2900-218-R

Report of Project MICHIGAN

USE OF A LARGE THERMOCOUPLE JUNCTION TO LOCATE TEMPERATURE DISTURBANCES

PHILIP L. JACKSON

January 1961

Fluid and Solid Mechanics Laboratory
Institute of Science and Technology
THE UNIVERSITY OF MICHIGAN
Ann Arbor, Michigan

NOTICES

Sponsorship. The work reported herein was conducted by the Institute of Science and Technology for the U. S. Army Signal Corps under Project MICHIGAN, Contract DA-36-039 SC-78801. Contracts and grants to The University of Michigan for the support of sponsored research by the Institute of Science and Technology are administered through the Office of the Vice-President for Research.

Distribution. Initial distribution is indicated at the end of this document. Distribution control of Project MICHIGAN documents has been delegated by the U. S. Army Signal Corps to the office named below. Please address correspondence concerning distribution of reports to:

U. S. Army Liaison Group
Project MICHIGAN
The University of Michigan
P. O. Box 618
Ann Arbor, Michigan

ASTIA Availability. Qualified requesters may obtain copies of this document from:

Armed Services Technical Information Agency
Arlington Hall Station
Arlington 12, Virginia

Final Disposition. After this document has served its purpose, it may be destroyed. Please do not return it to the Institute of Science and Technology.

PREFACE

Documents issued in this series of Technical Memorandums are published by the Institute of Science and Technology in order to disseminate scientific and engineering information as speedily and as widely as possible. The work reported may be incomplete, but it is considered to be useful, interesting, or suggestive enough to warrant this early publication. Any conclusions are tentative, of course. Also included in this series will be reports of work in progress which will later be combined with other materials to form a more comprehensive contribution in the field.

A primary reason for publishing any paper in this series is to invite technical and professional comments and suggestions. All correspondence should be addressed to the Technical Director of Project MICHIGAN.

Project MICHIGAN, which engages in research and development for the U. S. Army Combat Surveillance Agency of the U. S. Army Signal Corps, is carried on by the Institute of Science and Technology as part of The University of Michigan's service to various government agencies and to industrial organizations.

Robert L. Hess
Technical Director
Project MICHIGAN

CONTENTS

FIGURES

TABLE

USE OF A LARGE THERMOCOUPLE JUNCTION TO LOCATE TEMPERATURE DISTURBANCES[1]

ABSTRACT

A temperature disturbance within a large thermocouple junction produces a voltage which decreases with distance from the disturbance. With proper junction geometry, resulting voltage residues may be compared at two or more points on the junction. Positions and magnitudes of temperature disturbances are thereby determined. Useful measurement applications result.

1
INTRODUCTION

This report describes a unique use of a common sensing device—the thermocouple. Unlike the customary thermocouple junction, which measures temperature at a point, the large thermocouple junction locates temperature disturbances within the junction. A temperature disturbance at a point located on a large thermocouple junction will produce currents which fall off with distance from disturbance. Residual potential differences between selected leads indicate the location of the disturbance.

The voltage residues so produced can be used advantageously for a number of measuring applications. These include measurement of the magnitude and position of discrete heat sources, liquid level, fluid mixing, velocity gradients, and temperature equilibrium over a continuum. A large thermocouple may also be used to measure the atmospheric turbulence which deteriorates infrared and radar information in combat surveillance.

Analysis of the voltage potentials in a large thermocouple junction and confirming experiments are presented in this paper.

2
ANALYSIS

A special case of the large thermocouple junction is shown in Figure 1. This is a long junction, electrically equivalent to a transmission line.

---

[1] The author appreciates the help of W. C. Meecham and V. L. Larrowe for discussions and suggestions concerning this work.

The transmission-line equation

$$E_o = E_x \operatorname{sech} \sqrt{RG}\, x \tag{1}$$

where E_x is voltage generated

E_o is output voltage at end of junction

R is resistance per unit length of element

x is the distance from source to end of junction

G is conductance per unit length between elements

describes the voltage decrement from the disturbance to the end of a long junction.

A large thermocouple junction may be viewed as a number of nonadditive point thermocouple junctions placed along a transmission line. A temperature disturbance causes a voltage to be generated at one of these points. This voltage decreases with distance along the junction due to current leakage between elements.

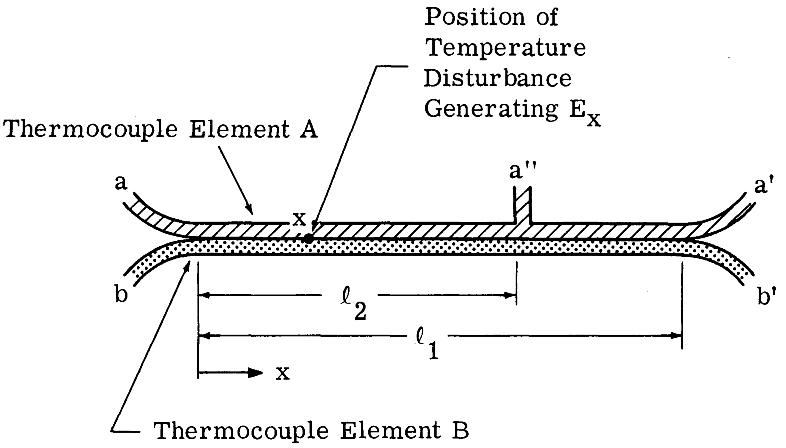

FIGURE 1. CONSTRUCTION OF LONG THERMOCOUPLE

Figure 1 illustrates a long thermocouple junction constructed by twisting, soldering or fusing two wires together. Five fixed leads are shown in Figure 1: a, a', a'', b, b', four located at the junction ends and one at a distance from an end. If a temperature disturbance occurs at point x, generating a voltage E_x, the two leads from the left end of the junction will produce a voltage difference of $E_x \operatorname{sech}\sqrt{RG}\, x$.

Since elements A and B may have different values of resistance per unit length, a reference voltage level of $\frac{R_b}{R_a + R_b} E_x$ above element B at point x is taken (see Appendix A). R_a is resistance per unit length for element A, and R_b for element B. Letting $\sqrt{RG} = K$, the voltages $E_{a'}$, $E_{a''}$, $E_{a'''}$, $E_{b'}$, $E_{b''}$, at locations indicated by the subscript, follow:

$$E_a = \frac{R_a}{R_a + R_b} E_x \operatorname{sech} Kx \tag{2}$$

$$E_{a'} = \frac{R_a}{R_a + R_b} E_x \operatorname{sech} K(\ell_1 - x) \tag{3}$$

$$E_{a''} = \frac{R_a}{R_a + R_b} E_x \operatorname{sech} K(\ell_1 - x) \cosh K(\ell_1 - \ell_2) \qquad x < \ell_2 \tag{4}$$

$$E_{a''} = \frac{R_a}{R_a + R_b} E_x \operatorname{sech} Kx \cosh K\ell_2 \qquad x > \ell_2 \tag{4a}$$

$$E_b = - \frac{R_b}{R_a + R_b} E_x \operatorname{sech} Kx \tag{5}$$

$$E_{b'} = - \frac{R_b}{R_a + R_b} E_x \operatorname{sech} K(\ell - x) \tag{6}$$

The voltage differences between leads are readily found by subtracting the value at one lead from the value at another. For instance, the voltage difference between lead a and lead a' is

$$E_a - E_{a'} = \frac{R_a}{R_a + R_b} E_x \left[\operatorname{sech} Kx - \operatorname{sech} K(\ell_1 - x)\right] \tag{7}$$

A voltage difference of zero occurs at $x = \frac{1}{2}\ell_1$.

For the two-dimensional junction of the voltage decrement is described by the equation

$$E_0 \simeq E_x \sqrt{\frac{2}{\pi\sqrt{rg}\ x}}\, e^{-\sqrt{rg}\ x} \tag{8}$$

for large value of x when edge effects are ignored (see Appendix B). r is resistance per unit square, g conductance per unit area. Thus, if the junction in Figure 2 extends sufficiently beyond the edges shown, the voltage difference between two leads on element A at the corners c, d is

$$E_c - E_d = \sqrt{\frac{2}{\pi\sqrt{rg}}}\, E_x \left(\frac{e^{-\sqrt{rg}\, x_c}}{\sqrt{x_c}} - \frac{e^{-\sqrt{rg}\, x_d}}{\sqrt{x_d}} \right) \tag{9}$$

Also,

$$E_e - E_f = \sqrt{\frac{2}{\pi\sqrt{rg}}}\, E_x \left(\frac{e^{-\sqrt{rg}\, x_e}}{\sqrt{x_e}} - \frac{e^{-\sqrt{rg}\, x_f}}{\sqrt{x_f}} \right) \tag{9a}$$

Thus a location on a plane may be found.

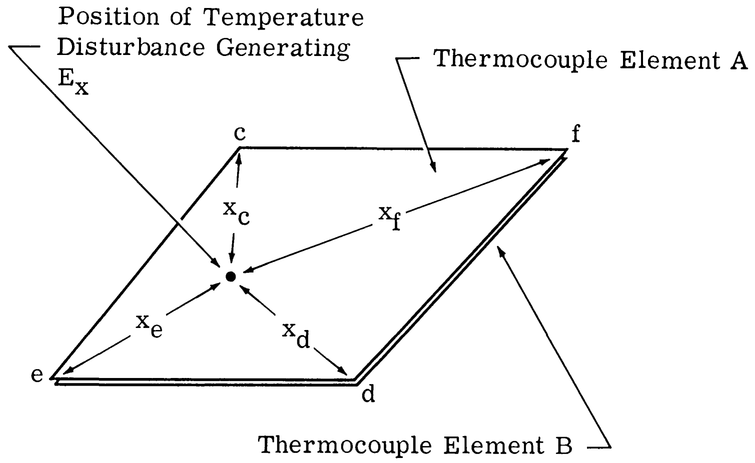

FIGURE 2. CONSTRUCTION OF A LARGE THERMOCOUPLE OF TWO FLAT ELEMENTS. Distance from point x to leads c, d, e, f shown at corners of element A.

3
EXPERIMENTS

Five experiments were performed to confirm the basic idea of using a large junction for position measurement, and to explore its applicability to several measurement applications. These experiments were preliminary in the sense that they were only intended to explore the measurement possibilities of a large thermocouple junction, and they do not exhaust the possible applications of this device. Ultimate sensitivity and accuracy were not investigated, nor were refinements for particular applications. Therefore, such techniques as linearizing by varying resistance or conductance in the junction, using many leads along a junction, using focused radiation for a heat source, or varying the impedances of the measuring instruments were beyond the scope of this effort.

Measurements were made with a Leeds and Northrup K-potentiometer and a 2430-A galvanometer in all but the fluid-mixing experiment, for which a Consolidated Electrodynamics Model 5-116 oscillograph with a 5-315 galvanometer was employed.

3.1. DISCRETE HEAT SOURCE APPLIED TO AN UNHEATED LONG JUNCTION

A discrete heat source was applied at various positions along junctions approximately 10 cm long. Voltage residue differences between pairs of the four end leads were plotted against the positions of the heat source. These experiments were performed to determine the dependence of voltage outputs on heat position and to give a basis to the above theory.

Long thermocouples were constructed of iron-constantan elements by twisting or soldering two parallel wires. Three wire sizes were used. The junction rested upon a large aluminum block insulated by 0.001-inch Mylar tape. Heat was conducted to a small portion of the couple through a wire attached to a 60-watt soldering iron. A lathe bed was used to position the heat source.

Results are shown in Figures 3 and 4 in the form of millivolt outputs between various pairs of leads plotted as functions of heat source position. In each case, the output is seen to be dependent upon the position of the applied heat source. In Figure 3, the voltage between two end leads of the same element ($E_a - E_{a'}$ of Figure 1) is of similar magnitude and opposite polarity when heat is applied at opposite ends of the couple. A null voltage occurs when the temperature disturbance is near the center. This corresponds to Equation 7. In Figure 4, the voltage between leads of opposite elements at one end of the long couple ($E_a - E_b$ of Figure 1) is at a maximum when heat is applied at this end. As predicted in Equations 2 and 3, the voltage decreases as the heat source moves toward the opposite end. Figure 4 also shows the voltage between opposing elements at opposite ends of the junction ($E_a - E_{b'}$ of Figure 1). With heat at one end, the voltage is relatively large. Its lowest value is near the center, and its maximum value is at $x = \ell_1$. Since element B (constantan) has a higher resistance than element A (iron), this result is expected considering Equations 2 and 6.

3.2. SMALL COOLING JET APPLIED TO A HEATED LONG JUNCTION

A long junction was heated for the purpose of locating heat conduction anomalies. This use of a heated junction extends the measuring possibilities to environments where no temperature disturbance normally exists. A small jet of air was placed on the junction at various distances from the ends. The cooled spot from the jet resulted in thermoelectric voltages of opposite polarities from those found in Type 1 experiments.

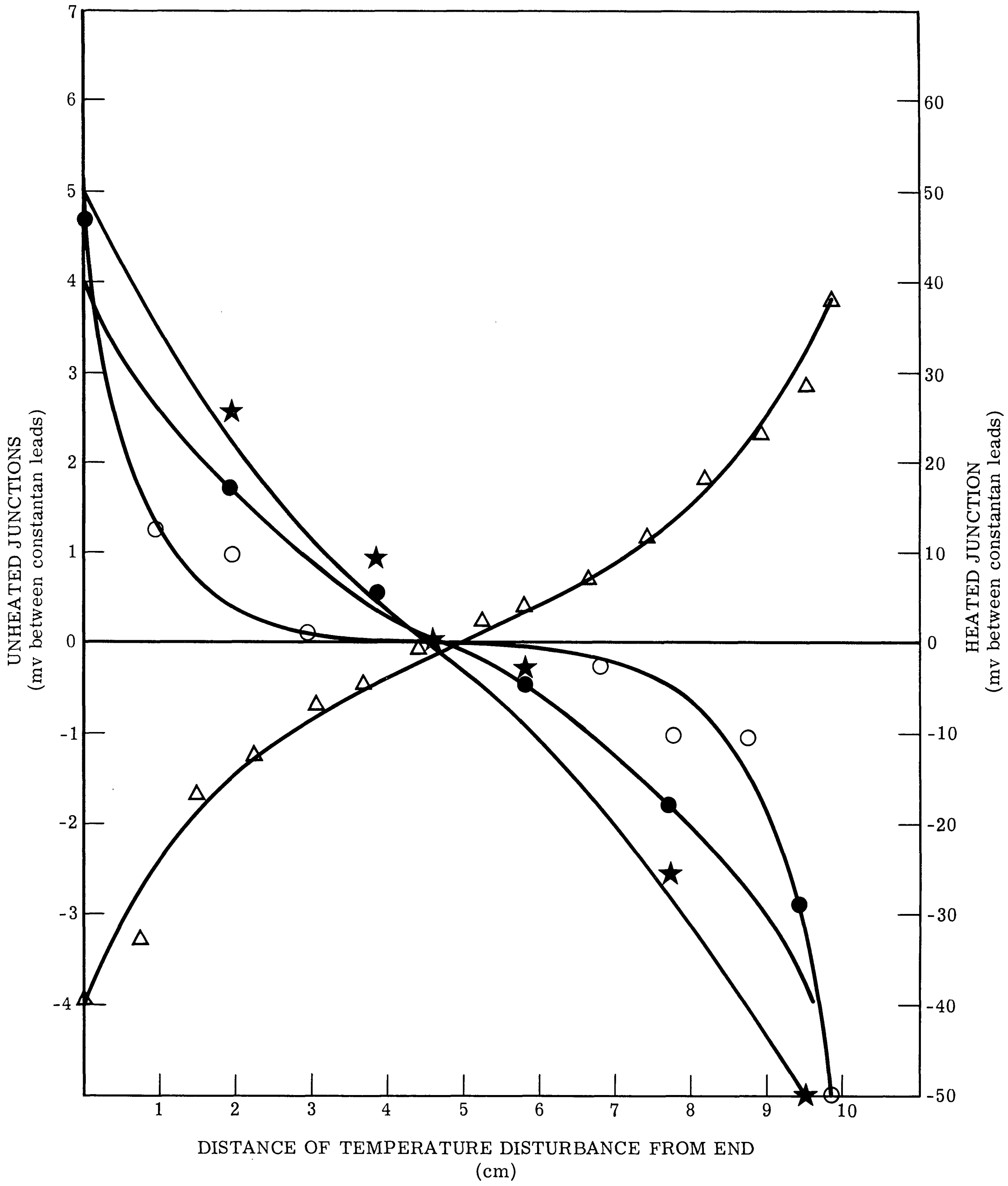

FIGURE 3. LONG IRON-CONSTANTAN THERMOCOUPLE VOLTAGE DIFFERENCES BETWEEN CONSTANTAN LEADS AT EACH END

Heated by metal contact	○ 30 B & S gauge, twisted, unbonded ● 24 B & S gauge, twisted, unbonded ★ 20 B & S gauge, twisted, unbonded
Cooled by 0. 5-cm-diameter air jet	△ 30 B & S gauge, not twisted, soldered, heated by 1. 25-amp, 1000-cps current

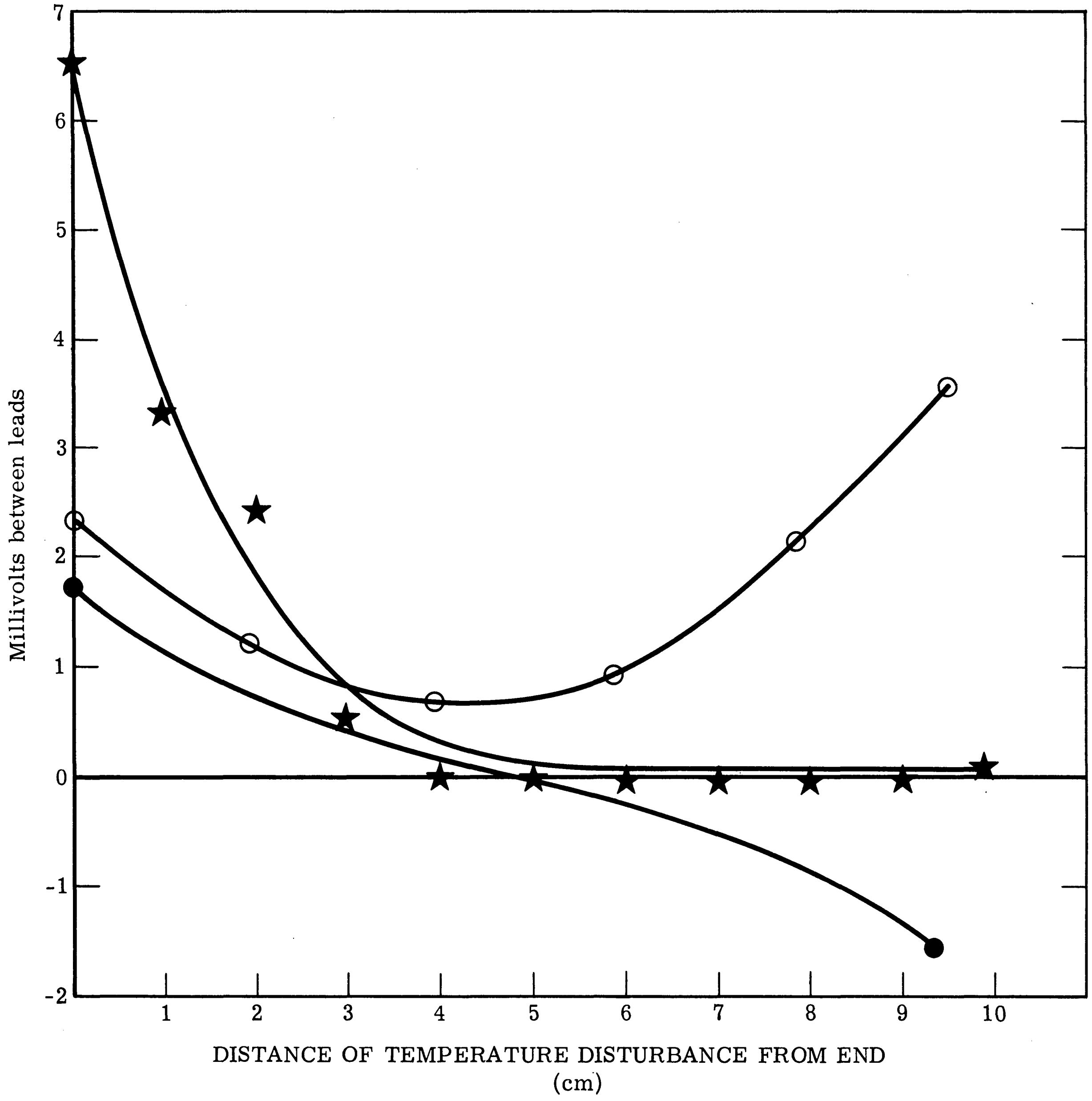

FIGURE 4. LONG IRON-CONSTANTAN THERMOCOUPLE VOLTAGE DIFFERENCES BETWEEN VARIOUS LEADS

★ 30 B & S gauge, twisted, unbonded, iron against constantan at end x = 0
○ 24 B & S gauge, twisted, unbonded, iron lead at x = 0, constantan lead at x = ℓ
● 20 B & S gauge, twisted, unbonded, iron lead at each end

Joule law heating (1.25 amp at a frequency of 1000 cps) was applied across the thermocouple junction. The air jet—0.5 cm in diameter with a velocity of 6.5 x 10^2 cm/sec—was positioned with a micrometer actuated lathe bed.

Figure 3 shows the output across the two constantan end leads as a function of position. These results are predicted by Equation 7, and indicate that the long thermocouple junction is capable of measuring other than temperature disturbances—in this case a fluid flow disturbance.

3.3. MIXING OF BOILING AND FREEZING WATER

The large thermocouple is particularly adapted to measuring gross temperature balance. To illustrate such an application, boiling and freezing water were stirred together until temperature equilibrium resulted.

Figure 5 is the reduction of an oscillograph time history of the temperature balance in the mixture. Two constantan end leads of a 30-gauge iron-constantan thermocouple 10 cm long were used. The mixing container was a 12 x 10 x 1 3/4-inch plastic tray. Temperature equilibrium was reached in 70 seconds. The temperature variations along the junction were of the same frequency as the mixing strokes.

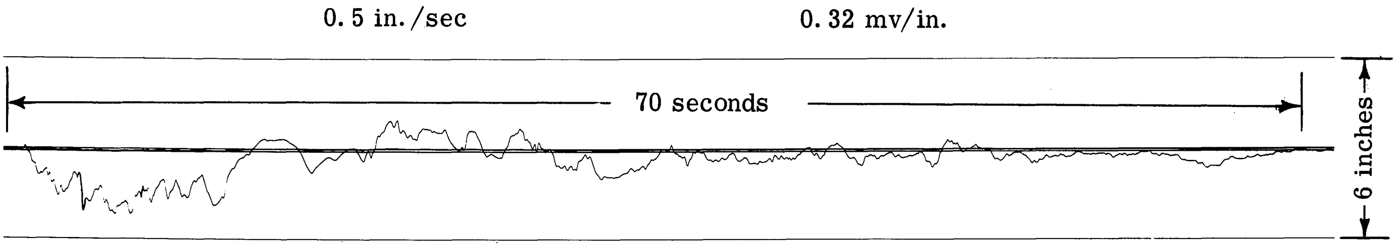

FIGURE 5. OSCILLOGRAPH TIME HISTORY OF LONG THERMOCOUPLE OUTPUT IN MIXING OF BOILING WITH 0°C WATER

Thus the degree of temperature balance over a continuum is shown. Its frequency, magnitude, polarity, and damping are indicated from a time history.

3.4. MEASUREMENT OF LIQUID LEVEL

A large thermocouple may be used to locate an interface between two substances. To illustrate this application, the water level in a container was measured by means of a heated long junction. Measurement was possible because the water-immersed portion of the junction cools faster than that remaining in air.

Again, Joule law heating (1.25 amp at a frequency of 1000 cps) was applied to the junction. The heated 30-gauge iron-constantan junction was supported vertically, and the water level was raised and lowered. Also, the results of minute water-level changes were observed. The resolution was limited by air currents in the room.

The results in Figure 6 show that the voltage output is a function of water level. A voltage output of the form $\frac{R_a}{R_a + R_b} E_x [1 - \text{sech}\, K(\ell - x)]$ is caused when end ab is immersed (see

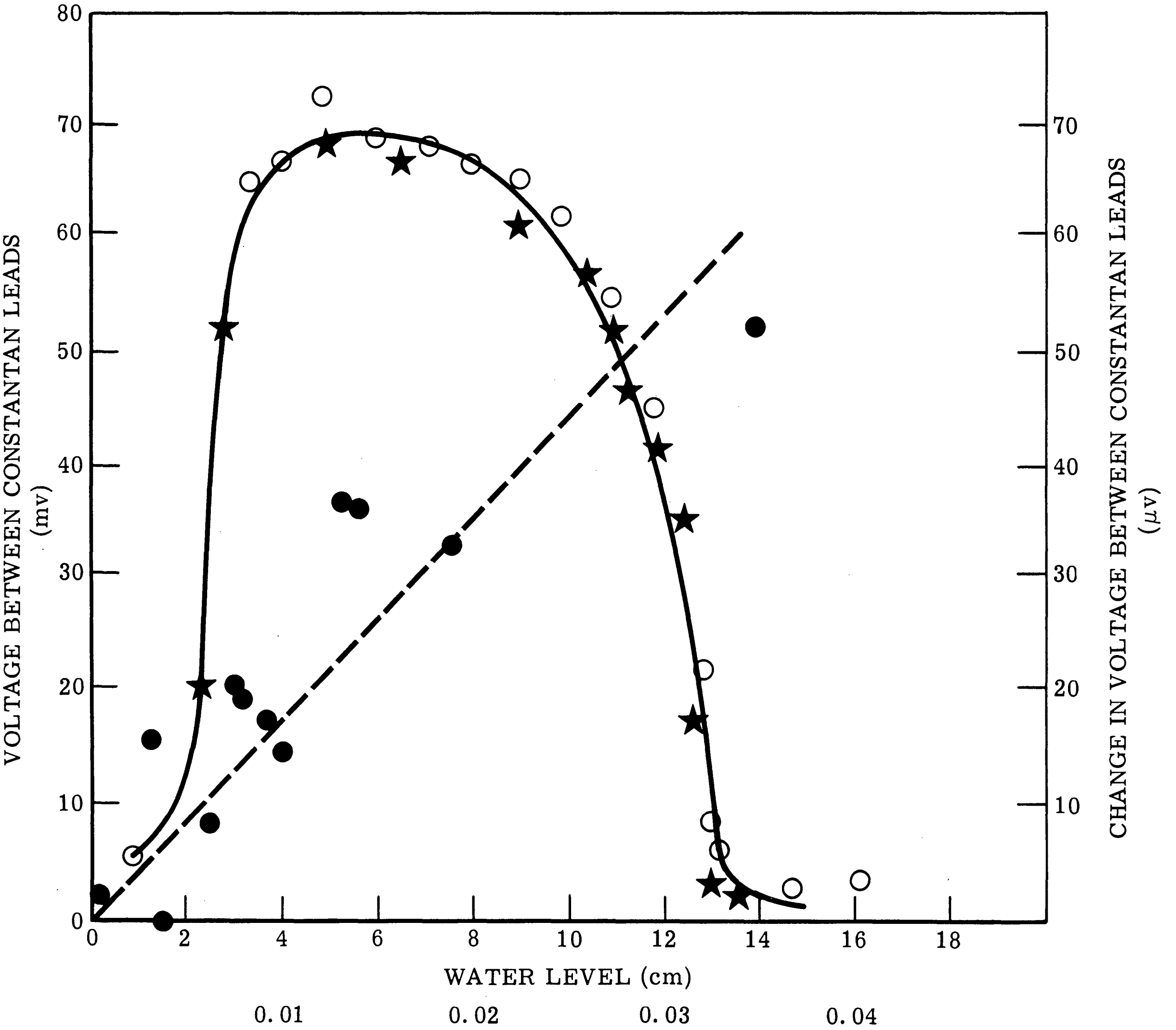

FIGURE 6. LONG IRON-CONSTANTAN THERMOCOUPLE WATER-LEVEL INDICATION

——— ○ Water level increased

★ Water level decreased

– – – ● Small change in water level (μv changes)

Figure 1). x is the position of the interface. Lead a (Figure 1) always responds as if the temperature disturbance were at x = 0, because the end of the junction is the same temperature as that close to the interface.

3. 5. DISCRETE HEAT-SOURCE LOCATION IN TWO DIMENSIONS

In this experiment temperature disturbances in two dimensions were investigated to demonstrate that the first four types of measurements can be extended to a surface from a length. In this case a rectangular plane was employed, but the type of surface does not appear limited. For example, a spherical or cylindrical surface could be employed.

A 1 x 0. 9-inch rectangle of 0. 001-inch Nichrome was taped to a commercial-grade aluminum plate. Copper-wire connections were taped to each corner of the Nichrome element. A sharpened 60-watt soldering-iron point was then placed at the indicated positions (Figure 2). The voltage outputs across the two opposite pairs of corners are recorded in Table I.

TABLE I. VOLTAGES ACROSS THE TWO DIAGONALS OF A 1 x 0. 9-INCH NICHROME-ALUMINUM THERMOCOUPLE

INCHES FROM CORNER	0	0. 2	0. 4	0. 6	0. 8	1. 0
0. 9	A: - .32 B: - 128. 0	+ 3. 85 - 14. 5	+ 5. 76 - 6. 72	+ 12. 2 - 3. 85	+ 30. 8 - 0. 64	+ 160. 0 + 2. 64
0. 8	A: - 4. 50 B: - 80. 0	- 7. 05 - 23. 2	+ 2. 63 - 6. 4	+ 12. 2 - 0. 64	+ 18. 0 - 1. 93	+ 128. 0 + 3. 22
0. 6	A: - 1. 28 B: + 1. 93	+ 0. 64 - 12. 2	+ 1. 28 - 8. 40	+ 3. 85 - 5. 14	+ 8. 00 - 0. 32	+ 4. 50 + 1. 24
0. 4	A: - 3. 80 B: - 6. 73	- 2. 30 - 3. 80	0 - 5. 10	+ 2. 30 - 1. 93	+ 4. 17 + 0. 64	+ 9. 62 + 2. 63
0. 2	A: - 12. 8 B: - 0. 96	- 10. 25 - 3. 52	- 4. 50 - 0. 64	+ 1. 93 + 1. 28	0 + 3. 70	+ 1. 93 + 8. 66
0	A: - 48. 2 B: + 3. 80	- 20. 0 0	- 10. 25 + 3. 80	- 11. 0 + 9. 60	- 4. 80 + 27. 0	+ 3. 20 + 145. 0

INCHES FROM CORNER

Boxes indicate position of applied heat.
A is voltage between 0, 0 and 1, 0. 9.
B is voltage between 0, 0. 9 and 1, 0.

This rough experiment indicates that position measurement is possible on a surface as well as on a length. It is thus concluded that a temperature disturbance corresponding to a point on the surface of a large thermocouple can be located by means of voltage residues.

4
DISCUSSION

These preliminary experiments introduce the kinds of measurements possible with the large thermocouple junction. However, they also expose several limitations and difficulties.

Because of the nature of the voltage decrement, linearity is difficult to achieve. Two approaches are possible. First, a relatively low resistance and low conductance in a junction allows the use of only a small portion of the decrement. Thus, as shown in Figure 2, the curve referring to the largest diameter of thermocouple (lowest resistance) is the closest to a linear curve. The second approach is to adjust the resistance or conductance so that the value $(RG)^{1/2}$ in Equation 1 varies with distance x in such a manner that $\operatorname{sech} \sqrt{RG}x = 1 - Kx$, where K is a constant.

The experiments also indicate that accuracy depends upon the type of junction and the uniformity of heat conduction to the junction. Thus, the twisted and unbonded junctions produce more erratic data points than the straight, soldered junction. The variations in conductivity between the elements and the difficulty of reproducing heater conduction to the twisted wires degrade the data.

Additional limitations are caused by the finite width of the heat source, conduction of heat along the junction, and the difficulty in maintaining constant temperature over the nondisturbed portion of the junction. These provide obvious obstacles to accuracy.

Appendix A
VOLTAGE REFERENCE FOR A LONG THERMOCOUPLE

The voltage decrements are unequal in two elements with different resistivities. As distance from the generating point is increased, the voltage in each element approaches asymptotically a voltage level which serves as a reference voltage for the entire length of the junction. At the position of this reference voltage, current flows only perpendicularly from one element to the other. The voltage generated in element A is E_a, and in element B the voltage is E_b. As the reference voltage level is somewhere between E_a and E_b, E_a is positive, and E_b is negative when element A is positive with respect to element B.

The propagation constant for element A is $(R_aG_a)^{1/2}$, and for element B is $(R_bG_b)^{1/2}$ As the form of the voltage decrement is the same in each element, the following equality holds at the end of the junction:

$$\operatorname{sech}\left(R_aG_a\right)^{1/2}x = \operatorname{sech}\left(R_bG_b\right)^{1/2}x$$

where x is the distance to the temperature disturbance from the junction end.

From this,

$$R_aG_a = R_bG_b \tag{10}$$

The size of the voltage decrement in each element is determined by the magnitudes of E_a and E_b.

The change in current along the junction is due to conductance between the elements, and is therefore equal in magnitude in both elements. The current change is the voltage at x divided by the characteristic resistance:

$$dI_x = -\frac{E_a \operatorname{sech}\left(R_aG_a\right)^{1/2}x \cosh\left(R_aG_a\right)^{1/2}x\,dx}{\left(R_a/G_a\right)^{1/2}} = \frac{E_b \operatorname{sech}\left(R_bG_b\right)^{1/2}x \cosh\left(R_bG_b\right)^{1/2}x\,dx}{\left(R_b/G_b\right)^{1/2}} \tag{11}$$

where x is the distance of the temperature disturbance from the measuring end of the junction. The sech function represents the voltage decrease from x to the end of the junction, and the cosh function represents the voltage increase from the end of the junction to the variable distance x.

Through the differentiation of Equation 2 and the use of Equation 1 to remove the hyperbolic functions, it is found that

$$\frac{\left(R_aG_a\right)^{1/2}}{\left(R_a/G_a\right)^{1/2}} E_a = - \frac{\left(R_bG_b\right)^{1/2}}{\left(R_b/G_b\right)^{1/2}} E_b$$

and therefore,

$$\frac{E_a}{E_b} = - \frac{G_b}{G_a} = - \frac{R_a}{R_b}$$

As the generated voltage is

$$E_x = E_a - E_b = E_a\left(1 + \frac{R_b}{R_a}\right)$$

then

$$E_a = \frac{R_a}{R_a + R_b} E_x$$

and

$$E_b = - \frac{R_b}{R_a + R_b} E_x$$

Appendix B
VOLTAGE DECREMENT FOR A LARGE FLAT THERMOCOUPLE

The voltage decrement between two infinite plates of resistance r per square and conductance g per unit area is derived as follows.

An annulus; with center at the voltage source position, with radial thickness Δx, and average circumference $2\pi x$, is considered. The resistance from the inner to the outer edge of the annulus is $r\Delta x/2\pi x$, giving a voltage drop of $\Delta E = -I(r\Delta x/2\pi x)$; so that, in the limit, $dE/dx = -Ir/2\pi x$, where I is current from the inner to the outer edge of the annulus. The conductance is $g\Delta x 2\pi x$, giving current between the plates of $\Delta I = Eg\Delta x 2\pi x$ in the annulus; in the limit, this becomes

$$\frac{dI}{dx} = - Eg2\pi x$$

as

$$x\frac{dE}{dx} = - \frac{Ir}{2\pi}$$

$$\frac{d}{dx}\left(x\frac{dE}{dx}\right) = -\frac{dI}{dx}\frac{r}{2\pi} = Rg\,xE$$

and

$$\frac{d^2E}{dx^2} + \frac{1}{x}\frac{dE}{dx} - rgE = 0.$$

Let

$$x' = i\sqrt{rg}x$$

$$dx = \frac{dx'}{i\sqrt{rg}}$$

where $i = \sqrt{-1}$. Then

$$-\ rg\frac{d^2E}{dx'^2} - \frac{rgdE}{x'dx'} - rgE = 0$$

When the common factor (- rg) is removed, the solutions of this equation are Bessel functions.

The solution for x large is found by the real part of the Hankel functions.

$$AH_0^{(1)} + BH_0^{(2)}$$

The real part of $H_0^{(1)}$ is

$$iH_0^{(1)} = \left[iJ_0(i\sqrt{rgx}) + iN_0(i\sqrt{rgx})\right]$$

$$\simeq i\left[\sqrt{\frac{2}{\pi\sqrt{rgix}}}\exp\,(ii\sqrt{rgx})\ \exp - \frac{i\pi}{4}\right]$$

$$\simeq i\left[\sqrt{\frac{2}{\pi\ \sqrt{rgx}}}\exp\ \ (-\sqrt{rgx}\ \ \frac{\exp\left(-i\frac{\pi}{4}\right)}{\sqrt{i}}\right]$$

as

$$\frac{\exp\left(i\frac{\pi}{4}\right)}{\sqrt{i}} = \frac{1}{i}$$

$$iH_0^{(1)} \simeq \sqrt{\frac{2}{\pi\sqrt{rgx}}}\exp\,(-\sqrt{rgx})$$

and as $H_0^{(2)} = J_0(i\sqrt{rgx}) - iN_0(i\sqrt{rgx})$ diverges, B = 0, and $A = E_0$. Therefore,

$E_x \simeq E_0\sqrt{\frac{2}{\pi\sqrt{rgx}}}\exp\,(-\ \sqrt{rgx})$, for x large.

PROJECT MICHIGAN DISTRIBUTION LIST 7
1 January 1961 — Effective Date

Copy No. Addressee

1 Army Research Office, ORCD, DA
Washington 25, D. C.
ATTN: Research Support Division

2-3 Commanding General
U. S. Army Combat Surveillance Agency
1124 N. Highland Street
Arlington 1, Virginia

4-40 Commanding Officer
U. S. Army Signal Research & Development Laboratory
Fort Monmouth, New Jersey
ATTN: SIGFM/EL-DR

41 Commanding General
U. S. Army Electronic Proving Ground
Fort Huachuca, Arizona
ATTN: SIGPG-DXP

42 Commanding General
Quartermaster Research & Engineering Command
U. S. Army, Natick, Massachusetts

43 Chief, Human Factors Research Division
Office of the Chief of Research & Development
Department of the Army, Washington 25, D. C.

44-45 Commander, Army Rocket & Guided Missile Agency
Redstone Arsenal, Alabama
ATTN: Technical Library, ORDXR-OTL

46-47 Commanding Officer
U. S. Army Transportation Research Command
Fort Eustis, Virginia
ATTN: Research Reference Center

48 Commanding General
Army Medical Research & Development Command
Main Navy Building, Washington 25, D. C.
ATTN: Neuropsychiatry & Psychophysiology
Research Branch

49 Commanding Officer, Ordnance Weapons Command
Rock Island, Illinois
ATTN: ORDOW-GN

50-53 Director, U. S. Army Engineer
Research & Development Laboratories
Fort Belvoir, Virginia
(50) ATTN: Chief, Topographic Engineer Department
(51-52) ATTN: Chief, Electrical Engineering Department
(53) ATTN: Technical Documents Center

54 Commandant, U. S. Army War College
Carlisle Barracks, Pennsylvania
ATTN: Library

55 Commandant, U. S. Army Command & General
Staff College
Fort Leavenworth, Kansas
ATTN: Archives

Copy No. Addressee

56 Commandant, U. S. Army Infantry School
Fort Benning, Georgia
ATTN: Combat Developments Office

57-58 Assistant Commandant
U. S. Army Artillery & Missile School
Fort Sill, Oklahoma

59 Assistant Commandant, U. S. Army Air Defense School
Fort Bliss, Texas

60 Commandant, U. S. Army Engineer School
Fort Belvoir, Virginia
ATTN: ESSY-L

61 Commandant, U. S. Army Signal School
Fort Monmouth, New Jersey
ATTN: SIGFM/SC-DO

62 Commandant, U. S. Army Aviation School
Fort Rucker, Alabama
ATTN: CDO

63-64 President, U. S. Army Intelligence Board
Fort Holabird, Baltimore 19, Maryland

65 Commanding Officer, U. S. Army Signal Electronic
Research Unit, P. O. Box 205
Mountain View, California

66-69 Office of Naval Research, Department of the Navy
17th & Constitution Avenue, N. W.
Washington 25, D. C.
(66-67) ATTN: Code 463
(68-69) ATTN: Code 461

70 The Hydrographer, U. S. Navy Hydrographic Office
Washington 25, D. C.
ATTN: Code 4100

71 Chief, Bureau of Ships
Department of the Navy, Washington 25, D. C.
ATTN: Code 690

72-73 Director, U. S. Naval Research Laboratory
Washington 25, D. C.
ATTN: Code 2027

74 Commanding Officer, U. S. Navy Ordnance Laboratory
Corona, California
ATTN: Library

75 Commanding Officer & Director
U. S. Navy Electronics Laboratory
San Diego 52, California
ATTN: Library

76-77 Department of the Air Force, Headquarters, USAF
Washington 25, D. C.
ATTN: AFOIN-1B1

78 Commander in Chief, Headquarters
Strategic Air Command, Offutt Air Force Base, Nebraska
ATTN: DINC

Distribution List 7, 1 January 1961 — Effective Date

Copy No.	Addressee
79	Aerospace Technical Intelligence Center U. S. Air Force Wright-Patterson AFB, Ohio ATTN: AFCIN-4B1a, Library
80-89	ASTIA (TIPCR) Arlington Hall Station, Arlington 12, Virginia
90-98	Commander, Wright Air Development Division Wright-Patterson AFB, Ohio (90-93) ATTN: WWDE (94) ATTN: WWAD-DIST (95) ATTN: WWRDLP-2 (96-98) ATTN: WWRNOO (Staff Physicist)
99-100	Commander, Rome Air Development Center Griffiss AFB, New York (99) ATTN: RCOIL-2 (100) ATTN: RCWIP-3
101-103	Commander, AF Command & Control Development Division Laurence G. Hanscom Field Bedford, Massachusetts ATTN: CCRHA-Stop 36
104	APGC(PGTRI) Eglin Air Force Base, Florida
105-108	Central Intelligence Agency 2430 E Street, N. W. Washington 25, D. C. ATTN: OCR Mail Room
109-114	National Aeronautics & Space Administration 1520 H Street, N. W. Washington 25, D. C.
115	Combat Surveillance Project Cornell Aeronautical Laboratory, Inc. Box 168, Arlington 10, Virginia ATTN: Technical Library
116	The RAND Corporation 1700 Main Street Santa Monica, California ATTN: Library
117-118	Cornell Aeronautical Laboratory, Inc. 4455 Genesee Street Buffalo 21, New York ATTN: Librarian VIA: Bureau of Naval Weapons Representative 4455 Genesee Street Buffalo 21, New York
119-120	Director, Human Resources Research Office The George Washington University P. O. Box 3596, Washington 7, D. C. ATTN: Library
121	Chief, U. S. Army Air Defense Human Research Unit Fort Bliss, Texas ATTN: Library
122	Chief, U. S. Army Armor Human Research Unit Fort Knox, Kentucky ATTN: Security Officer
123	Chief, U. S. Army Infantry Human Research Unit P. O. Box 2086 Fort Benning, Georgia
124	Chief, USA Leadership Human Research Unit P. O. Box 2086, Presidio of Monterey, California
125	Chief Scientist, Department of the Army Office of the Chief Signal Officer Research & Development Division, SIGRD-2 Washington 25, D. C.
126	Columbia University Electronics Research Laboratories 632 W. 125th Street New York 27, New York ATTN: Technical Library VIA: Commander, Rome Air Development Center Griffiss AFB, New York ATTN: RCKCS
127	Coordinated Science Laboratory University of Illinois, Urbana Illinois ATTN: Librarian VIA: ONR Resident Representative 605 S. Goodwin Avenue Urbana, Illinois
128	Polytechnic Institute of Brooklyn 55 Johnson Street Brooklyn 1, New York ATTN: Microwave Research Institute Library VIA: Air Force Office of Scientific Research Washington 25, D. C.
129	Visibility Laboratory Scripps Institution of Oceanography University of California, San Diego 52, California VIA: ONR Resident Representative, University of California Scripps Institution of Oceanography, Bldg. 349 La Jolla, California
130	U. S. Army Aviation, Human Research Unit U. S. Continental Army Command P. O. Box 428, Fort Rucker, Alabama
131	Cooley Electronics Laboratory University of Michigan Research Institute Ann Arbor, Michigan ATTN: Director
132	U. S. Continental Army Command Liaison Officer, Project MICHIGAN The University of Michigan P. O. Box 618, Ann Arbor, Michigan
133	Commanding Officer, U. S. Army Liaison Group, Project MICHIGAN The University of Michigan P. O. Box 618, Ann Arbor, Michigan

AD Div. 30/5

Institute of Science and Technology, U. of Michigan, Ann Arbor
USE OF A LARGE THERMOCOUPLE JUNCTION TO LOCATE TEMPERATURE DISTURBANCES by Philip L. Jackson. Rept. of Project MICHIGAN. Jan 61. 14 p. incl. table, illus.
(Rept. no. 2900-218-R)
(Contract DA-36-039 SC-78801) Unclassified report

A temperature disturbance within a large thermocouple junction produces a voltage which decreases with distance from the disturbance. With proper junction geometry, resulting voltage residues may be compared at two or more points on the junction. Positions and magnitudes of temperature disturbances are thereby determined. Useful measurement applications result.

(over)

UNCLASSIFIED

I. Title: Project MICHIGAN
II. Jackson, Philip L.
III. U. S. Army Signal Corps
IV. Contract DA-36-039
SC-78801

Armed Services
Technical Information Agency
UNCLASSIFIED

AD Div. 30/5

Institute of Science and Technology, U. of Michigan, Ann Arbor
USE OF A LARGE THERMOCOUPLE JUNCTION TO LOCATE TEMPERATURE DISTURBANCES by Philip L. Jackson. Rept. of Project MICHIGAN. Jan 61. 14 p. incl. table, illus.
(Rept. no. 2900-218-R)
(Contract DA-36-039 SC-78801) Unclassified report

A temperature disturbance within a large thermocouple junction produces a voltage which decreases with distance from the disturbance. With proper junction geometry, resulting voltage residues may be compared at two or more points on the junction. Positions and magnitudes of temperature disturbances are thereby determined. Useful measurement applications result.

(over)

UNCLASSIFIED

I. Title: Project MICHIGAN
II. Jackson, Philip L.
III. U. S. Army Signal Corps
IV. Contract DA-36-039
SC-78801

Armed Services
Technical Information Agency
UNCLASSIFIED

AD Div. 30/5

Institute of Science and Technology, U. of Michigan, Ann Arbor
USE OF A LARGE THERMOCOUPLE JUNCTION TO LOCATE TEMPERATURE DISTURBANCES by Philip L. Jackson. Rept. of Project MICHIGAN. Jan 61. 14 p. incl. table, illus.
(Rept. no. 2900-218-R)
(Contract DA-36-039 SC-78801) Unclassified report

A temperature disturbance within a large thermocouple junction produces a voltage which decreases with distance from the disturbance. With proper junction geometry, resulting voltage residues may be compared at two or more points on the junction. Positions and magnitudes of temperature disturbances are thereby determined. Useful measurement applications result.

(over)

UNCLASSIFIED

I. Title: Project MICHIGAN
II. Jackson, Philip L.
III. U. S. Army Signal Corps
IV. Contract DA-36-039
SC-78801

Armed Services
Technical Information Agency
UNCLASSIFIED

AD Div. 30/5

Institute of Science and Technology, U. of Michigan, Ann Arbor
USE OF A LARGE THERMOCOUPLE JUNCTION TO LOCATE TEMPERATURE DISTURBANCES by Philip L. Jackson. Rept. of Project MICHIGAN. Jan 61. 14 p. incl. table, illus.
(Rept. no. 2900-218-R)
(Contract DA-36-039 SC-78801) Unclassified report

A temperature disturbance within a large thermocouple junction produces a voltage which decreases with distance from the disturbance. With proper junction geometry, resulting voltage residues may be compared at two or more points on the junction. Positions and magnitudes of temperature disturbances are thereby determined. Useful measurement applications result.

(over)

UNCLASSIFIED

I. Title: Project MICHIGAN
II. Jackson, Philip L.
III. U. S. Army Signal Corps
IV. Contract DA-36-039
SC-78801

Armed Services
Technical Information Agency
UNCLASSIFIED

AD

UNCLASSIFIED

DESCRIPTORS

Thermocouples
Oscillographs
Voltage
Temperature

UNCLASSIFIED

AD

UNCLASSIFIED

DESCRIPTORS

Thermocouples
Oscillographs
Voltage
Temperature

UNCLASSIFIED

AD

UNCLASSIFIED

DESCRIPTORS

Thermocouples
Oscillographs
Voltage
Temperature

UNCLASSIFIED

AD

UNCLASSIFIED

DESCRIPTORS

Thermocouples
Oscillographs
Voltage
Temperature

UNCLASSIFIED

AD Div. 30/5

Institute of Science and Technology, U. of Michigan, Ann Arbor
USE OF A LARGE THERMOCOUPLE JUNCTION TO LOCATE TEMPERATURE DISTURBANCES by Philip L. Jackson. Rept. of Project MICHIGAN. Jan 61. 14 p. incl. table, illus.
(Rept. no. 2900-218-R)
(Contract DA-36-039 SC-78801) Unclassified report

A temperature disturbance within a large thermocouple junction produces a voltage which decreases with distance from the disturbance. With proper junction geometry, resulting voltage residues may be compared at two or more points on the junction. Positions and magnitudes of temperature disturbances are thereby determined. Useful measurement applications result.

(over)

UNCLASSIFIED

I. Title: Project MICHIGAN
II. Jackson, Philip L.
III. U. S. Army Signal Corps
IV. Contract DA-36-039
SC-78801

Armed Services
Technical Information Agency
UNCLASSIFIED

AD Div. 30/5

Institute of Science and Technology, U. of Michigan, Ann Arbor
USE OF A LARGE THERMOCOUPLE JUNCTION TO LOCATE TEMPERATURE DISTURBANCES by Philip L. Jackson. Rept. of Project MICHIGAN. Jan 61. 14 p. incl. table, illus.
(Rept. no. 2900-218-R)
(Contract DA-36-039 SC-78801) Unclassified report

A temperature disturbance within a large thermocouple junction produces a voltage which decreases with distance from the disturbance. With proper junction geometry, resulting voltage residues may be compared at two or more points on the junction. Positions and magnitudes of temperature disturbances are thereby determined. Useful measurement applications result.

(over)

UNCLASSIFIED

I. Title: Project MICHIGAN
II. Jackson, Philip L.
III. U. S. Army Signal Corps
IV. Contract DA-36-039
SC-78801

Armed Services
Technical Information Agency
UNCLASSIFIED

AD Div. 30/5

Institute of Science and Technology, U. of Michigan, Ann Arbor
USE OF A LARGE THERMOCOUPLE JUNCTION TO LOCATE TEMPERATURE DISTURBANCES by Philip L. Jackson. Rept. of Project MICHIGAN. Jan 61. 14 p. incl. table, illus.
(Rept. no. 2900-218-R)
(Contract DA-36-039 SC-78801) Unclassified report

A temperature disturbance within a large thermocouple junction produces a voltage which decreases with distance from the disturbance. With proper junction geometry, resulting voltage residues may be compared at two or more points on the junction. Positions and magnitudes of temperature disturbances are thereby determined. Useful measurement applications result.

(over)

UNCLASSIFIED

I. Title: Project MICHIGAN
II. Jackson, Philip L.
III. U. S. Army Signal Corps
IV. Contract DA-36-039
SC-78801

Armed Services
Technical Information Agency
UNCLASSIFIED

AD Div. 30/5

Institute of Science and Technology, U. of Michigan, Ann Arbor
USE OF A LARGE THERMOCOUPLE JUNCTION TO LOCATE TEMPERATURE DISTURBANCES by Philip L. Jackson. Rept. of Project MICHIGAN. Jan 61. 14 p. incl. table, illus.
(Rept. no. 2900-218-R)
(Contract DA-36-039 SC-78801) Unclassified report

A temperature disturbance within a large thermocouple junction produces a voltage which decreases with distance from the disturbance. With proper junction geometry, resulting voltage residues may be compared at two or more points on the junction. Positions and magnitudes of temperature disturbances are thereby determined. Useful measurement applications result.

(over)

UNCLASSIFIED

I. Title: Project MICHIGAN
II. Jackson, Philip L.
III. U. S. Army Signal Corps
IV. Contract DA-36-039
SC-78801

Armed Services
Technical Information Agency
UNCLASSIFIED

AD

UNCLASSIFIED

DESCRIPTORS

Thermocouples
Oscillographs
Voltage
Temperature

UNCLASSIFIED

AD

UNCLASSIFIED

DESCRIPTORS

Thermocouples
Oscillographs
Voltage
Temperature

UNCLASSIFIED

AD

UNCLASSIFIED

DESCRIPTORS

Thermocouples
Oscillographs
Voltage
Temperature

UNCLASSIFIED

AD

UNCLASSIFIED

DESCRIPTORS

Thermocouples
Oscillographs
Voltage
Temperature

UNCLASSIFIED