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ELECTRONIC TEMPERATURE CONTROLLER FOR INDUSTRIAL APPLICATIONS

BY

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Abstract. This paper presents an automatic temperature regulator which allows maintaining a constant temperature in an industrial enclosure. The temperature of the enclosure is measured with a resistive sensor placed in one of the arms of a perfectly balanced resistive bridge. The low voltage value is inserted in the instrumentation amplifier whose output is a measurement signal. The output element is a triac which supplies a lamp bulb (simulates a heating resistance load) at a voltage of 220 VAC. The triac control pulses is synchronous with the zero crossing of the supply voltage. This controller would be very useful to measure and adjust the temperature in the domain of industrial applications.

Key words: analogic temperature control; thermostatic enclosure.

1. Introduction

The daily activities requires knowledge of several important parameters for making decisions about the evolution of physical, chemical, electrical processes that are present in the activity.

Temperature is one of the most important parameters measured and controlled in a process, regardless of its nature (physical, chemical etc.). If the temperature value is measured then the evolution of an industrial process or the state of a heating system can be known. At the same time, if some

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predetermined temperature limits are exceeded, some conclusions can be drawn regarding the process, a situation of failure etc.

To control the temperature of a process, an automatic setting is made. By automatic adjustment is meant the set of operations performed in a closed or open loop. The aim of these operations is to maintain the temperature at a constant value or within a given range (Liu, 2010).

The automatic character of the control is given by the fact that there is no direct intervention of the human factor in the control cycle; by this, the temperature is automatically maintained at a preset value.

In the paper there is presented an electronic temperature controller which allows analog accurate temperature measurement and switching on / off of a consumer (electrical resistance, light bulb etc.) if the measured value of the temperature is lower or higher than a prescribed value.

2. Block Diagram of the Temperature Controller

As seen in Fig. 1, the controller consists of the following functional blocks: temperature measurement block (TMB), temperature setting block (TSB), comparison block (CB), command synchronization block (CSB) and output block (OB). Below are some information that describes these blocks.

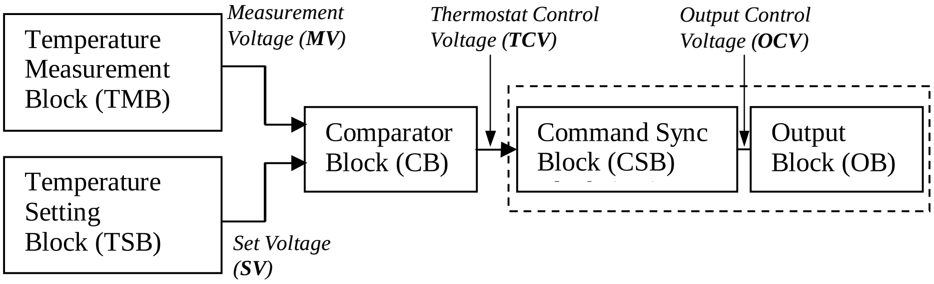


Fig. 1 – The block diagram of the temperature controller.

The first input element of the controller is ***Temperature Measurement Block*** (**TMB**). It is designed around the DC Wheatstone Bridge working in unbalanced mode. This bridge is used where small changes in resistance are to be measured like in sensor applications. This is used to convert a resistance change to a voltage change of a transducer (Țățulescu, 1997).

This bridge is used to convert a resistance change of resistive temperature detectors PT100 to a voltage; to perform this function, we used the combination of this bridge with operational amplifier (OpAmp). The signal output from operational amplifier is *Measurement Voltage* (**MV**) and is proportional to the measured temperature.

Another functional element of the controller is ***Temperature Setting Block*** (**TSB**). It uses an inverting OpAmp whose output voltage, called *Set Voltage* (**SV**) is adjustable from a variable resistance.

The two voltage signals (**MV** and **SV**) are compared in the ***Comparator Block*** (**CB**), also made with an OpAmp and whose output (called *Thermostat Control Voltage* - **TCV**) is switched according to the relationship between the two voltage signals (Subțirelu, 2011).

The ***Command Synchronization Block*** (**CSB**) received from the comparator with the zero crossing of the AC voltage of the power triac is composed of two Op-Amp comparators and several logical gates. This block provides the command signal (called *Output Control Voltage*- **OCV**) for the execution element (in this case, a triac). Command signal is in the form of pulses.

Finally, the ***Output Block*** (**OB**) consists of the optical signaling elements (LEDs), the galvanic separation (optocoupler) between measurement/control and 220 VAC, the execution (triac) and the load – heating element (in this case, an incandescent bulb). The LED lights up when the temperature drops below the prescribed value and gives the heating element's start command.

The electrical diagrams of each block are further explained and simulated by Multisim.

3. Blocks Description and Simulation of Operation

Fig. 2 shows the Multisim simulation of PT100 temperature transducer.

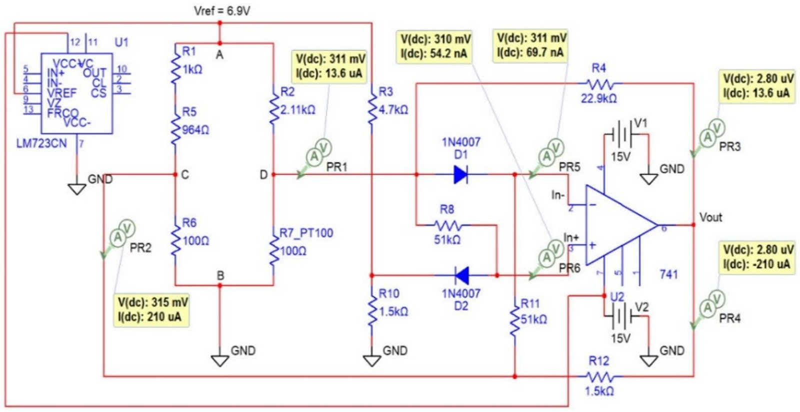


Fig. 2 – Temperature Measurement Block (TMB): Multisim modeling for 0°C temperature measured by PT100.

A constant voltage of 6.9V is provided by the integrated LM723 stabilizer. This voltage has two functions: it feeds the measuring bridge in diagonal AB and fixes the non-inversion potential of the instrument amplifier made with OpAmp.

As seen in Fig. 2, the operation of the transducer is modeled Multisim for the 0°C temperature, *i.e.* the 100 Ω resistance of the R7_PT100. For this measurement point it is observed that:

– the measuring bridge is slightly unbalanced (the potential difference between points C and D is 315mV-311mV = 4 mV);

– the voltage at the output of OpAmp is approximately 0 (2.8 μV respectively).

Table 1 summarizes the results for 7 simulated measurement points of temperature.

Table 1

Voltage values (MV) obtained for the temperature range [-40 ÷ +40]°C

No.	Temperature °C	PT100 resistance Ω	Measurement voltage mV
1	–40	84.21	–839
2	–20	92.13	–419
3	–10	96.07	–209
4	**0**	**100**	**0**
5	10	103.9	+208
6	20	107.79	+416
7	40	115.54	+831

From the table it is easy to see that we have (see also Fig. 3):

– a linear range of temperature: –40°C ÷ 0 ÷ +40°C;

– a linear resistance range for PT100 RTD: 84.21 Ω ÷ 100 ÷ + 115.54 Ω;

– a linear voltage range at the output of the transducer: –839 mV ÷ 0 ÷ +831 mV.

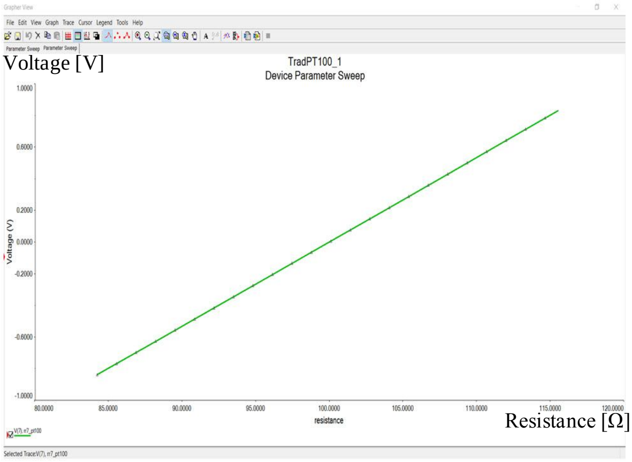


Fig. 3 – Device parameter sweep for temperature measurement transducers.

Fig. 4 shows the electrical circuit and the modeling/simulation result for ***Temperature Setting Block*** (**TSB**) and ***Comparator Block*** (**CB**).

Simulation of the measured value (***MV***) is done with the potentiometer R2 (1kΩ). The ***Set Voltage*** (***SV***) is adjustable from a variable resistance (R11).

On the left side of Fig. 4 shows the case where the measured temperature value (***MV*** = 797 mV) is higher than the setpoint temperature (***SV*** = = –501 mV); in this case the output of the comparator switches to –14 V, the transistor Q1 (NPN) is blocked and the command signal picked up on the emitter resistance (R9) is level "0".

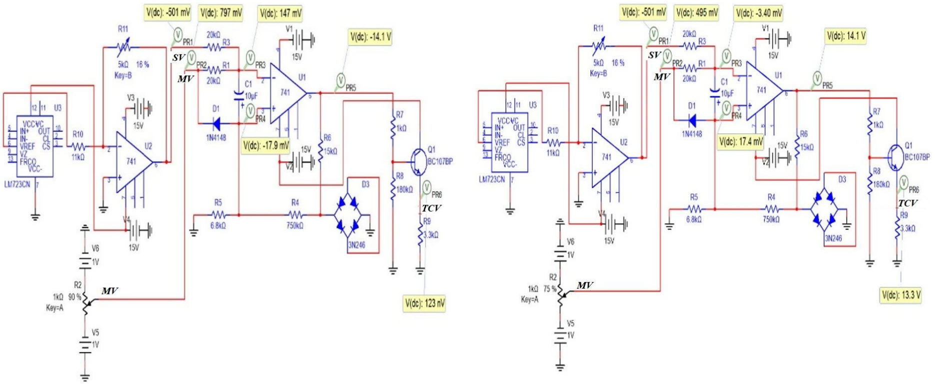


Fig. 4 – Multisim modeling of (TSB) and (CB) blocks.

If the voltage level corresponding to the measured temperature is lower than the prescribed voltage level then the comparator switches to + 14V and in the emitter Q1 the control signal is level "1" (see Fig. 4, right).

The electrical circuit for ***Command Synchronization Block*** (**CSB**) is shown in Fig. 5.

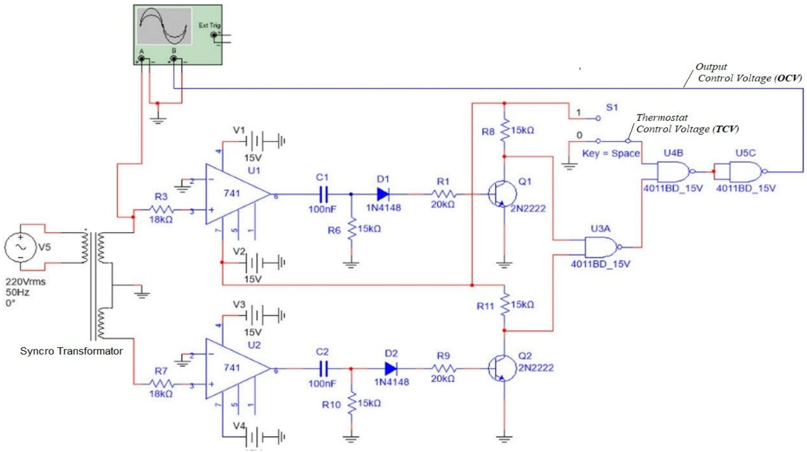
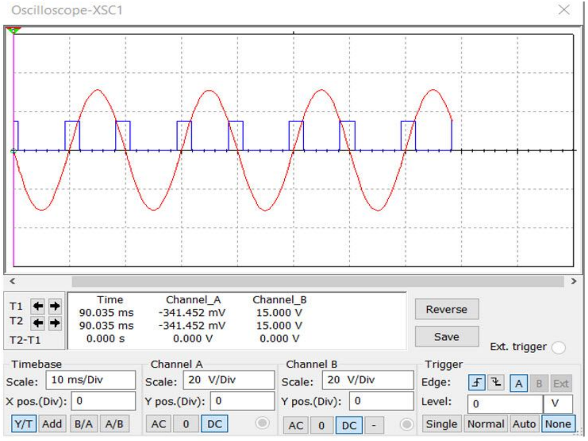


Fig. 5 – Electrical circuit for Command Synchronization Block (CSB).

The Command Synchronization Block generates short pulses at zero feed voltage crossings. Operational amplifiers U1 and U2 (LM741) works as a *zero-crossing comparator*. Such a comparator can be used to convert a sine wave into a square wave by the clipping action shown in Fig. 6.

With the derivation and rectifier groups R6-C1-D1 and R10-C2-D2 are obtained pulses at each zero crossing of the feed voltage. Short pulses with fast fronts with 100 Hz frequencies are output at the first NAND gate (U3A).

Validation of the OFF/ON command given by the comparator block (simulated by the S1 switch) is performed with the NAND gate (U4B of the integrated circuit 4011).



	Time	Channel_A	Channel_B
T1	90.035 ms	-341.452 mV	15.000 V
T2	90.035 ms	-341.452 mV	15.000 V
T2-T1	0.000 s	0.000 V	0.000 V

Timebase
Scale: 10 ms/Div
X pos.(Div): 0

Channel A
Scale: 20 V/Div
Y pos.(Div): 0

Channel B
Scale: 20 V/Div
Y pos.(Div): 0

Trigger
Edge: A
Level: 0 V

Fig. 6 – Pulses with frequency of 100 Hz for zero-crossing synchronization.

Fig. 7 shows the electrical circuit and the modeling/simulation result for the output block diagram that has signaling, galvanic separation and actuation elements (heating resistance coupling).

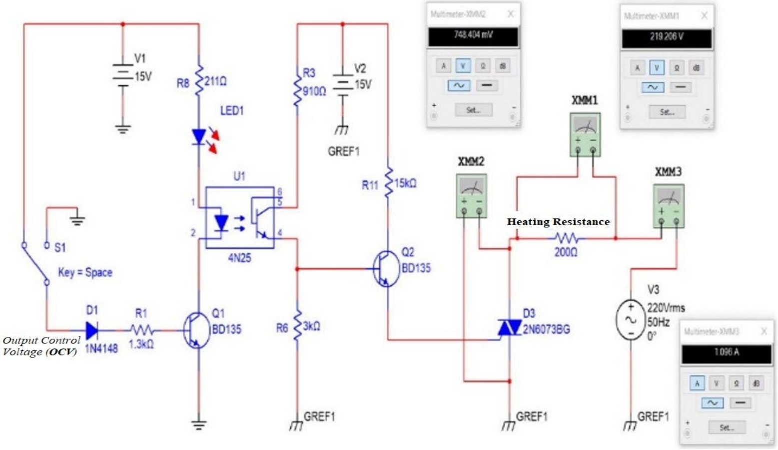


Fig. 7 – Multisim modeling of Output Block (OB) circuit.

The LED lights up when the measured temperature is lower than the preset temperature (also shows the heating resistance supply). As shown in the Fig. 7, the U1 optocoupler (4N25 type) makes the galvanic separation between the measurement and control circuit and the heating resistance supply circuit. The heating resistance is connected to 220 VAC by the D3 triac.

4. The Hardware Platform and Experimental Results

Fig. 8 presents an image of the electronic board of temperature controller (in the left side) and a platform for verifying the experimental function of the controller (in the right side).

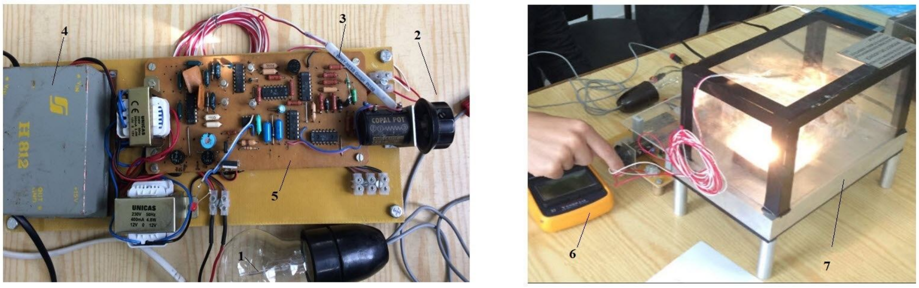


Fig. 8 – Detail of the controller (left) and the experimental platform (right).

The main components of the assembly are:
– an incandescent bulb used to simulate the heating resistance (1);
– a temperature setting multi turn potentiometer positioned to the right of the assembly (2);
– a temperature sensor PT100 RTD (3);
– a double voltage source 220 Vca / 2 × 15 Vcc (4);
– electronic board (5);
– digital multimeter for functional verification (6);
– thermostatic enclosure (7).

Checking correct operation of the controller requires the following operations:
– with an 25 kΩ multi turn potentiometer a voltage range of –178 mV to –488 mV can be obtained; for this voltage range a temperature range of between 7°C and 20°C is obtained; this is the temperature that can be prescribed/set;
– the prescribed voltage and temperature levels are measured with a precision DMM (Fluke 289);
– 2 temperature thresholds are set for the enclosure thermostat (10°C and 20°C);
– it can be seen if the comparator switches to raising/lowering the temperature above/below the preset threshold.

The LED lights up when the temperature drops below the prescribed value and gives the heating element's (an incandescent bulb) start command.

Table 2 shows the experimental results obtained for the two preset temperature values (10°C and 20°C).

Table 2

Voltage Values (MV) Obtained for the Temperature Range [–40,…,+40]°C

No.	Set temperature °C	Set voltage SV V	Measurement voltage MV V		Measurement temperature °C	
			High	Low	High	Low
1	10	–0.233	0.2493	0,2027	10.7	8.7
2	20	–0.464	0.4776	0.4403	20.5	18.9

There is a hysteresis interval between the two preset temperature (10°C and 20°C).

5. Conclusions

In the paper there is presented an electronic temperature controller which allows analog measurement accurate temperature measurement and switching on/off of a consumer (electrical resistance, bulb etc.) if the measured value of the temperature is lower or higher than a prescribed value. Experimental assembly can be used in practical applications or for teaching purposes.

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REGULATOR ELECTRONIC DE TEMPERATURĂ PENTRU APLICAȚII INDUSTRIALE

(Rezumat)

Această lucrare prezintă un regulator automat de temperatură care permite menținerea unei temperaturi constante într-o incintă industrială. Temperatura incintei

este măsurată cu un senzor rezistiv plasat într-unul din brațele unei punți rezistive perfect echilibrate. Valoarea de joasă tensiune obținută este introdusă în amplificatorul de instrumentație a cărui ieşire este un semnal de măsurare. Elementul de ieşire din regulator este un triac care alimentează un bec cu incandescență (simulează o sarcină tip rezistență de încălzire) la o tensiune de 220VAC. Impulsurile de comandă pentru triac sunt sincrone cu trecerea prin zero a tensiunii de alimentare. Acest regulator electronic analogic poate fi foarte util pentru măsurarea şi reglarea temperaturii în domeniul aplicațiilor industriale.