IJREAT International Journal of Research in Engineering & Advanced Technology, Volume 4, Issue 2, April - May, 2016
ISSN: 2320 – 8791 (Impact Factor: 2.317)
www.ijreat.org

Proportional Temperature Control For Food Grade Rotary Roaster Furnace Using RF Transceiver

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ABSTRACT

The paper presents the explanatory implementation of the Proportional Temperature Controller developed for food grade rotary type roasters used mainly in industries engrossed in manufacturing rice based food products. The design proposed here mainly aims to replace the conventional Analog Temperature Meter and to automate the manual process of AC voltage regulation. It is to be noted that the regulated AC voltage controls the vibrator speed supplying the fuel to the Roaster furnace. The concept presented here replaces the analog temperature meter by temperature measurement through temperature sensor, microcontroller and analog to digital converter. Moreover the Temperature measured here is communicated to another circuit regulating the AC voltage using RF transceivers. The basic simulation prior to the implementation and programming for the circuit has been performed in Proteus ISIS 7 Professional Software and Arduino Platform v 1.0.6 respectively. The microcontroller Atmega328 is boot loaded with Arduino boot load. The accuracy of the system had been tested by the practical implementation of the circuit. The graph based on the actual readings is presented in the paper.

General Terms: Temperature, Vibrator, Speed, Roaster, Puffed Rice.

Keywords: Microcontrollers, Pulse Width Modulation (PWM), Temperature Sensor, Duty Cycle, RF transceivers, Liquid Crystal Display (LCD), Single Stage or First order RC filter

1. INTRODUCTION

Advancement in technology has introduced advanced microcontrollers and it is getting more and more sophisticated and intelligible [1, 3]. Today as the manual process is getting costly and as they are inaccurate, the microcontroller based systems are automating this process with efficiency and lower operating cost. Microcontrollers acts as the brain of the system [1]. A microcontroller is a single chip integrated circuit containing a processor, memory and programmable input/output peripherals [1-3, 8]. Today every modern device includes the microcontroller for their efficient operation and satisfy the modern day needs [1]. The block diagram of the microcontroller system is shown in Fig. 1.

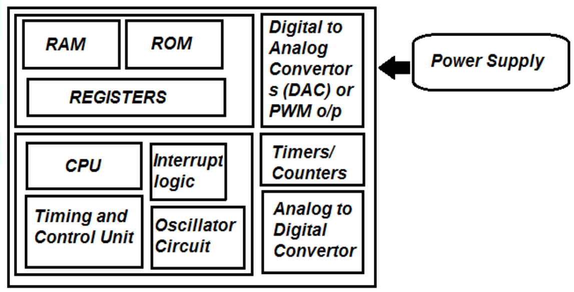

Fig. 1. General Microcontroller Block Diagram

The design here is for the proportional temperature control of the sand used in the production of puffed rice and other rice based products in rotary roasters. The furnace underneath this roaster heats the circulating sand in the roaster and proper temperature control of this sand produces the good taste and quality products. The design discussed here measures the temperature of the sand using Resistance Temperature Detector (RTD) which is a temperature sensor, MCP3551 Analog to Digital Convertor (ADC) and Atmega328 microcontroller. The temperature measured is then transmitted using nRF24L01 RF transceivers operating at 2.4 GHz (ISM band). The temperature value is received by the nRF24L01 module at receiver circuit and provides acknowledgement to transmitting circuit [2]. The Atmega328 microcontroller at receiving section displays the temperature on LCD and also generates the PWM frequency of the duty cycles based on the mapping between temperature and PWM signal's duty cycle in programming. These PWM signals producing 5V pulsating voltage signals passes through first order RC filter and generates average voltage at output depending on the duty cycle of PWM signals at input. This voltage finally controls the firing angle of the Silicon Controlled

Rectifier (SCR) by controlling the RC constant of capacitor connected to the gate of SCR and produces regulated AC Voltage [7]. This AC voltage is applied to the vibrator whose vibration speed controls the rate of flow of powdered charcoal to the furnace. The design proposed here also comprises of 4x3 keypad so as to enter the temperature to be maintained for the sand in the roaster.

2. PULSE WIDTH MODULATION

Pulse Width Modulation is a modulation technique in which the width of the periodic pulse sequence is varied according to the amplitude of the signal for encoding the amplitude of a signal right into a pulse width or duration of another signal. A duty cycle is the percentage of one period in which a signal is active. A period is the time it takes for a signal to complete an on-and-off cycle. Based on the temperature received at receiving nRF24L01 end the microcontroller varies the duty cycle of the PWM wave. The PWM wave generated by microcontroller is the high frequency square pulses with maximum amplitude corresponding to 5V and minimum to 0V. This signal then passes through first order RC filter as shown in Fig. 7. The PWM signals for different temperature ranges generated by microcontroller are shown in Fig. 2.

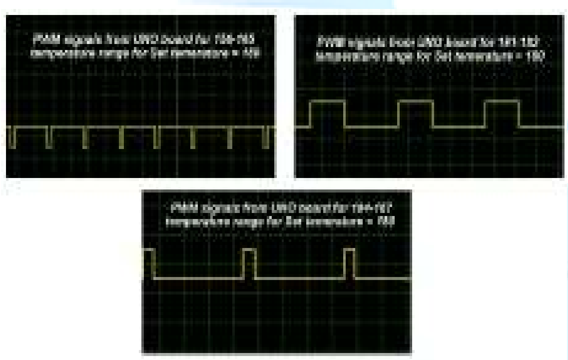

Fig. 2 PWM Signals of duty cycles controlled by microcontroller according to temperature range.

3. ROASTER PLANT

Fig. 3 shows the diagram of roaster plant where central part is the rotary type and the sand circulates in it containing the polished paddy or rice beans. The optimum temperature of the sand converts these beans to puffed rice. The temperature requirement varies from 160 to 250°C depending on the weather, raw material quality and humidity conditions. So to maintain the temperature the charcoal powder, which acts as a fuel is supplied to the furnace through a vibrator by controlled vibrating speed at the right end of the Fig. 3. The user of the system can enter the temperature to be maintained using a 4x3 keypad interfaced with microcontroller at the receiver end.

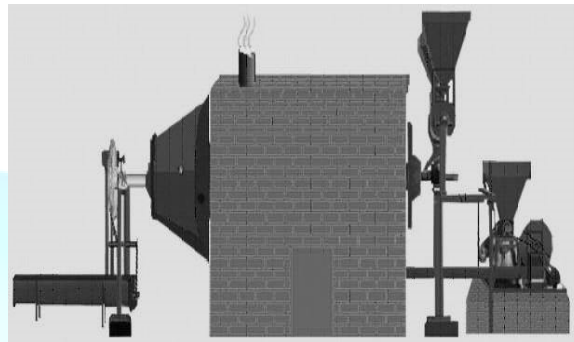

Fig. 3 Roaster Plant

4. BLOCK DIAGRAM OF TRANSMITTER

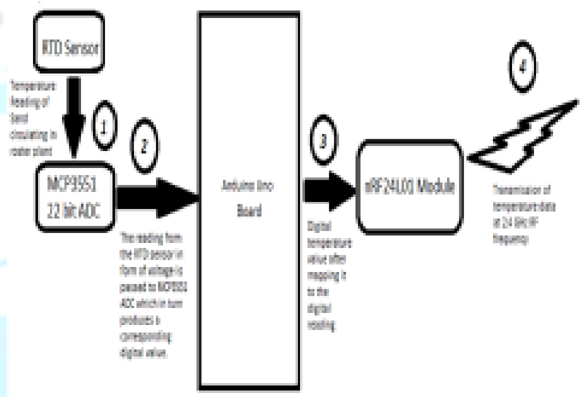

Fig. 4 Block Diagram of Transmitter

The block diagram of the Transmitter section of the circuit is shown which consists of the 3 major portions excluding Arduino Uno board [4] as follows:

1. Arduino Based Uno Board:

Arduino is an open-source prototyping platform based on easy-to-use hardware and software. Arduino boards are able to read inputs - light on a sensor, a finger on a button, or a Twitter message - and turn it into an output - activating a motor, turning on an LED, publishing something online [4]. The Arduino based Uno is a microcontroller board based on the ATmega328P [4]. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button [4].

2. RTD Temperature Sensor:

An RTD (resistance temperature detector) is a temperature sensor and PT100 is the model of RTD used here. It is made up of platinum, nickel or copper as major constituents and the resistance of all these material increases with increase in temperature. Measurement principle is to measure a change of resistance value by applying electric current to an RTD element. (0.5mA to 2mA).

3. MCP3551 ADC:

MCP3551 is a low power and low noise single channel 22 bit Analog to Digital Convertor (ADC) with automatic internal offset and gain calibration from Microchip. The RTD is interfaced with it to convert the analog voltage to digital byte code which finally is interfaced with Arduino Uno Board. The real temperature versus byte codes graph is shown in Fig. 5. The byte code received by the Microcontroller is mapped to temperature by the equation as in Eq. (1).

$$\text{Temperature} = (\text{byte code value} - 7673)/27.788 \quad (1)$$

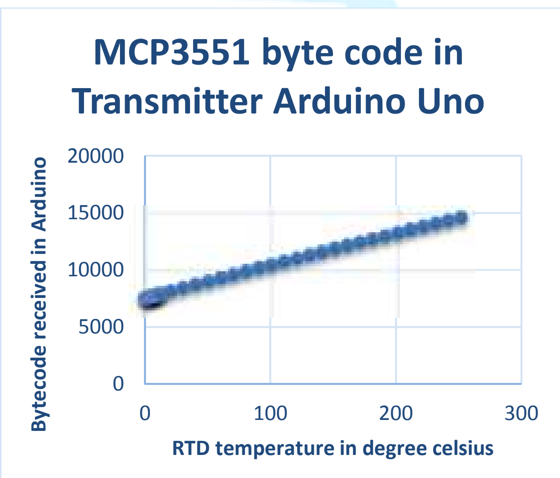

Fig. 5 Graph of byte code versus Real RTD temperature in simulation.

4. nRF24L01 module:

nRF24L01 is a low power 2Mbps RF transceiver for the 2.4GHz ISM (Industrial, Scientific and Medical) band [2.9]. Each of this modules are present at both transmitting and receiving section which mainly deals with high speed and reliable data transmission between both circuits with low loss in data packets. The temperature value mapped by the transmitting side microcontroller is send to receiver microcontroller by these modules, eliminating the requirement of wired medium between rotary roaster part containing sand and static positioned receiver circuit interfaced with vibrator.

5. BLOCK DIAGRAM OF RECEIVER

As soon as the receiver starts it configures the nRF24L01 module and reads 3 digit temperature value at which user desires to set the temperature of sand in the Roaster central section under the furnace known as Set Temperature **(T_{st})**. Then in the receiver the nRF24L01 receives the transmitted temperature value from transmitter and passes data to Arduino Uno board at receiving section through SPI which is called the Received Temperature **(T_{rt}).** The error is calculated by the Eq. (2) and is mapped to corresponding PWM duty cycle. This PWM output passes through single stage RC filter as shown in the Fig. 7 and average DC voltage is produced which is then applied to AC regulator which finally controls the vibration rate of Vibrator. As a result fuel supply is maintained according to the error value in Eq. (2). Thus the proportional control of the sand's temperature is achieved.

1. 16x2 LCD display:

LCD (Liquid Crystal Display) screen is an electronic display module which are economical; easily programmable; have no limitation of displaying special and even custom characters (unlike in seven segments), animations and so on. The 16x2 means LCD can display 2 rows containing maximum of 16 characters. As soon as circuit start the LCD displays the text to prompt the user to enter the Set temperature (Tst) value. Then the Received Temperature (Trt) is continuously updated in it on reception of it through transmitter module.

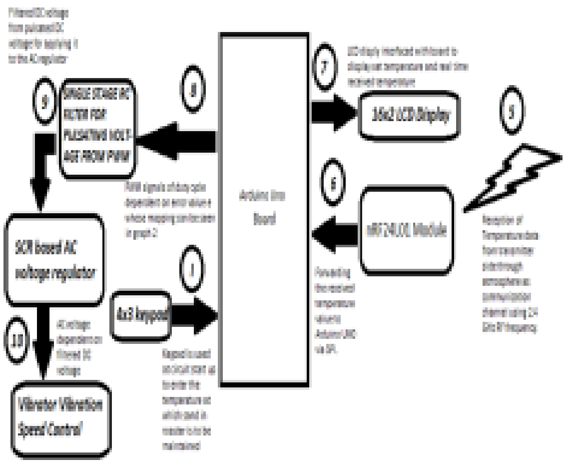

Fig. 6 Block Diagram of Receiver Module

$$\text{Error (e)} = (T_{st} - T_{rt}) \quad (2)$$

2. 4x3 Keypad:

Basically, the 4x3 keypad contains push buttons that are arranged in four rows and three columns and produce twelve characters. It is also known as "4x3 switch matrix" due to the arrangement of switches in a matrix form. The internal construction of these keypads includes metal dome contacts and conductive rubber. At the initial stage it is used to enter 3 digit temperature value for Set Temperature (Tst).

3. Single Stage or First Order RC filter:

A resistor–capacitor circuit (RC circuit), or RC filter or RC network, is an electric circuit composed of resistors and capacitors driven by a voltage or current source. A first order RC circuit is composed of one resistor and one capacitor and is the simplest type of RC circuit. The 5V PWM output signal is applied at V_{in} in the RC filter and filtered non pulsated output voltage is generated at V_{out} as shown in the Fig. 7.

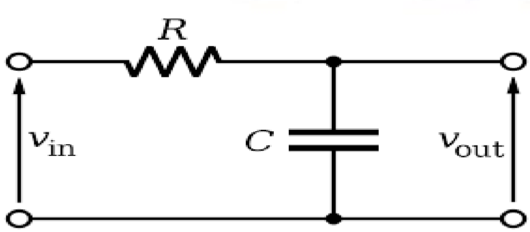

Fig. 7 Single Stage or First Order RC filter

SCR based AC voltage regulator:

SCR (Silicon Controlled Rectifier) is used to control the firing angle of the AC voltage wave.Firing angle is the phase angle of the voltage at which the SCR turns on. Thus AC voltage is regulated at the output by applying filtered DC voltage from RC filter at input. The DC voltage controls the charging and discharging rate of the RC circuit at the gate of the SCR which in turn controls the firing angle and thus the output AC voltage is regulated.

4. Vibrator:

Vibrator is a part of Roaster plant and it can be seen at the right hand side of the Fig. 3. The vibration rate of the vibrator is controlled by the regulated AC voltage output from SCR based AC regulator. The regulated AC voltage controls the quantity of fuel supplied to the furnace which heats the sand circulating in the central portion of the roaster. Thus the temperature of the sand is controlled by proportional control strategy.

The Error (e) from Eq. (2) versus the Voltage (Both filtered DC voltage and AC voltage) is shown in chart in Fig. 8.

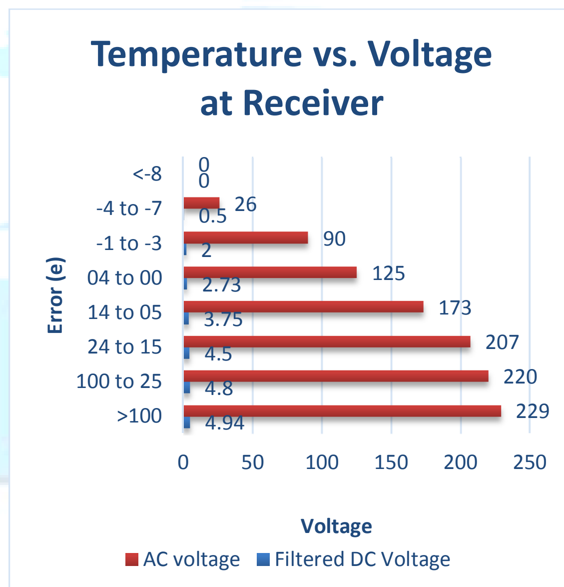

Fig. 8 Chart of Error vs. Voltage

6. ALGORITM FOR TRANSMITTER AND RECEIVER SECTION

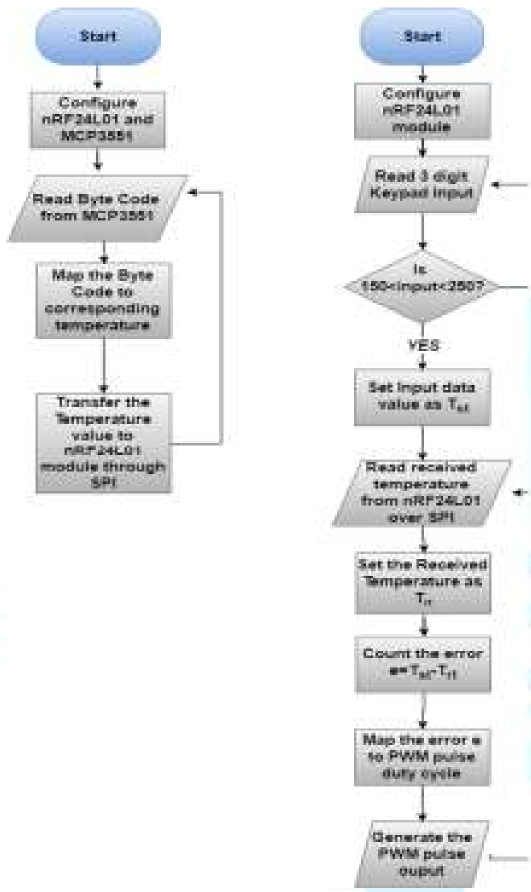

Fig. 9 Transmitter flow chart on left hand side and Receiver flow chart on right hand side

The algorithm in the form of flow chart for Transmitter and Receiver section is shown in the Fig. 9 [5].

7. RESULT

The quantity of powdered fuel entering the roaster is controlled by the vibration rate of the vibrator which is ultimately controlled by the receiver microcontroller. The Transmitter sends the temperature of the sand sensed by the RTD from the transmitter to receiver. Thus Temperature of the sand or received temperature (T_{rt}) sensed by RTD and set temperature (T_{st}) are compared and AC voltage is accordingly regulated. The chart in Fig. 8 shows the error vs. voltage readings obtained during real time testing after implementation. Thus in Fig. 8 we can clearly observe the variation in AC voltages with error resulted from Eq. (2).

8. CONCLUSION

The design here automates the Roaster plant temperature control system and no human intervene is required during the operation.

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