Pramāṇa, Vol. 22, No. 6, June 1984, pp. 567–572. Printed in India.

Automation of the direct current comparator resistance bridge

R AIDUN, R CATON and SIGURDS ARAJS
Department of Physics, Clarkson University, Potsdam, New York 13676

MS received 17 September 1983; revised 12 March 1984

Abstract. The direct current comparator resistance bridge, Model 9975, manufactured by Guildline Instruments, Inc., which permits electrical resistance measurements up to eight digits, has been fully automated. Details of this automation are described in this paper. The performance of the automated bridge is demonstrated with applications to electrical resistivity studies on some metallic alloys.

Keywords. Direct current comparator resistance bridge; electrical resistance; automation; metallic alloys.

1. Introduction

Electrical resistivity measurements of magnetic materials *vs* temperature can yield information about magnetic phase transitions. However, determination of the critical indices of electrical resistivity for these materials at their magnetic phase transition requires precision measurement of many data points in the neighbourhood of the transition. Furthermore, the determination of critical indices should be carried out in thermal equilibrium for each measured data point. For this purpose the heating rate must be very small ($\simeq$ 1 K/hr) in the region of transition. Therefore, each experimental run requires many hours of tedious, time-consuming data taking and transcribing which allows the possibility of human error.

In order to collect a continuous and precise data set in a convenient way (allowing the experimenter to pay closer attention to the more important aspects of the experiment), prevent human error and make a long experimental run possible we decided to automate our electrical resistivity measurement system.

2. Apparatus for electrical resistivity measurements

A conventional potentiometric method of measuring electrical resistance by the four-probe technique involves a comparison of the voltage drop across the sample with a standard cell. This requires four balance operations, two with normal currents and two with reversed currents, with a major disadvantage of undesirable thermal voltage transients generated while switching in the detector circuit. Also, the resolution and the accuracy obtainable in this method are limited and cannot be better than the stability of the currents in the resistors under test and in the potentiometer.

The apparatus used is the direct current comparator resistance bridge, Model 9975, developed by Klusters and MacMartin (1970) and produced by Guildline Instruments, Inc. This comparator bridge compares four terminal resistors by measuring the current ratio corresponding to voltage drop equality. A current ratio, corresponding to a turns ratio, is maintained by a self-balancing d.c. comparator and is adjustable in ppm steps. The two current sources are isolated so that, at balance, there is no current in the potential circuit. The bridge reads the resistance ratio—resistance under test to a standard resistance—(R_x/R_s) directly. Therefore, this technique greatly eliminates the problems associated with a conventional potentiometric method and increases the precision in electrical resistivity measurements up to eight digits.

3. Automation

The bridge consists of eight rotary switches on the front panel, each of which, at balance, represents one of the eight significant digits of the resistance ratio. Each switch reads from -1 to 10 with 11 equally spaced, 30-degree positions. To take a precise set of electrical resistivity-temperature data one has to keep the bridge at balance by readjusting the eight R_x/R_s dials. At the same time, with the bridge at balance, the operator has to read out and record the thermocouple voltage and the R_x/R_s dials. Better precision can be obtained by shortening the delay between the two readings and also between two adjacent data points.

In order to automate the experiment a model DSP-1 microcomputer (S-100 Bus) was used with a mainframe manufactured by Ithaca Intersystem, Inc. It consists of a power supply, a mother board, front panel switches and a 4 MHz Z-80 microprocessor board. A combination of two memory boards (total of 56K) manufactured by Godbout Electronics was used. Both boards are designed to run full speed at 4 MHz. The microcomputer has been interfaced with three multimeters.

The microcomputer controls the five least significant R_x/R_s dials marked $\times 10^{-3}$ to $\times 10^{-7}$. To do this, the shaft of each rotary switch was attached to the shaft of one stepping motor by combination of two universal joints (figure 1). It was not necessary to automate all the eight dials because the three most significant R_x/R_s dials marked from $\times 1$ to $\times 10^{-2}$ are not varied often. Figure 2 is the block diagram of the system. A voltmeter is used to read the output of the comparator bridge galvanometer. This output is from 0 to 10 V for full scale deflection of the internal galvanometer. We define the bridge to be completely balanced when the voltage of the output is between $+2$ mV and -2 mV. The computer is given an initial reading of the last five R_x/R_s dials and achieves balance by sending positive or negative pulses to the proper stepping motors to turn the dials. The computer keeps track of all the changes in order to read the R_x/R_s dials. This process goes on until the voltmeter reading is between $+2$ mV and -2 mV, when the bridge is at balance. The nanovoltmeter reads the thermocouple (Pt-13 % Rh) voltage (temperature of the specimen), with 0.01 K resolution.

After the microcomputer balances the bridge it stores the R_x/R_s dial readings and the corresponding output of the thermocouple in its memory. The program which runs the experiment also keeps track of the time and thus the heating rate. Therefore, one point of data consists of the R_x/R_s value, the value of thermocouple voltage (temperature), the time of the reading, and other optional readings if necessary.

The main console for the system consists of a Lear Siegler ADM3A dumb terminal. The other I/O device is a Decwriter II manufactured by the Digital Equipment Co. This device is used mainly for generating hard copy output of the data points. Also, there is a

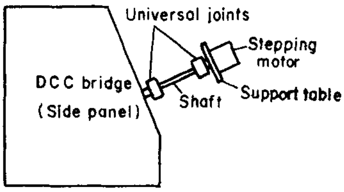

Figure 1. Side view of the direct current comparator resistance bridge and its accessories.

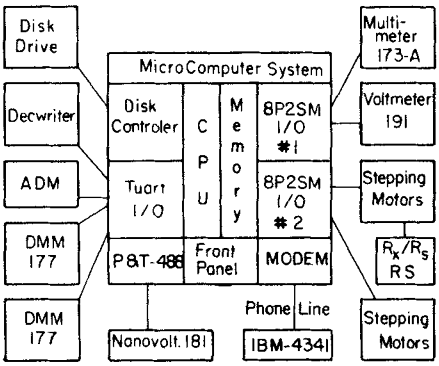

Figure 2. Block diagram of the system.

disk system, manufactured by North Star Co. that provides the necessary capability of saving and restoring the large number of data points and programs. For each reading the data is printed as a hard copy and stored in the computer memory simultaneously. Because of limited memory space each block of a hundred data points is stored on a disk and the computer memory is then ready to store new data. Figure 3 is the brief flow charge of the system's program.

4. Interface

There are two different types of serial/parallel *I/O* boards in this system. They are the TUART *I/O* board manufactured by Cromemco Inc. and the 8P2SM *I/O* board manufactured by Micro DaSys. A IEEE-488 Bus to S-100 Bus adaptor board manufactured by Pickles and Trout (P&T-488) allows the S-100 system to act as a talker, listener, or controller on the 488 Bus. This board is equipped with provisions for interrupt operation.

Three digital multimeters with in-house interfaces installed are serially interfaced through one of the parallel ports of the TUART board. Another digital multimeter with the parallel data output option installed provides electrically isolated binary coded decimal (BCD) output. The nanovoltmeter, with an interfaced option installed, is interfaced to the microcomputer by the IEEE-488 Bus. This is the only device in the system that uses the Bus, therefore it has been placed in the talk only mode. The interface board in the computer listens to the meter whenever the control program wants to read the meter.

As mentioned above, there are five stepping motors that control the last five R_x/R_s dials. These motors are controlled by 20 bits of parallel output from one of the 8P2SM boards. Each motor is driven by a pulse from a Darlington pair transistor switch (see

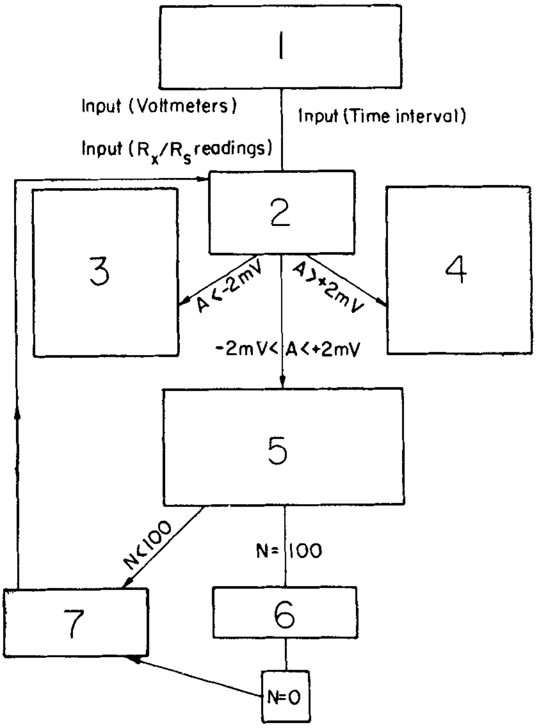

Figure 3. Program of the system. 1. Initiate all ports, variables, time, and IEEE-488 interface board, 2. Read the output of the bridge galvanometer A, 3. Decrease the R_x/R_s dial readings, 4. Increase the R_x/R_s dial readings, 5. Read the voltmeters in use, store readings, and corresponding R_x/R_s values, 6. Store the block of 100 data sets, 7. Delay for the determined time interval.

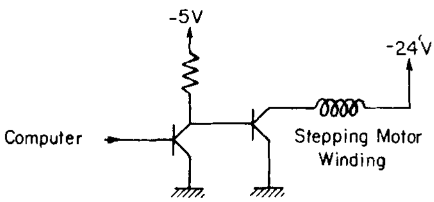

Figure 4. Darlington pair transistor and winding configuration of the stepping motor.

figure 4). Each switch is driven by a buffer board that receives its signal from the computer. By pulsing the motor's windings (each motor contains four windings) in the proper sequence it is possible to move the motors to a known position in either direction.

In order to interface the stepping motors to the R_x/R_s dials it is necessary to provide some sort of position sensing. This is due to the fact that the stepping motor turns 1.8 deg/step while the R_x/R_s dials turn 30° between adjacent positions. In order to turn the dials from one position to the next position it is necessary to move 16.67 steps of the stepping motor. Since it is not really possible to move fractions of a step, a round-off error occurs and accumulates rather rapidly when the system is running. To prevent this

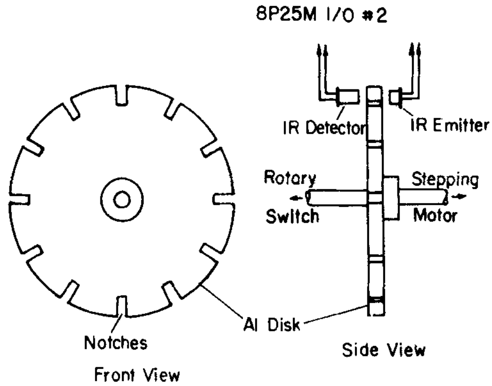

Figure 5. IR emitter and detector positions with the notched disk.

the shafts connecting the stepping motors to the R_x/R_s switches are fitted with aluminum disks that are notched at 30° intervals. On one side of the disk an IR emitter is mounted. An IR detector is mounted looking directly at, but on the other side of, the disk (see figure 5). By sensing the notches it is possible for the computer to accurately manipulate the R_x/R_s dials.

5. Results

We have made resistivity measurements of some metallic samples with this system and some of them are presented in figures 6 and 7. The data are reproducible and they are as accurate and precise as the data taken manually by the bridge. The data are stored on the disk with corresponding information such as the time of each data point reading of the bridge's galvanometer. The investigator receives information about the heating rate

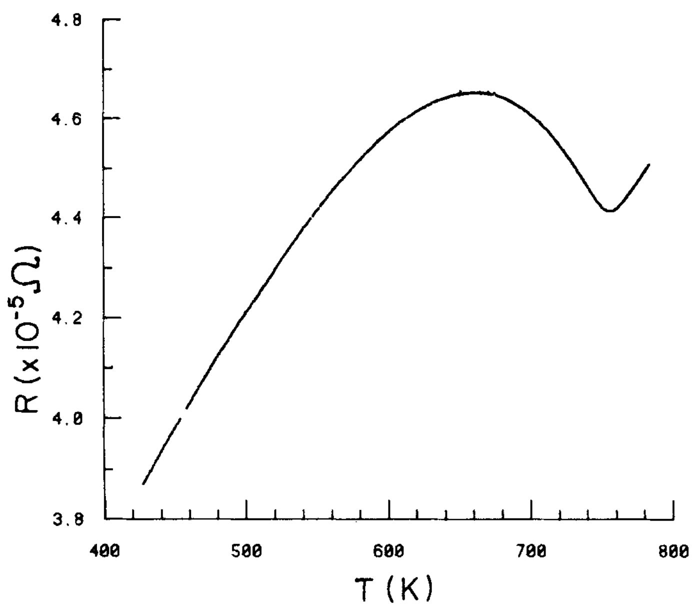

Figure 6. Electrical resistance of a sample of 16 at. % Mn in Cr alloy as a function of absolute temperature. The R vs. T curve contains about 2500 data points.

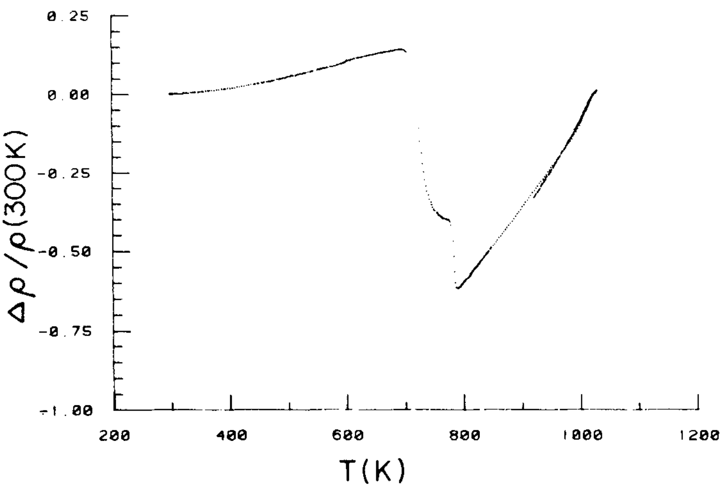

Figure 7. Relative change of the electrical resistivity of glassy metal $Fe_{83}B_{14}Si_3$ (with 21 ppm of N) undergoing crystallization as a function of the absolute temperature. $\Delta\rho = (T) - (300\,K)$, where $\rho(T)$ is the electrical resistivity at the absolute temperature T. Heating rate $\simeq$ (6–8) K/min. Data taken every 2 K.

and the accuracy of each data point. The microcomputer is interfaced with the Clarkson University computer model IBM-4341, making it possible for the investigator to transmit data to the large computer for further analysis such as differentiation and curve fitting, etc.

6. Conclusions

While the automation described above concentrated on the measurement of resistivity *vs* temperature by way of example, the use of the system can be quite general. The approach to automation reported here can be used for any experiment requiring the tedious operation of and data acquisition from a precision potentiometer or current comparator bridge. The advantages of this automated system are: faster data acquisition, reduced chance of error, storage of data on disk, and freeing the experimenter to concentrate on more important aspects of the experiment. The faster data acquisition allows one to accumulate more data at more closely-spaced intervals which is useful, for example, when precision curve fitting is required. During long data runs the chance of human error increases when performing tedious, precision, potentiometric measurements by hand; the automation eliminates errors of this sort (e.g., transcription of data errors). Having the data stored on disk allows for much more flexibility when analyzing large quantities of data. Perhaps the most important asset of the automation is that it frees the experimenter to concentrate on the flow of the experiment. During long runs it is quite possible to accumulate a large amount of useless data because a small detail was overlooked due to the fact that the experimenter's senses were totally absorbed in the tedious details of hand data acquisition. With this system such an event is much less likely.

Reference

Klusters N L and MacMartin M P 1970 *Trans. IEEE* **IM-19** 219