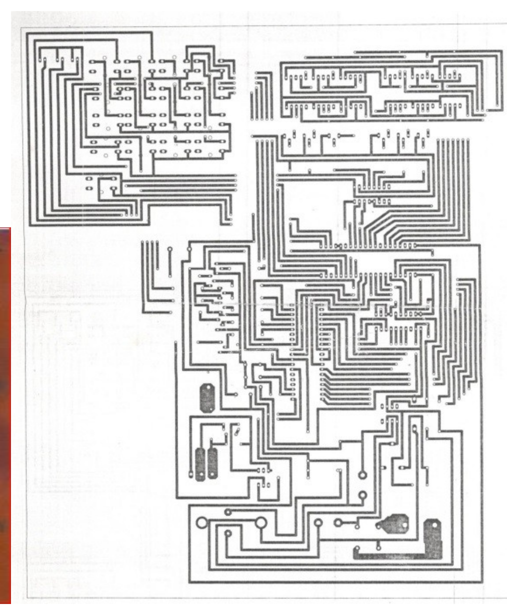

*Figure 5: Printed Circuit Board of the system*

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## III. SOFTWARE DESCRIPTION

The software required for the execution of the PID algorithm in equation (9) was written using the instruction sets of the AT89S52. It is an 256 by 8-bit, 8K bytes ISK flash memory chip. The program was initially debugged using

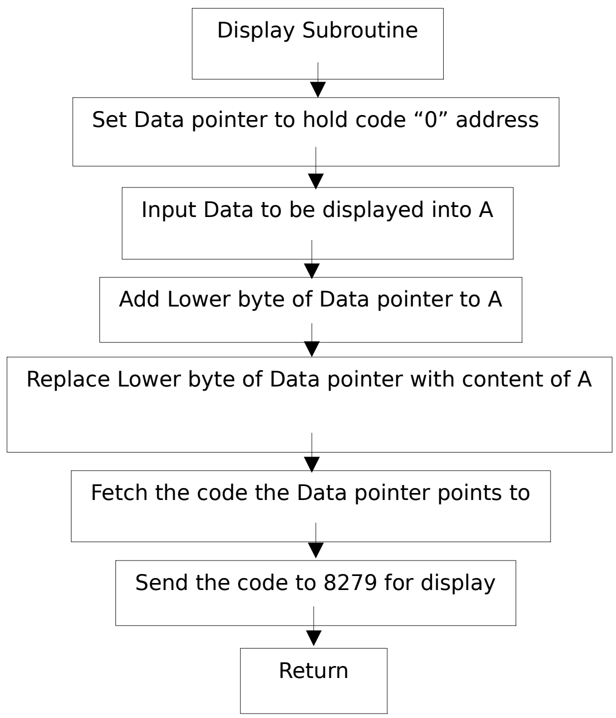


***Figure 6: Display Subroutine flowchart***

Reads51 debugger software. This program was then burned into the microcontroller by a hand-held programmer (topWin). Two of the flowcharts from which the instruction for the execution of the algorithm was written are shown in Figure 6 and Figure 7.

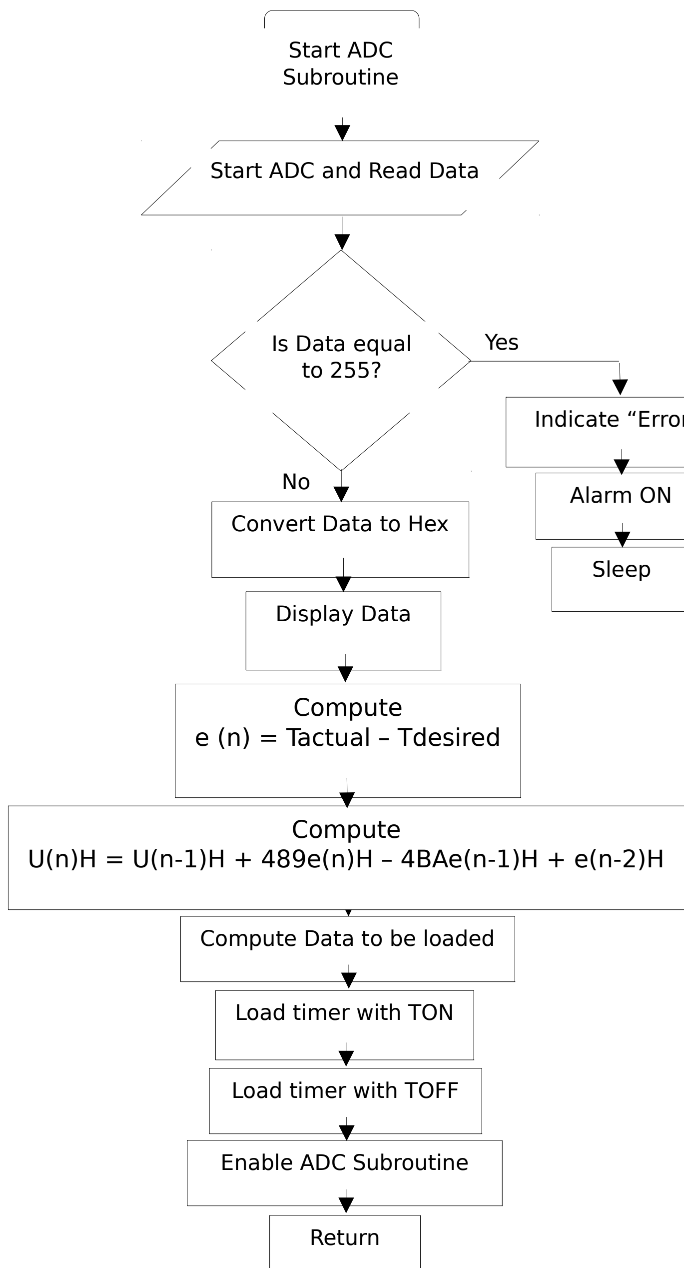


*Figure 7: ADC Subroutine Flowchart*

## IV. RESULT & DISCUSSION

| S/No. | Set-point Temperature (ºC) | Steady-state Temperature (ºC) | Steady-state Error (%) |
|---|---|---|---|
| 1 | 30 | 31 | 3.33 |
| 2 | 40 | 42 | 5.00 |
| 3 | 50 | 51 | 2.00 |
| 4 | 60 | 60 | 0.00 |
| 5 | 70 | 71 | 1.43 |
| 6 | 80 | 81 | 1.25 |
| 7 | 90 | 91 | 1.11 |
| | | Total | 14.12 |
| | | Mean error | 2.02 |

The design requirements imposed on the microcomputer system is that it should be stable, have low overshoot, fast response and zero steady-state error. The temperature control capability of the system was investigated. Temperature ranges from 30ºC to 90ºC were set and compared with the measured steady state values as shown in Table 1. The mean steady state error of the system was 2.02%. There are some probable sources of this error. The first one could be due to the conversion efficiency of the ADC. This arises from quantization error in analog-to-digital conversion of the measured temperature. Moreover, the non-linear response of the thermistor could also affect the results since the voltage/temperaturecharacteristics of the sensor is non-linear. Another source of error could be due ambient conditions. Due to inadequate lagging there could beinteraction between the system and the environment thereby causing deviation between the actual and the set point temperatures.

***Table 1: Steady-state response of the system***

## V. CONCLUSION

The results in Table 1 show that the design specification for the system was met. While some analog systems could significantly reduce this 2.02% error or even eliminate it due to its ability to provide smooth excitation to the plant, this represents a good trade-off when compared to the ease with which the microcomputer based system or control parameters could be made without necessarily changing the hardware.

## VI. ACKNOWLEDGEMENTS

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