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Abstract
The long term accuracy and stability of linearized thermistor circuits used for temperature measurements in a solar home monitoring project are being evaluated by periodic calibration.

1. INTRODUCTION

The accurate measurement of small temperature differences encountered in a solar heating system pose special problems in acquiring detailed performance data on the system. In particular the temperature sensors need to be sensitive to small temperature changes, accurate and reliable over the temperature range. Also considered must be the interchangeability, dependability, ease of calibration and compatibility with existing data acquisition equipment. Finally the cost of the sensor, sensor interfacing and installation must be examined for the best compromise.

Linearized thermistor circuits (LTC's) were selected for use in the University of Tulsa's Solar Home Energy Evaluation Project (S.H.E.E.P.) since they offer the advantages of reasonable accuracy (± .27 °F 90°-212°F), interchangeability and microprocessor compatibility. The cost per temperature sensing channel was about $20 and included LTC, hardware and signal conditioning. Contrasting the several distinct advantages of the linearized thermistor circuit is the question of thermistor stability and dependability. Therefore as part of the S.H.E.E.P. program, periodic calibration of the LTC's is performed to assure accurate temperature and temperature differential measurements and to develop some insight into long term LTC stability.

2. LINEARIZED THERMISTOR CIRCUIT

The LTC is a temperature sensing device which produces an output voltage that varies linearly with temperature. They consist basically of a thermistor composite and a resistor composite connected in a bridge circuit as shown in Figure 1. The temperature sensing element, the thermistor composite, is two thermistors encased in an epoxy bead. The resistor composite is comprised of two metal film precision resistors which govern the temperature range over which the LTC produces a linear response. Thus a compromise can be made between range and linearity. Yellow Springs Instruments offers a variety of thermistor and resistor composites under the tradename ®Thermilinear Components. The YSI 44201 was selected for use in the S.H.E.E.P. program. It has a rated accuracy and interchangeability of 0.27°F over the range 90°-212°F and a sensitivity of 6 mv/°F at 2 volts input. Increasing the input voltage directly increases the sensitivity but produces some thermistor self heating error.

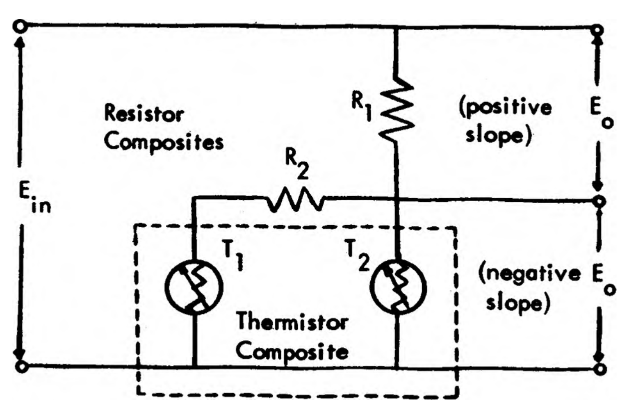

Figure 1. LINEARIZED THERMISTOR CIRCUIT
LINEAR VOLTAGE vs. TEMPERATURE

2.1 TEMPERATURE PROBE ASSEMBLIES

The probes consist of the thermistor composite potted with silcone heat transfer grease into the sealed end of a length of tubing. The resistor composite and electrical connections were attached to the other end of the tubing. Brass tubing was used for probes to be inserted into thermal-wells and teflon tubing was used for long probes immersed in the storage water.

3. LTC STABILITY AND ACCURACY

3.1 CALIBRATION

Calibration checks were performed on the individual thermistor composites before LTC construction and on the LTC's at regular intervals after construction and installation.

3.2 ENVIRONMENTAL CONDITIONS

Table 1 summarizes some of the environmental conditions that the individual probes in operation have been subjected to. In addition to the probes in operation, control probes (not electrically connected) were placed in the collector and heat exchanger fluid loops.

TABLE 1. ENVIRONMENTAL PARAMETERS

LOCATION	TEMP. RANGE	CYCLIC NATURE	OPERATION TIME (hours)
Collector fluid loop (thermal-well)	80°-270°F	abrupt daily flucuations	6000 >212°F-200 hrs
Heat exchanger fluid loop (thermal-well)	80°-210°F	abrupt daily flucuation	6000
City water inlet (thermal-well)	60°-100°F	small change with DHW use	6000
Preheat coil outlet (thermal-well)	70°-160°F	smooth transition with DHW use	6000
DHW outlet (bead epoxied to pipe)	120°-140°F	smooth transition with DHW use	3000
Storage tank (submerged in water)	80°-180°F	smooth transition	1000
Computer room (shelf)	65°-80°F	smooth transition	not in operation
Outside house (ventilated shelter)	-5°-106°F	daily flucuation	6000

3.3 FAILURES

There have been ten LTC failures to date. All failures have resulted in erroneous and erratic temperature readings. From forty thermistor composites there have been eight failures, only one of which was prior to probe assembly. There have been two failures due to faulty soldering connections and no resistor composites have yet failed. Three of the thermistor composite failures occurred within a few weeks after assembly, possibly the result of some unnoticed strain placed on the thermistor leads during construction. The final four thermistor composite failures all occurred in the probes submerged in the storage water. These probes were constructed from brass tubing nesting inside a long plastic tube. Although no water was found inside the brass tubes, they were all pitted badly indicating electro-chemical corrosion. Whether this was the cause of the thermistor failures has not yet been established. Replacing the brass and plastic with one long teflon tube with a small brass fitting on the end has produced a probe which has performed satisfactorily for approximately 1000 hours.

3.4 RESULTS

Several calibration checks performed on the remaining probes have indicated good accuracy and stability over the temperature range 80°F-190°F. With the exception of three, all probes tracked each other within ± 0.25°F. Agreement with a laboratory thermometer was in general ± 0.4°F. One of the three probes not tracking the group read 0.4°F higher than the average of the rest over the temperature range 150°-190°F and was a spare shelf life probe. The other two probes were storage tank probes, one of which read 0.4°F lower than average over the range 110°-150°F while the other read approximately 2°F lower than average over the entire range. An input voltage of 4 volts to individual probes produced less than 0.1°F self heating error in a well stirred bath.

From these calibration checks 6 probes were found that have tracked each other within ± 0.07°F over the temperature range for all tests.

These probes are used for critical temperature difference measurements, while the other probes are used for the less critical measurements.

4. CONCLUSIONS

No evidence of thermistor degradation due to high temperatures above 212°F, large temperature flucuations or to applied voltage has been found in the probes after 6000 hours of operation. There is an indication that occasionally a thermistor is produced whose epoxy encasement is physically weaker than normal allowing slight strain from lead wires to damage the thermistor composite. The method of damage to the thermistor composites within brass tubing submerged in the storage water is not yet understood but seems to be prevented by using inert tubing such as teflon.

In addition to the advantages of ease of interfacing with instrumentation, temperature sensitivity and cost, the linearized thermistor circuits, with care, can provide very accurate temperature measurements over long periods of time with little if any degradation.

REFERENCE

(1) G.E. Kouba, "A Microprocessor Compatible Temperature Measuring System," page 191, PROC. DOE CONF. ON PERFORMANCE MONITORING TECHNIQUES FOR EVALUATION OF SOLAR HEATING AND COOLING SYSTEMS, Washington, D.C., April 3-4, 1978.

BIOGRAPHY

Gene E. Kouba received the B.S. and M.S. degrees in Mechanical Engineering at Oklahoma State University in 1972 and 1974 respectively. The title of the master's thesis was "Modeling Inflows into Stratified Lakes with Vertical Scale Distortion" and was funded by the Oklahoma Water Resources Research Institute. Presently Kouba is a Research Associate for the Solar Energy Research Laboratory at The University of Tulsa. He is a co-principal investigator of the Solar Home Energy Evaluation Project.