DEVELOPMENT OF MICROCONTROLLER BASE THERMO-EMF MEASUREMENT SYSTEM

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A B S T R A C T

The principle of conservation of energy, which states that energy neither be created nor destroyed; it can only change from one form to another. In hydropower plant, potential energy (of water) is converted into electrical energy by turbine. In an electrical heater, the electrical energy is converted into heat energy. In a steam engine, heat energy is converted into mechanical (kinetic) energy.

This research paper provides a practical development of the Microcontroller base Thermo-EMF Measurement. The Seebeck effect is the basic effect found in any material which has conducting nature or semiconducting nature, the basic equations relating EMF, resistivity and temperature are well explain. A few of the practical thermocouple circuits are refer and analyzed, temperature and EMF measurement with a basic ice-point as reference circuit. The atomization of the basic concept is done using the microcontroller with calibrated conversion formula for converting temperature into EMF. The development of sample holder for measuring EMF and resistance of the sample also explained.

This paper also gives the graphical representation and calibrations check for the developed prototype for EMF and thermal resistance measurement of $CoZrFe_{12}O_{19}$ and $CoZrSnFe_{12}O_{19}$ materials with the variation of temperature.

Keywords: Microcontroller, EMF measurement, Sample Holder, Seebeck Effect

1. Introduction

We are familiar with the principle of conservation of energy, which states that energy can neither be created nor destroyed; it can only change from one form to another. For example, in a battery/cell, the chemical energy is converted into electrical energy. In a hydro-power plant, potential energy (of water) is converted into electrical energy by a turbine. In an electric heater, the electrical energy is converted into heat energy. In a steam engine, heat energy is converted into mechanical (kinetic) energy [1]. You may like to know: Can we reconvert heat energy into electrical energy?

Answer to this question was provided by Seebeck in 1821 by some materials like Iron, Copper, Lead and Bismuth etc. He also explored a long series of such materials called Seebeck series to select the required thermoelectric materials on the basis of their electron density [2]. The assembly of two different materials (wires) having two junctions is called the thermocouple and there is a generation of thermo EMF due to contact potential at these two junctions for a temperature gradient. In the recent years an increasing concern of environmental issues especially the global warming and limitations of energy resources motivate the researchers towards thermo power generation. Recently, owing to the thermoelectric modules having efficient results in power generation and energy recycling systems without any content of toxic or pollutants, this technology is regarding as an alternative Green Technology [2-3]. Thermoelectricity is considered as a key to overcome the energy crisis in all the technical and scientific regions because of its some special characteristics as:

- This technology is portable and totally free from any type of pollution and external agencies.
- Its operation is easy and there is no use of moving parts.
- All the thermoelectric materials are non toxic and non radioactive which is one of the chief characteristic of eco friendly system
- A very wide range of thermoelectric materials (all metals, non metals and semiconductors) is available that means the material can be selected in order of the requirements of cost, dimensions, physical and chemical conditions etc.
- The chip sized thermoelectric devices are also possible by nano and thin film technologies.
- Thermoelectric power sources are flexible and capable to operate at the elevated temperatures.

Typical values of thermo-EMF per degree rise in temperature for some thermocouples are given in Table 1 On account of their reliability and low cost, thermocouples are suitable as small power supply units in space satellites, ships etc. Thermocouples are extensively used as thermometers, particularly for measuring high temperatures [1]

Table 1- Thermo-EMF generated by some typical thermocouples.

Thermocouple	**Thermo-EMF*10^{-6} VK^{-1}**
Copper-Iron	13.9
Iron-Constantan (J)	50.2
Chromel-Alumel (K)	39.4
Copper-Constantan (T)	39
Chromel-Constantan (E)	58.5

Figure 1 describes the generation of thermo EMF from an "assembly" of two dissimilar metals (materials) called thermocouple. When one of the two junctions of the thermocouple is kept hot and the other is cold then the temperature gradient is established which causes the generation of thermo-EMF[4].

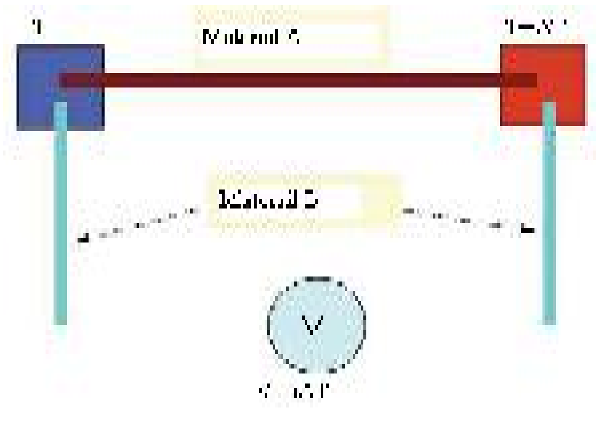

Figure 1. - Generation of thermo-EMF with the temperature gradient at the two junctions of a thermocouple.

In this case when we check linearity of the thermocouple with variation of temperature it is found to be resistance and EMF of thermocouple decreases with increase in temperature.

MEASUREMENT TECHNIQUES:

Comprehensive temperature plan was acquired if sole thermocouple over the measurement plane of the ISO burner was traversed. The measured values of temperature, heat flux and a sample in ISO 2685 propane-air burner needs to be taken at a distance of 75 mm (3 inch) from the burner face. As reported by few researchers an experiment that was conducted on 3-inch x 3-inch samples where the temperature distribution was found to be uniform and the mean temperature reading of 1119^{o}C was obtained. Among the types of temperature measuring devices are thermocouple, liquid-in-glass thermometers, resistant temperature detectors (RTDs), thermostats and optical pyrometers. Thermocouple is the most common sensor that determines the temperature in fire test, the circuit is made up of two wires of different metals or their alloys that are joined together at one end and open at the other end, an electromotive force (EMF) is generated due to the voltage differential between the open ends when the junction is heated. The voltage differential between the open wire terminals is the outcome of the temperature differences connecting the joints. These two junctions are the hot and cold junctions that are the measuring and reference junctions respectively [5].

Electrical resistivity is measured by a four-probe ac method that eliminates the influence of contact resistance and minimizes the contribution of the thermal EMF arising from the Peltier effect. The latter effect is particularly troublesome in thermoelectric materials where the Peltier contribution can lead to serious errors in measurements of the electrical resistivity [6]. Since the EMF arising from the Peltier effect is of thermal origin, it takes a fraction of a second to develop in the sample. If the excitation current is reversed in a time shorter than the time needed to develop the Peltier-generated EMF, the Peltier contribution can be effectively eliminated and a purely ohmic signal can be measured [7]. We use a Linear Research LR-140 bridge with the excitation frequency of 16 Hz in our measurements of electrical resistivity. From the measured value of resistance R and sample dimensions (distance between the voltages leads L and the sample cross-section area S), the electrical resistivity r is given by

$$\rho=R\frac{S}{L}$$ --------------------(1)

Assuming that the sample is in the form of a rectangle, the percentage uncertainty in r is given as

$$\frac{\delta\rho}{\rho}=\frac{\delta R}{R}+\frac{\delta w}{w}+\frac{\delta t}{t}$$ ---------------(2)

Where w and t are the width and thickness, dR, dw, dt, and dL are the uncertainties of R, w, t and L, respectively. If the sample is a rod of diameter D, then the percentage uncertainty in r is

$$\frac{\delta\rho}{\rho}=\frac{\delta R}{R}+2\frac{\delta D}{D}+\frac{\delta L}{L}$$ --------------(3)

There are two distinct error sources in the electrical resistivity measurements. The first one comes from the resistance measurement dR/R, while the second one originates from the determination of the geometrical factors of the sample, namely dw/w+dt/t+dL/L or 2dD/D+dL/L. Based on the ac resistance bridge specifications, dR/R is within ±0.1%. Sample's cross-sectional area S is determined by measuring w and t (or D in the case of a rod) with a micrometer which has an uncertainty of ±0.01 mm. For samples with uniform width and thickness of typically 2 35 mm2 , dw/w+dt/t, and 2dD/D are estimated to be within ±0.4%. dL/L is the most uncertain part in Eqs. (2) and (3) for samples with uniform cross section. Usually L is taken as the distance between the centers of the voltage contacts but that will result in an error when the size of the contacts is not a small percentage of the distance between the contacts. In our case, voltage leads are inserted into two small holes drilled into the sample—and as probe separation L we take the shortest distance between the small holes (about

0.5 mm diameter). The uncertainty in L (measured under the microscope) is within ±0.5%. The total error in measurements of the electrical resistivity is estimated to be within ±1%. However, if the sample is not of uniform cross section, the error in the determination of the cross-section area will be larger than ±0.4% and the resulting uncertainty in the resistivity measurement may exceed ±1%.

As voltage probes we use thin niobium wires. They serve the purpose of both resistivity measurements as well as measurements of the Seebeck coefficient. The primary advantage of using niobium is its very small and nearly constant absolute thermopower. For instance, its Seebeck coefficient changes from −2.28 mV/K at 300 K to −1.24 mV/K at 1200 K. Moreover, niobium is stable and relatively inert to ambient conditions.

EXPERIMENTAL PROCEDURE

Prototype Designing

The temperature of the sample holder is sensed by the temperature sensor LM-35 [8] and then it compares with the set point, set by the user and this analog data is then given to the ADC which is already inbuilt in a AVR AT-Mega16 microcontroller. AT-Mega16 microcontroller is used to control the ON/OFF control action is done through the given switches. The AT-Mega 16 microcontroller is programmed in embedded C language using Code Vision AVR IDE [9].

The heater start heating as soon as the user entire's the set point. When the temperature reaches at the set point then the system will perform the ON/OFF action for maintaining the set temperature and thermo-EMF is measured.

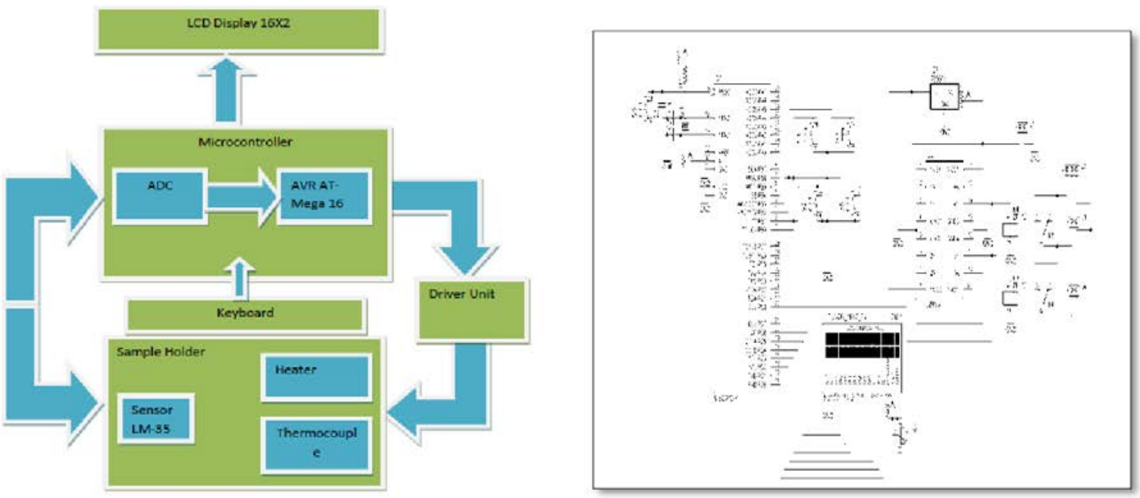

Figure 2 - a) Experimental Block Diagram b) Complete Circuit diagram of prototype

a) **Microcontroller** The AVR 8-bit microcontroller architecture was introduced in 1997. By 2003, Atmel had shipped 500 million AVR flash microcontrollers. Atmel says that the name AVR is not an acronym and does not stand for anything in particular. The creators of the AVR give no definitive answer as to what the term "AVR" stands for. However, it is commonly accepted that AVR stands for **A**lf and **V**egard's **R**ISC processor. An ATmega16 AVR Microcontroller is used for carrying out all the required computations and control [10]. It has an in-built Analog to Digital converter. Hence an external ADC is not required for converting the analog temperature input into digital value. In the following discussion we will briefly discuss about the temperature sensor used, the microcontroller and the project in general. An inexpensive temperature sensor LM35 is used for sensing the ambient temperature. The system will get the temperature from the sensor IC and will display the temperature on the LCD. This temperature is compared with the set point temperature declared by the user (also displayed on the LCD) using a keypad. We are implementing On/Off control for controlling the temperature. The temperature must be within a certain range otherwise continuous on/Off of the controlling elements will cause damage to them. We consider the temperature range to be ±2°C compared to the set temperature. If the Room /Chamber temperature goes beyond the upper limit then fan will be switched ON and if temperature goes below the lower limit then heater will be switched ON [11].

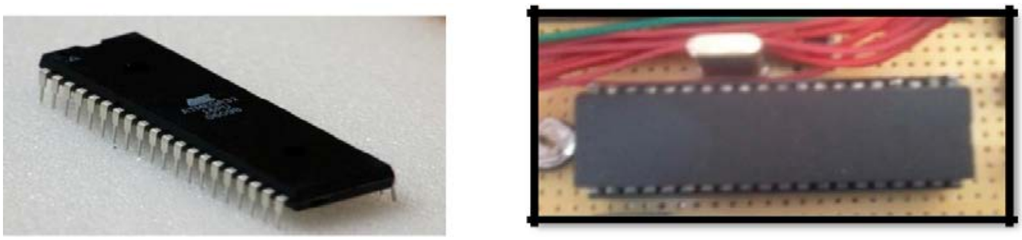

Figure 3- ATmega 16 Microcontroller

b) Display Unit:

LCD (Liquid Crystal Display) screen is an electronic display module and find a wide range of applications. A 16x2 LCD display is very basic module and is very commonly used in various devices and circuits. These modules are preferred over seven segments and other multi segment LEDs. The reasons being: LCDs are economical; easily programmable; have no limitation of displaying special & even custom characters (unlike in seven segments), animations and so on [12].

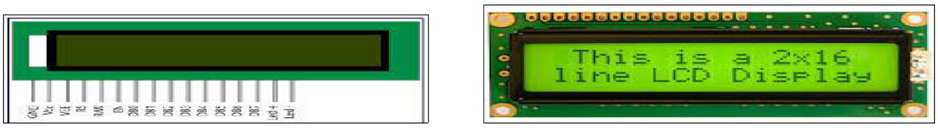

Figure 4- LCD Display Unit 16X2

A **16x2 LCD** means it can display 16 characters per line and there are 2 such lines. In this LCD each character is displayed in 5x7 pixel matrix. This LCD has two registers, namely, Command and Data. The command register stores the command instructions given to the LCD. A command is an instruction given to LCD to do a predefined task like initializing it, clearing its screen, setting the cursor position, controlling display etc. The data register stores the data to be displayed on the LCD.

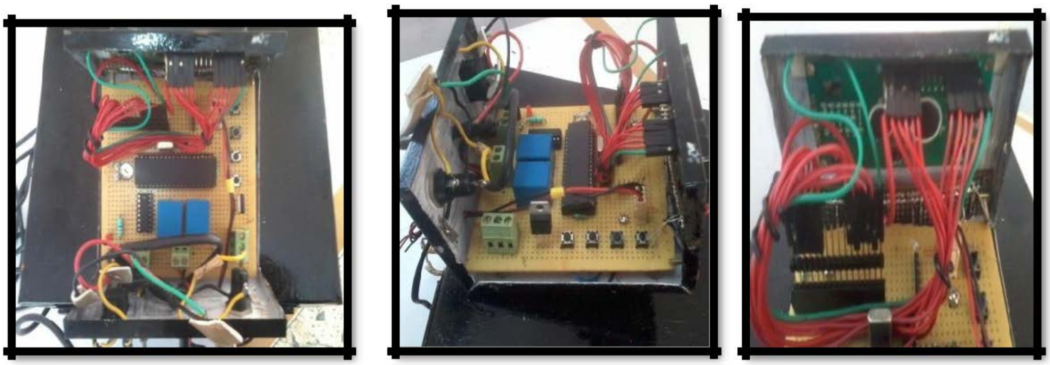

Figure 5- Internal and side view of prototype

IC AD595:

The AD594/AD595 is a complete instrumentation amplifier and thermocouple cold junction compensator on a monolithic chip. It combines an ice point reference with a pre calibrated amplifier to produce a high level (10 mV/°C) output directly from a thermocouple signal. Pin-strapping options allow it to be used as a linear amplifier-compensator or as a switched output set point controller using either fixed or remote set point control. It can be used to amplify its compensation voltage directly, thereby converting it to a stand-alone Celsius transducer with a low impedance voltage output. The AD594/AD595 includes a thermocouple failure alarm that indicates if one or both thermocouple leads become open. The alarm output has a flexible format which includes TTL drive capability. The AD594/AD595 can be powered from a single ended supply (including +5 V) and by including a negative supply, temperatures below 0°C can be measured. To minimize self-heating, an unloaded AD594/AD595 will typically operate with a total supply current 160 µA, but is also capable of delivering in excess of ±5 mA to a load. The AD594 is precalibrated by laser wafer trimming to match the characteristic of type J (iron-constantan) thermocouples and the AD595 is laser trimmed for type K (chromel-alumel) inputs. The temperature transducer voltages and gain control resistors are available at the package pins so that the circuit can be recalibrated for the thermocouple types by the addition of two or three resistors. These terminals also allow more precise calibration for both thermocouple and thermometer applications [13]. The AD594/AD595 is available in two performance grades. The C and the A versions have calibration accuracies of ±1°C and ±3°C, respectively. Both are designed to be used from 0°C to +50°C, and are available in 14-pin, hermetically sealed, sidebrazed ceramic DIPs as well as low cost cerdip packages [13].

Sample Holder:

The selection of various components in the present design is in such a way that the possible challenges of high temperature fabrication have been well taken care. From the mechanical, thermal, electrical and vacuum point of view, the suitable and very low cost materials are considered. A copper plate, having the length of ~50 mm and thickness of ~2 mm is used for both holding the sample and making the heater to reach the desired sample temperature. To raise the sample temperature a copper platform is chosen due to its high thermal conductivity (~Cu ~4.01 W cm−1 K−1 at 300 K and ~3.79Wcm−1 K−1 at 600 K), these values are almost comparable to of Silver and gold. The purpose of selecting copper material over silver and gold is also due to its easy availability and relatively very low cost. A size of suitable dimension (~50 mm length, ~5 mm width & ~2 mm thickness) of one end of copper plate is used to make the heater. At this end, flexible mica sheet of good thermal conductive and electrical insulating property is wrapped and over this a kanthal wire of 40 SWG (~0.12 mm) diameter, which resistance is ~35 mm, is tightly wound in ~15 mm in length to make the resistive heater. The use of mica sheet in between kanthal wire and copper plate avoid the direct electrical contact with each other, which also protect the heater from any electrical short circuit. High temperature epoxy cement is applied over the kanthal wire to safe the heater, as at high temperature recoiling and breaking issues in thin wire occurs. Each end of the kanthal wire is joined with copper wire for supplying the current in heater. The design of such a small heater closed to sample position has small exposure to vacuum environment, which also minimize the heat loss [14].

In the high temperature resistivity measurement heat loss is a major factor in the error contribution. The significant temperature gradient created across the sample due to heat loss give rise to Thermo-EMF voltage which also gets added in to the measurement of actual sample voltage. To minimize the conductive heat loss from sample supporting copper plate, a rectangular gypsum bar is attached at the heater end side using screw. Thermal conductivity of the gypsum is very low (~0.17 W/mK at room temperature), and also effective for thermal insulation in high temperature region.

Figure 6 -a) Sample Holder, b) Complete view of Sample Holder with furnace.

Working Principle:

Thermocouple consists of two different conductors forming an electrical junction at different temperatures. Due to thermo effect, thermocouples produce voltage which is dependent on temperature [4]. This voltage is given to the IC AD595 which is complete instrumentation amplifier with cold junction compensation. This voltage is in ADC form. It combines ice point reference with the pre-calibrated amplifier to produce a high level output

(10mV/ºC) directly from the thermocouple output. Output of this IC AD595 can be processed by microcontroller to give this ADC voltage into temperature which is displayed into LCD. We know the temperature is the function of resistance as the temperature increases the resistance will be increased. By using formula,

Heat= (current^2*resistance)*time----------- (4)

And by Ohms law we can calculate voltage as well using resistance

Result:

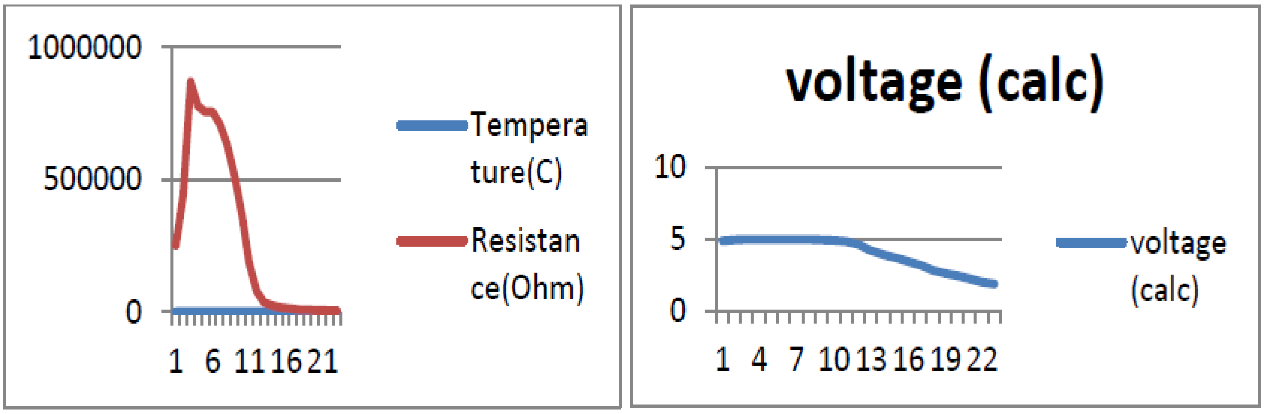

Figure 7-Resistance and Thermo-EMF v/s Temperature for $CoZrSnFe_{12}O_{19}$ material (Doped Luminescence).

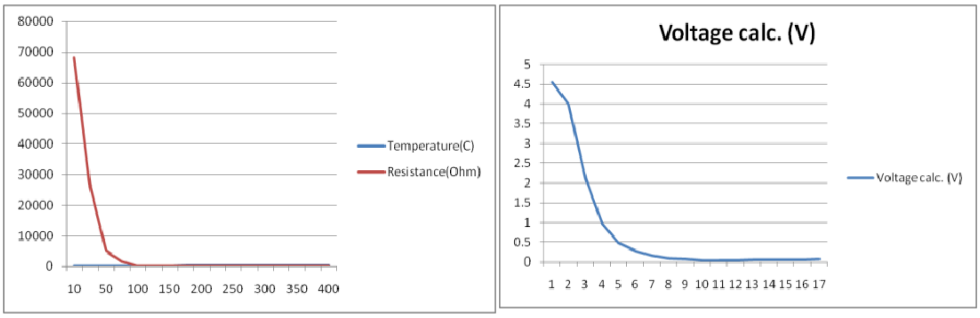

Figure 8 - Resistance and Thermo-EMF v/s Temperature for $CoZrFe_{12}O_{19}$ material (Pure Luminescence).

Conclusion

Thermocouples are inexpensive and versatile temperature sensors. With proper installation and reference junction compensation, thermocouples can be used for routine and accurate temperature measurement [1]. These advantages are substantial when large numbers of temperatures need to be measured. Data acquisition vendors sell systems for temperature compensation of thermocouple junctions. These devices are essentially zone boxes with an independent sensor for measuring reference junction temperature. A knowledgeable experimentalist can build his own zone box and use a digital multimeter, with suitable amplification, to measure temperature with thermocouples. As long as the reference junction is accurately measured, a home-
made zone box is likely to be more accurate than a commercial electronic thermocouple compensation device. Commercial devices for reference junction compensation are usually poorly insulated and they are often attached to electronic equipment with internal heat sources. Any uncertainty or error in reference junction temperature results in a proportionate uncertainty or error in the indicated temperature of the measuring junction.

The document provides detailed descriptions of procedures for converting thermocouple EMF measurements to temperature. Step-by-step instructions for converting ice-point and floating reference junction compensation are given. Use of a zone box for the reference junctions of multiple thermocouples is described.

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