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The CANADIAN RADIOSONDE

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THE ADAPTATION OF THE CANADIAN RADIOSONDE TO RAWINSONDE

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A REFRIGERATED PRESSURE CALIBRATION CHAMBER FOR THE CANADIAN RADIOSONDE

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DEVELOPMENTS IN THE CANADIAN RADIOSONDE

by

H.H. BINDON

The subject of my talk this evening is concerned with some late developments in the Canadian Radiosonde. Before proceeding to the main subject, it may be well to examine the Radiosonde system from first principles. Your attention is directed to Fig. 1.

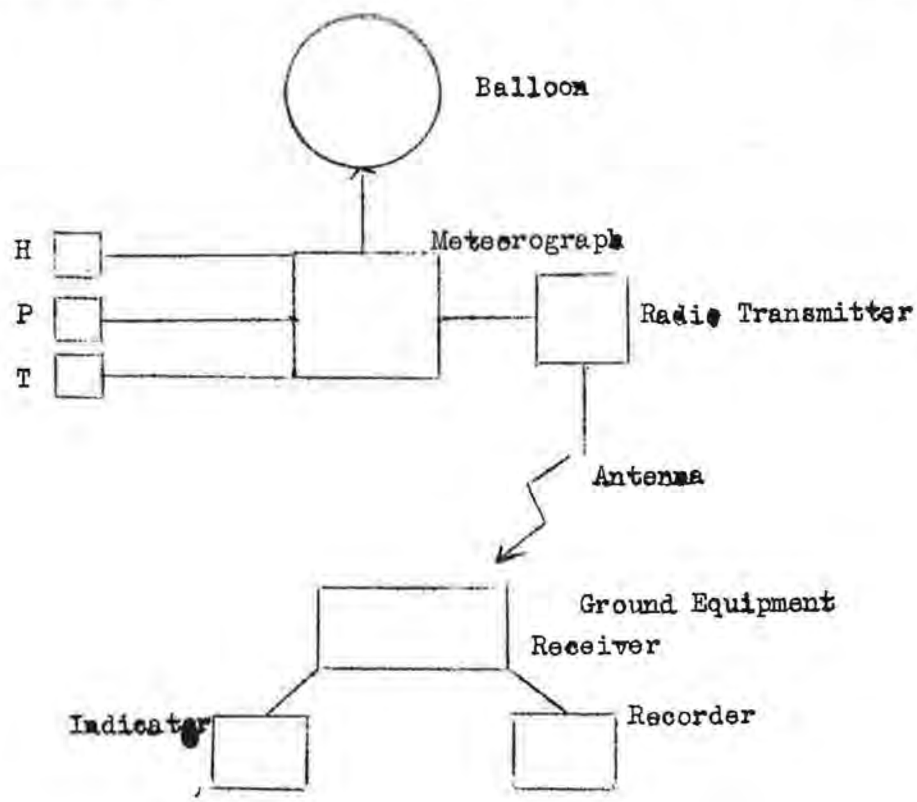


Fig. 1.

The radiosonde is lifted by a hydrogen filled balloon and the function of the instrument is to measure the pressure temperature and relative humidity at all points in its path of ascent by means of suitable detecting elements. The sensing elements in the Canadian Radiosonde physically move contact-bearing arms, which key a simple airborne radio transmitter. The transmitter sends out pulsed radio frequency signals at varying time intervals. The pulses are received by a suitable radio receiver on the ground which amplifies the pulses and feeds them into a recording unit. The details differ in other radiosonde systems, as for example, the U.S. radiosonde but the block diagram is essentially the same.

Quantities Measured

For a complete assessment of the atmosphere, it is necessary to measure, in addition to the pressure temperature and humidity, the three dimensional motion of the atmosphere, the radiational flux and also the liquid water content. Of these latter quantities, only the horizontal motion of the atmosphere is presently measured at some Canadian stations by means of special ground equipment that will be discussed by Mr. W. Smith.

To reiterate, the following quantities are measured:

Pressure	(P)	Radiosonde	Rawinsonde
Temperature	(T)	Radiosonde	Rawinsonde
Relative Humidity	(H)	Radiosonde	Rawinsonde
Horizontal Direction			Rawinsonde
Horizontal Speed			Rawinsonde

The Reason for the Use of Radiosondes

It might be appropriate at this time to indicate why the Meteorological Services of the world are spending so much money and effort in setting up and operating radiosonde and rawinsonde stations. The science of meteorology is in essence a study of the hydrodynamics and thermodynamics of the atmosphere. V. Bjerknes was probably the first meteorologist to fully grasp this fact and to attempt the formidable task of formulating the differential equations of motion of the elastic fluid called the air.

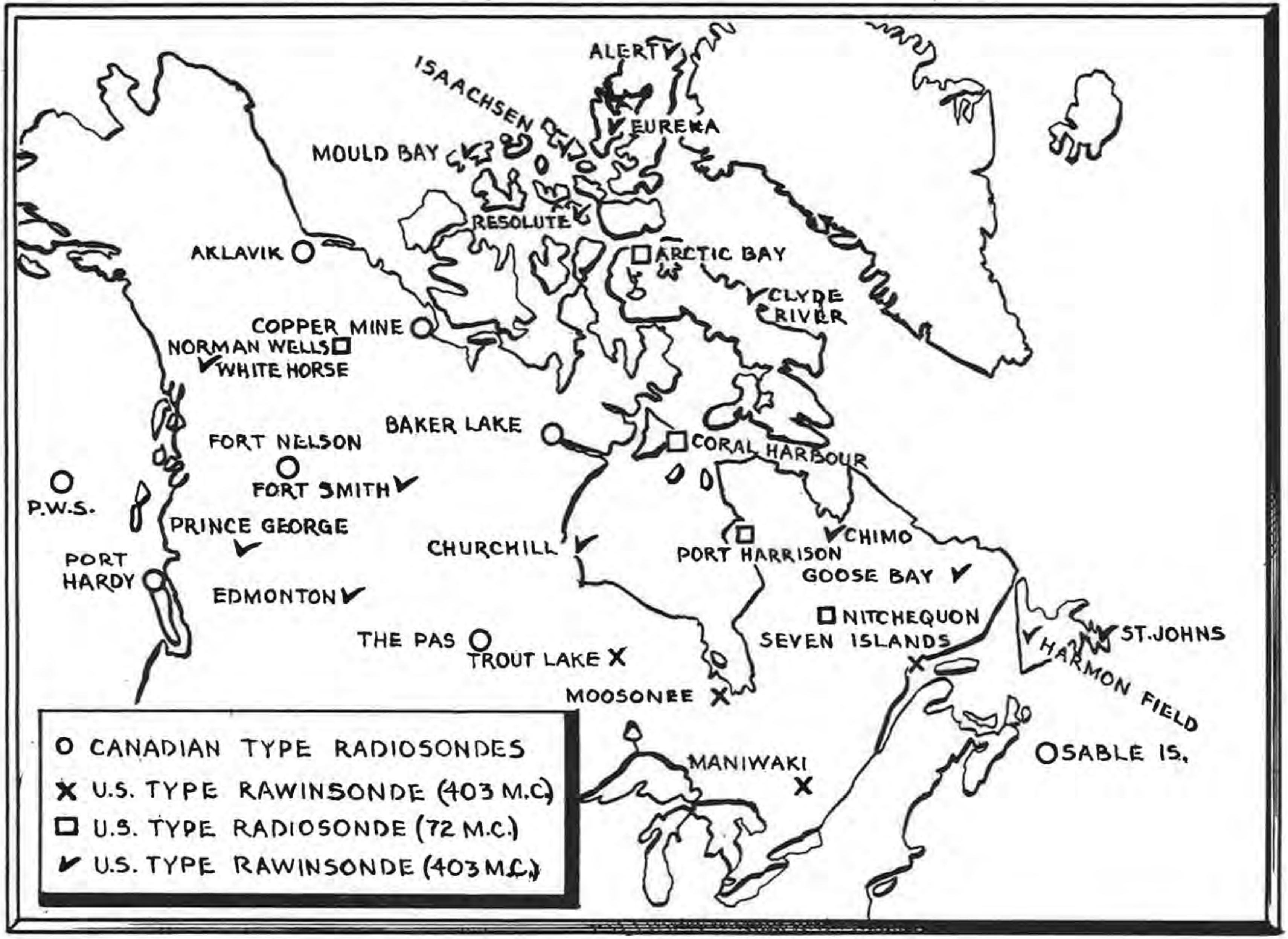
From a practical standpoint, forecasting the weather is of the utmost importance. If the forecasting problem is to be scientifically approached, it is necessary to set up the appropriate hydrodynamical equations of motion of the atmosphere and from a knowledge of the existing field of motion, compute the values of the significant variables at some future time. This approach to the forecast problem is, of course, not being followed today but a number of attempts are being made in this direction by making full use of modern electronic computing machines. In any event it would appear that if the forecast problem is possible of solution, we may only look for the solution along these lines.

If the hydrodynamical-thermodynamic approach is accepted, it is obvious that it is essential to know the values of the significant variables and their rates of change at enough points in the atmosphere or no progress may be made in the forecasting problem. Although this approach was recognized for some time, the synoptic meteorologist had to be content with a sketchy network of surface observations. The advent of aviation and requirements for more precise forecasts developed by the last war, provided the finances necessary to establish the primary networks. It was, of course, necessary to develop the instruments but this again was chiefly dependent upon the finances available. The present networks although very much beyond the wildest dreams of a meteorologist at the first of the century, are not yet adequate and are continually being added to.

Canada's Radiosonde Program

To understand Canada's stake in this program, reference should be made to the map in Fig. 2. The entire Canadian Network is indicated and the stations marked O, ◘, X are the ones that must be supplied with airborne and ground equipment by Canada. The Table below indicates the presently existing stations for which airborne equipment is supplied by Canada

Canadian Type Radiosondes	U.S. Type 72 MC. Radiosondes
Aklavik	Arctic Bay
Coppermine	Port Harrison
Fort Nelson	Coral Harbour
The Pas	Nitchequon
Baker Lake	Norman Wells
Sable Island	
The Weather Ship	
Port Hardy	
Yearly Total 6,400	Yearly Total..4,000



Canadian Radiosonde Network
Fig. 2

U.S. Type 403 MC. Radiosondes

Maniwaki
Moosonee
Trout Lake
Yearly Total 2,400

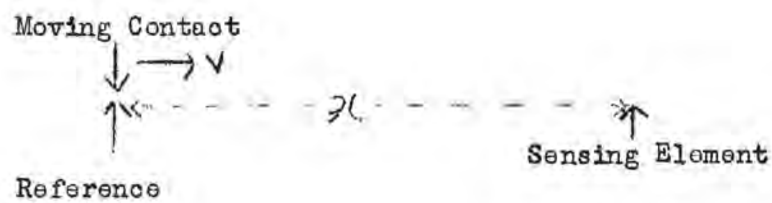
Thus the total number of sondes that must be procured annually to operate these stations is 12,800. If we assume an average cost of $30.00 per sonde, the total cost of the airborne equipment is $384,000.00 per year.

It may be seen from this figure that when the capital and operating costs of the associated ground equipment and personnel is added to this amount the whole program is expensive. However, when the overall possible saving that may accrue from a more accurate forecast is taken into account, this expenditure will be underwritten many times over.

The Canadian Radiosonde

The Canadian radiosonde as originally developed by Mr. Jacobsen who previously headed the Instrument Section, is based on the so-called Olland chronometric principle.

The chronometric type meteorograph in effect, converts a geometrical length into an interval of time. The geometrical length is generally the distance between a fixed reference point and a point on a moveable arm activated by the sensing element. An index is made to move over this geometrical length at a uniform rate and its time of coincidence over the fixed reference point and the point on the sensing arm, is usually indicated by the making of an electrical contact.



Radiosondes built on this principle are generally arranged so that a contact is rotated at a uniform rate which after contacting the reference points, contacts the points on the three sensing elements in order in its cycle.

The moving electrical contact in the Canadian radiosonde consists of a conducting strip in the form of an Archimedian spiral with the equation.

$r = K\theta$. where the pitch is .375 inches. If differentiated $\dot{r} = K\dot{\theta}$ where $\dot{\theta}$ is the angular rotation of the spiral disk. The edge of the spiral is provided with two fixed reference contact points which are in the form of nubs 40° apart. The conducting ribbon is set in a flat insulator which, in the present sonde, is a plastic material. The three contacts attached to the arms which are physically moved by the sensing elements, rest on the flat surface of the disk and move in flat arcs approximately along radial lines from the centre of the spiral (See Fig. 3.)

If the contacting arm is a distance X out from the centre of the spiral, it will make a contact once in each rotation of the spiral. The relationship between a distance (Δx) measured radially to the spiral and the line and Δt is approximately indicated by the following equation:

$$X_1 - X_2 = .2885 \quad (t_1 - t_2)$$

Where X in inches t in seconds

$\therefore$ .001 inches = .00366 seconds

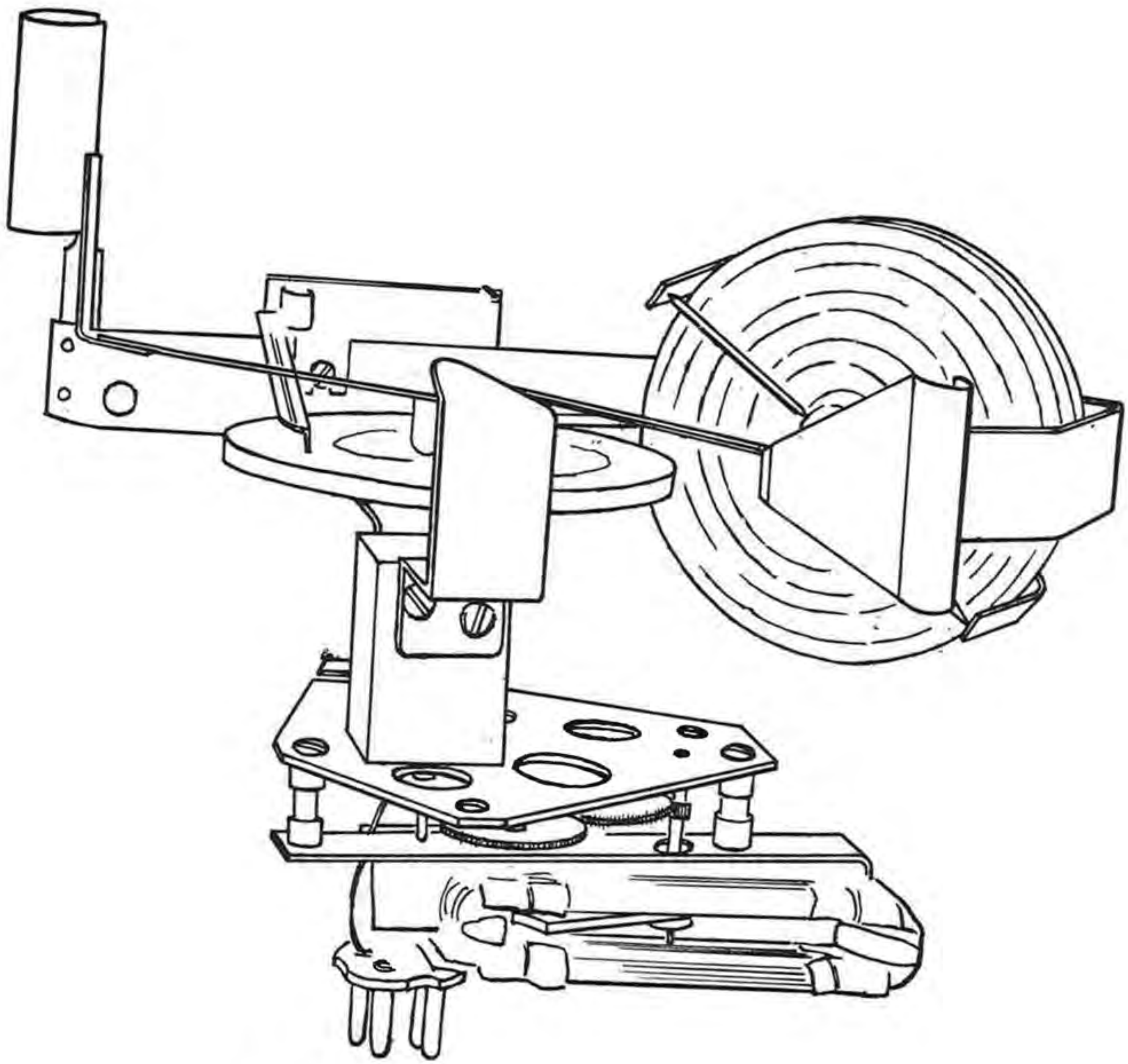
As presently designed:

1 mb.	corresponds to a motion of	.0008" approx.
1 degree C.	" " " " "	.00618" "
1% R/H	" " " " "	.00125" "

The very short lengths involved indicate the necessity for eliminating backlash. This problem has been solved in the Canadian radiosonde by having all contact arms flexibly hinged with the elimination of all pivots and linkage.

The Spiral Contact Drive

It is obvious that it is essential to contrive to have the spiral rotated at an exactly uniform rate. This is accomplished in the Canadian Radiosonde by a primitive form of electric motor of the "hit and miss" type. The rotor consists of a permanent magnet which rotates about an axis placed at one side of the simple field coil. The shaft of the rotor carries a cam or eccentric which is orientated in



The Canadian Radiosonde Meteorograph
Fig. 3

correct phase with the position of the rotor and forces a contact to open and close for each revolution of the motor. The opening and closing gives impulses to the rotor at the correct times and the motion is maintained through the remainder of the cycle by inertia. The motor operates on $4\frac{1}{2}$ volts.

The motor is held at a constant speed of 1500 R.P.M. by having the moveable contact resting on the eccentric made of a phosphor bronze reed which is weighted by solder so as to have a natural vibration period of 1,500 vibrations per minute. After starting, the motor accelerates up to 1,500 r.p.m. At this rate, the natural period of the reed is reached and the rotation of the rotor is stablized and is held by the reed. It hunts about 1,500 r.p.m. as the reed tends to accelerate or decellerate the motor as it departs from this rotation frequency. The motor on the Canadian instrument has proved quite satisfactory and is able to maintain its rate to 1/1500 of a cycle. This is sufficiently accurate, when the accuracy required is taken into account and also the possible accuracy of measurement on the recorder.

Necessity for Redesign

The Canadian radiosonde as originally designed was very ingenious in conception and design. Since it was first designed various beneficial improvements have been made but an analysis of the design revealed some major faults. These were:

1. The sonde was apparently not registering the true ambient temperature but a temperature somewhat higher.

2. The production of the sonde was extremely difficult due to the design of the spiral contacting system used.

3. The production was limited due to the methods of calibration used.

The problem faced by the Instrument Section was primarily one of redesign to try to correct the above difficulties. It was decided that the redesign would be carried out in two steps. The first step would be a redesign of the present instrument to correct as far as possible, the above deficiencies, but arranged so that there would be no break in production of the instruments. The second step would be a radical redesign of the entire radiosonde.

Initial Redesign

There are a number of possible ways in which the temperature indications of a radiosonde may be rendered incorrect. The more important are enumerated below:

1. Radiational effects due to the direct or reflected radiation from the sun.

2. Heat exchange between the radiosonde case and the temperature sensing element.

3. Lag in the sensing element.

4. Conduction of heat from the instrument to the bimetal via the support.

Experimental indications and statistical comparisons with adjacent ascents made by U.S. type radiosondes appeared to indicate that the temperatures indicated by the Canadian radiosonde were high. As the lag of the bimetal used in the Canadian radiosonde is small, it appeared most probable that the discrepancy was due to the position of the bimetal in the radiosonde case and also due to the design of the case itself. The existing arrangement places the radiosonde transmitter below the meteorograph. Although attempts have been made to insulate the two, these components act as a heat source. The design of the case is such that a chimney effect is set up and the top of the case acts as a trap for the ascending warm air originating in the transmitter and battery assembly.

In the case of the Canadian radiosonde, it therefore appeared that heat exchange between the case of the instrument and the bimetal was likely to be the main source of error. In order to overcome this, the element was raised on a shaft. This slight alteration greatly improves the position of this element in the present case as it allows a direct circulation of air over it. The full advantage of the new design will not be felt until a new case is designed. Experiments along this line are now being undertaken in a miniature wind tunnel. The redesign it is hoped will also at the same time and in the same way improve the circulation over the humidity element.

Production Problems

Probably the greatest difficulty with the Canadian radiosonde as presently designed is the difficulty in calibration. As designed, it is not possible to standardize the calibration of any of the elements so that individual calibration may be eliminated by holding the components to exact tolerances. Another practical difficulty was due to the former method of the "floating" contacts. Physical contact was only made with the spiral via a spring contact and only when the contact touched the raised spiral in the cycle. The rest of the time the contacts were moving in the plane of the spiral but in the air. This system was supposed to decrease friction and appeared very attractive in theory. In practice however, this type of contact was a great source of difficulty in preparing the instruments for calibration. The trouble was due to the difficulty in being sure that the contacts moved in the plane of the spiral. The contacts were also difficult to manufacture and adjust. It was also found that if the spring contacts were too stiff, they would slow down the spiral on contact and the resulting irregular motion would introduce an error into the results.

To overcome this difficulty, the spiral was reduced to a conventional direct contact between the arm, moving on a flat non-conducting plate and the spiral was embedded in the non-conducting plate flush with its surface. The contact arms rest lightly on the flat surface and as a result the problem of tracking has been solved to a large extent and the handling and adjusting of the instruments has decreased markedly.

The present spiral is constructed of a die-cast raised spiral with the intervening parts filled in with plastic. It is anticipated that a more satisfactory spiral may be constructed by printing methods and experiments to obtain an improved spiral are under way.

Calibration Problems

The chief difficulty in maintaining production of the Canadian radiosonde is the simultaneous pressure and temperature calibration which was considered necessary. Mr. Hooper will describe a calibration chamber recently designed for this purpose. This chamber probably represents the best that can be done in the way of simultaneous calibration in air. It is obvious however, that this method is difficult and will never lend itself to successful large scale production of the instruments as it is unlikely that any commercial manufacturer would be prepared to undertake this type of calibration. As a result it is essential to give careful consideration to the calibration problem in order to get on a basis where it may be handled by industry.

Experiments which have been carried out in the Laboratory, indicate that the aneroid capsule used in the sonde is sufficiently well temperature-compensated, that a calibration at room temperatures is adequate. The possibility of separating the pressure calibration from the temperature calibration, would do much to speed up the process as the pressure calibration at a fixed temperature may be carried out relatively easily and rapidly.

It is technically difficult to construct a chamber to hold a large number of instruments and at the same time have a uniform temperature over all the sensing elements. It has been found that the new design of the bimetal temperature element and the spiral will allow the instrument to be operated upside down with the element in a constant temperature bath. It is therefore quite practicable to design a series of constant temperature baths so that groups of instruments may be moved from one bath to another. When such a system has been designed and constructed, the capacity for calibration may be increased as much as desired and work is now proceeding in this direction.

The calibration of humidity is also a source of considerable delay and difficulty. The accuracy required in this element is not so great as with the pressure and temperature elements. It is therefore quite possible to calibrate these elements against standard spirals. A group of the humidity elements may be placed on standard spirals, rotated by a telechron drive so that they all turn at a standard rate. This procedure will possibly lend itself to automatic calibration

Final Redesign of the Canadian Radiosonde

The Canadian radiosonde has altered considerably by a process of gradual evolution. This, no doubt, was the only way changes could be made without disrupting the actual production of instruments. A considerable backlog of experience has been accumulated and the time is now ripe for a complete redesign based on this experience.

In a redesign, it is fundamental to decide if the Olland principle is satisfactory for a radiosonde design.

The difficulty inherent in the Olland principle is -

> The necessity for using sensing elements that will physically move a contact arm.

The advantages are:

1. The meteorograph may be relatively simple and if properly designed may be accurate and easily calibrated.

2. The airborne radio equipment is essentially simple and therefore lends itself to low cost production.

3. The ground equipment is relatively inexpensive and simple in operation.

It would therefore appear that the Olland type radiosonde has numerous advantages and a redesign of this type of instrument is contemplated.

Some Features of the Redesign will be as follows:

1. The temperature element and humidity element will be designed so that they may be placed in a position remote from spiral and motor and well ventilated in the radiosonde case.

2. The present type of flat spiral will be retained.

3. The instrument will be such that the drive motor is detachable, so that the spiral may be independently driven by a constant speed motor.

4. Automatic calibration of the temperature and pressure sensing elements will be devised.

5. The humidity elements will be calibrated against standard spirals.

6. The instrument will be precision die-cast of magnesium alloy.

7. The present electric motor drive principle will be retained with certain improvements.

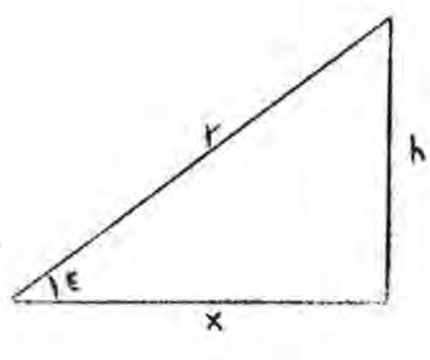
It is anticipated that a very accurate and inexpensive instrument will result if these design principles are followed.

THE ADAPTATION OF THE CANADIAN RADIOSONDE TO RAWINSONDE

by

WENDELL R. SMITH

For tracking balloons to measure winds aloft, the standard method has been for many years the single theodolite. Indeed, this method is likely to remain in use for many more years. But optical methods fail in precipitation, cloud, or fog -- in short, in any meteorological condition which limits horizontal or vertical visibility. During the last War, however, the electronic art reached the stage of development where radio could supplement, even if it did not supplant, optical methods. The radiosonde was in common use during the early stages of the War. All that remained was to develop a method for locating the transmitter in space and establishing the projection of its position on a flat earth. Radio conferred an additional benefit in that most methods permitted the measurement of yet another position co-ordinate (slant range). Thus, for tracking a balloon, we require azimuth angle and any two of: height, elevation angle, or slant range. Height is taken from the RAOB. The geometry of the various systems is given in Fig. 1. x, in conjunction with the azimuth angle, gives the projected position of the balloon relative to the station at the instant of measurement. We will now survey briefly some of the possible radio methods for tracking balloon-borne transmitters.



$$x = \sqrt{r^2 - h^2} \quad \text{or} \quad x = r\cos\left(\sin^{-1}\frac{h}{r}\right)$$

$$x = h \cot \epsilon$$

$$x = r \cos \epsilon$$

Fig. 1

Two methods have been available since the early days of radio for establishing the bearings of ships at sea from a land station. These are the loop and Adcock systems, both of which may be considered examples of the radiogoniometer. In more recent years, the Adcock system has been adapted to a cathode-ray oscillograph presentation, with improved accuracy. The crossed loop system is used extensively in aircraft as a radio compass. But in all these applications it is extremely difficult to obtain a bearing which is reliable to closer than one degree. And these systems yield no information about elevation. This defect could be eliminated by erecting a duplicate installation at the other end of a measured base line and computing slant range, as is done in the two-theodolite method. The accuracy of the range measurement would suffer, however, from the inaccuracies in the azimuth measurements from which the range was computed.

Radar, of course, was the most spectacular of the wartime developments in electronics. The germ of the idea came from work done in inospheric investigation by Sir Edward Appleton and others. With the advent of the microwave or resonant-cavity magnetron radar began to assume its present form. As the name implies (RAdio Direction And Ranging) radar should be eminently suited for tracking balloon-borne transmitters. Among commercially available sets, the gun-laying or fire-control types give the nearest approach to the accuracy required in angular and slant-range measurements. But a full-fledged radar installation is very costly in both equipment and personnel. Indeed, so expensive is it that it can be considered in this Service only at places where there is an already-existing installation for some other purpose such as navigation, early warning or anti-aircraft fire control. Radar makes possible the measurement of all four co-ordinates mentioned in the first paragraph, and the choice of co-ordinates depends upon the type of radar employed. The general purpose or navigational radars are not capable of measuring elevation angle very accurately but are good in azimuth and reasonably so in slant range. For this reason, on the Pacific Weather Ships it is customary to measure azimuth and plot slant range against height, giving the co-ordinate x.

Another series of navigation systems developed during the War is typified by the British GEE and its U.S. copy, LORAN (Long RAnge Navigation). These systems operate on the same basic principle, that of measuring the relative time delay in the transmission of pulsed signals from three or more transmitters located many miles apart. Each pair of transmitters gives a position line, and the position of the receiving station is found from the intersection of two such lines obtained from two transmitter pairs. One transmitter may be common to both pairs, so that three transmitters are sufficient to give a position. The position lines take the form of hyperbolas, since this is the locus of points which move such that the difference in distance from the moving point to two fixed points is constant. The transmitters are at the foci of these curves. For this reason the systems are known as hyperbolic. One transmitter is generally arranged to control the other in a pair, hence the terminology "master" and "slave". A system could be devised along these lines for upper wind-finding by locating a "master" and two "slaves" on the ground, dispensing with the usual monitoring facilities between master and slave, and sending the "receiver" aloft in the balloon. This would require an additonal transmitter in the air-borne equipment to relay the information to a ground-based receiver. The positional accuracy of such an ultra-high-frequency system should be very good. Unfortunately, it would demand much laborious chart work, and the airborne equipment would be expensive because of the necessity for incorporating accurate timing circuits. The ground equipment also would be complex.

The system developed either by or for the U.S. Army Signal Corps, and known as the SCR-658, appears most promising for the purpose. In fact, it is the one predominantly in use in this Service for upper wind-finding by radio. The Metox Society in Paris is currently manufacturing a slightly improved copy of this equipment with the very descriptive name of Radiotheodolite. Both these systems are examples of very-high-frequency direction-finding equipment. The actual direction-finding is done on a transmitter which emits an essentially frequency-modulated signal, with an approximately constant carrier amplitude.

The heart of the receiving equipment is a directional antenna system and motor-driven switch. The antenna is a broadside stacked array of 32 half-wave elements suitably interconnected, and occupying an area three wave-lengths square. This is an example of the generic type known as the billboard array. A brief discussion of directional antennas might now be in order.

Antenna response is most usefully shown in polar co-ordinates, with the length of the radius vector corresponding to the voltage (or current) response to an incident electromagnetic field of unit strength. The angle between radius vector and reference axis will represent the angle of incidence of the radiation. It is convenient to take the axis in the plane of the antenna system. For a broadside array the maximum response will be along the normal to the antenna, as shown in Fig. 2. The beamwidth is defined as the angle between two radii vectores whose lengths (in terms of power) are equal to one-half the maximum length. Since power is proportional to the square of voltage or current, beamwidth will then be

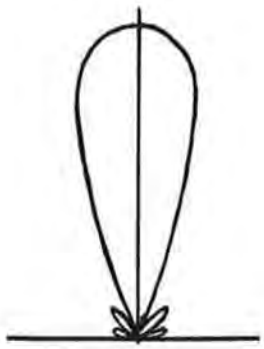


Fig. 2

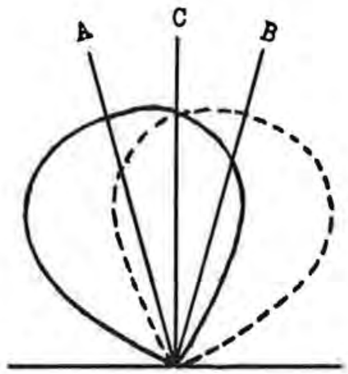


Fig. 3

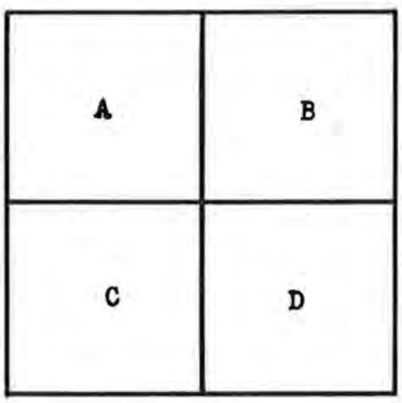


Fig. 4

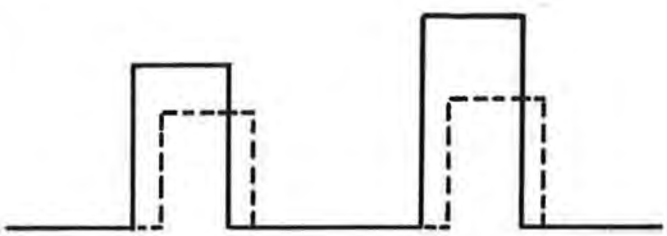


Fig. 5

defined in terms of 70.7% of maximum voltage (or current) response. Beamwidth is given to a good approximation by dividing the length of the array in wave-lengths into the number 51. Since the antenna system under consideration is square, its beamwidth will be the same in elevation as in azimuth. And a linear dimension of three wave-lengths gives a beamwidth in each case of approximately 17°.

A beamwidth of this magnitude is far too coarse for the purpose. But another device of the radar engineer comes to our rescue and sharpens up the response to a point where it will meet the requirements. Again with reference to Fig. 2, it has been found that if the antenna is divided in the centre into two independent sections, the response from the right-hand half fed directly into a receiver, the response from the other half being delayed a fraction of one cycle, maximum response of the antenna system now occurs along a line slightly tilted away from the normal. By delaying the response from the right hand half and feeding the receiver directly from the other half conditions are reversed, as shown in the dotted pattern of Fig. 3. The same effect can be achieved in a direction at right angles to this by dividing the antenna longitudinally into two sections. Thus in the working system the antenna is divided into four equal sections or bays. The output from each bay is fed into the motor-driven switch and due provision made in the coupling for providing the delayed response as required. Thus, in Fig. 4, if bays A and C are fed directly to the receiver, and bays B and D fed through delay cables, the antenna response pattern is shifted to one side. On the next half-revolution of the switching motor, bays B and D will be connected directly to the receiver, bays A and C connected to it through the delay cable. The pattern will then be shifted in the other direction. These two positions will correspond to the two patterns shown in Fig. 3 and give azimuth indications. Similarly, elevation indications will come from interconnecting bays A and B, C and D in pairs.

In addition to switching antenna bays, the motor switch performs two other functions. Four times during each revolution it turns on the direction finding part of the receiver, and twice per revolution initiates a saw-tooth wave which deflects the beam of a cathode-ray tube laterally. In this way the direction-finding is done, as in Fig. 5, which shows the pattern generated on the cathode-ray tube screen for one revolution of the motor switch. During the first half-revolution (shown by the solid line) the following events take place; the beam of the cathode-ray is shifted to the right at a uniform rate; antenna bays A and B are connected directly, bays C and D through delay cables, to the receiver; the receiver is switched on and the first rectangular pulse appears (elevation); the receiver is then cut off;

antenna bays B and D are connected directly, bays C and A through delay cables, to the receiver; the receiver is again turned on to give an azimuth pulse; finally the cathode-ray tube beam is returned to a new starting-point a little to the right of its previous one. On the next half-revolution the dotted part of Fig. 5 is formed. This switching is done at the rate of 30 complete cycles per second, so that a stationary pattern is formed. Reference again to Fig. 3 will show how an "on-bearing" signal is recognized. If the signal is received from the direction A, there will be maximum response from the full-line pattern and a small response from the dotted-line pattern. The same situation will exist in reverse at B. Only at C (along the normal to the antenna) will the responses be equal and the pulses on the oscillograph in Fig. 5 equal in magnitude. The actual antenna bearings for an "on bearing" signal can be read off dials. By this means it is possible to measure azimuth and elevation angles somewhat more closely than to one-fifth degree.

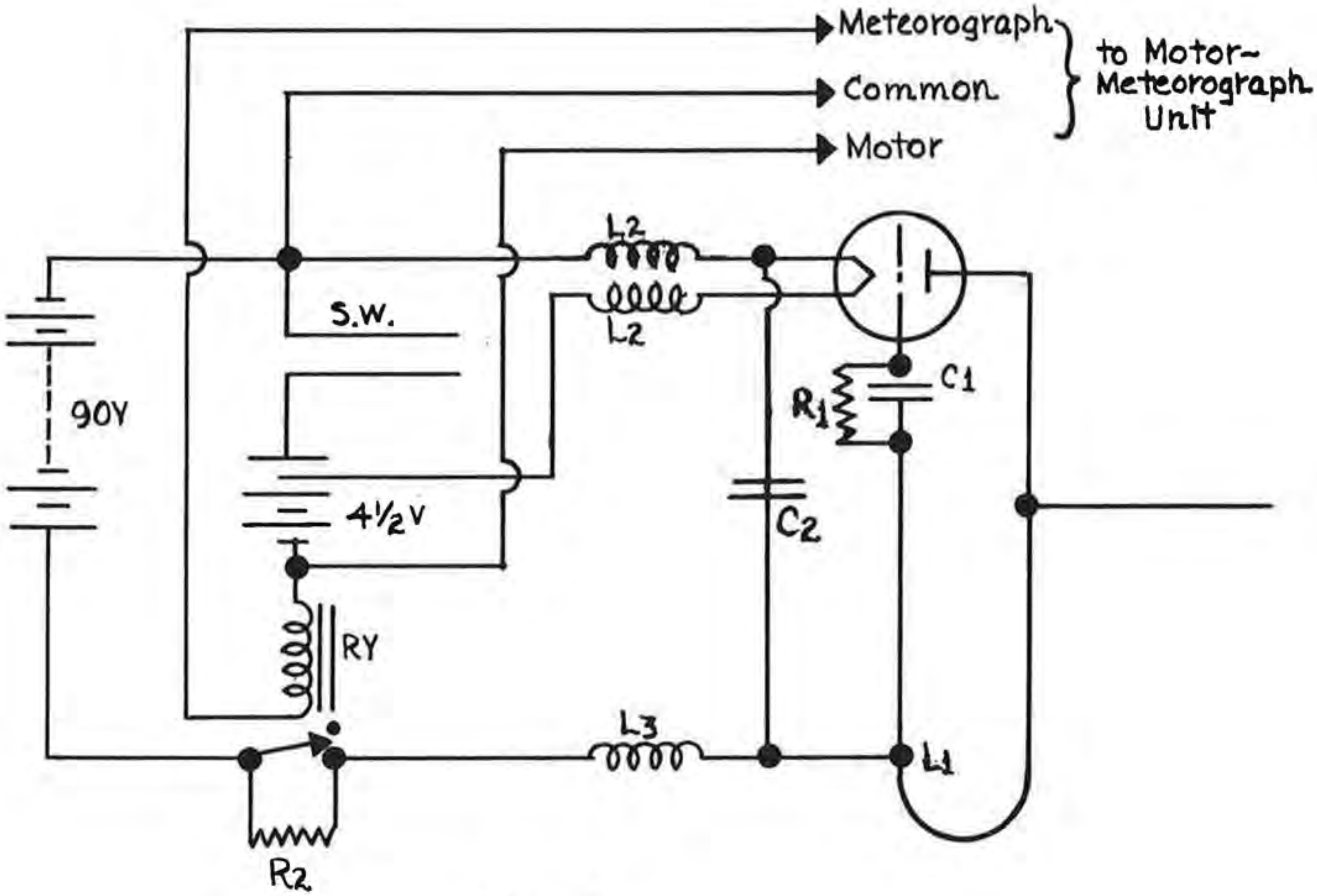
After some preliminary high-frequency amplification the receiver divides the signal into two channels. The one carrying the direction-finding information is keyed by the motor switch. The "radiosonde" channel carries the frequency-modulated signals from the meteorological elements in the radiosonde, residual amplitude variations are smoothed out, and the output from this channel is fed to a recorder. An instantaneous deviation of 200 kcs. in carrier frequency from the unmodulated value of 403 mcs. is sufficient to give maximum output to the recorder.

To adapt the Canadian radiosonde to use with this type of rawinsonde ground equipment, then, a transmitter is required with the following characteristics:

1. An approximately constant carrier power output of the order of one watt at a frequency of 403 mcs. to 405mcs.

2. On radiosonde signal to shift this carrier frequency downward by approximately 200 kcs.

The circuit of Fig. 6 performs this function admirably. The meteorograph unit is plugged into the socket on the transmitter as shown. On radiosonde signal the Meteorograph lead is connected to Frame, completing the circuit in the relay coil, drawing down the armature, and opening the short-circuit across the 470-ohm resistor. This puts the resistor in series with the plate circuit of the transmitter, which lowers the carrier frequency by the necessary 200 kcs. In the absence of radiosonde signal the plate circuit resistor is short-circuited out and the transmitter operates in the conventional manner.


Meteorograph
Common
Motor
to Motor-
Meteorograph
Unit
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L2
S.W.
90V
4½V
C1
R1
C2
RY
L3
L1
R2

Fig. 6

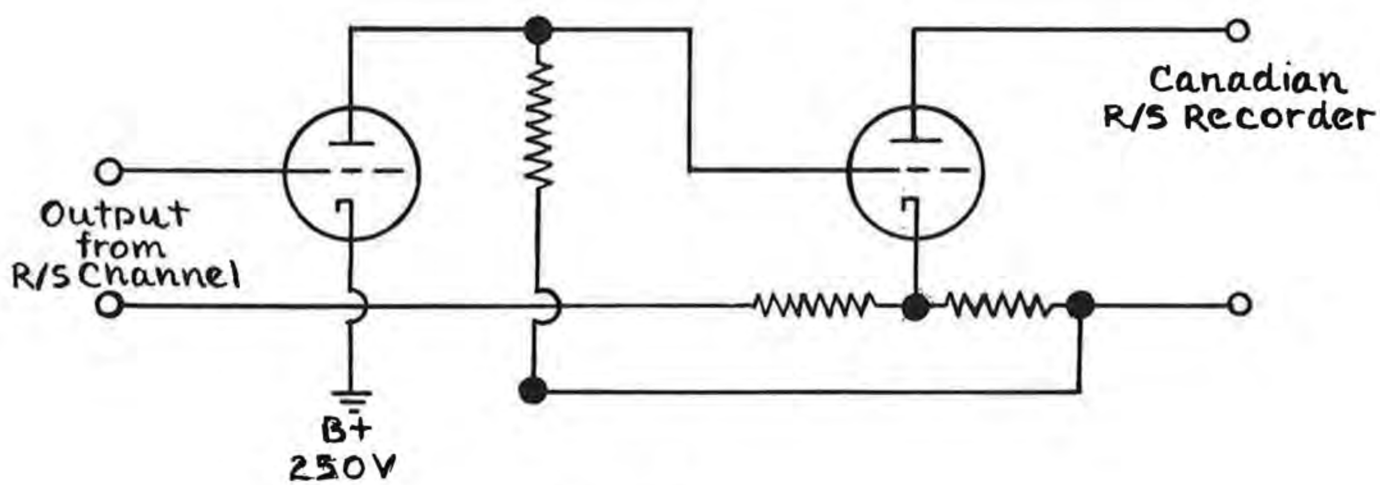
Canadian
R/S Recorder
Output
from
R/S Channel
B+
250V

Fig. 7

True, the power output is lowered on signal, but to the observer on the ground this does not cause an objectionable change in the pattern on the face of the cathode-ray tube. It might be worth mentioning in passing that this is a rudimentary form of frequency modulation

The modification required on the ground equipment is equally simple. The two existing output stages in the radiosonde channel of the receiver will be rewired, requiring only three resistors instead of the dozen or more resistors and capacitors currently used. The direction-finding channel will be unaltered. The output from these rewired stages will then be taken directly into the Canadian radiosonde recorder. This modification is shown in Fig. 7. Since the keynote of the Canadian radiosonde appears to be simplicity, the system outlined here is certainly in keeping.

Just as in the other direction-finding systems described previously there has been some drawback, so there is in the V.H.F.D.F. system. No doubt many of you are familiar with the fact that operating instructions on the SCR-658 are to discontinue wind-finding readings after the elevation angle has decreased to 15 degrees. The reason for this will be apparent from Fig. 8

(a)

Fig. 8(b)

At low elevation angles there is a very good possibility of the signal reaching the antenna via both the direct and reflected paths. As the vector diagram in Fig. 8 (b) will show, the error in observed elevation angle will depend on the point of reflection and on the intensity of the reflected wave.

Since, with radio methods there is the possibility of choice in the co-ordinates measured, the obvious means of eliminating the effect of reflection is to measure slant range rather than elevation angle. For this, an interrogating oscillator on the ground and a transponder element in the airborne equipment would be required, and the antenna system could then be non-directional in elevation. The interrogating oscillator would send out a short high-energy pulse which would be received by the transponder. The latter would then cause the main (air-borne) transmitter to emit a signal which would be received on the ground. The time interval between interrogating and received pulses, less the delay in the transponder unit, would then be a measure of the slant range. The effect of reflected waves would then be completely eliminated since, if reflection were present, it would cause an additional slightly delayed signal to be received. The direct signal would arrive first, and it would be the one used to determine the slant range.

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A REFRIGERATED PRESSURE CALIBRATION CHAMBER

FOR

THE CANADIAN RADIOSONDE

by

A.W. HOOPER

The Canadian radiosonde which operates on the Olland principle, is given individual calibration in a chamber in which the pressure and temperature are lowered so as to simulate the normal conditions encountered during the actual ascent of the radiosonde. The chamber originally used for the purpose by the Meteorological Division had inadequate capacity to take care of the increasing requirements for sondes. Planning for the construction of an improved calibration chamber was begum in 1949 but the necessary components could not be assembled until 1951. Construction was completed in October 1951 and a test calibration carried out in that month. The tests were entirely satisfactory and the chamber has been in continuous operation in routine calibration since that time.

The following specifications for the chamber were decided on:

1. It must handle 60 Canadian meteorographs at one time.

2. It was to be refrigerated to cover a range from +38°C. to -60°C. and to be varied from 1100 to 10 mb.

3. It was to be capable of being brought to any temperature within its range and be held with great stability within plus or minus 1/10 of a degree C. at any pressure to the nearest whole millibar.

4. Provision must be made to adjust pressure or temperature up or down, with speed and certainty. A means of condensing out excess moisture from the air must be provided to fill the chamber with extremely dry air and thereby eliminate the possibility of "frosting" of sondes, resistance thermometers, etc., which had proved troublesome in previous chambers.

5. It was necessary to provide for an accurate means of measuring temperature and pressure and provide for a uniform temperature over all the temperature elements on the sondes which are placed in racks under calibration.

6. Finally it was essential that the complete calibration of the sixty instruments should be performed in as short a period as possible and not to exceed eight hours. It was necessary that the chamber should be as far as possible automatic and capable of operation by non-technical personnel.

The completed chamber with the door open and containing sixty Canadian type radiosondes on racks is illustrated in Fig. 1.

Mechanical Construction

The chamber is fabricated from a steel cylinder, 24 inches in diameter and 40 inches in length, open at one end closed with a convex steel plate at the other. The convex plate carries a small cylindrical chamber at its outer centre, to house the motor that drives the air circulator. The open end is fitted with a hinged door provided with an observation window of several panes of armour plate glass separated by intervals of dry air to prevent frosting at low temperatures. Sealing of the door is accomplished by inserting a ring of $\frac{1}{2}$ inch square rubber in annular grooves cut in the inner and outer retaining plates. For details of the door see Fig. 1.

Pressure Arrangements

Pressure variations are accomplished by the use of one Welch Wagner pressure vacuum pump and two Welch Wagner pressure vacuum pumps.

Pressure measurements are made by means of a Wallace and Tiernan precision mercurial manometer.

Sealing of the refrigeration evaporation lines was simply accomplished by stretching a standard sewing machine bobbin rewind tire over each line and holding it in place by a plate screwed to a machined pipe cap, which carries the line through a short piece of iron pipe, welded to the chamber body.

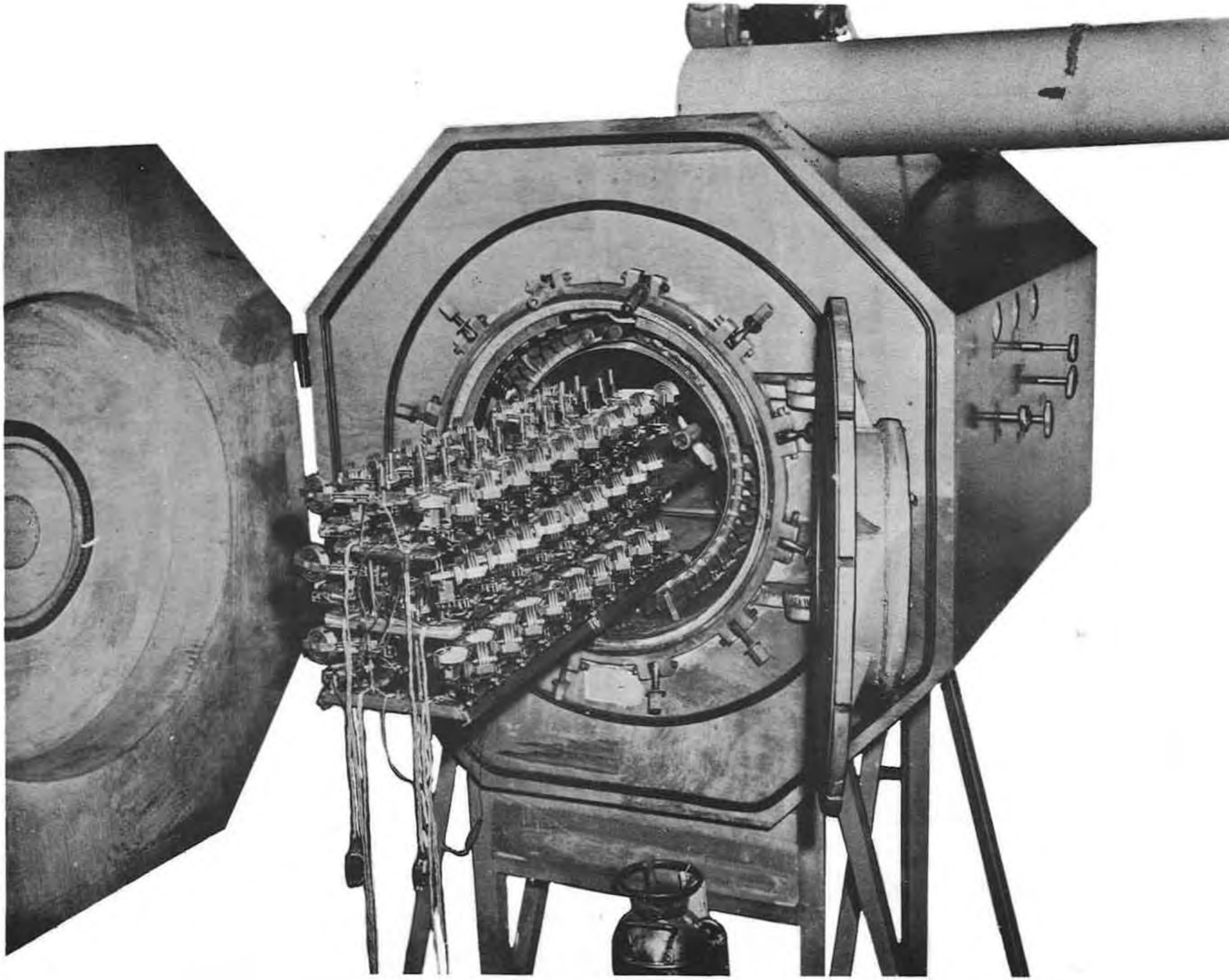


Fig. 1

Cannon pressure plugs were found entirely satisfactory to introduce one hundred and sixteen necessary electrical conductors that must be passed through the wall of the chamber.

In practice, the simulation of temperature and pressure drop to conditions of actual flight is only carried out to a temperature of -45°C. For temperatures below this, a higher pressure (near atmospheric) is used. The reason for this is to increase the heat exchange which becomes very slow at lower pressures. A problem arises when the pressure is raised by the introduction of air into the chamber when temperatures are very low. If precautions are not taken the moisture carried in from the outer air will cause a thick coating of frost on all interior objects in the chamber. This problem was solved by leading the pressure line along the bottom outside surface of the pressure vessel and thence up one side in a series of convolutions. The drying of the incoming air is thus assured by the freezing out of the moisture through this long cooled inlet. Although an alternative outlet has been provided, no trouble due to a plugged pressure line has been encountered.

Refrigeration

The refrigeration system is illustrated in Figure 2. In the design of the refrigeration, various refrigerants were considered. Freon 22 was considered as a possible solution but closer examination indicated that the saturation curve of $C_3 H_8$ (Propane) was most favourable, while the cost was low. Propane had been used for ten years in the refrigeration chamber No. 1 without incident. Danger from the inflammable nature of propane may be minimized by adequate precautions in design.

The most efficient refrigeration system was sought and at first the cascade system was thought to be the answer but abandoned when it was found difficult to design such a system for operation by non-technical personnel. The compound system as used in the refrigeration calibration chamber No. 1 (R.P.C. #1) was followed in the redesign.

In order to achieve speedy cooling of the air in the chamber, it was decided to design an evaporator in a tubular form, well finned for ease of heat exchange and parallel to the circular walls of the chamber but not contiguous to it (the previous chamber had a cold wall system of cooling which had many defects in practice). This design would allow for the rapid circulation of the chamber air over the evaporator with great cooling efficiency. On the basis of this decision, the writer designed a parallel riser type evaporator (see Fig. 2) which introduced the liquid refrigerant into the evaporator by means of a distributing inlet manifold laid along the bottom of the evaporator in the manner of a ship's keel. The risers may be likened to the ribs of a ship. They differ however in completing the greater part of a semicircle, the upper ends terminating in a suction manifold of which there are two, lying parallel to the inlet manifold, one on each side of the top centre of the structure. From each of these, the refrigerant is led to the suction line, by means of three short and equally spaced pipes, to ensure as well as possible equality of suction pressure over the entire assembly. The risers, spaced $1\frac{1}{2}$" apart, are passed through longitudinal fins of copper, at 1" spacing, giving the maximum area for heat transfer. The entire assembly is constructed about a copper cylinder open at each end.

Control of refrigeration in the chamber is achieved by means of two thermostatic expansion valves coupled in parallel to the liquid line (See Fig. 2). The first of these, a "Detroit" #673 diaphragm valve, is used to pull down to -40°C. The second, a "Detroit" #793 differential expansion valve, begins to take over at a somewhat higher temperature than -40°C. and is in full control at all temperatures below -40°C. This principle has been described by Carter* (see below). The control described in this paper differs from Carter's in the location of the evaporator bulb, as complete automatic transition was desired and achieved.

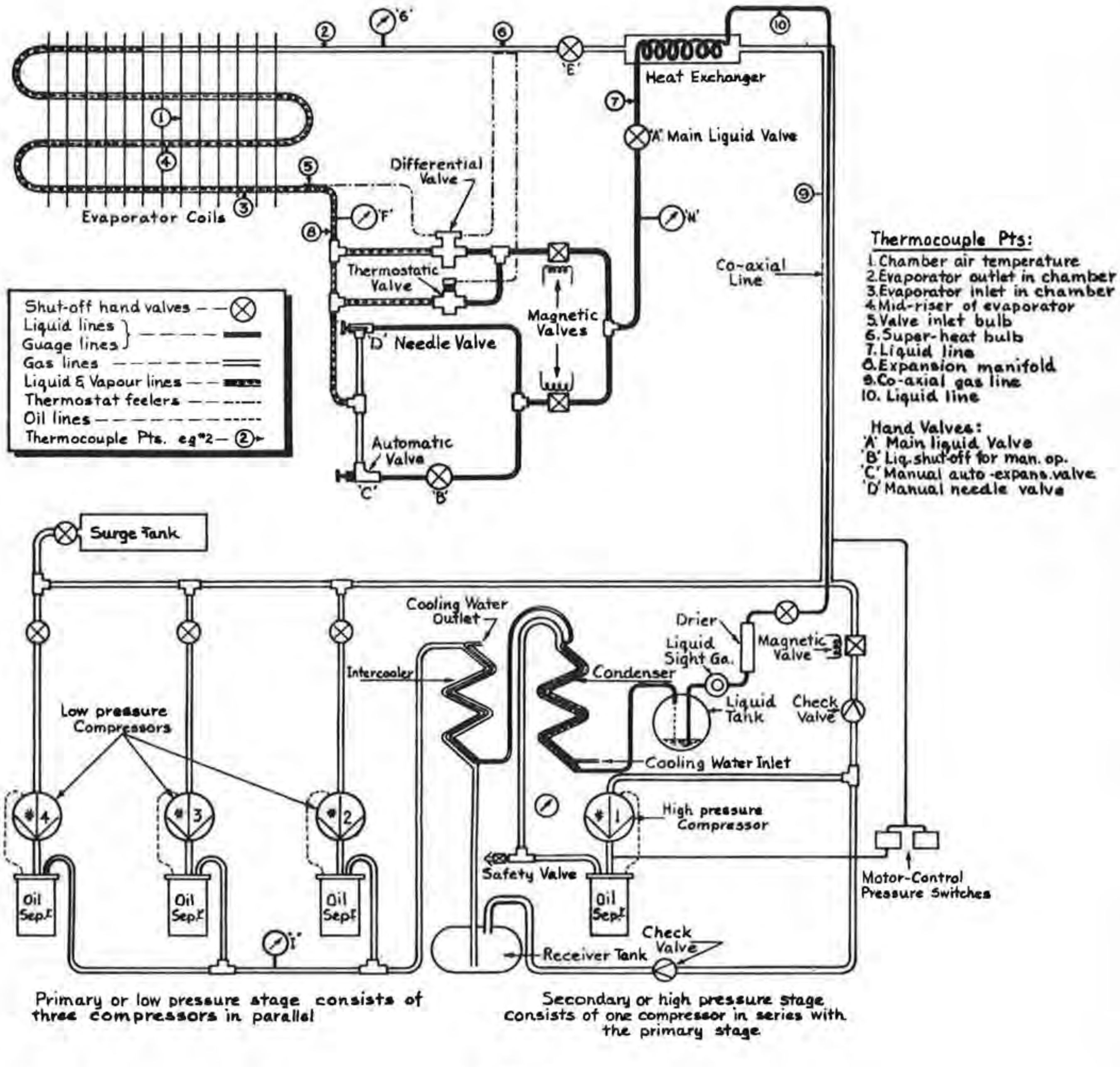
The two valves have, to date, operated trouble free. Nevertheless, in event of trouble, two alternative controls have been incorporated in the design. The first makes use of a manually controlled, automatic expansion valve and the second as a final alternative, is controlled by a hand operated needle expansion valve.

As a safeguard, in view of the use of propane, the design features valves located at strategic points in the system, enabling any section requiring repair to be isolated and evacuated. Where the necessity for component replacement exists, unions are used, whereas all other joints are silver soldered. Thus all servicing of the system may be undertaken with suitable wrenches and screwdrivers.

A group of ten copper /constantan thermocouples are located at significant points throughout the system making it possible when servicing or adjusting to obtain an immediate temperature reading at any point of interest.

The lowest evaporator temperature thus far achieved has been -90°C.

(* Carter - Published in July 1945 issue of "Refrigerating Engineering".)



Heat Exchanger
'E'
'6'
'A' Main Liquid Valve
Differential Valve
Evaporator Coils
'F'
'H'
Co-axial Line
Thermostatic Valve
Magnetic Valves
'D' Needle Valve
Automatic Valve
'C'
'B'
Shut-off hand valves
Liquid lines
Guage lines
Gas lines
Liquid & Vapour lines
Thermostat feelers
Oil lines
Thermocouple Pts. eg #2
Thermocouple Pts:
1. Chamber air temperature
2. Evaporator outlet in chamber
3. Evaporator inlet in chamber
4. Mid-riser of evaporator
5. Valve inlet bulb
6. Super-heat bulb
7. Liquid line
8. Expansion manifold
9. Co-axial gas line
10. Liquid line
Hand Valves:
'A' Main liquid Valve
'B' Liq. shut-off for man. op.
'C' Manual auto-expans. valve
'D' Manual needle valve
Surge Tank
Cooling Water Outlet
Drier
Liquid Sight Ga.
Magnetic Valve
Intercooler
Condenser
Liquid Tank
Check Valve
Low pressure Compressors
Cooling Water Inlet
#4
#3
#2
#1
High pressure Compressor
Safety Valve
Oil Sep.r
Motor-Control Pressure Switches
'I'
Receiver Tank
Check Valve
Primary or low pressure stage consists of three compressors in parallel
Secondary or high pressure stage consists of one compressor in series with the primary stage

Fig. 2

Insulation

For the low temperatures required, an efficient insulation is necessary. The general requirements were:- favourable "K" factor, low moisture absorption and fire resistance. Spun glass wool offered the best compromise, having a "K" factor of .22 B.T.U. per sq.ft/hr.at 50°F. In practice, a minimum thickness of twelve inches was found necessary and even this is hardly sufficient when ambient temperatures are 90°F. or higher.

While complete sealing of the insulating cabinet had been considered, it was found necessary in practice to allow for ample "breathing". Complete freedom from frozen moisture in the insulation has justified this design feature.

Heating

Provision for heating in the chamber is essential for two reasons:

(1) To return the chamber to room temperature from the lowest temperatures rapidly and thus permit the removal of the instruments condensation free.

(2) To allow for the necessary close temperature control which is attained by balancing heating against the refrigeration.

It was found that a total 4200 watts would provide ample reserve for the above purposes without resorting to an immersion heater and reverse cycling in the refrigeration system. Three heats are provided, 4200 watts (high), 1200 watts (medium) and 1000 watts (low). These ranges are obtained by using six 500 watt "Chromalox" 24" strip heaters in parallel and two 600 watt nichrome open coil heaters, also in parallel. In "High" both systems are connected in parallel, for "medium" the open coils are used alone, and for "low" the two systems are connected in series. While selection of heat is obtained by means of a large capacity three range switch, the application of the selected heat is controlled by means of a magnetic switch, which is manually operated or by thermostatic control as required. The thermostat is used as a high limit control for a pre-selected temperature rise. In practice, it is set at room temperature for chamber warm up, rendering attention by the operator unnecessary. A red light indicates when heat is applied.

To balance the refrigeration and hold at a selected temperature, "low" heat is selected and temperature balance is effected by varying the voltage supplied to the heater by means of a variac. In this manner, it has been found practicable to maintain a temperature to plus or minus .05°C. The design requirement is to calibrate the instruments to plus or minus 0.1°C.

Air Circulation

It is essential to provide for complete circulation of the air in the chamber so that the air temperature may be as uniform as possible over all the temperature elements of the sixty instruments under calibration. This is a fundamental design requirement. Several systems were tried and the chamber probed for gradients. A satisfactory system was found and consists of a six vane propeller type fan in which the pitch angle extends almost to the center of the hub. This fan is made to rotate at the inner end of the chamber and the plane of the fan is set off sufficiently from the end to allow for some centrifugal circulation, thus eliminating any possibility of dead air at the end of the chamber.

The fan is driven by single phase A.C. capacitor start motor, of 1/40 h.p. The motor is mounted in a separate chamber at the rear of the pressure chamber. The shaft rotating the fan passes through a small opening. In so locating the motor, two problems were overcome.

(a) The matter of the capacitor which extreme pressure changes may cause to erupt.

(b) The tendency for the motor to overheat at low air pressures.

The first problem was simply solved by locating the capacitor in a junction box located outside the chamber. The second by wrapping a close fitting coil of 1/4" copper pipe around the outside of the motor frame and cooling by passing water through the coil.

Temperature Measurement

The temperature is measured by a platinum resistance thermometer wound on open cross frame using a bifilar winding and located permanently within the chamber at a suitable position among the array of sondes. The resistance of the thermometer is measured on a suitable bridge.

The electrical wiring was by necessity complex. In order therefore that the system could be handled by non technical personnel, it was necessary to give considerable thought to simplification and centralization of all controls and switches and at the same time provide necessary safety devices.

The chamber is located in a large room and the refrigeration machinery in a small adjacent room. As a consequence of the use of propane as a refrigerant, it was necessary to provide certain safety precautions. A system of forced ventilation was installed. This was provided by a "Sirocco" centrifugal fan using a vapour proof motor with inlet flush with the floor of the compressor room, leading the air near the floor surface to the outside. As propane is heavier than air, in event of a leak, the dangerous gas would be removed. A system of warning lights and bells makes it impossible to use any electrical equipment with the fan not operating.