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MARINE METEOROLOGY

Modifications of the Airplane Psychrograph and Adaptation of the Humidity Strip to Airplane Soundings

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Director

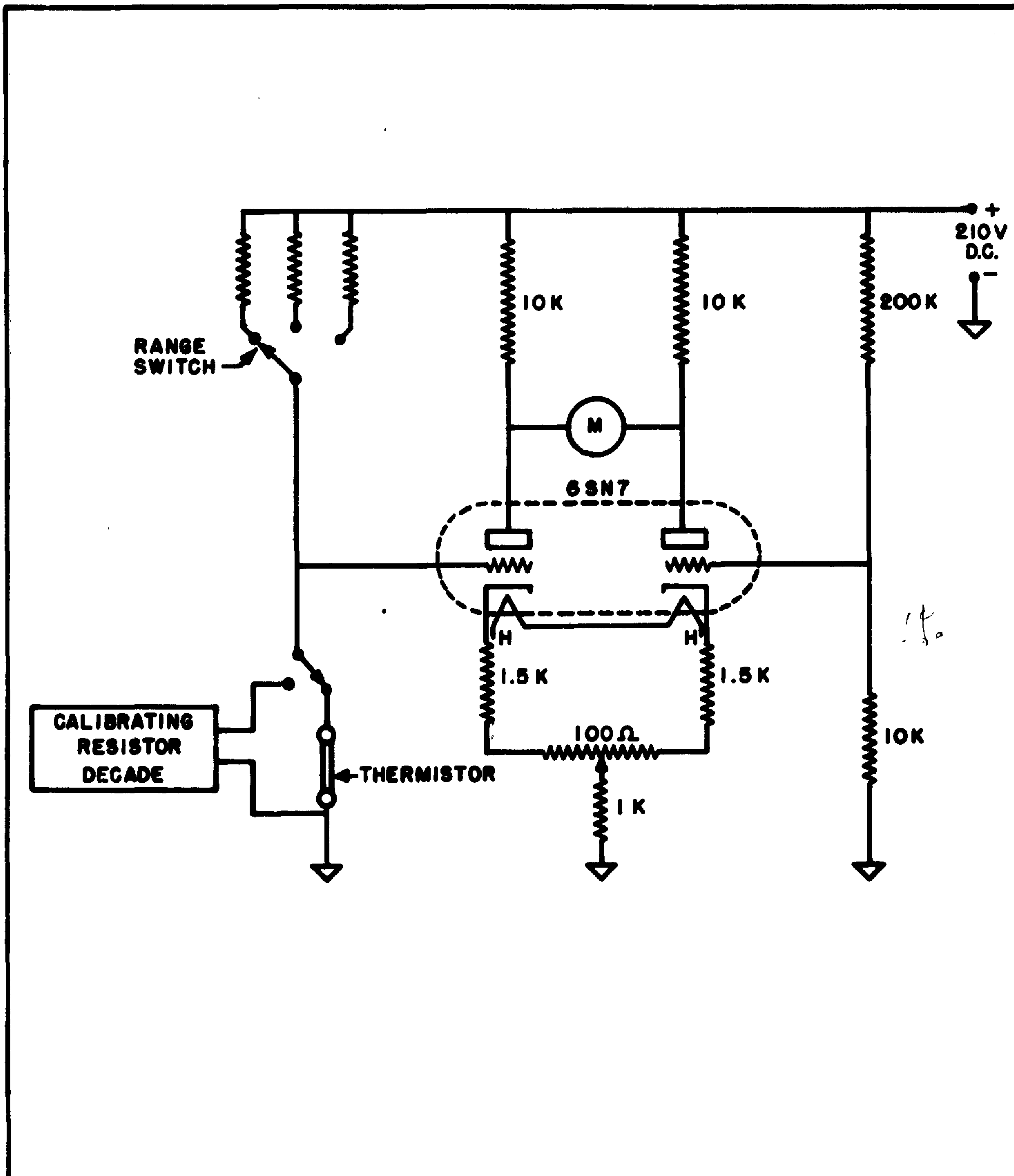
Introduction

The following is a brief history of the development of airplane hygrometry by the marine meteorology group at the Woods Hole Oceanographic Institution, including a more detailed description of its present status.

The primary requirement of the airborne equipment is that it furnish records of the vertical and horizontal distribution of temperature and water vapor in the lowest 5,000 feet of the atmosphere. Particular attention has been paid to the accuracy of measurement of water vapor to make possible studies of the accumulation and diffusion of water vapor through the atmosphere.

Modifications of the M. I. T. Psychrograph

The first airplane soundings, early in 1946, were made using an original M.I.T. psychrograph described by Katz (1) in connection with an Esterline Angus, 0-1 milliampere recording meter. For easy reference the basic circuit is shown in Figure 1. This instrument was later modified so as to reduce the voltage applied across the thermistors, thus reducing internal heating. The modification consisted of using parallel 6SN7 tubes in place of the single one, shunting the 1.5K cathode resistors with 1k resistors and reducing the bridge supply voltage from 210 to 105 V.D.C. It should be pointed out that the effect of internal heating of the thermistors with the original psychrograph was evident only at low ventilation speeds, as for instance, when making ground checks. The modification successfully



+
210V
D.C.
−
10K
10K
200K
RANGE
SWITCH
M
6SN7
H
H
1.5K
1.5K
100Ω
10K
1K
CALIBRATING
RESISTOR
DECADE
THERMISTOR

FIG. 1

reduced the heating with no loss in circuit stability.

While the psychrograph is generally satisfactory, it was desirable that further improvements in the system be made. For example, in rough air, the pen of the Esterline Angus recording meter would often lift from the paper and the ink drain back into the well. Thus, attention to the meter was required at the very time it was least easily afforded. (This situation can only be appreciated by someone who has tried to service an instrument which is mounted on the seat behind him in a violently bouncing light airplane). Furthermore, an airplane-mounted psychrograph cannot function properly for long with the air temperature below freezing. While measurements can be made with a frozen wick, the long thawing periods and heat releases upon freezing make the records uncertain and difficult to interpret.

In 1947 an attempt was made to extend the useful range of the wet and dry-bulb tecnhique to below-freezing temperatures so that the sounding program could be continued later into the fall, if not through the winter. It is notable here that while a dew-point recorder was available, the small size of the sounding plane, a Stinson Voyager, prohibited its use.

On the basis of the work of Lange (3) and others, a housing was constructed which contained an electric heater and the wet- and dry-bulb thermistors, so arranged that an air sample was heated to the extent that the wet-bulb temperature was above freezing. A third element, separately mounted, was switched into the recording circuit in sequence to record the temperature of the unheated air.

The first model of the heated psychrograph failed to function properly, probably due to the fact that the dry-bulb thermistor could "see" the heater and was overheated by radiation. In this model the wet-bulb water supply was kept from freezing by an immersed electric heater.

Another housing was then constructed which consisted of three connected ducts at right angles to each other. The first duct admitted the unheated air and contained a dry thermistor, the second contained the electric heater, while the third contained the dry- and wet-bulb thermistors and water supply. The general arrangement of this model is shown in Figure 2. Flight tests were then made when the air temperature was above freezing so that comparisons could be made between results obtained both with and without heating. Some typical tabulations are shown below in Table I. The apparent increase in water vapor content in the heated air may be due to improper mixing within the housing or to the fact that dynamic temperature corrections were made without taking into account the decreased density of the heated air.

Even though the heated psychrograph could undoubtedly have been improved, it was abandoned for the following reasons:

1. Since three temperatures, heated wet- and dry; and unheated dry-bulbs must be recorded by one meter, the rate-of-climb in a sounding had to be greatly reduced to preserve continuity.
2. The volume of air passing through the housing obviously changes with air speed with a consequent variation in the

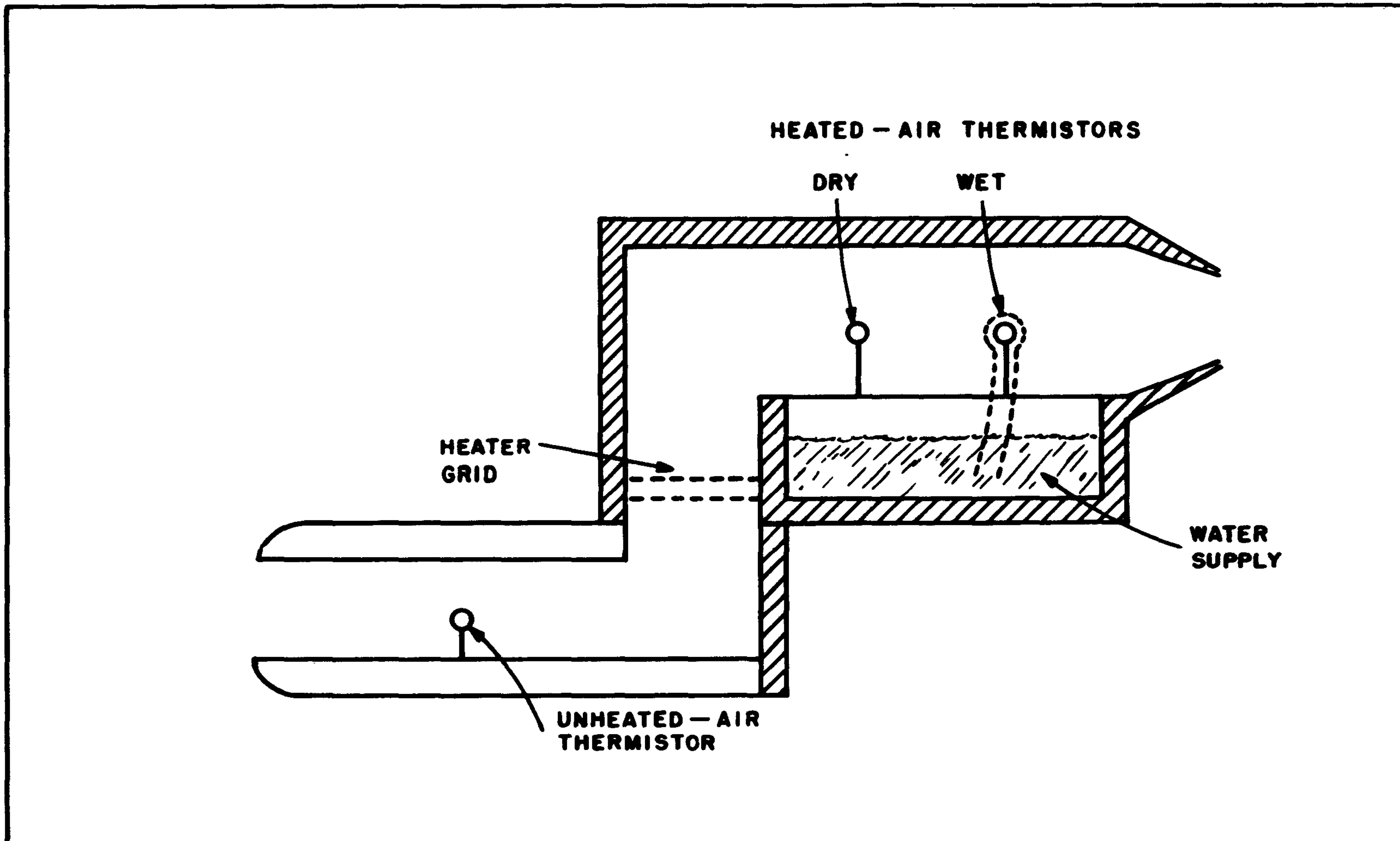

HEATED — AIR THERMISTORS
DRY
WET
HEATER
GRID
WATER
SUPPLY
UNHEATED — AIR
THERMISTOR

FIG. 2

Table I

Comparison of Mixing Ratio Values Determined with and without Heating of the Air

Comparison #1 - 2000 ft.

Corrected Dry-bulb °C	Corrected Wet-bulb °C		Mixing Ratio gm/kg
	No Heating		
12.1	6.1		3.8
11.5	5.7		3.7
11.2	5.6		3.7
		Average	3.73
	With Heating		
23.5	11.4		4.0
23.6	11.4		3.9
23.8	11.4		3.9
		Average	3.93

Comparison #2 - 1000 ft.

Corrected Dry-bulb °C	Corrected Wet-bulb °C		Mixing Ratio gm/kg
	No Heating		
8.5	5.9		4.85
8.7	6.1		4.90
8.7	6.2		4.95
8.9	6.3		5.00
		Average	4.92
	With Heating		
13.9	8.6		5.00
13.6	8.6		5.00
13.7	8.6		5.00
13.6	8.7		5.15
		Average	5.04

degree of heating. Therefore, it was often difficult to make fair comparisons of wet- and dry-bulb temperatures withour simultaneous records. This was particularly true with soundings made in rough air.

3. A device was made which automatically switched the heated dry-bulb thermistor to a more suitable recorder range. Even with this arrangement, however, the greatly increased spread between wet- and dry-bulb temperatures when heating already dry air sometimes required manual range switching.

The heated psychrograph cannot be recommended without qualification as an airborne humidity measuring device. In addition to the limitations mentioned above, the observer cannot easily recognize dry inversions, adiabatic lapse rates, etc., and is thus at a disadvantage in carrying out observing procedures. As a laboratory instrument, however, the heated psychrograph might prove to be useful in many cases.

Construction of a New Psychrograph

Concurrently with the above, a new psychrograph bridge was built to work into a recording meter which would function properly in turbulent flight. As the recorder a Leeds and Northrup Speedomax self-balancing potentiometer with a 5 millivolt full scale sensitivity was chosen. In addition to the mechanical advantage mentioned above, the inherent sensitivity of the recording potentiometer offers further advantages. For example, the new bridge circuit requires only 0.1 volt across the thermistor as against 10 volts in the original psychrograph, permitting the use of very small thermistors at low ventilation speeds with negligible errors due to internal heating. No vacuum tubes are necessary, and the power supply is a 1.5 volt dry cell, which are over-all simplifications. Also, the same recorder can be used in connection with the University of Chicago type dew-point apparatus described by Brissman (1)(2) for use in larger planes or at a fixed station.

The new psychrograph is similar to the M.I.T. original only in that the switching circuits are the same. Figure 3 shows the circuit diagram as used with wet- and dry-bulb thermistors. This instrument is in use at the present time. When the wet-bulb temperature falls below freezing, only the dry-bulb temperature is used.

Anyone wishing to construct a similar instrument should consider the temperature-resistance range of the thermistors to be used. The resistor values shown in Figure 3 are for use with thermistors 0.045" in diameter, 1" total length, 0.4" active length and with a nominal resistance of 800000 ohms at 20°C. These elements were made on special order by the Washington Institute of Technology.

Adaptation of the Humidity Strip to Airplane Soundings

As was pointed out previously, a dew-point recorder and its power supply are too large for the small airplane available and

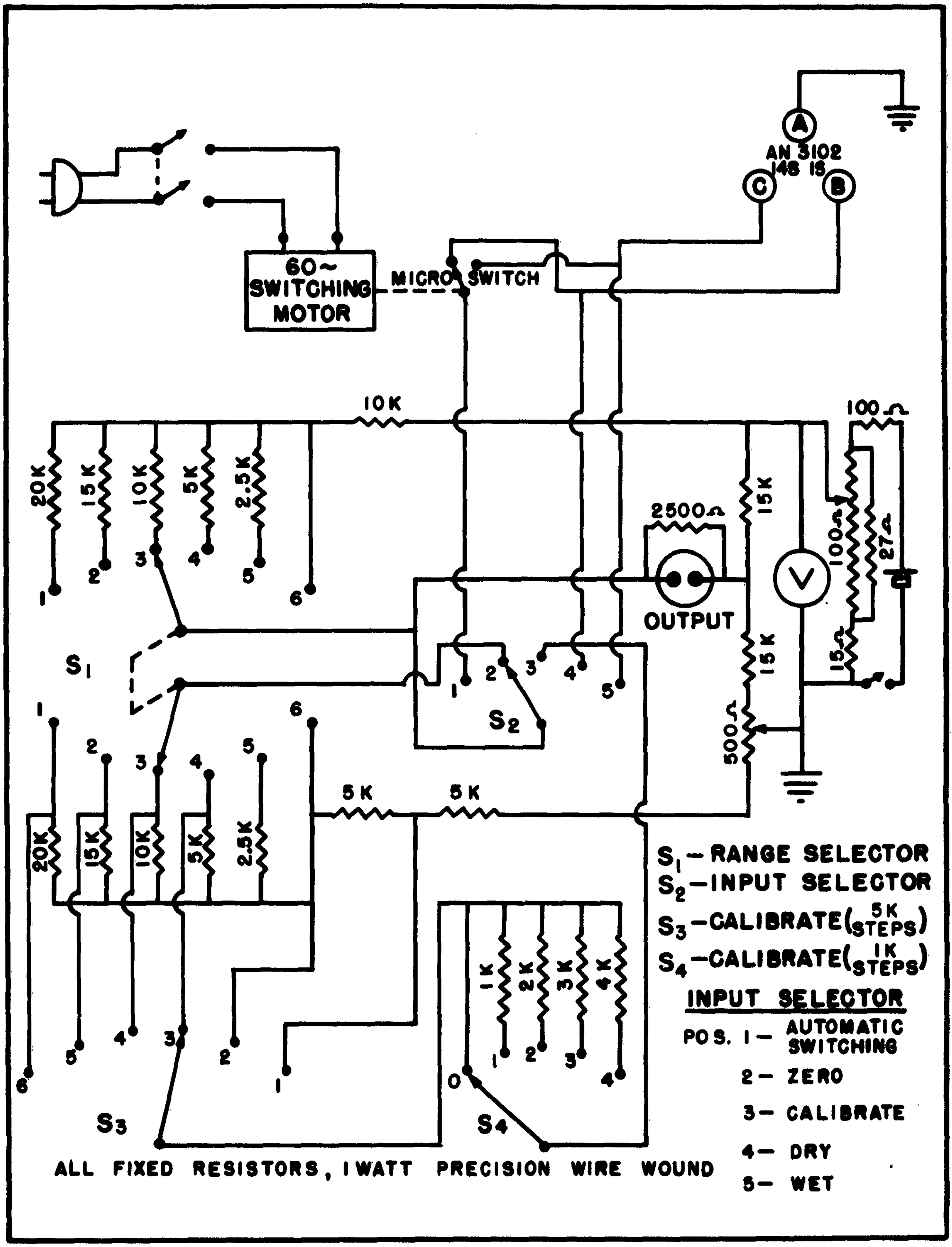

60~
SWITCHING
MOTOR
MICRO SWITCH
AN 3102
14S 1S
A
B
C
10K
20K
15K
10K
5K
2.5K
15K
2500Ω
100Ω
100Ω
27Ω
15Ω
OUTPUT
500Ω
S1
S2
S3
S4
5K
5K
1K
2K
3K
4K
S1 - RANGE SELECTOR
S2 - INPUT SELECTOR
S3 - CALIBRATE (5K STEPS)
S4 - CALIBRATE (1K STEPS)
INPUT SELECTOR
POS. 1 - AUTOMATIC SWITCHING
2 - ZERO
3 - CALIBRATE
4 - DRY
5 - WET
ALL FIXED RESISTORS, 1 WATT PRECISION WIRE WOUND

FIG.3

the psychrograph is not usable below freezing. Therefore, in preparation for winter soundings, testing and circuit building was begun in the past summer of 1950 using the radiosonde humidity strips manufactured by Bendix-Friez. The strips were connected in a bridge circuit and various sources of a.c. supply potential were tried. The first, a vacuum tube oscillator, either operated at too high a frequency or had poor wave form at low frequencies, the final effect being to produce a broad null at balance or changes in off-balance output with changes in stray capacitances.

A vibrator-type chopper supply was then tried and was quite successful but required considerable space and weight because transformers and condensers were required for wave shaping. Use of a small filament transformer to reduce the voltage from the 110 V, 60 cycle supply was not satisfactory due to poor regulation of the supply.

The final and successful system makes use of a small selsyn motor connected as an a.c. generator, the rotor of which is driven at a constant speed by the timing motor of the L & N recorder. The generator field is supplied from the primary power source which is a heavy duty storage battery. A small audio transformer is connected between the generator output and the bridge circuit to provide isolation and to increase the supply voltage from 1.5 volts to about 4 volts. The only further requirement was to provide a means of compensating for the gradual decrease of the storage battery output. This was accomplished by incorporating a standardizing switch and potentiometer into the circuit, as shown in the diagram in Figure 4. The peak voltage appearing across the bridge itself under operating conditions is 2.5. To facilitate range switching and standardizing, the circuit was built into a small box which is carried in the observer's lap during a sounding.

The humidity strip is mounted on a bracket which is easily attached to or removed from a strut of the airplane. A cover, made from a single layer of diaper cloth, is provided in order to prevent dust contamination of the strip. As can be seen in the photograph in Figure 5, the cover is stretched over a hinged framework is such a way that the strip is easily replaced. The hinge being well forward, no fastening is required to hold the cover down in flight.

It is important to mention that an absorbent screen should not normally be used around a humidity sensitive element. In our particular case, soundings are never made through liquid water drop clouds and the ventilation rate is very great. Successive ascents and descents through a humidity discontinuity level produce records that indicate no error due to the cloth screen.

In order to test the accuracy of the strips, comparisons have been made with a sling psychrometer as the standard. Also, comparisons against time were made to determine whether the strip was stable for use over periods of three or four hours. Results plotted in Figure 6 are indicative of the variation bet-

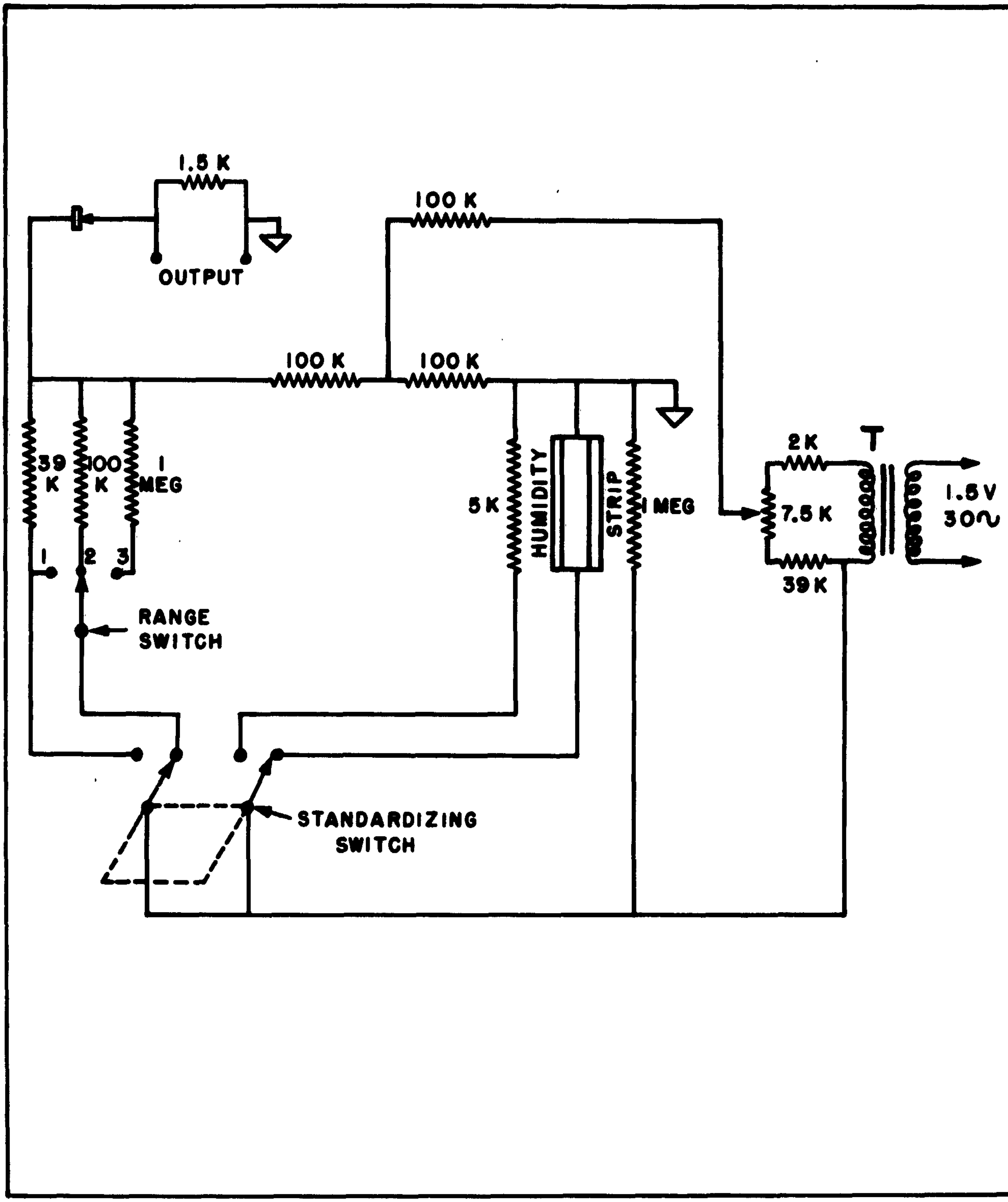

1.5 K
100 K
OUTPUT
100 K
100 K
39 K
100 K
1 MEG
5 K
HUMIDITY
STRIP
1 MEG
2 K
T
7.5 K
1.5 V
30~
39 K
1
2
3
RANGE SWITCH
STANDARDIZING SWITCH

FIG.4

FIG.5

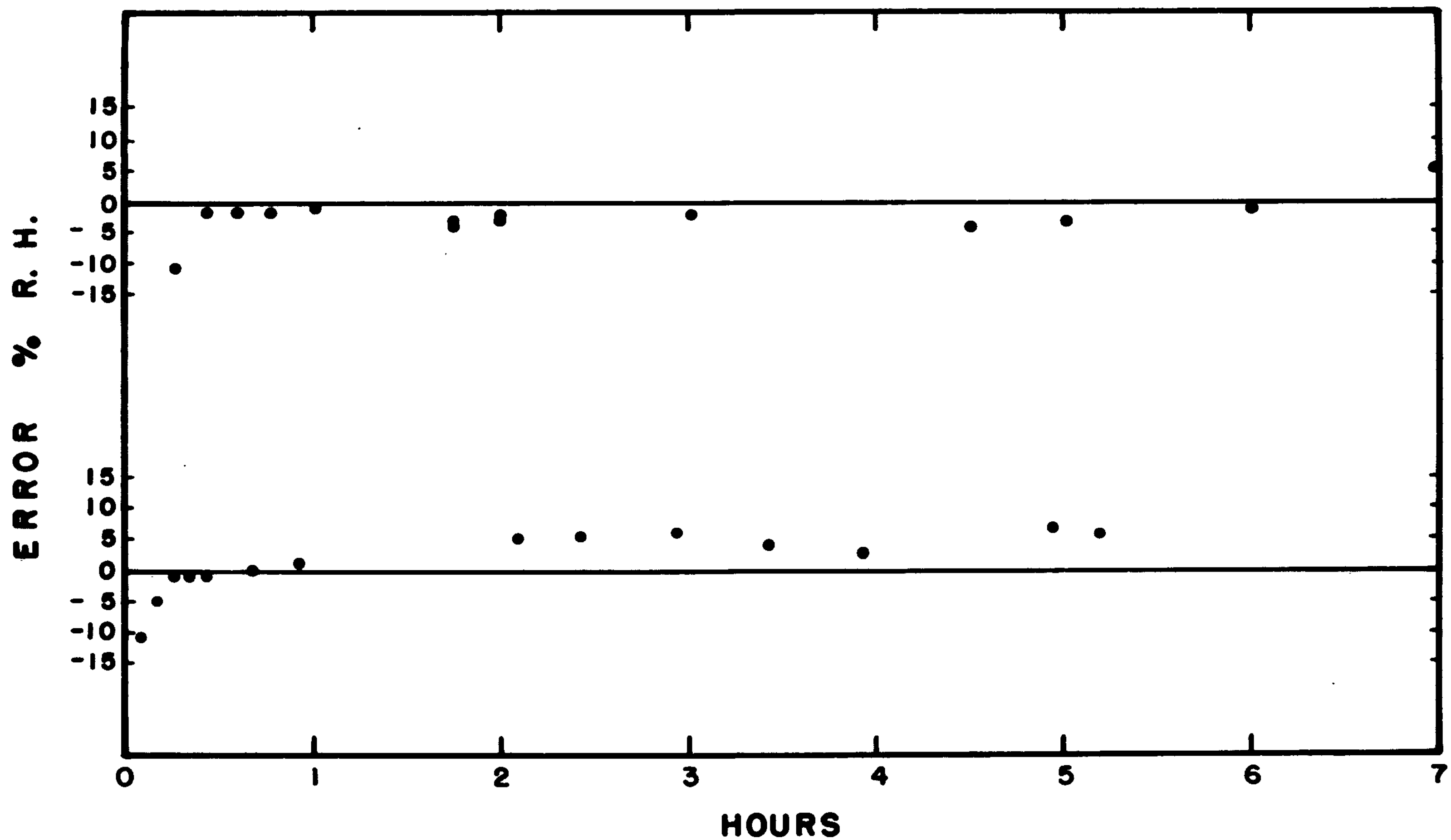


FIG. 6

ween strips, the change of indication with time, and the degree of accuracy.

Since both temperature and humidity must be considered in determining the lag of the humidity strip, quite an elaborate setup would be necessary to make lag determinations in the laboratory. A simpler but effective method was to fly the strip and recorder through a discontinuity of temperature and humidity in the free atmosphere. A reproduction of the record of one such flight is shown in Figure 7. As can be seen from an inspection of the humidity trace, approximately 45 seconds elapse between apparent equilibrium before and after the large change. While this is only a rough figure, it does establish an outer limit of lag under operating conditions.

No testing was done at saturation humidities since no observing is contemplated under those conditions.

Lagmeter

A device which has been useful in the determination of the lag coefficient of thermistors seems worthy of mention here.

The first so-called lagmeter was built at the M.I.T. Radiation Laboratory during the last war. As will be seen from the diagram in Figure 8, it simply consists of an adjustable voltage source, a multiple switch, a variable thermistor substitute, and suitable connectors.

In operation, the proper thermistor, recorder and power connections are made and the heat-record switch placed in the

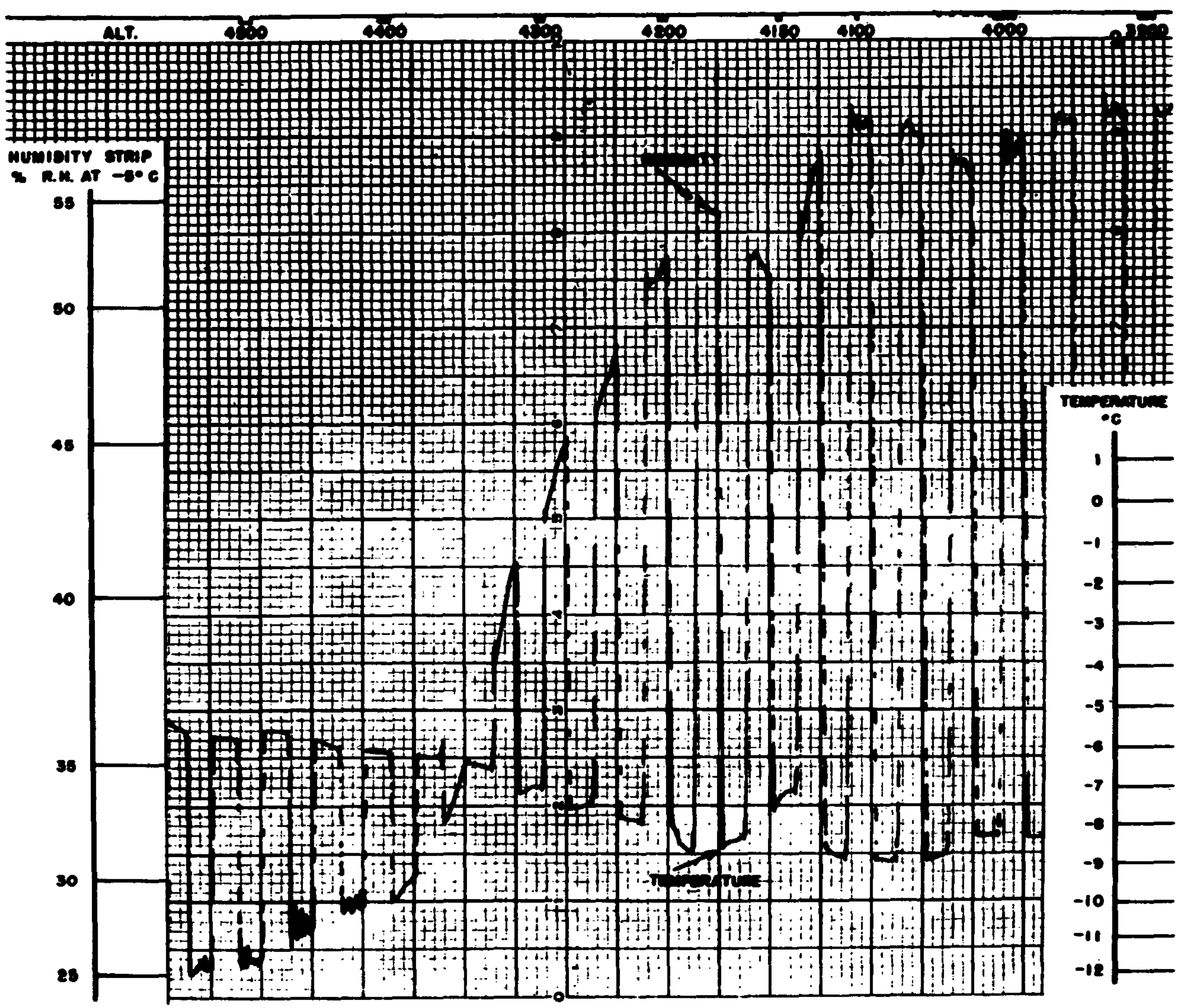

ALT.
4500
4400
4300
4200
4150
4100
4000
HUMIDITY STRIP
% R.H. AT −5° C
55
50
45
40
35
30
25
TEMPERATURE
°C
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
TEMPERATURE

FIG. 7

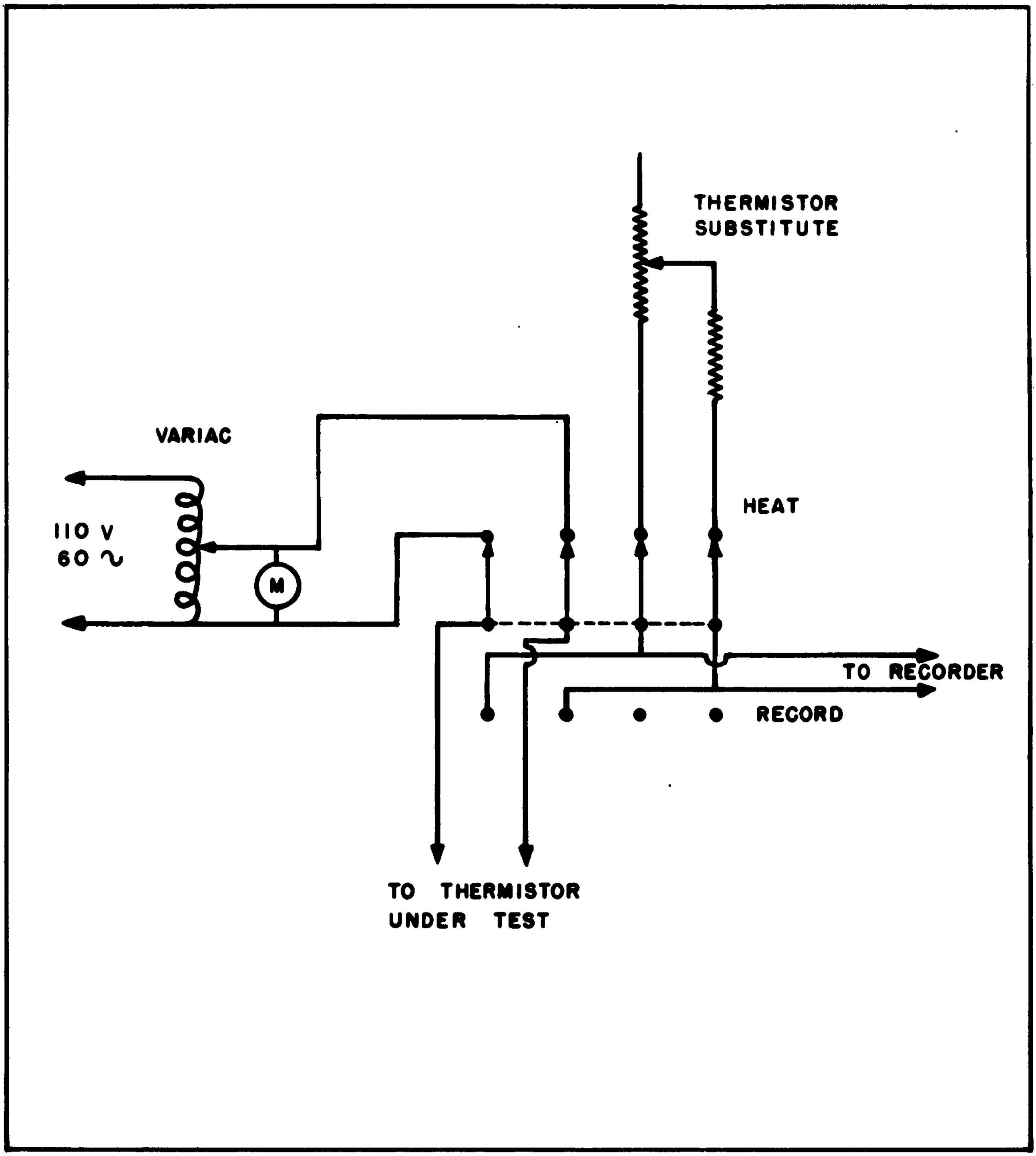

THERMISTOR
SUBSTITUTE
VARIAC
110 V
60 ∿
M
HEAT
TO RECORDER
RECORD
TO THERMISTOR
UNDER TEST

FIG.8

"record" position. The recording system is then adjusted so that the recorder trace is near the bottom of its scale. With the heating voltage turned very low or off the switch is thrown to "heat" and the thermistor substitute adjusted so that the recorder trace is near the top of the scale. Now, with the thermistor operating under test conditions, the heating voltage is turned up slightly and after a few seconds the switch is placed at "record". This process is repeated until the recorder trace at the start of cooling is at the top of the scale. It is obvious that the response of the recorder itself must not be a limiting factor and that the chart speed be constant and fast enough for analysis.

It is understood that the conditions of heating with the lagmeter are different from those where the thermistor is immersed in mediums of different temperatures and that the tests are limited to the cooling time only. However, comparison of results by the lagmeter and more conventional methods show no significant difference.

An advantage of this system is that tests can be made under actual operating conditions. This is of practical importance in view of the fact that even though lag coefficients may be known for various ventilation speeds, the ventilation speed itself at the point occupied by the thermistor under operating conditions is not usually known.

The writer wishes to point out that much of the development described was due to the efforts of Andrew F. Bunker and Donald Parson, Jr., of this group.

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