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Alteration of Precise Measurements by Thermocouples Due to Their Operating Conditions

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Abstract: **Thermocouples; the key of precise measurements are considered as the integral part of temperature and emf measuring systems not only in indusial areas but also in research and technical fields. This all is due their normal approach, accurate results and the possibility of their performance in some critical conditions like the molten steel state, metal vapors and the magnetizing processes etc. This report puts an objection on the accuracy of such measurements due to the effect of operating conditions which allow the presence of electric and magnetic fields and sometimes the stress also. The main objective of this research work is to explain how there is alteration of temperature-emf relations which affect the corresponding measurements. Hence this paper informs to take into account the effect of electric field, magnetic field and stress in the operating conditions of thermocouples which alters the temperature-emf relations in the high temperature range of 300K to 600K.**

Keywords**: Thermocouple, Electric Field, Magnetic field, Stress, Temperature and emf.**

I. INTRODUCTION

Thermocouple; an assembly of dissimilar metals having two junctions and generate thermo emf when the temperature gradient is established at these two junctions. These thermocouples generally used to convert the heat into electrical energy **[1],[2],[3]**.

Thermocouples and measurements: Other than the conversion applications the thermocouples are widely used for measurements **[4],[5],[6]**. These are considered as best measuring tools for temperature and emf due to their low cost, variety of thermoelectric materials in all ranges, design a measuring system without pollutants, free from moving parts, no use of toxic materials and quick responses. These measurements are carried out by the mathematical dependences which involve some constants along with temperature and emf as the variables. Some equations to verify this fact are **[7]:**

$$E_{AB} = \frac{dE_{AB}}{dT}\,\Delta T$$

$$\frac{dE_{AB}}{dT} = \alpha_a - \alpha_b$$

Hence $E_{AB} = (\alpha_a - \alpha_b)\,\Delta T$

Here E_{AB} is the relative Seebeck emf (thermo emf) developed at the two junctions of the thermocouple due to the temperature gradient (ΔT). But α_a and α_b are the Seebeck Constants, this means the generated thermo emf and temperature will be measured by their direct dependencies.

All of these measurements are based on the temperature-emf relations; hence their dependencies should be accurate for the accuracy of corresponding results.

II. SELECTION OF THERMOCOUPLES

The major objective of this research work is to report about the alteration of temperature-emf measurements due to the effect of operating conditions, by generally used thermocouples which are market available and are the integral part of every measuring system. Hence we select four common thermoelectric materials i.e. Constantan, Copper-Fe alloy (Nichrome), Iron and Copper. Actually the market available Nichrome due to specific applications is not a proper alloy of Nickel and Chromium but of Copper and Iron with a little fraction of Nickel and Chromium. Then fabricate these four materials into five thermocouples namely: Fe-Constantan, Fe-Nichrome, Cu-Fe, Cu-Nichrome and Nichrome-Constantan. These all thermocouples are known as the efficient thermocouples due to their good thermoelectric properties and a subject of large researches **[8]**.

The experimental parameters of all the thermocouples are measured by digital multimeter HP 34401A with an accuracy of six decimal places. These are list in the Table 1.

TABLE 1: Experimental Parameters of Thermoelectric Materials

Sr. No.	Parameter	Copper	Iron	Constantan	Nichrome
1.	Resistance (Ohm)	0.1918	0.7062	0.5174	1.6874
2.	Area of Cross-Section (m^2)	$1.51x10^{-6}$	$9.5x10^{-7}$	$1.112x10^{-6}$	$9.7x10^{-7}$
3.	Length (m)	$48x10^{-2}$	$48x10^{-2}$	$48x10^{-2}$	$48x10^{-2}$
4.	Resistivity ρ (Ohm-m)	$6x10^{-6}$	$1.4x10^{-6}$	$1.2x10^{-6}$	$3.41x10^{-6}$
5.	Electrical Conductivity σ ($S\ m^{-1}$)	$1.67x10^{6}$	$7.143x10^{5}$	$8.33x10^{5}$	$2.933x10^{5}$

All the thermoelectric materials are characterized for the interest of their compositions, by XRF techniques from the Tata Institute of Fundamental Research (TIFR), Bombay (INDIA). The characterization peaks are mentioned in the Fig. 1,2,3 and Fig. 4 for the Constantan, Copper, Iron and Nichrome thermoelectric Materials respectively.

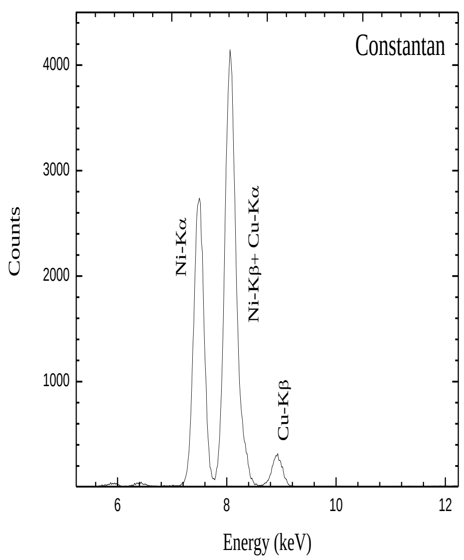


Fig 1: XRF of Constantan Wire

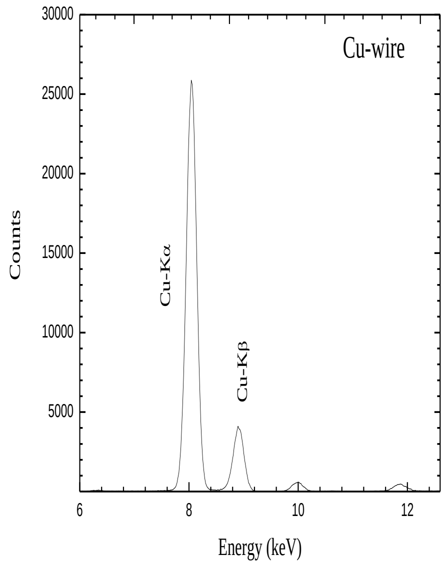


Fig 2: XRF of Copper Wire

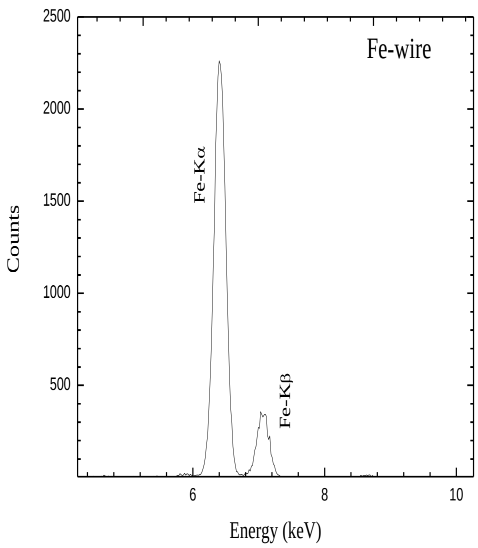


Fig 3: XRF of Iron (Fe) Wire

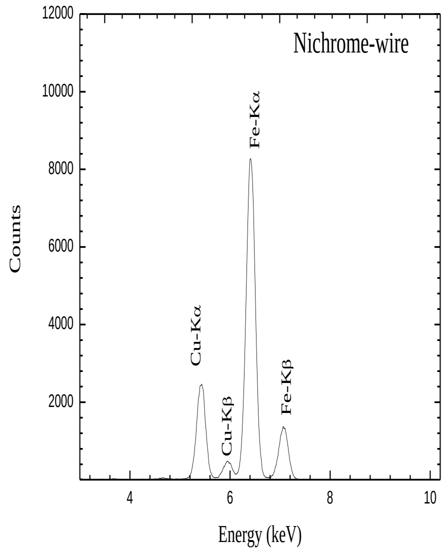


Fig 4: XRF of Nichrome Wire

Effect of Electric Field:

The effect of electric fields is also considered for all the thermocouples for its influence on thermo emf generations **[9], [10]**. These effects are studied in detail by applying the different magnitudes of the electric field on all the thermocouples. The electric field of different strengths (4V, 8V and 12V) are applied in parallel and perpendicular orientations, where as these orientations are only the configuration of thermocouple and applied electric fields. The various strengths of applied electric fields are shown in table 2.

Effect of Stress:

The stress also affect the generation of thermo emf **[11], [12]**, which in turn affect temperature-emf relations of the thermoelectric material. In the present work, we apply the mechanical stress by applying mechanical load on the individual thermoelectric wires. The stress (force/area) act on the individual thermocouple wires is given in Table 2.

TABLE 2: Applied Stress and Strength of Electric field in Parallel and Perpendicular Modes

Sr. No.	Applied load (gm)	Stress (10^5 Nm^{-2})		Strength of Applied Electric Field (vm^{-1})					
				Parallel Electric Field			Perpendicular Electric Field		
		Iron	Constantan	4V	8V	12V	4V	8V	12V
1.	100	10.32	8.813	8.33	16.67	25	16.67	33.33	50
2.	200	20.64	17.626						
3.	300	30.96	26.439						
4.	400	41.28	35.252						
5.	500	51.6	44.065						

Effect of Magnetic Field:

Same as of the electric field, the effect of magnetic field also vary the results of measurements by thermocouples due its effect to improve the thermoelectric properties **[13], [14]**. The parallel and perpendicular magnetic fields of different magnitudes (260gauss, 360gauss and 460gauss) are applied on each thermocouple for the investigations of measuring means.

III. EXPERIMENTAL PROCEDURE

The experimental procedures for the four different conditions are:

Normal Mode*:* The heating and cooling arrangements are obtained by electric furnaces and fresh tap water respectively. The digital multimeter of HP 34401A is used for thermo emf and other measurements with an accuracy of six decimal places.

Stress Mode: The stress is applied by the mechanical load on the individual thermoelectric wires with the help of steel hangers. The suitable insulation is used to prevent any electrical connection between the load hangers and thermoelectric wires. The range of applied load is from 100gm to 500gm which results to the stress of 10^5 orders of magnitude.

Electric Field Mode: The electric field is applied in parallel and perpendicular orientations on the selected thermocouple with the help of two aluminum plates (25Cm×22.6Cm) of parallel plate capacitor set up. The parallel and perpendicular orientations are just the configurations of applied field and thermocouple. The potential difference applied for both the orientations is 4V, 8V and 12V. The separation between aluminum plates for parallel and perpendicular orientation is 24 Cm and 48Cm respectively. The experimental arrangement is shown in the Fig. 5,6,7 and Fig.8 as below:

Fig 5: Normal Mode

Fig 6: Stress Mode

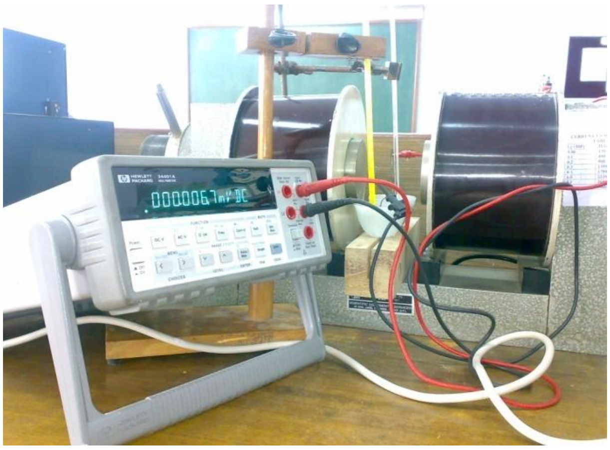


Fig 7: Perpendicular Magnetic Field Mode

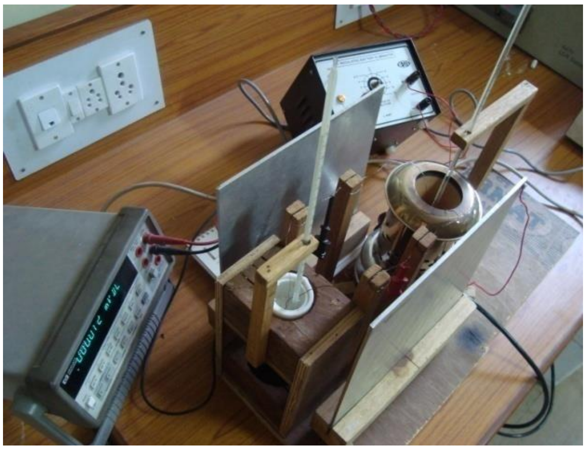
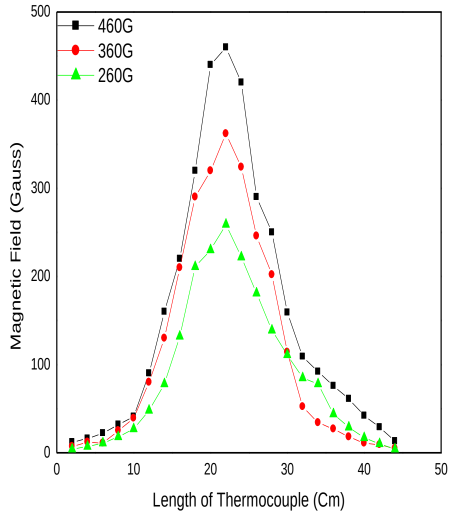


Fig 8: Perpendicular Electric Field Mode

Magnetic Field Mode*:* The magnetic field in two orientations i.e. parallel and perpendicular is applied on the each thermocouple by electromagnets. The heating and cooling arrangements are same as of the normal mode and the magnetic field is maximum at the centre of the thermocouple for the perpendicular mode; whereas for the parallel mode the strength of magnetic field is minimum at the centre of thermocouple. The distance between two poles of the electromagnet is only 8Cm in the perpendicular orientation but in the parallel orientation this distance increases to 50Cm. This variation of strength of magnetic field with the length of thermocouple is given in the following Fig. 9 and Fig. 10 for the perpendicular and parallel orientations respectively.



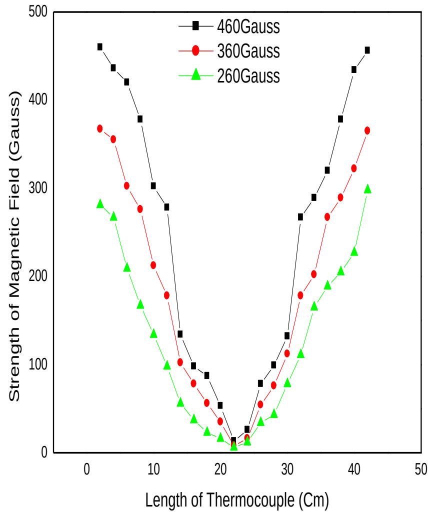


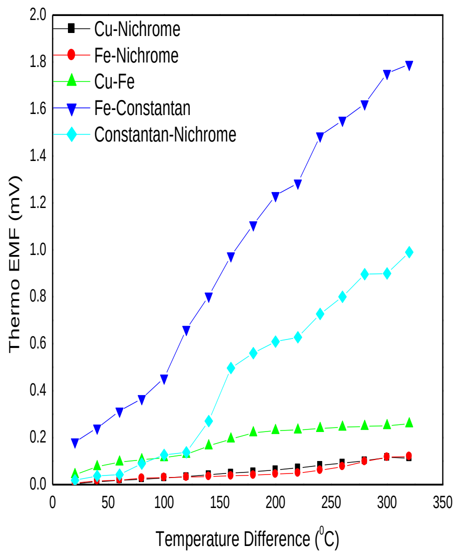
Fig 9: Perpendicular Orientation **Fig 10: Parallel Orientation**

IV. RESULTS AND DISCUSSION

The thermo emf which relates to the temperature gradient goes on increasing from the normal mode to the electric field and magnetic field modes. Actually this enhancement is the alteration of thermo emf and temperature gradient relations.

Normal Mode and Stress Modes:

In the normal mode the magnitude of thermo emf at the temperature difference of 330^{0}C is only 1.8mV for the Fe-Constantan thermocouple but for the stress of 500gm load in the same thermocouple it approaches to 4.2mV at the same temperature gradient. This variation of temperature- emf dependence can be compared for all the other thermocouples for all the mechanical stress corresponding to 500gm form the Fig. 11 (Normal Mode Thermo EMF Generation) and Fig. 12 (Stress Mode of 500 gm)



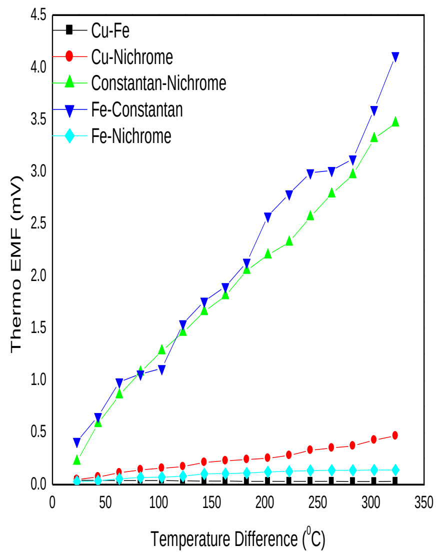
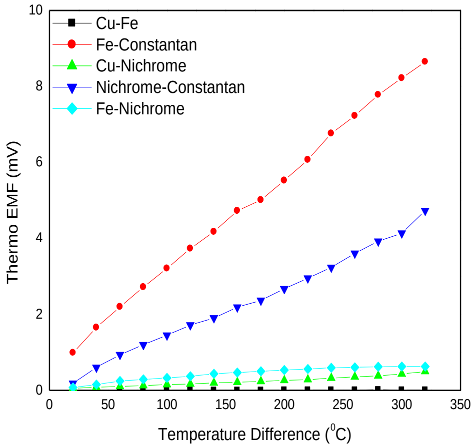


Fig 11: Normal Mode **Fig 12: Stress Mode (500gm)**

Normal Mode and Electric Field Mode:

For both the parallel and perpendicular electric field modes the variation of generated thermo emf is in a wide range for all the thermocouples. In the following graphs only the higher electric field (12V) is considered. Such that for the Fe-Constantan thermocouple, in the parallel mode the emf is 9mV but for the perpendicular mode it is 4.3mV where as for the normal mode this is only 1.8mV at the same temperature gradient of 330^{0}C temperature for the same thermocouple. The graphical comparison is enough for the other comparisons.



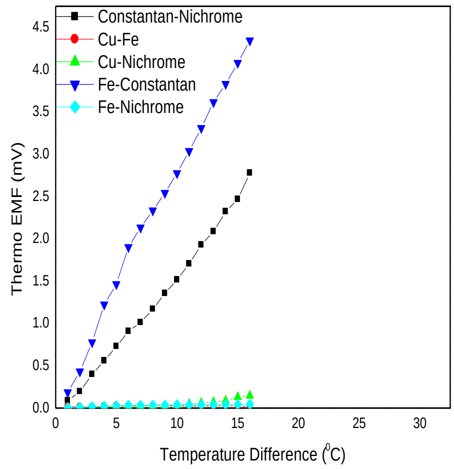
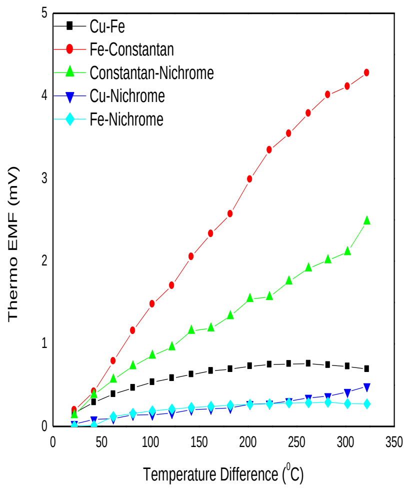


Fig 13: Parallel Electric Field Mode (12V) **Fig 14: Perpendicular Electric Field Mode (12V)**

Normal mode and Magnetic Field modes:

As of the other modes the effect of magnetic field enhances the thermo emf generations, which is the other aspect of temperature-emf dependences. If we consider only higher strength of applied magnetic field (460gauss) for both the parallel and perpendicular modes, then it can be observed that for the perpendicular mode the thermo emf at the temperature difference of 330^0 C for Fe-Constantan thermocouple is 9mV but in the parallel mode it is only 4.3mV at the same temperature difference, these are the wide enhancements form the normal mode in which it is only 1.8mV for the same thermocouple at the same temperature gradient. These enhancements lead to alterations of temperature-emf measurements, which can be studied for the other thermocouples also.



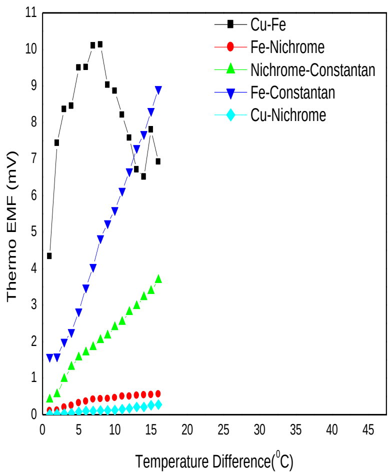


Fig 15: Parallel Magnetic Field Mode (460Gauss) **Fig 16: Perpendicular Magnetic Field Mode (460Gauss)**

V. CONCLUSION

This research work explains that how the effect of stress and other fields affect the generation of thermo emf. Approximately in all the operating conditions of thermocouples the electric or magnetic fields exist (sometimes together also) which affect the thermoelectric properties in such a way that the thermo emf increases across all the temperature differences. This means when the temperature or emf are measured from their relations or standard values, there is the involvement of such fields also which are generally ignored and cause errors. Hence one should keep in mind the effect of such operating parameters for the accurate measurements by thermocouples.

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