ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN
ANN ARBOR

TECHNICAL REPORT NO. 31

ICE WARNING DEVICES

S.E.M.L. 1945

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Published by the

Groupement Francais pour le Development des Recherches
Aeronautiques

G.R.A. Paris 1945

Translated by

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MYRON TRIBUS

Project 2128-1

AIR MATERIEL COMMAND, U. S. AIR FORCE, WRIGHT-PATTERSON AIR FORCE BASE
CONTRACT NO. AF 33(600)-23549, E.O. NO. R-664-802B

July, 1953

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ICE WARNING DEVICES

TERMINOLOGY

Before describing the different types of devices mentioned in this report, we believe it will be useful to specify our terminology. This terminology is identical to that proposed by Professor E. Brun in G.R.A. Bulletin No. 3.*

I. Icing Detector

An apparatus which detects or measures the ice being formed or about to form. The detection or measurement may be performed inside a cloud or at a distance.

These devices include:

IA. Detectors of Instantaneous Icing

These are devices capable of detecting icing as it occurs or of providing measurements on the icing rate or the expected rate. The detectors of instantaneous icing include:

IA-1. Warners of Instantaneous Icing

Instruments which detect icing as soon as it occurs.

IA-2. Indicators of Icing Rate

Devices which measure the rate of icing.

*Translation available from E. R. I., University of Michigan

IB. Fore-Detectors of Icing

Devices which determine whether or not a cloud ahead of the airplane is apt to cause icing. The devices may provide measurements which determine the probable icing rate. The fore-detectors of icing include:

IB-1. Fore-Warners of Icing

Devices which detect at a distance the existence of a cloud zone capable of causing a deposit of ice.

IB-2. Fore-Indicators of Icing Rate

Devices which measure at a distance from the icing-cloud zone and permit the determination of the probable icing rate.

II. Relation Between Detectors and Protection Devices

"Anti-Icing": Operation which prevents the formation of ice.

"Safety-Interval": Length of time which elapses between the warning signal from a fore-warner and the first ice deposit.

"Thermal Anti-Icing Time": Time required for a component which is to be protected to reach the temperature required for ice protection.

"Thermal Anti-Icing Power Indicator": Indicator whose signal is proportional to the thermal power required for anti-icing.

"De-Icing": Removal of ice after it has been deposited.

SUMMARY

This report is intended to give a brief description of the "warners of instantaneous icing"* which have been developed at Mount Lachat during 1945.

*Translator's note: see definition of terms

In the first chapter we show the principle and some details of construction for the icing probes S.G.2 and S.G.3 which form the essential element of the warners described in this report. We also give a description of indicators which are to be discussed in later publications. These probes (S.G.2 and S.G.3), which are simple and small, close the electrical circuit of a warner when a small moving pointer, the "finger", is blocked by ice.

The next three chapters are devoted, successively to:

1) Warners of instantaneous icing, I.G.12, 14, and 15. One of these is especially suited as a detector of icing in an induction manifold as on an engine equipped with a carburetor. It has undergone satisfactory tests on an A.S.12, 550-hp engine.

2) The ice-warner I.G.13 which is made up of two I.G.15 warners and an electrical thermometer whose temperature readings are recorded by means of photoelectric cells.

3) The warners of instantaneous icing, I.G.21, 22, and 23, in which the icing on an obstacle placed at the throat of a venturi is detected by a finger probe, S.G.2 or 3. These instruments have undergone satisfactory preliminary tests in the icing wind tunnel and have been studied with a view towards adapting them to use on an airplane in their present form. The last mentioned one, I.G.23, gives an indication of the icing intensity.

INTRODUCTION

If one wishes to study icing phenomena accurately, it is especially necessary to be able to measure precisely both the thickness of ice deposited on a given obstacle and the rate of icing, i. e., the derivative of the thickness with respect to time.

Another quantity of interest is the thermal anti-icing power, i. e., the power necessary to insure anti-icing.

Of course, in most cases one is satisfied with only approximate values; thus, for an aircraft carburetor or nacelle, the required equipment may be only a simple "warner of instantaneous icing" which detects the ice as it forms. Or a "warner of instantaneous danger" may be used in lieu of a "fore-detector". This last apparatus, which we have suggested as a ready substitute for a "fore-detector," yields an indication of the danger present in the icing by recording the time necessary to de-ice a test surface.

We have solved the problem of measuring the thickness of ice and the rate of icing by using a photoelectric-cell type of indicator. It comprises two periscopes and a multistage amplifier (Figure 1).

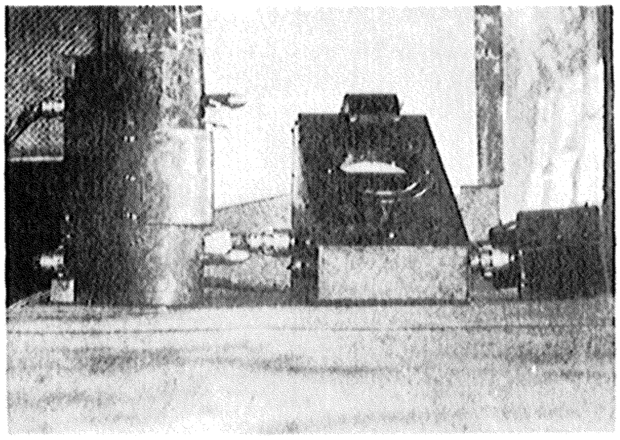


Figure 1. A Thickness-Of-Icing Indicator Which Utilizes Photoelectric Cells.

A certain complexity results from the use of the photoelectric cells, but this does not limit the usefulness of the instrument in icing studies. If desired, the instrument could be adapted for aircraft use, but we do not believe the flight safety would be increased by the greater precision. More crude devices should suffice.

It may appear, a priori, a much simpler problem to design a simple ice-warning instrument. Nevertheless, to our knowledge there does not exist any safe and sensitive device which is independent of the wind velocity. Our "finger probes" may perhaps possess the required qualities. Having been built only a few months ago, they have not yet been subjected to all the desired tests. Up to now no defect has been observed during laboratory and icing wind-tunnel tests and it may be hoped that these performances will be verified by flight tests, a test airplane and on air lines.

Besides their use as simple warners, these finger probes may also be used in more complicated instruments. Two indicators of thermal anti-icing power have been designed. The first one is based on an idea proposed by M. Moraux, Chief of the Mt. Lachat station. These indicators are now being tested at our wind tunnel at Mt. Lachat.

In the first indicator, the icing of a low thermal capacitance surface is detected by means of a finger probe which closes the de-icing circuit of this surface. As soon as the de-icing is achieved, the circuit

is opened. Since the intensity of the de-icing current is large, the cycle is short. When icing takes place a relay puts a condenser under slow charge. When the ice is melted, the condenser is switched to slow discharge. After a few cycles the voltage across the capacitor oscillates between two values which are close enough so that the average voltage appears on a voltmeter placed across the capacitor.

The I.G.20 indicator (Figure 2) is a dual indicator of thermal anti-icing power.

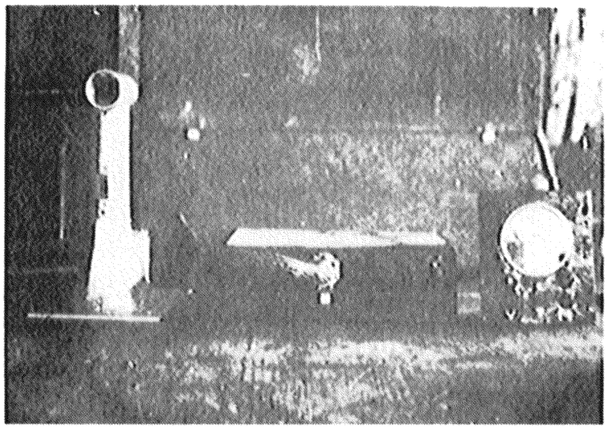


Figure 2. Dual Indicator of Thermal Anti-Icing Power, I.G.20

The circuit elements of the control box (impulse motor, relays, condenser, and voltmeter) are supplied with 24 volts and are connected through appropriate relays:

1) Either to the probe checking the icing of an obstacle placed in the throat of a venturi; or

2) to the probe controlling the icing of a surface placed on the leading edge of the mast which holds the venturi.

In the second indicator (I.G.30) the two probes control the icing of the two halves of a small bar of an electrical resistor (or a bar covered with a resistance wire) as shown in Figure 3.

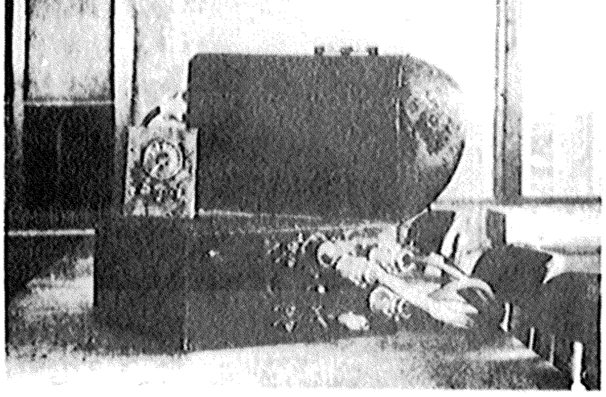


Figure 3. Thermal Anti-Icing Power Indicator, I.G.30.

One half of the bar is shunted so that the current in it is a certain constant fraction of the current in the other half. The control box of the instrument contains relays which act on a moveable slide-wire rheostat in such a manner that the electrical power to the bar takes on the value necessary to obtain icing on half of it, the other half, which is not shunted, being anti-iced. The current intensity is read on an ammeter, which gives the thermal anti-icing power corresponding to the case of the icing encountered. The precision depends upon the shunt.

The photoelectric-cell indicators (thickness and icing rate) and finger-probe instruments (thermal anti-icing power) will be described in separate notes as soon as they have been subjected to tests sufficiently numerous to warrant a judgment of their value.

In this report we have restricted ourselves to the description of ice-warning devices which use probes, I.G.12, 13, 14, 15, and 16 and to warners of "instantaneous damger" which use probes I.G.21, 22, and 23. The test records for all three instruments, with sufficient documentation, will be published at the end of the current winter season.

CHAPTER 1

"FINGER" ICING PROBES

1. Historical Note

In the month of December, 1944, we studied the first warning device I.G.10 which used finger probe S.G.1; it was constructed by January, 1945 (Figure 4).

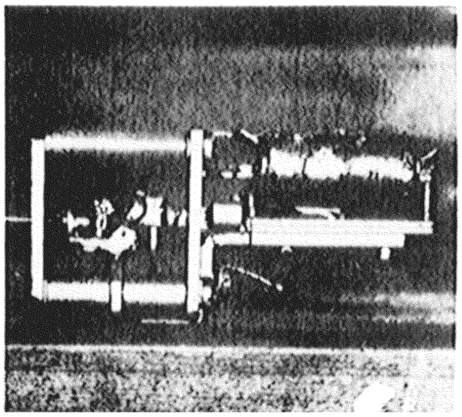


Figure 4. Probe S.G.1

M. Sion, experimenter, was entrusted with its construction and we are indebted to him for several improvements in our warning devices.

After having run some satisfactory tests in the wind tunnel at Mt. Lachat in April, 1945, we asked the "CLUSES" workshop to build eight similar probes. Some improvements were made, particularly in the fabrication technique which really belongs to the watchmaker's art. These probes, S.G.2, were delivered to us from August 1 to November 1, 1945.

Meanwhile, we had completed satisfactory tests on a probe simpler in its mechanical setup, but which required more complicated electrical circuits. A model of this new probe had been built at "CLUSES" while we were making tests on an S.G.2 probe which we modified to an S.G.3. A special control box was used for these tests.

The especially satisfactory results obtained with the S.G.3 probe prompted us to think that in many cases it should be preferred to others, since the safety and mechanical simplicity achieved compensate for the presence of supplementary relays.

2. Description of the S.G.2 Probe

We shall not describe the probe S.G.1 which differs from the probe S.G.2 only in minor details of construction (square cross section instead of circular) and by the absence of a contact to control rotation (see Figure 4).

On the outside, the finger probe S.G.2 looks like a cylinder 40 mm (1-3/4 in.) in diameter and 90 mm (3-1/2 in.) long. A 1-mm-diameter rod connects it to the "finger" which is a pointer 10 mm long, 3 mm wide (at the center), and 0.5 mm thick, on the average. The length of the rod connecting the finger to the probe mechanism is fixed in such a manner that the finger can oscillate freely at a few tenths of a millimeter above the surface on which the ice is to be detected. As we shall see, this finger may take several different shapes.

The volume of the probe can be reduced by one half if the exterior casing is the only protection for the mechanical parts (Figure 5).

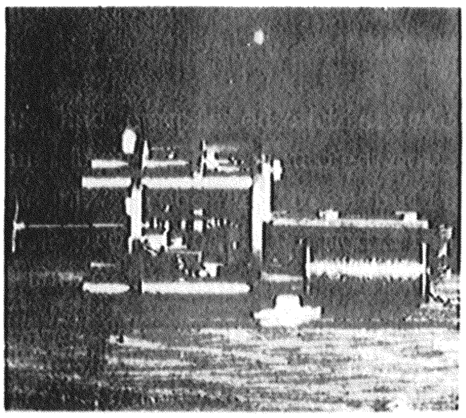


Figure 5. Probe S.G.2

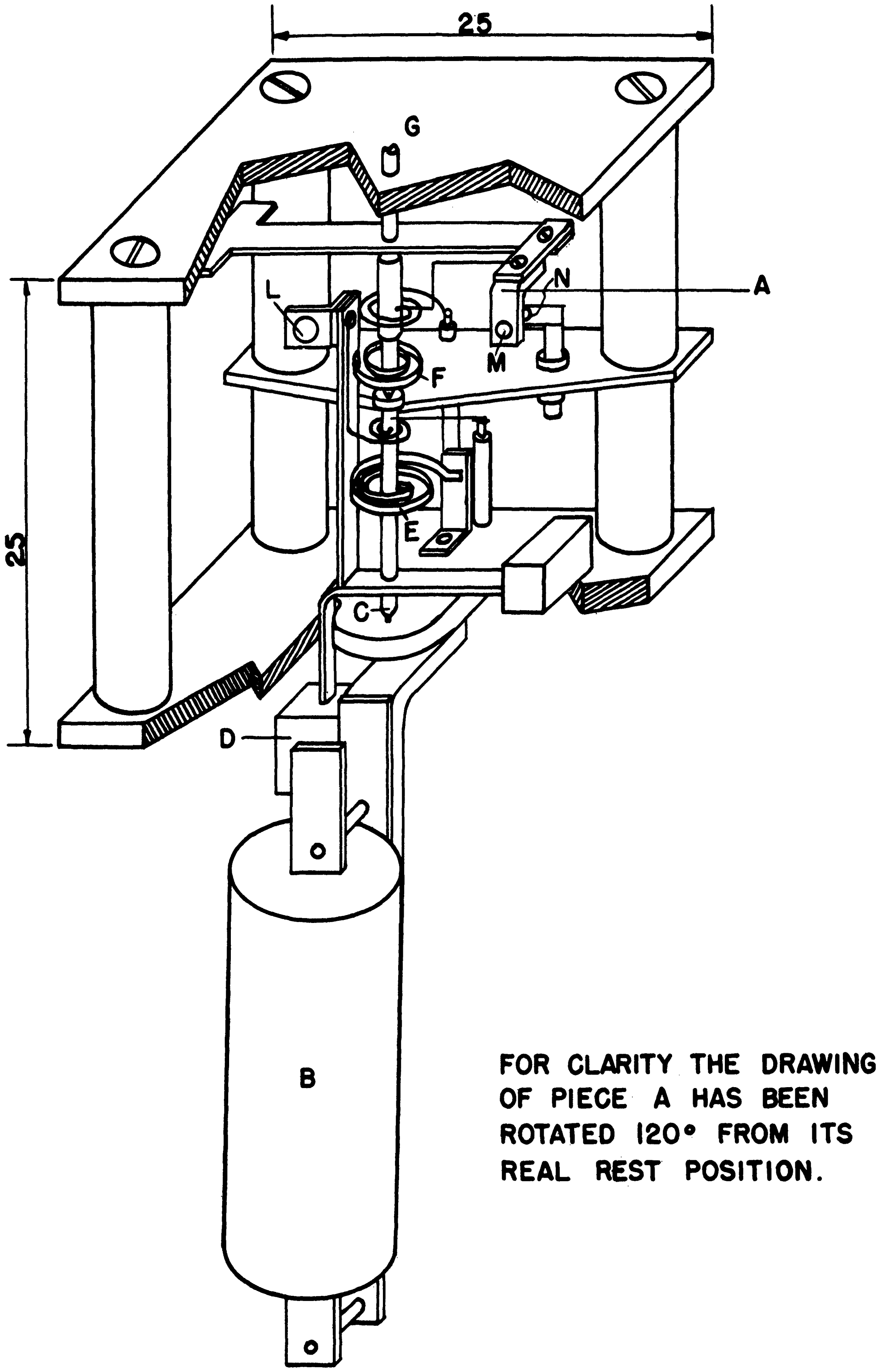


FIG. 6 FINGER PROBE S.G.1, S.G.2.

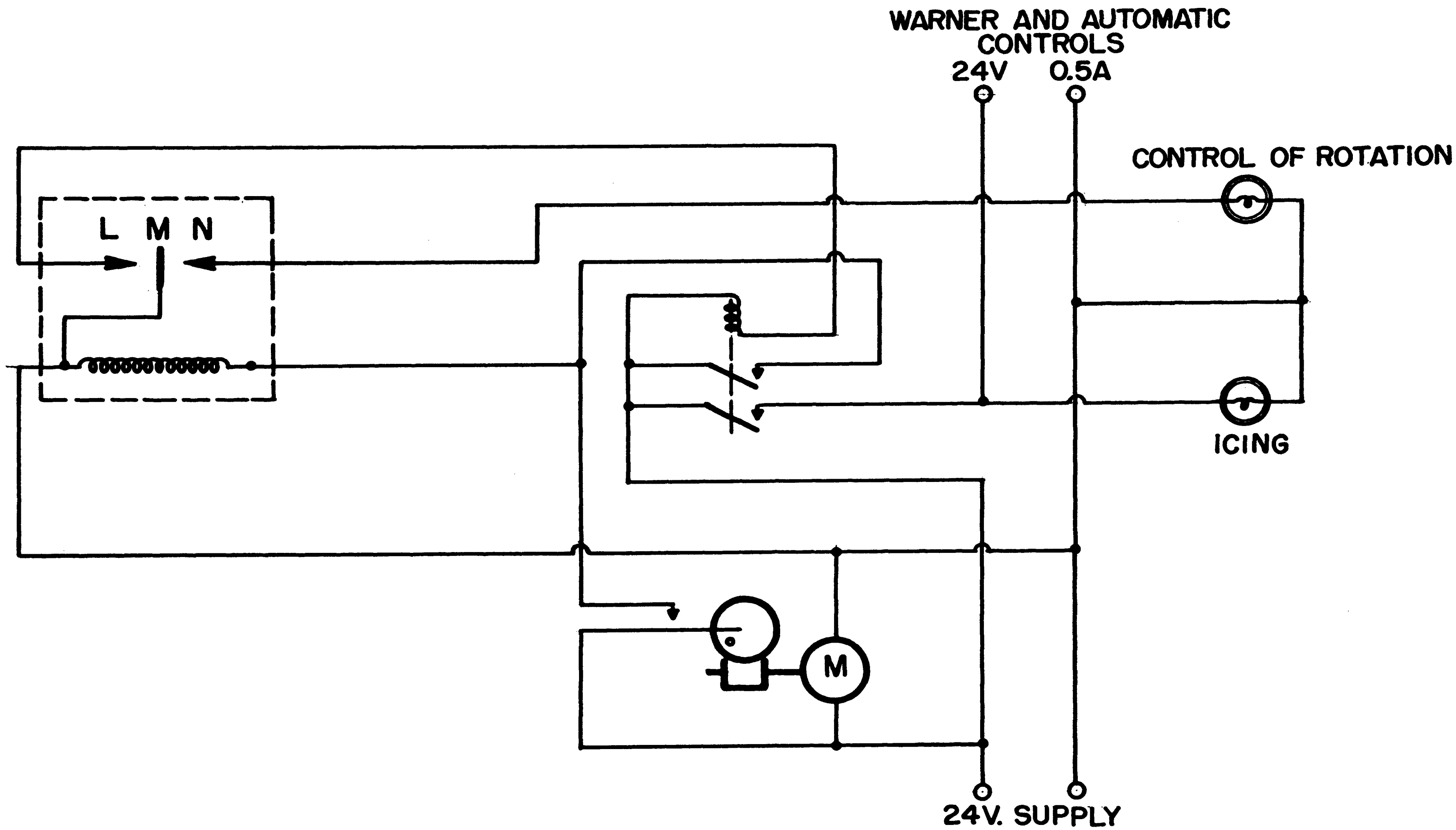


FIG.7

SCHEMATIC DRAWING OF THE CIRCUIT FOR THE ICING PROBE S.G.-1 AND S.G.-2.
ICE WARNING I.G. 10.

The probe S.G.2 is formed (Figure 6) by an electromagnet B which, under 24V, attracts a small mass D swinging about the axle C. (C is referred to as the primary axle.) When the current is cut, the small mass is brought back to its initial position by a spiral spring E.

The primary axle C is connected through a spring F to a second axle G placed in alignment with it. At the free end of this axle (called the secondary axle) there is a rod to which the finger is attached.

The primary and secondary axles are equipped with a platinized contact. The contacts L and M touch each other if there is current in the electromagnet B and if the finger remains blocked in its original position (occurrence of ice). When the contacts L and M touch each other they close a circuit (Figure 7). This circuit controls a relay which closes both the warning circuit and the circuit supplying the electromagnet B. The electromagnet thus remains excited as long as the finger is blocked.

When the finger is freed (melting or sublimation of the ice), the contacts separate under the action of the spring F. The relay comes to its rest position, the warning circuit and the electromagnet circuit open, and the small weight is permitted to take its initial position.

In order that a new cycle may start, a current is periodically sent through the electromagnet for a fraction of a second. This is accomplished by the impulse motor which drives a cam through a reduction gear and actuates a pair of contacts. Nothing takes place in the circuits controlled by the relay as long as the finger is free to oscillate.

An auxiliary circuit is closed by the stop N which limits the rotation. This circuit contains the pilot lamp which indicates rotation of the finger. The lamp gives assurance that the instrument is receiving the impulses and is operating normally.

3. Description of the Probe S.G.3

The probe S.G.3 (Figures 9 and 10) differs from the probe S.G.2 in that the icing contact and the secondary axle have been eliminated. The small mass is rigidly tied to the finger. The functions performed by the interior mechanism of probe S.G.2 are now carried on by relays properly connected.

In this probe, the impulses are sent to a relay which is self-locking until the circuit controlled by the rotation of the finger is shut, thus freeing this relay. Another relay closes the "ice-warner" circuit if the first relay remains locked for more than a specific time interval fixed either by an RC network or a thermal relay.

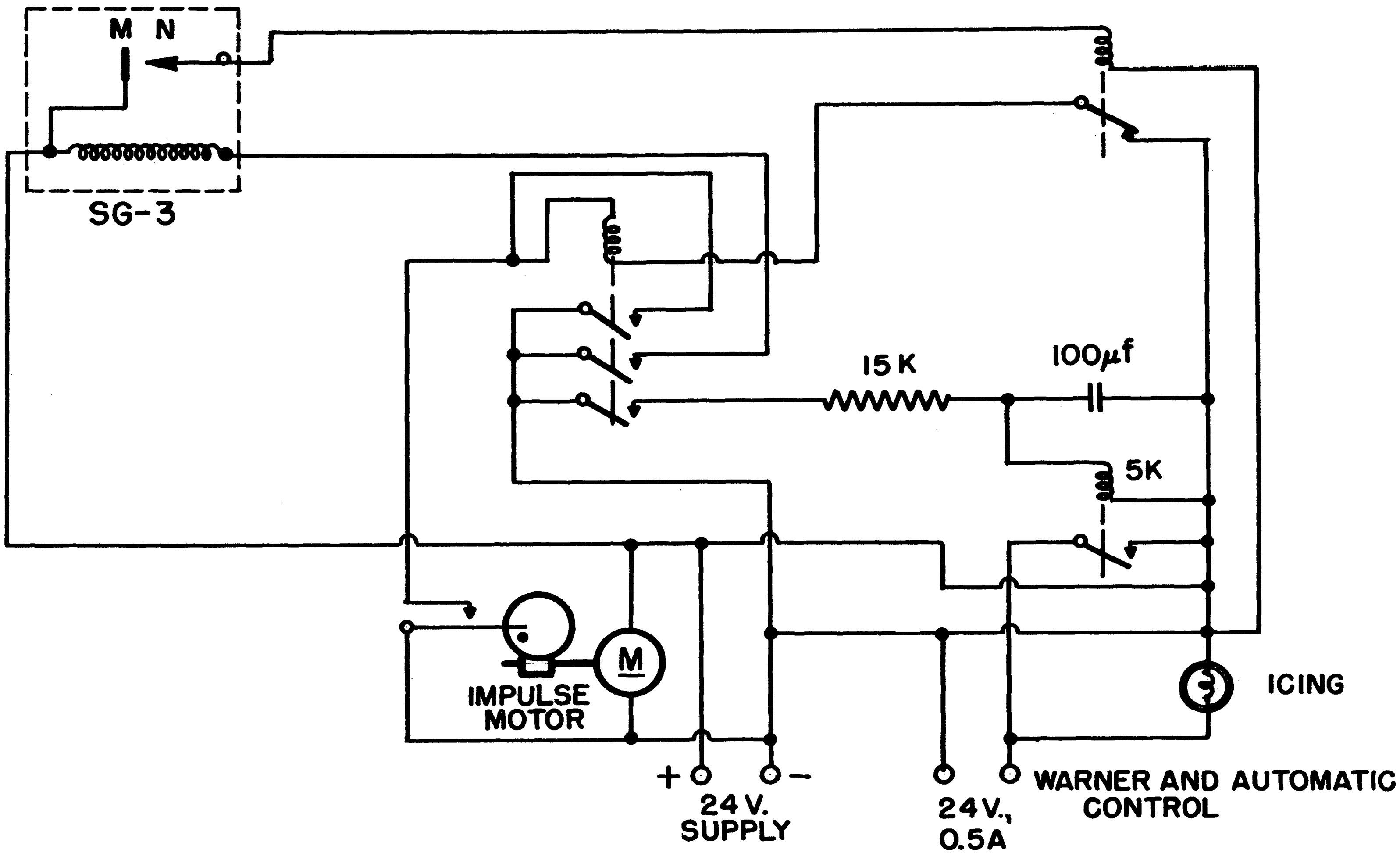
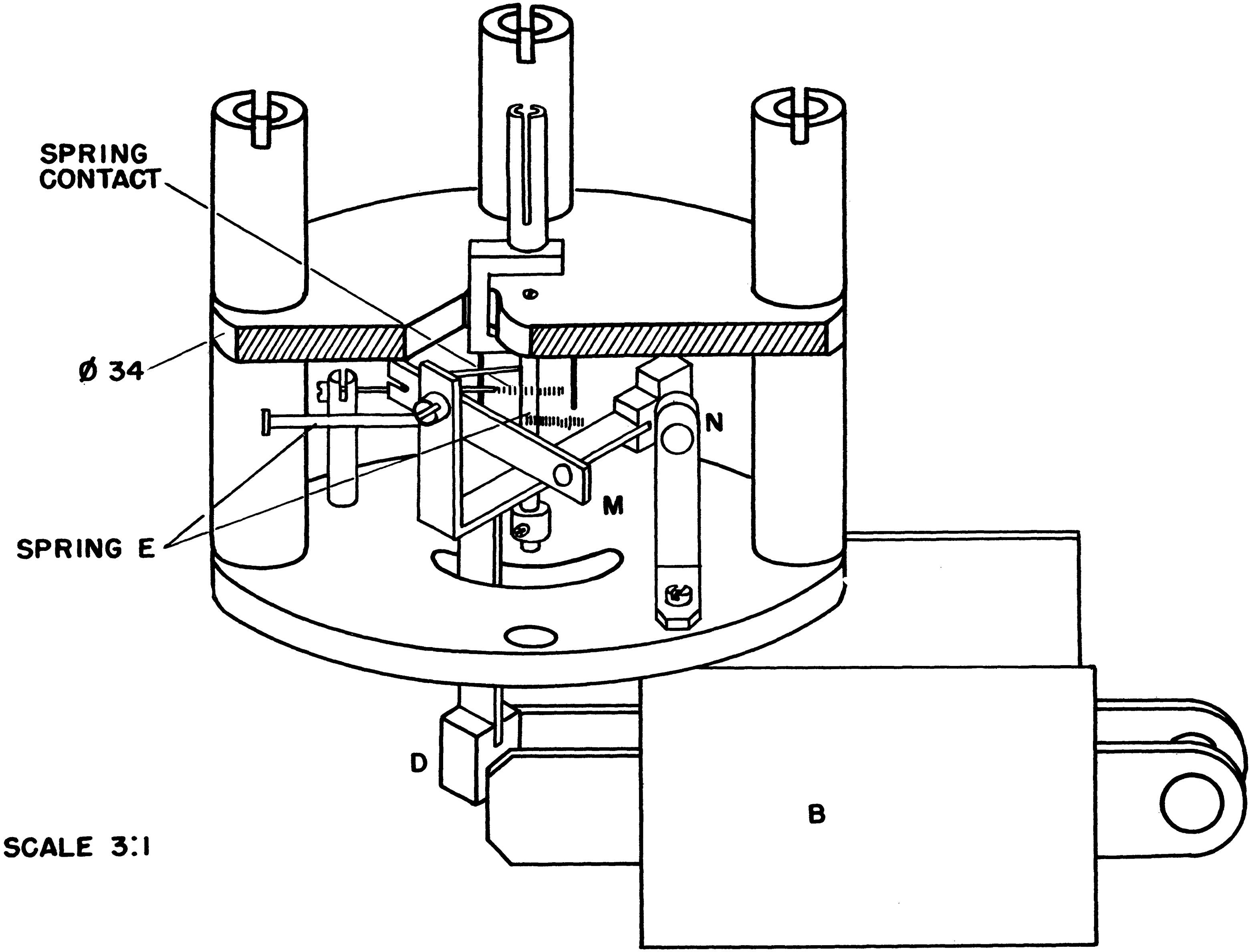


FIG. 8

DIAGRAM OF THE CIRCUITS CONNECTED TO THE ICING PROBE
SG-3



SCALE 3:1

FIG. 9 PROBE SG. -3

The probe is thus greatly simplified since it has only one axle, a single recoil spiral spring, and one pair of contacts. The safety is increased since most of the mechanical or electrical failures will cause a tripping of the warner. The causes of trouble are thus fewer, and the need for adjustments during manufacture is reduced. The space occupied by the probe is less. The shock due to the contacts MN (Figure 6) in probe S.G.2 is eliminated. In the case of fragile ice, the shock is very undesirable.

The circuits of the probe S.G.3 can be partially simplified as we have done in warner I.G.15, which is especially suited for fragile ice.

This arrangement has some disadvantages which restrict its possible usages:

1) The speed of the impulse motor must not vary over too large an extent.

2) The relays are not automatically freed when the ice leaves; an electrical impulse is necessary.

3) The impulse signal received by the probe cannot be made as short as in the circuits of Figure 8.

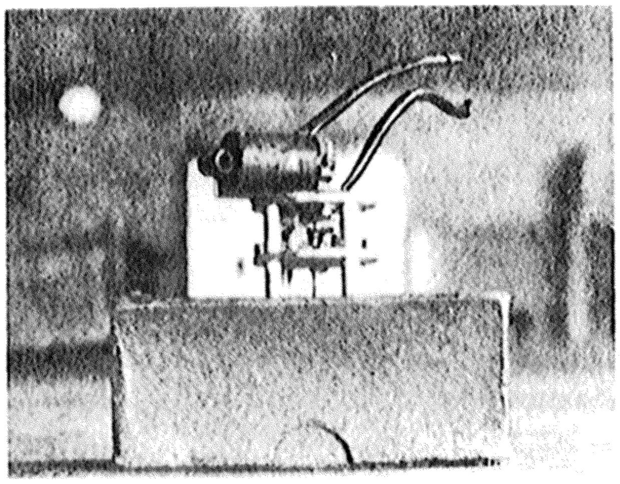


Figure 10. S.G.3 Probe

CHAPTER II

ICING WARNERS I.G.12, 14, 15, AND 16

4. General Remarks

The warners of instantaneous icing serve to detect icing as soon as it occurs on the surfaces which they control.

Our warning devices consist of:

1) A probe, S.G.2 or S.G.3, the finger of which sweeps a portion of the surface S.

2) A "control box" which contains the different relays, the impulse motor, and the sockets for the connecting cables to the probe and panel.

3) A "control panel" which has mounted in it receptacles for the instruments' power supply and sockets for the connecting of auxiliary warners or of other automatic controls. Also provided is a socket for connecting the cable with the "control box" as well as with a switch and two signal lamps. A green lamp indicates rotation of the secondary or of the single axle of the probe. A red lamp indicates icing occurrence. In some instruments we have combined the control panel and control box in one single control panel.

5. Warner I.G.12

This instrument has been designed to check the icing of a surface whose de-icing is not governed by the instrument itself. The control of the icing should be accomplished by an outside relay. The instrument has been primarily tested in the intake manifold of a 550-HP RENAULT AS-12 engine.

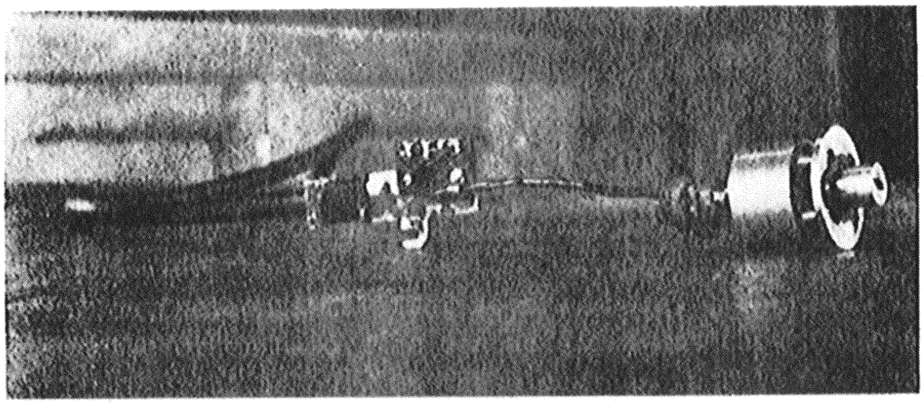


Figure 11. Probe S.G.2 with Its Mounting Frame for the AS-12 Engine.

As shown in the wiring diagram of Figure 12, the circuits are quite similar to those of the prototype warner I.G.10. To it, we have only added:

1) A relay between the rotational contact N and the green lamp in order to reduce the current in the contacts MN.

2) Some capacitors across the relays in order to reduce the difficulties caused by engine vibrations transmitted to the probe, since the contacts do not close the circuits sharply and the relays do not operate properly when actuated by a fluctuating current.

3) Some resistors and capacitors shunted across the probe contacts, the impulse motor, and the relays in order to suppress the sparks at the break.

4) A capacitor across the impulse motor brushes to extinguish the sparking and suppress the static which disturbs radio reception.

The relays used require about 10 milliamperes at 24 volts. It would be better to use relays requiring only 1 or 2 ma. This would reduce the current in the shunt and also the current in the contacts. We have observed a very slight pitting on the contacts after several hours of operation of the I.G.12 apparatus. On the other hand, the contacts did not show any change in the devices which we shall describe below. On these devices we have been able to reduce the current required by the relays which are controlled by the probe contacts.

The impulse motor is a JAEGER tachometer motor to which a reduction gear and worm gear have been added. The impulses are emitted approximately every four seconds and last from one-fourth to one-half second.

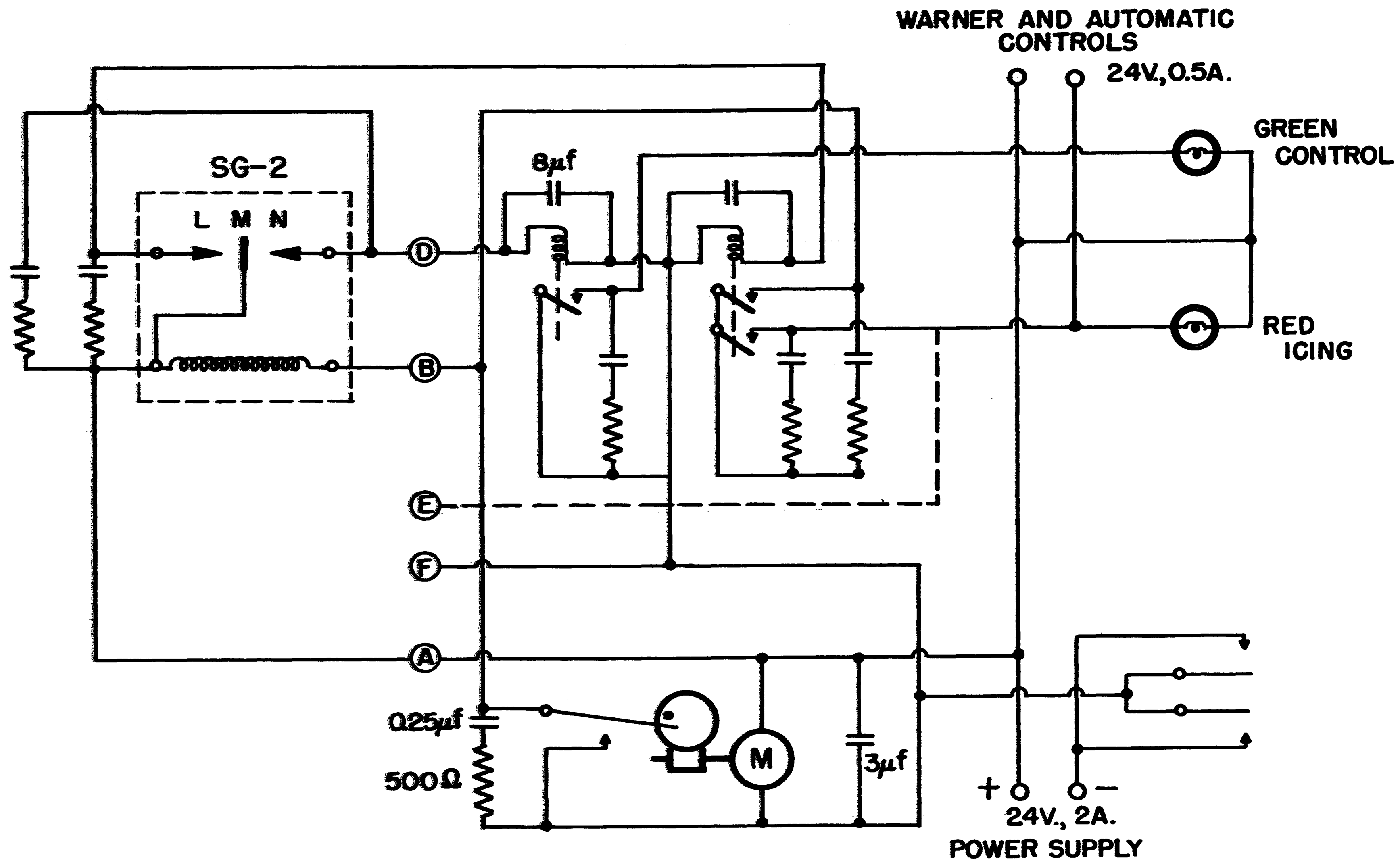


FIG. 12

DIAGRAM OF ICE WARNER FOR USE IN INTAKE MANIFOLD IG-12 (HC.3)

This instrument (Figures 12 and 13) operated successfully on a test stand shaken by an eccentric grinding wheel electrically driven. The probe support was subjected to vibrations of 2 mm amplitude and frequencies ranging from 0 to 3000 cpm. It does not operate satisfactorily when mounted on an AS-12 engine because at idling speeds, where the vibrations attain large amplitudes, the contact M strikes the two contacts L and N alternately under the action of the forced vibrations. The oscillation causes permanent and simultaneous lighting of the green and red signal lamps.

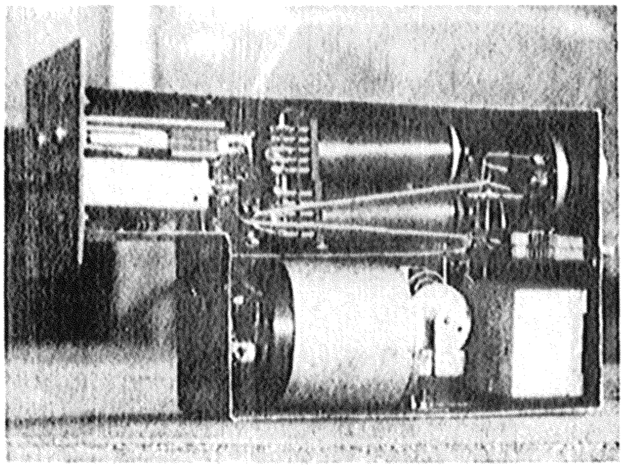


Figure 13. Control Panel for I.G.12

6. Warner I.G.14

In order to avoid the irregularities noticed in the operation of the I.G.12 warner, we have designed an icing warner with a probe, S.G.3, for use in an induction manifold. Since there is only one contact, this probe eliminates the previous difficulties. Its mechanical simplicity makes it quite appropriate for severe conditions of both large amplitude vibrations and varied frequencies. It is also capable of withstanding infiltrations of oil or water.

The first tests were run with a probe, S.G.2, the contact L of which was not used. A junction box was placed between the probe and the panel, I.G.12 (Figure 14). The results were satisfactory and a control box and a panel, I.G.14, have been built in accordance with Figure 15. While waiting for the completion of the probe S.G.3 we fastened together the primary and secondary axles of a type S.G.2 probe by welding a rigid rod on the contacts L and M.

The relay R 1 which is connected to the contact N is a low-inertia relay which consumes only one milliampere. The shunt condenser has been increased to 4 microfarads in order that the green control lamp may have time to light up, but, owing to the 500-ohms resistor in series with it, no spark or corrosion of the contacts has been noticed.

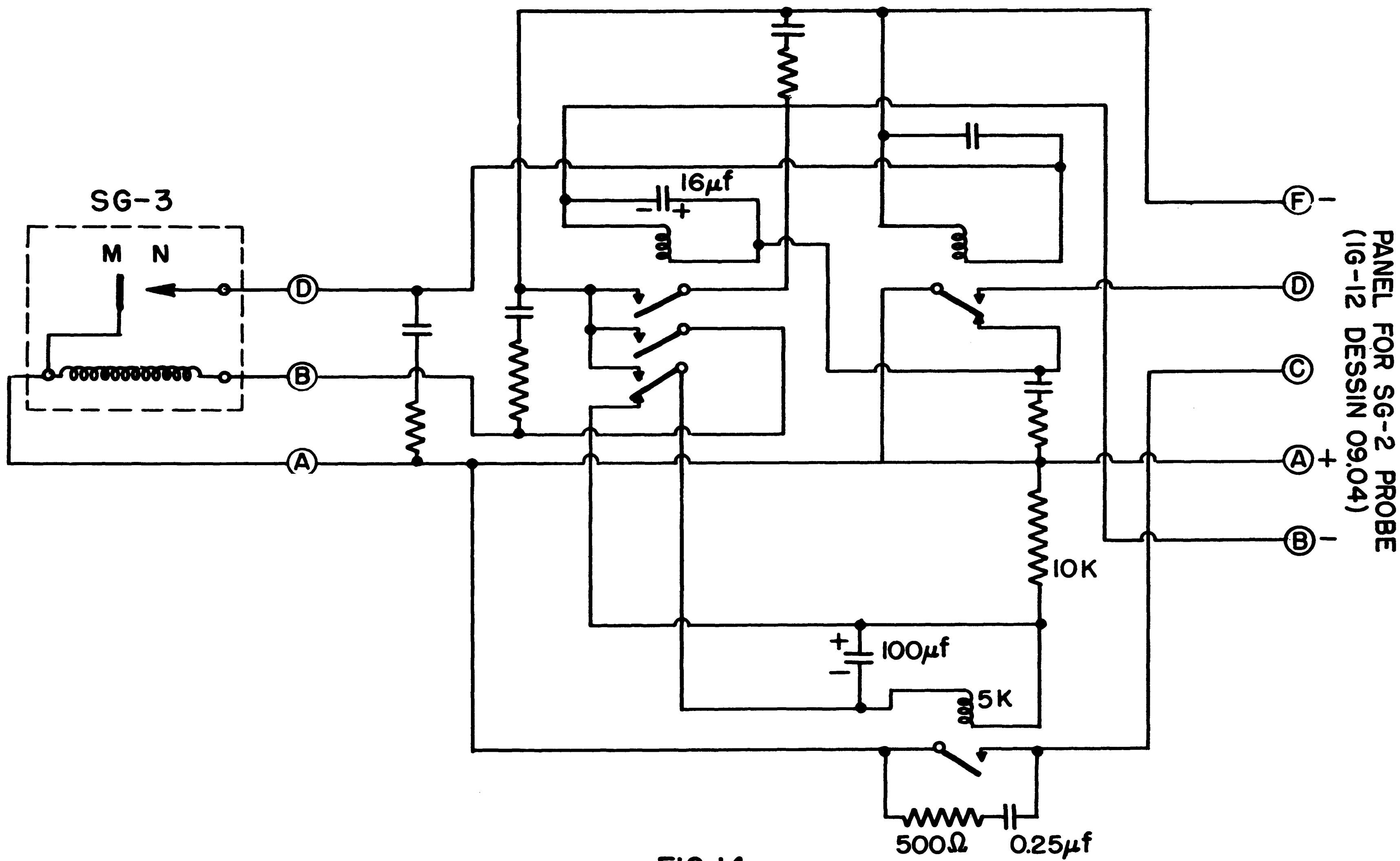


FIG. 14

JUNCTION BOX FOR THE SG-3 PROBE CONNECTING TO A PANEL FOR AN SG-2 PROBE
(IG-12)

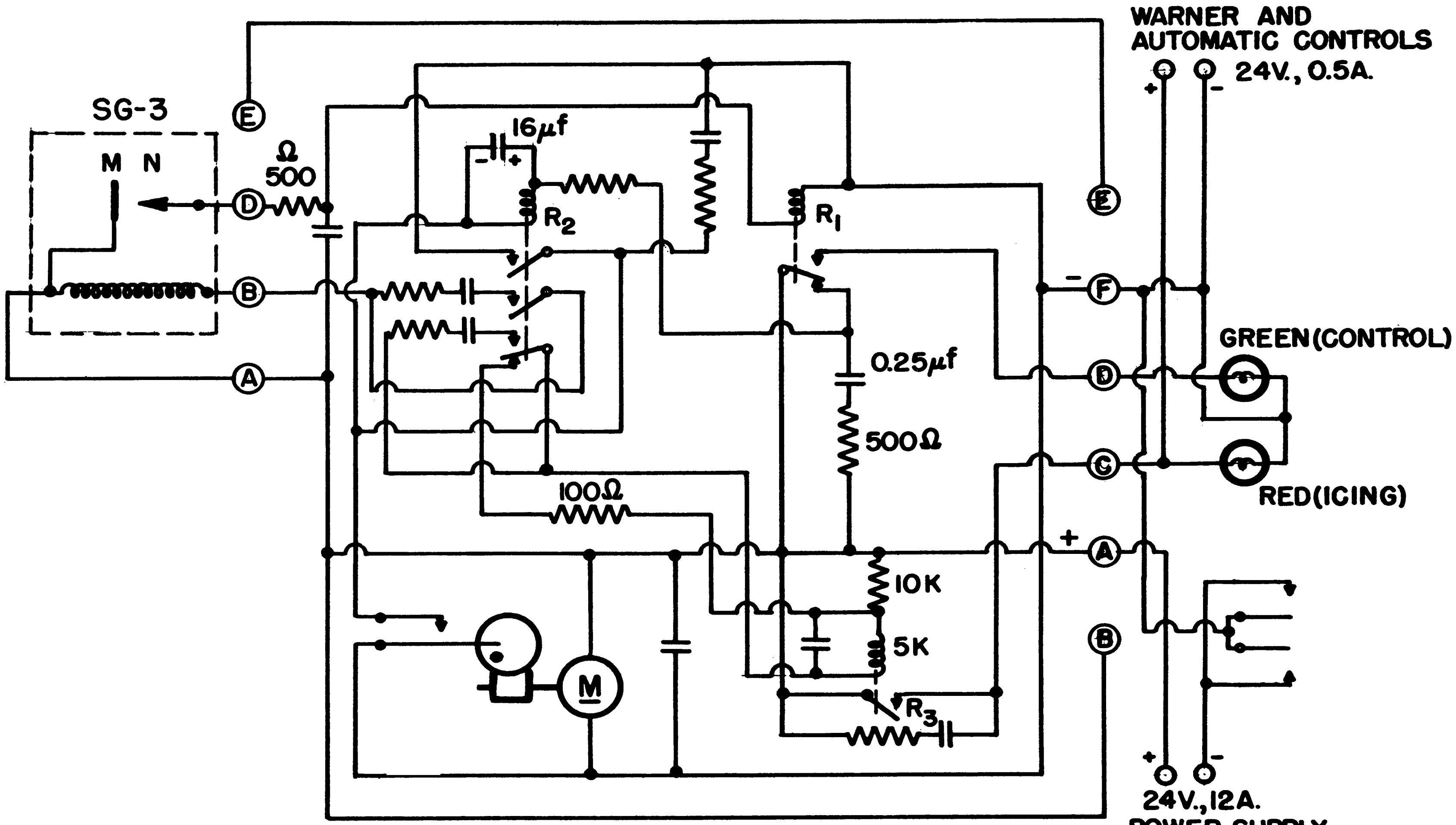


FIG. 15

CONTROL PANEL AND CONTROL BOX FOR THE SG-3 PROBE IG-14

(MAY BE USED AS A JUNCTION BOX)

The relay R 1 which is connected to the contact N is a low-inertia relay which consumes only one milliampere. The shunt condenser has been increased to 4 microfarads in order that the green control lamp may have time to light up, but, owing to the 500-ohms resistor in series with it, no spark or corrosion of the contacts has been noticed.

The relay R 2, which is controlled by the impulses and also by the relay R 1, has had its apparent inertia augmented. This may be accomplished in any one of several ways. For example, the magnetic circuit can be so arranged that the apparent inertia is greater. A large capacitor can be placed across the windings of R 2 or across the contact of R 1 which commands R 2. By so increasing the inertia, the number of oscillations of R 2 which occur at each impulse are reduced to one or two. These oscillations are caused in the following way: the impulse signal sent out by the impulse motor blocks the relay R 2 which closes the circuit of the electromagnet of the probe; if there is no ice, the contact MN occurs, and the relay R 1 opens the circuit of R 2 which then opens that of the electromagnet. The contact M pulls away from N and, if the impulse signal emitted by the impulse motor has not yet been completed, the relay R 1 again closes the circuit of R 2. Since R 2 is not yet open, the cycle starts again. If no apparatus is present to dampen these oscillations, a large number of them can be observed during the impulse even though it lasts only a fraction of a second. One should pay close attention to the order in which the contacts which are governed by relay R 2 close and to the necessary period which is required to affect these contacts. This period should be chosen long enough to increase the inertia effect. The relay R 2 closes the circuit of R 3 through a 10,000-ohm resistance. This relay R 3 of 5,000-ohms resistance is shunted by a 100-microfarad capacitor so that it closes the circuit of the red signal lamp and of the warners with a time delay of about one second. When the relay R 1 comes to its rest position, the 100-microfarad capacitor is short-circuited and the relay R 3 immediately opens the circuit of the warners.

Instead of this combination of resistances and capacitors which provides an ordinary relay with a controlled apparent inertia, a special thermal-delay relay can be used. We have used such a relay for the prototype of our I.G.22 "warner of instantaneous icing danger". One has then a relay exhibiting an inertia of the same order of magnitude at both opening and closing, and this may be undesirable in certain cases.

Finally, we would like to mention a manufacturing detail which we have introduced into several of our probes. The forces on the probe being small, it is important that the friction be negligible. This problem is easily solved in the probe itself; but when one mounts the probe as a part of a warner, the axle of the probe should coincide with the hole that has been drilled in the surface S which is being felt by the probe. In order to avoid this condition, which requires a very accurate assemblage, we have filed the

piano-wire probe axles over two lengths of about 5 mm so as to reduce the thickness of the axle to a few tenths of a millimeter in these regions. The two flat surfaces thus obtained are normal to each other. One thus builds an axle capable of transmitting the entire torsional couples while remaining flexible. The frictional resistances due to an imperfect assemblage are largely diminished and easily made quite negligible.

This instrument, I.G.14, has been tested on an AS-12 RENAULT engine of 550 HP. The normal speed of this engine is 3100 rpm. In the absence of icing no difficulty was observed during the operation at any speed. Unfortunately, the weather conditions did not permit us to observe any icing of the carburetor during November, 1945. Thus, we cannot ascertain that the I.G.14 warner satisfies all the conditions one may require of a good ice-warning device. Nevertheless, because of the principle on which the S.G.3 probe is based, it is certain that the instrument will indicate correctly if the finger locks. It has been assured that violent vibrations have no effect on the control. It is still necessary to verify that the ice subjected to severe vibrations will stick correctly to the surface which is controlled by the finger and to the finger itself.

7. I.G.15 Warner for Fragile Ice

In certain cases one may fear that the continuous action of the finger on a piece of brittle ice, such as that observed at times on wires, would break this ice. Or one may worry that the continuous pressure of the finger will cause it to move slowly up to the end of its stroke.

A similar sort of trouble may occur if the ice which has been detected by the finger slowly melts on the controlled surface while it freezes in a direct proportion on the upstream surface. The finger would then creep slowly into the ice with a continuous motion of translation parallel to the axis of the probe.

These troubles may be avoided by not closing the circuit of the electromagnet in the probe S.G.3 through the relay which locks itself at the moment of the impulse. Rather, the impulses themselves should be sent to the probe and to the relay at the same time. The impulse circuit is thus divided into two circuits, one for the probe and the other for the relay.

In this fashion one obtains the diagram of Figure 16, which is simpler than the diagram for I.G.14. In certain cases this reason may be sufficient for its use unless other reasons dictate to the contrary.

The relay R 1 is a low-inertia relay. The relay R 2, on the other hand, should possess a large apparent inertia. Then the working of the apparatus is quite simple: the impulse sent to the probe causes the contact

MN. The relay R 1 short-circuits the coil of R 2 thus opening the circuit of relay R 2 which is in series with a resistance. The impulse which has just reached R 2 is interrupted, as it will not have time enough to close the circuits governed by R 2.

This setup is simple. However, it exhibits three defects which may be negligible in many cases:

1) When icing has occurred, and then the ice melts, the warner I.G.15 indicates the end of icing only at the first impulse which follows it. The other warning devices signal the cessation of icing immediately. This defect is not acceptable in the case of an indicator for icing intensity.

2) If the speed of the impulse motor varies too much, the impulse emitted by the motor will be too short to close the relay R 2. Even if there is icing, R 2 will not close. This defect causes us to use an impulse motor whose speed does not vary greatly when the temperature and the supply voltage change. In certain cases one may require that a voltage regulator be used. However, the other types of warners are not entirely unaffected by such phenomena, and one should always keep the duration of the impulses above a certain lower limit. This lower limit is less in other warners than in the I.G.15.

3) During the time of the impulse the probe remains in the extreme position in which the contact occurs. The danger then exists of icing occurring during this time and the instrument remaining stuck without indicating icing. In the I.G.14-type warners this danger seems to be small since the finger stays in the extreme position only during a small fraction of a second.

8. The I.G.16 Icing Warner

The I.G.16 is a warner of the type I.G.15 equipped with an extra relay to eliminate the last defect mentioned concerning the I.G.15. A time-delay relay is mounted on the circuit of the control signal lamp and closes the warner circuits if the probe stays blocked in a position of contact for a length of time larger than a given time interval (Figure 17).

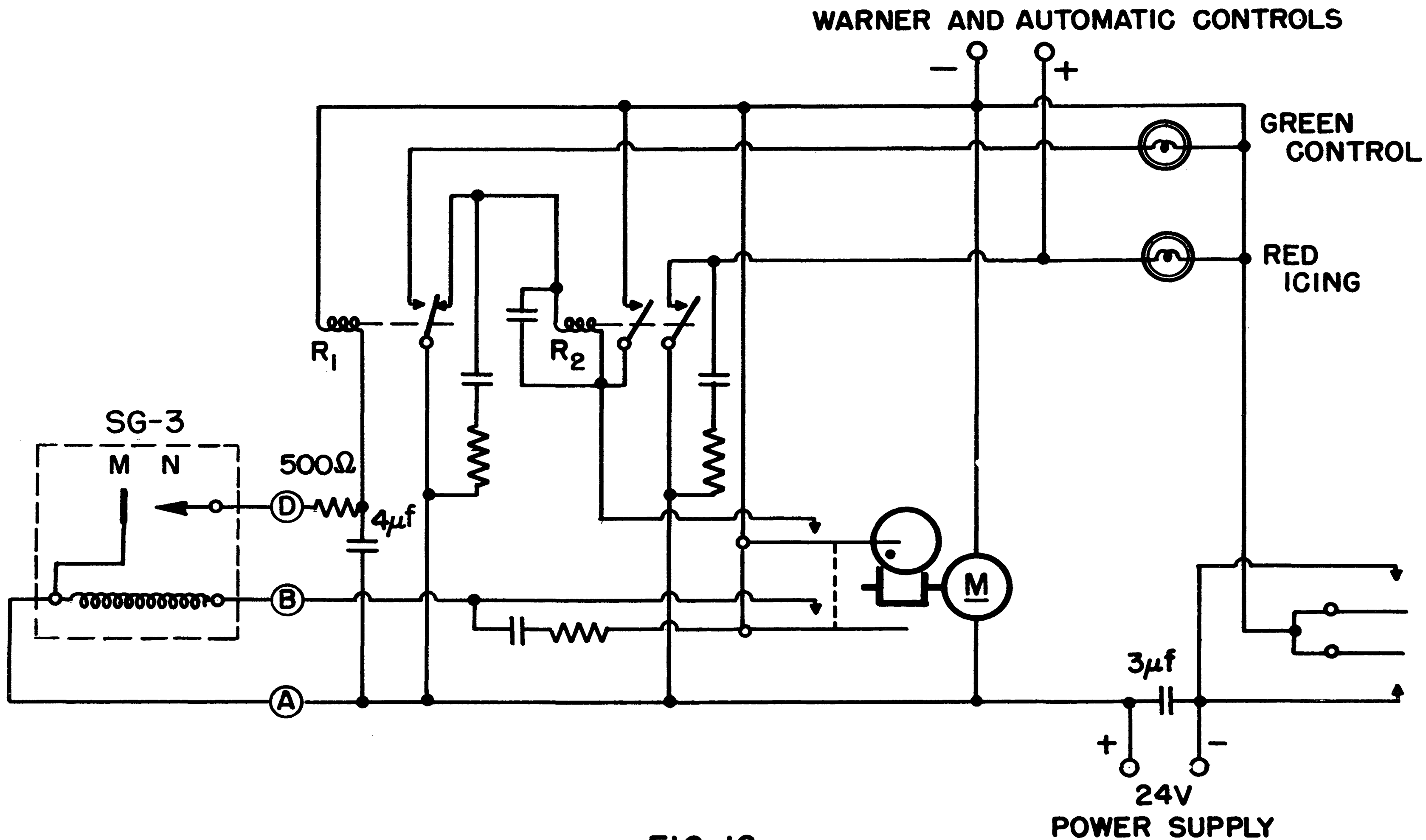


FIG. 16

ICE WARNER, IG-15, FOR FRAGILE ICE

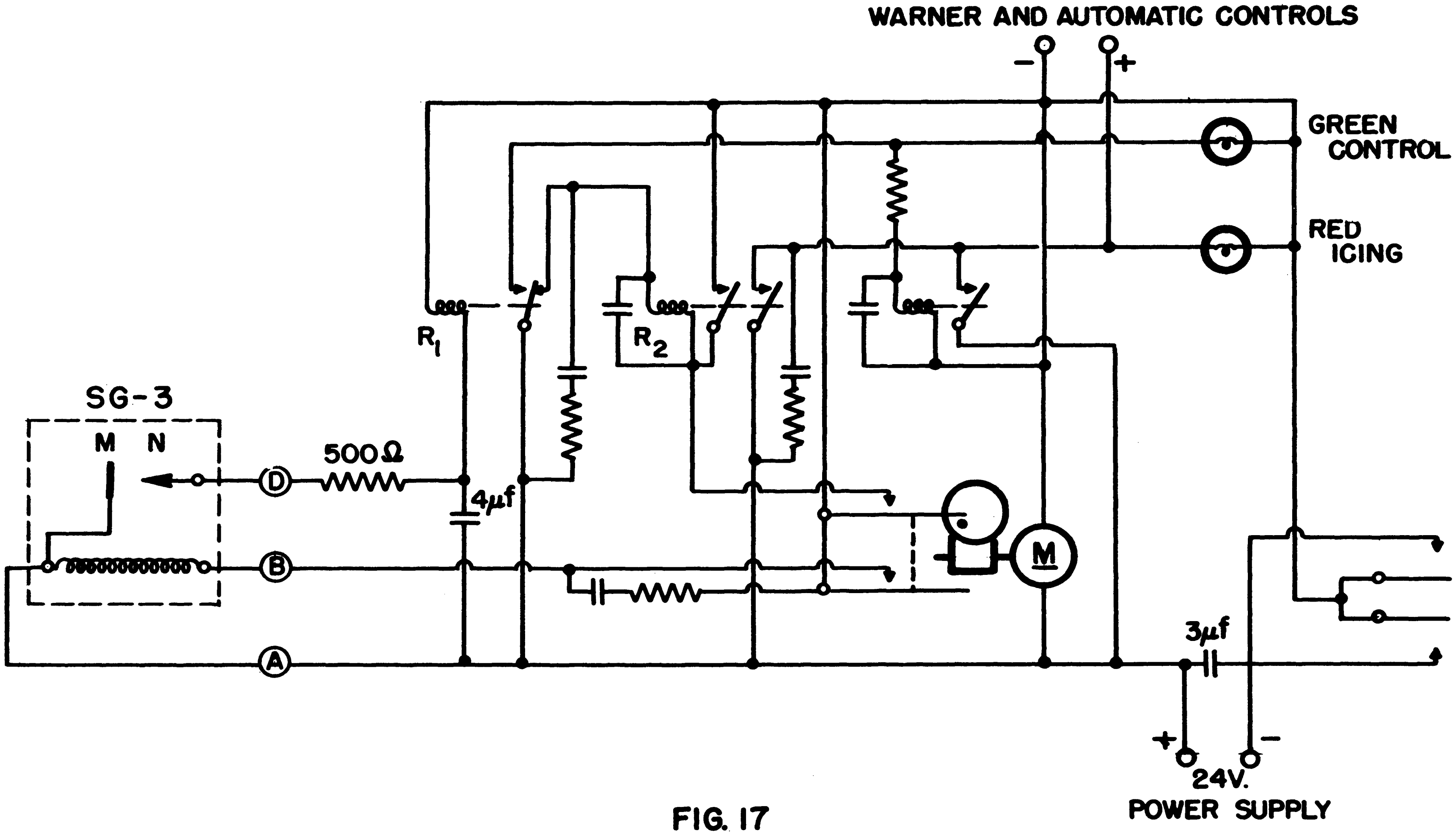


FIG. 17
ICE DETECTOR IG-16

CHAPTER III

OPERATION OF THE I.G.13 ICING WARNER IN A GROUND LABORATORY

9. General Remarks

We have devoted a special chapter to the I.G.13 icing warner operated as part of a ground laboratory in view of its apparent complexity and in view of the several developments it has required. It is designed to warn the personnel of the Mount Lachat station that one or several of the following phenomena are occurring. A selector enables one to choose the interesting case or cases at a given moment.

1) The outside temperature drops below one of the two limits determined by an internal adjustment of the instrument executed in accordance with the artificial icing conditions in the wind tunnel.

2) Icing is occurring naturally on wires which have been placed in the outside wind.

3) Icing is occurring naturally on an airfoil profile which has been placed in the outside wind.

The apparatus shown in Figures 18 and 19 consists of the following:

1) A control panel

2) A control box, No. 1, comprising the components connected to the probes which detect natural icing.

3) A control box, No. 2, which comprises the devices used to note the conditions of artificial icing.

4) A 24-volt d-c power supply.

5) A weather vane fitted with two finger probes.

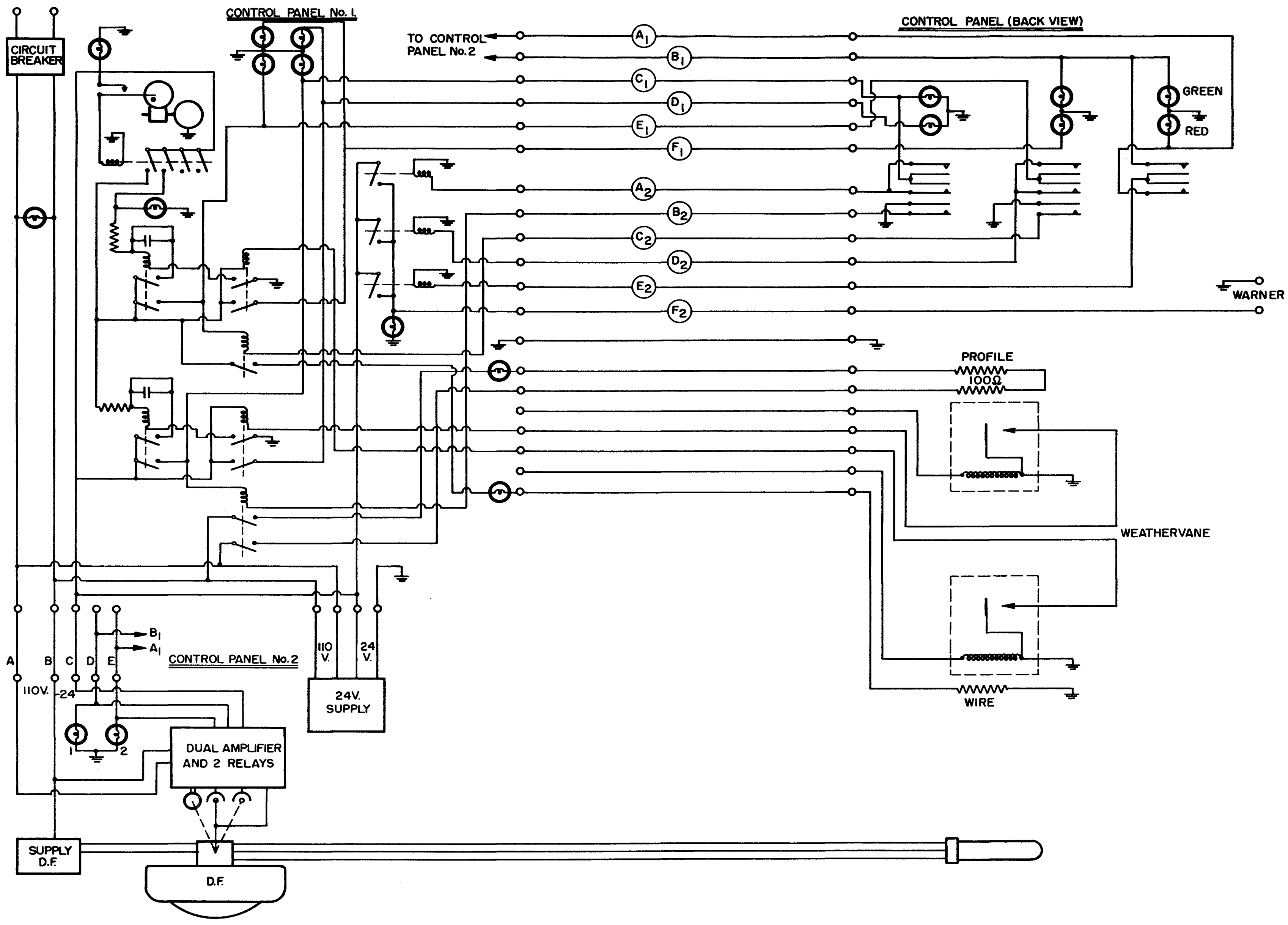


FIG. 18
GENERAL ARRANGEMENT IG-13

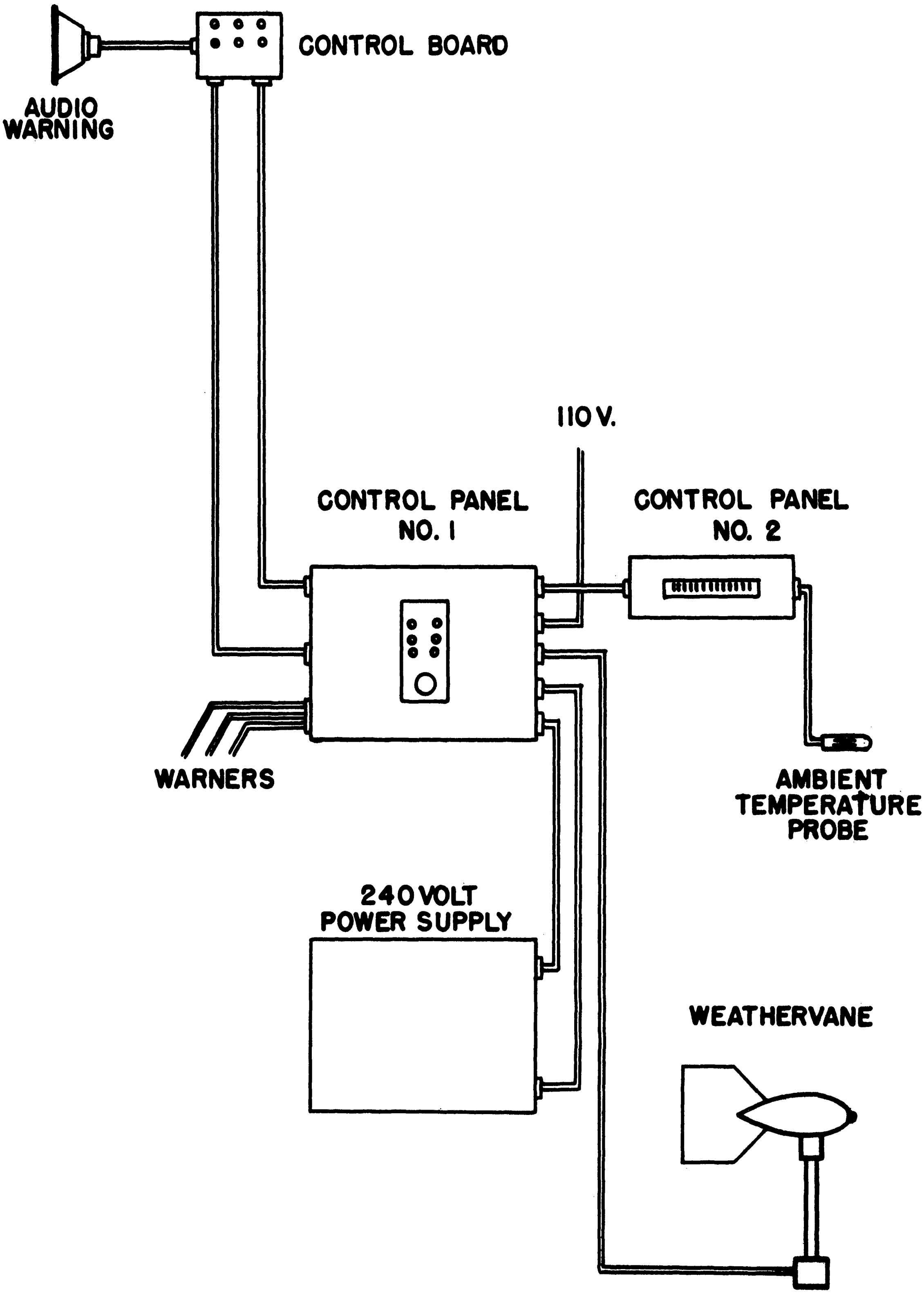


FIG. 19 ICE WARNER FOR GROUND USE, IG-13 GENERAL ARRANGEMENT.

6) A temperature-sensing device.

7) Audio or visual alarms placed in the different rooms at the station.

The main power supply is from the 110-volt a-c supply line.

10. Artificial Icing

The artificial-icing warning circuits include the following elements which are located for the most part in control panel No. 2:

1) An ambient-temperature-measuring device placed in the weather shelter.

2) A receiver for the temperature-measuring device with a measuring range from -30°C to +35°C. The receiver is encased and is equipped with a mirror fixed on a moving coil and placed in a tube. This remote-reading electrical thermometer is supplied independently with 24 volts d-c from a power supply connected to the 110-volt supply line.

3) A lamp shines a beam of light onto the mirror which has been affixed to the receiver. The beam of light is reflected and strikes one or both of the two photoelectric cells, depending on the positions of the mirror. The cells and suitable masks are mounted on movable holders. The locations of these masks determine the values of the chosen temperatures.

4) A double amplifier with two 25-L-6 vacuum tubes is used to amplify the current from each of the photoelectric cells. In the circuit of each one of the vacuum tubes there is located a relay which closes the circuit when the corresponding cell is lighted. This circuit is supplied directly with 110 volts a-c.

5) Green signal lamps for the higher operating temperature and red ones for the lower operating temperature are installed on the control panel No. 2 and on the control board. A selector switch on the control board allows the alarm circuits to be closed for various positions in the station when one or the other of the determined temperatures is reached. The selector switch can also be set to remove all connections between these audio alarms and the artificial-icing warnings. However, the lights continue to give visual indication on the control panel.

11. Natural Icing on Wires

The circuits for warning of natural icing on wires are comprised of the following elements:

1) An S.G.3 probe mounted on the weather vane. The finger of this probe consists of a large needle which oscillates between two wire grids placed in two parallel planes 3 mm apart.

2) Relays which have been installed according to diagram I.G.15 on control panel No. 1.

3) An impulse motor which distributes its impulses to the two ice-warning circuits through a relay containing four groups of contacts.

4) Green signal lamps for an indication that rotation is occurring in the probe and red ones to indicate icing.

5) A selector switch which either permits or prevents the closure of the warning circuits in case of icing and also either permits or prevents the de-icing of the wire grids.

6) A relay connected through a selector to the red signal-lamp circuits and which, upon closing, places 24 volts across the wires which have been placed in series with a 25-watt, 24-volt lamp.

12. Natural Icing on an Airfoil Profile

The elements which make up the warning circuit for natural icing on the airfoil profile are the same as for the icing on wires. However, there are the following differences:

1) The finger, which is of conventional dimensions, oscillates on the leading edge of the weather vane.

2) The de-icing of the weather vane is accomplished with 110 volts a-c at two amperes, flowing through a resistance which is nominally rated at 24 volts - 50 watts. The resistor is placed far enough from the leading edge so that the body of the weather vane is de-iced at the same time that the finger is freed.

13. The Weather Vane

The weather vane is shown in the drawing of Figure 20. The purpose of the weather vane is to hold the two S.G.3 probes which are used in the warning circuits for natural icing.

The weather vane consits of two parts:

1) The streamlined body with its tail. The S.G.3 probes, as well as the resistances for de-icing, are mounted on this body. The electric circuits are connected to an eight-pronged socket.

2) A control case is mounted in the body of the weather vane. This control case consists of a rectangular frame and a series of eight electrical contactors with slip rings. A plate seals the bottom of the weather vane. Two ball bearings have their outside cages attached to the weather vane and their interior cages fastened to the supporting axle which is fixed with respect to the earth. The fixed axle is hollow and holds the rings and contains the connecting wires from these rings to the control panel No. 1.

14. Control Panel

This small control panel is placed in the office of the director of the station, while the other control panels are located in the experimenter's room. The weather vane is located on a terrace in an open space.

The indications of the signal lamps, as related to the positions of the selector switch, are specified by the table of Figure 21. In an alternative arrangement the de-icing can be accomplished independently of the switching.

15. Conclusions

At the present time, the warner I.G.13 has not yet been completed. The relays and the electrical thermometer have not yet been delivered. Thus, it is not possible to judge its practical value. One may say, nevertheless, that the only real difficulties that are expected should arise from the slip rings in the weather vane which have been built under field conditions and may deteriorate rapidly.

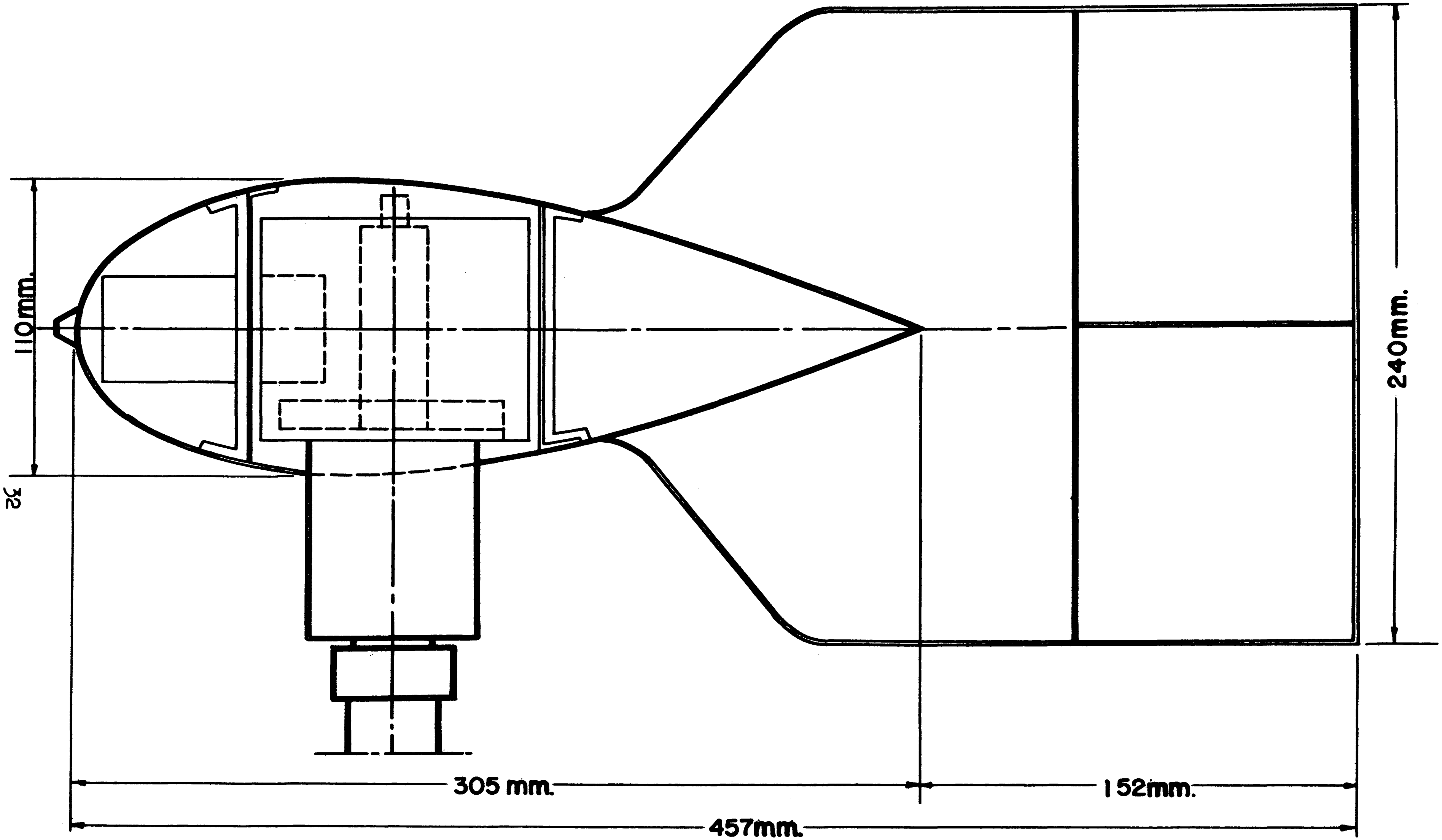


FIG. 20 WEATHERVANE IG-13

IG. 13

Icing Warner Operating on the Ground

		A. I Artificial Icing	N.I. 1 Natural Icing on Wires	N.I. 2 Natural Icing on Profile
Green lamps		Temperature $\leq \theta_1$	Rotation control	Rotation control
Red lamps		Temperature $\leq \theta_2$	Icing of the wires	Icing of the profile
Commutator	High	The warners operate for $\theta \leq \theta_2$	The warners operate in case of icing. Automatic de-icing of the wires.	The warners opeate in case of icing. Automatic de-icing of the profile.
	Middle	No warner	No warner. No wire de-icing.	No warner. No profile de-icing.
	Low	The warners operate for $\theta \leq \theta_1$	The warners operate in case of icing. No wire de-icing.	The warners operate in case of icing. No profile de-icing.

Fig. 21

CHAPTER IV

WARNERS OF INSTANTANEOUS DANGER I.G.21, 22, AND 23

16. General Remarks

The warners of instantaneous icing danger are intended to detect the formation of ice either before or, at the very latest, at the same time as any part of the airplane is subjected to icing.

Our warners of instantaneous danger of icing comprise the following:

1) A warner of one of the types described in Chapter I.

2) An obstacle placed in such conditions as to increase the icing.

3) A de-icing device allowing the "resetting to zero."

4) Secondarily, an indicator of de-icing time.

The simplest way to de-ice is through the use of electrical-resistance heating wires, a method we have previously adopted. It remains now to determine the shape of the obstacle and the conditions in which it should be placed in order to increase its icing.

This shape and these conditions have been chosen following a series of tests which were entrusted to Mr. Sion, experimenter, at the end of May, 1945. These tests took place under both artificial - and natural - icing conditions and have been run on obstacles of various shapes and mounted at first in the stream of the wind tunnel (50 meters per second) and then in the throat of a venturi specially built for these tests (contraction ratio = 4, square cross section, throat 100 mm by 100 mm, with one side removable, total length 900 mm).

The conclusions drawn from these tests are as follows:

1) The simplest obstacle shape, and that giving results at least equal to all the other shapes, is a rectangular-cross-section bar of small dimensions (flat-side face to the wind 2 to 3 mm across). This shape is effective even if a streamlined tail is placed behind it.

2) The obstacle placed at the throat of the venturi is covered with a layer of ice at least twice as thick as that which coats the same obstacle when placed out of the venturi. There is a slightly increased thickness at the edges.

3) At a time when no obstacle, even a fine wire, ices in the stream of the wind tunnel, icing can be observed on the blade mounted at the throat of the venturi. An example of this phenomenon is seen in the photograph of Figure 22 taken May 31, 1945, at 12:30, in the wind tunnel at Mount Lachat. Natural icing had taken place on all the wires which support the venturi. But as the temperature rose gradually, icing stopped on any obstacle located outside the venturi, while ice continued to deposit distinctly at the throat of the venturi. Ice can be seen on the blade fixed at the throat. The suspension wires holding the front of the venturi remained clear. The white flashes visible in some spots outside the venturi are only reflections. Thus, the probe exhibits a prior warning, but this affect is probably rather small, for later, the temperature having raised a little, the phenomenon ceased. Some tests on the warners of instant danger of icing based on these indications will determine exactly the extent of the prior warning.

4) In short, by placing an appropriate obstacle at the throat of a venturi installed on an airplane, one is assured of obtaining a surface icing before or, at the latest, at the same time as any other.

17. The Warner of Instantaneous Danger of Icing I.G.21

The warner I.G.21 is made up of:

1) A panel which contains all of the controls and relays.

2) An antenna consisting of a short shaft carrying the venturi and containing the probe (Figure 23).

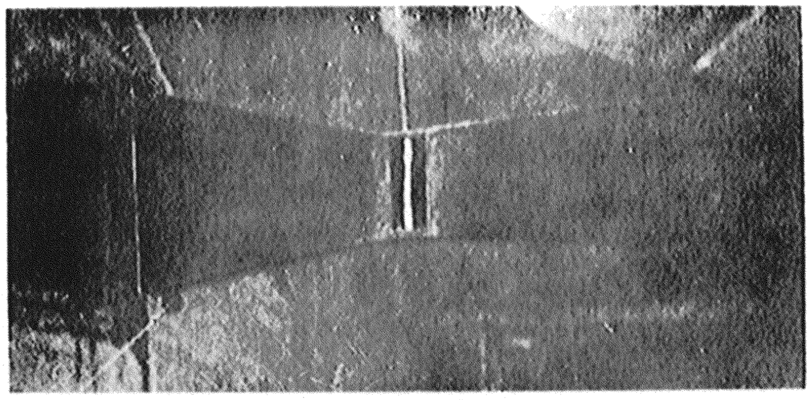


Figure 22. Prior Icing Through the Use of a Venturi.

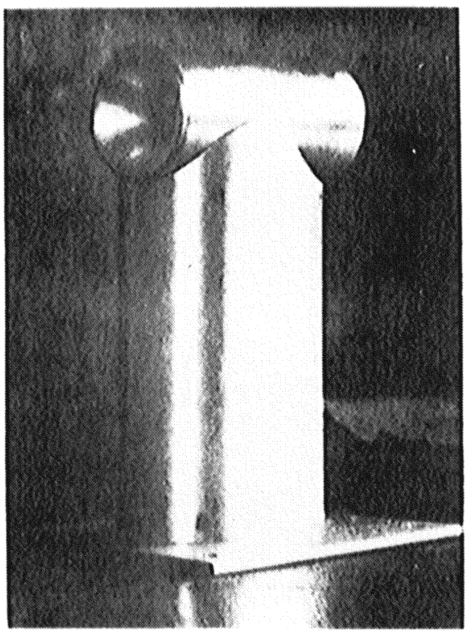


Figure 23. Venturi Used for Ice Detector

The control panel is an I.G.12 panel to which a relay for the closing of the de-icing circuit of the venturi has been added (Figure 24).

The lever for the starting of the control has three positions:

1) Stop.

2) Operation without de-icing. The circuit of the relay for de-icing will not be closed when the switch is in this position.

3) Operation with de-icing. The circuit of the relay which controls the de-icing closes as soon as icing occurs.

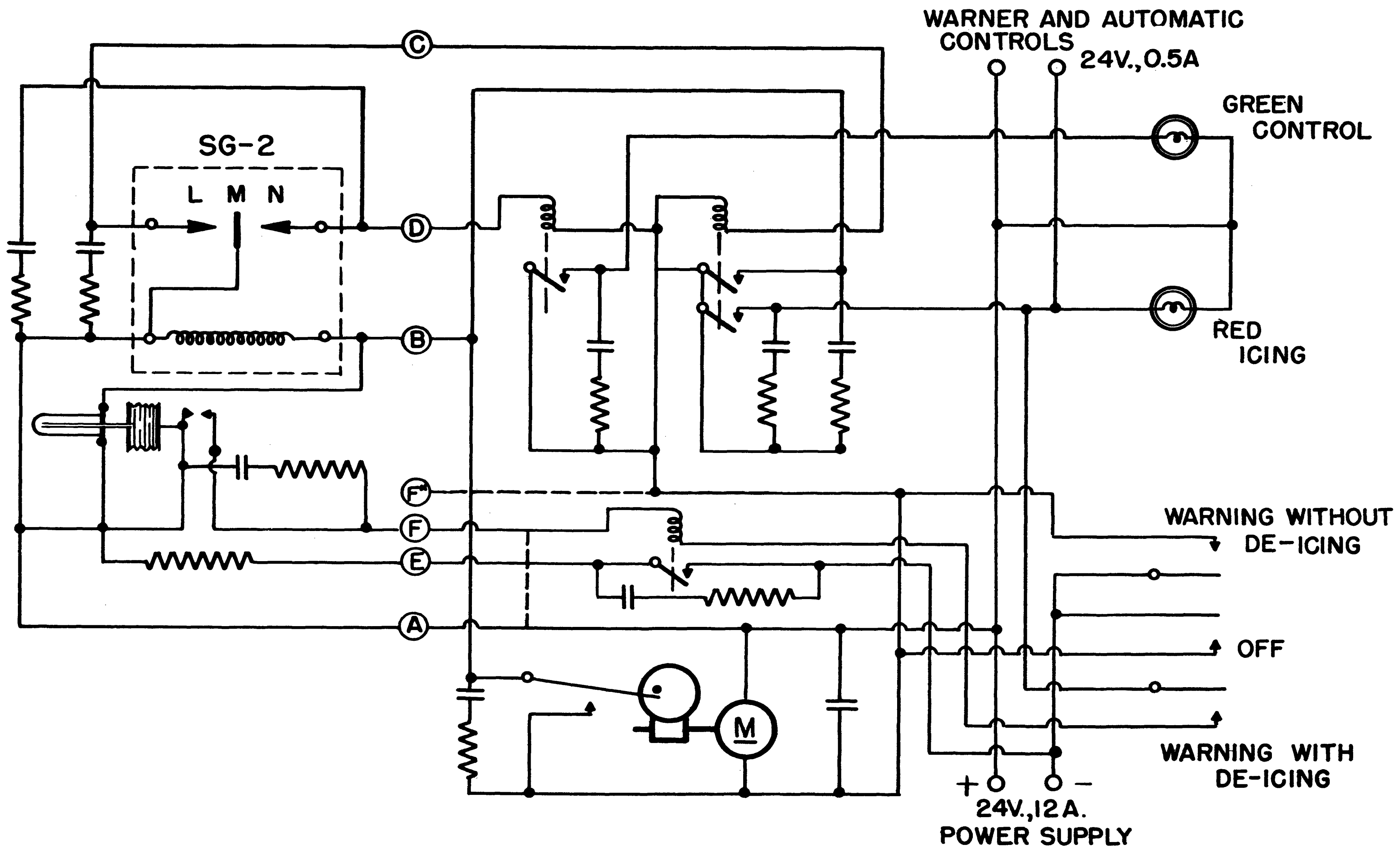
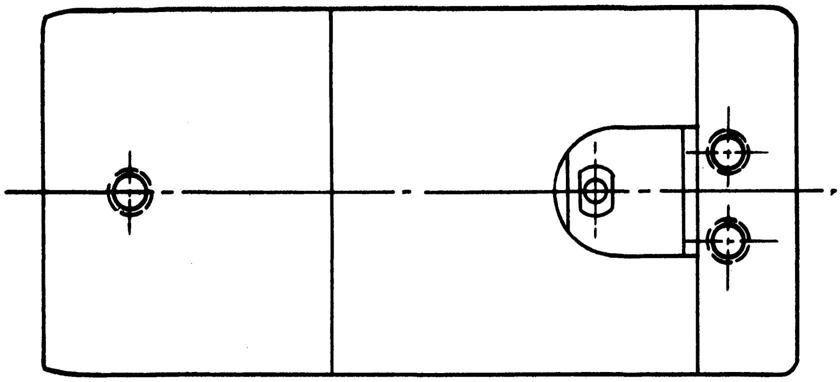
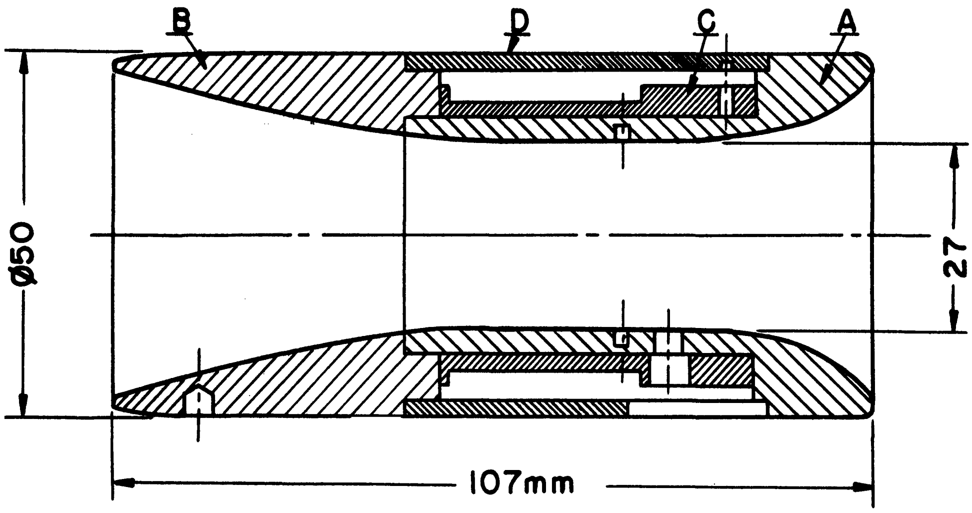


FIG. 24
ICE WARNER DIAGRAM IG-21
(116.H4C)

PLAN VIEW



CROSS SECTION



SCALE 1:1

FIG. 25 VENTURI FOR ICE WARNER
1G21(116H4C)

Originally a circuit called "safety circuit" had been planned which was to prevent the closing of the de-icing circuit when the wind tunnel was not operating or when the airplane was grounded. It was feared that an abnormal blocking of the probe would close the de-icing circuit in such conditions and that the heat generated (250 watts) would seriously damage the instrument while there was no airstream to dissipate it. In fact, no undesirable blocking occurred and this circuit is superfluous. The preliminary tests simply utilized the position of the switch "Operation without de-icing".

The electrical circuits being conventional, only the antenna of the warner is worth describing. It is composed, as we said before, of a venturi and its support.

The venturi consists of three parts:

1) A converging section A and the diverging section B screwed one into the other.

2) A cylinder C on which is wound a wire of about two ohms resistance between two layers of asbestos which are fastened with a silicate.

3) A cylinder D which insures the continuity of the exterior cylindrical surface of the venturi (Figures 25, 26, 27).

The obstacle which is installed at the cylindrical throat of the venturi has a rather complicated shape which we shall explain later (Figure 28). It is fastened into the venturi by means of two screws.

The shaft contains the probe S.G.2 mounted on a plate which is fastened to the venturi. The shaft and plate are fastened together with five screws. Two 12-ohm de-icing resistors are connected in series (total, 25 watts) and are mounted on the shaft in which holes have been drilled. The purpose of these holes will be explained later. A six-pronged socket is located at the bottom of the mast in contact with the surface of the airplane (wing or fuselage) so that the cable which connects the control panel to the antenna only runs on the interior of the airplane.

The finger is a rod which is driven in a longitudinal motion by a crank.

The de-icing of the obstacle is obtained by means of thermal conduction from the de-icing resistance heaters in the venturi.

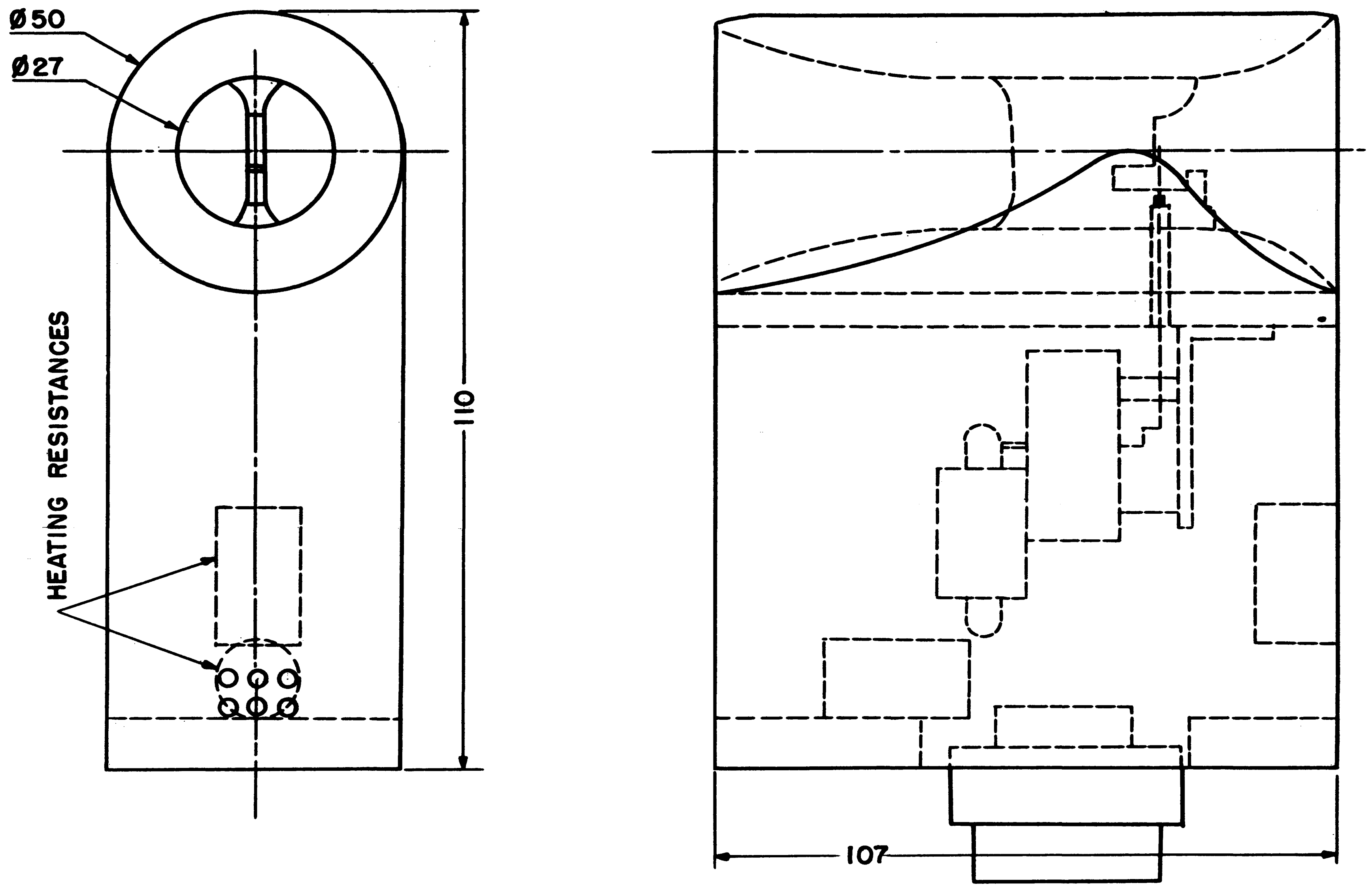


FIG. 26 ANTENNA FOR WARNER OF INSTANTANEOUS ICING.

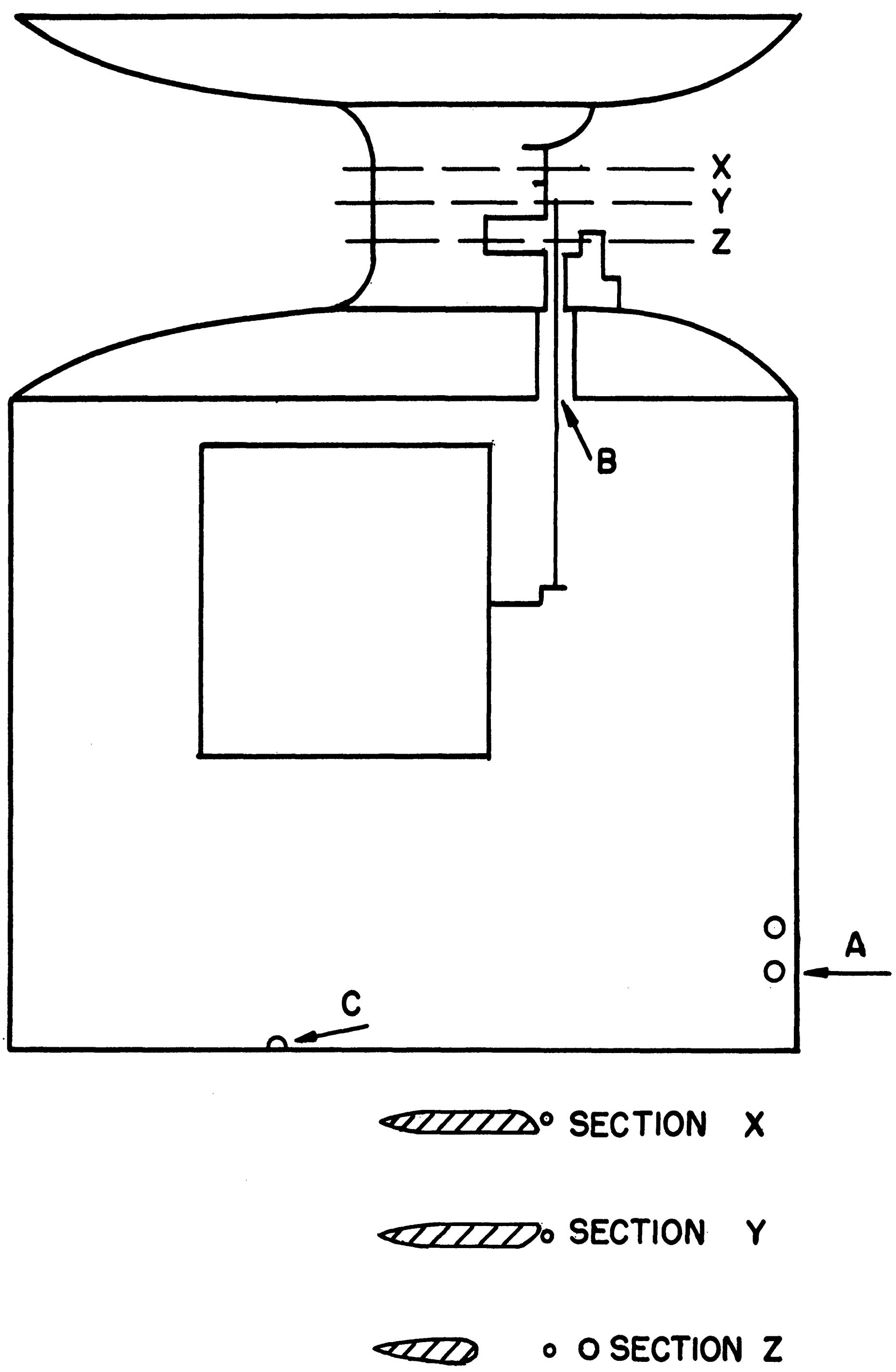
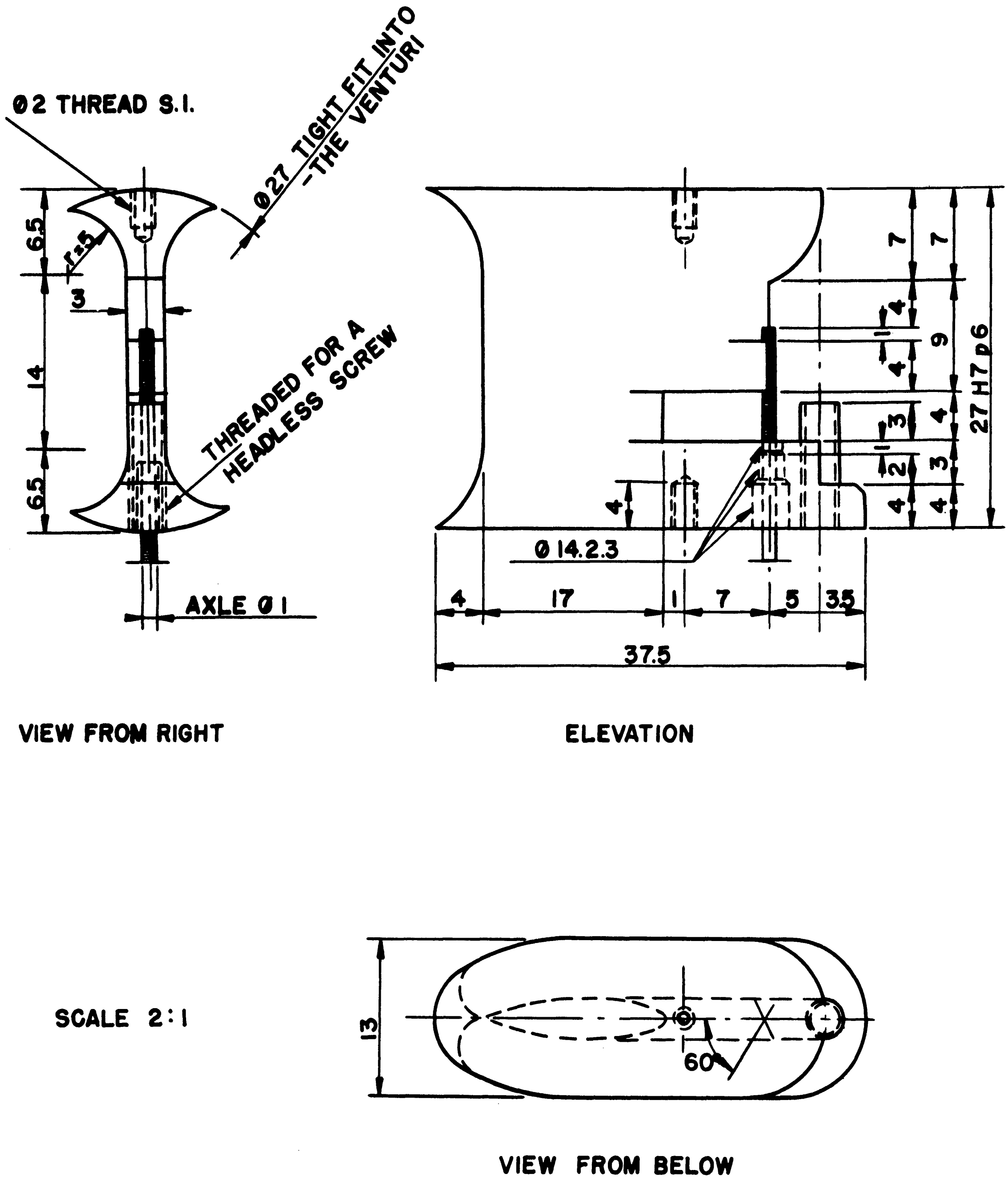


FIG. 27
WARNER FOR INSTANTANEOUS ICING DANGER I.G.-21
ANTENA PLAN



SCALE 2:1

FIG. 28 - WARNER OF INSTANTANEOUS ICING DANGER IG-21 OBSTACLE PLACE IN VENTURI

The different openings cut in the shaft and the peculiar shape given to the obstacle were chosen to avoid the two following phenomena which were observed on the first instrument tested at the beginning of November, 1945:

1) Water droplets may remain between the finger and the obstacle, or along the finger at its joint with the venturi. When the airplane enters a region below 0°C, the water droplets freeze and the warner indicates "Icing" incorrectly.

2) The icing may start suddenly during an impulse and as the ice deposits on the finger for the duration of the impulse it prevents the finger from resuming its rest position.

The first phenomenon is prevented by sloping the surface of the obstacle close to the finger in order that the water droplets retained between the finger and the surface by capillarity will be blown out, and also by establishing a circulation of air around the finger in its passage from the shaft to the throat of the venturi (A, B, Figure 27). At the holes, which are drilled in the forward portion of the shaft, there is a total pressure, while in the throat of the venturi there exists a strong suction which also occurs at the point where the finger emerges. This exit has been drilled so that there exists, not the total pressure, but pressure nearer to the static pressure in the venturi. Other holes drilled in the rear portion of the shaft allow the water which comes through the front holes to be exhausted. All of these holes are de-iced by the resistances in the shaft.

The second phenomenon is almost completely avoided by placing a de-icing stud before the lower part of the finger and heating it at the same time as the rest of the obstacle. Also, the phenomenon should be practically nonexistant if a probe of the type S.G.3 is used (warner I.G.22).

Such an instrumnet has given satisfactory service up to now, but the tests have not been numerous enough so that we could say that the instrument is faultless. It is important that various tests be performed in the wind tunnel and in flight in order that the imperfections which affect any prototype can be found. However, the instrument seems to possess the best qualities of safety of operation in its present form I.G.22, and to furnish the most accurate indications in its form I.G.23.

18. Warner of Instant Icing I.G.22

This warner differs from the preceding warner only in that the probe S.G.2 has been replaced by a probe S.G.3. Thus, greater operational safety and easier adjustments are obtained.

The electrical circuits of the instrument are represented in Figure 31. They are very similar to those of the warner I.G.14. A relay to close the de-icing circuit has been added and a thermal-delay relay has been substituted for the delayed relay. This new relay is made up of a glass vacuum tube which contains a fine wire wound on two pieces held apart by springs. When the wire is heated by an electric current one of the pieces moves and sets up a contact. At 52 milliamperes this relay works with a delay of 0.75 second at the closing as well as at the opening of the circuit which it governs. This symmetry of the delaying action constitutes a disadvantage which we have discussed in paragraph 6. Except for the prototypes I.G.22 and I.G.23, all our instruments in the future will probably be equipped with relays which are delayed by means of resistance-capacitor circuits. Nevertheless, the circuits have been established in such a way that the de-icing circuits will be opened as soon as the finger is freed.

19. Warner of Danger - Indicator of Icing Intensity I.G.23

The combination "warner of danger - indicator of icing intensity" I.G.23 (Figure 29) is a warner of type I.G.22 to which has been added a circuit which records "de-icing time". This de-icing time gives an indication of the icing conditions encountered since it is proportional to the amount of heat necessary to de-ice the obstacle. This amount of heat is itself in direct relation to the quantity of heat which should be supplied to any part of the airplane in order to clear it of ice deposited under the same conditions.

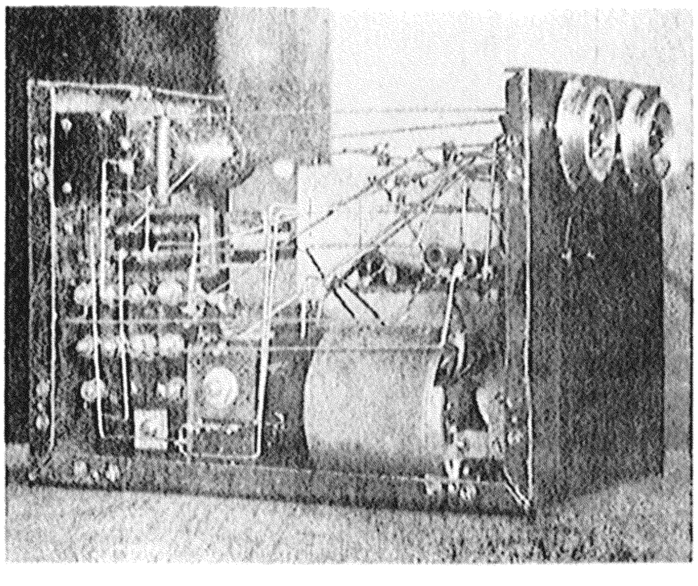


Figure 29. Control for I.G.23

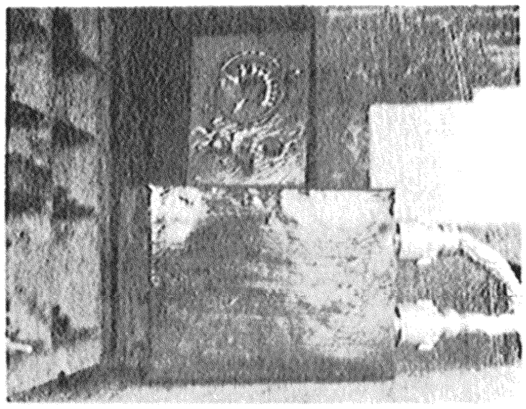


Figure 30. Panel and Control I.G.23

The control board for this case then consists of an indicating dial (Figures 30, 32) which is in addition to the usual sockets, commutators, and signal lamps.

The recording is made in the following manner:

A 2,000-microfarad condenser is connected to the de-icing circuit by means of a 10,000-ohm resistor. The indicator is a milliammeter (0-0.5 milliamperes) mounted as a voltmeter at the terminals of the condenser. When de-icing is achieved the condenser is discharged. The deflections of the indicator are practically proportional to the time over the first third of the scale, but in any case the indicated numbers are only guiding points. Long experimentation on these instruments and our indications of thermal anti-icing power, ice thickness, and icing rate, enables one to establish a scale of the icing which can be used to calibrate the instrument in place.

Meanwhile, we can say that the indicator I.G.23 gives guiding signals concerning the icing intensity. This is a vague term designating the degree of violence of icing. These guiding signals will be gradually made precise as our means of studying icing is improved.

We should note in passing that a particular arrangement of the commutator enables us to read at the "Off" position the input voltage on the milliammeter.

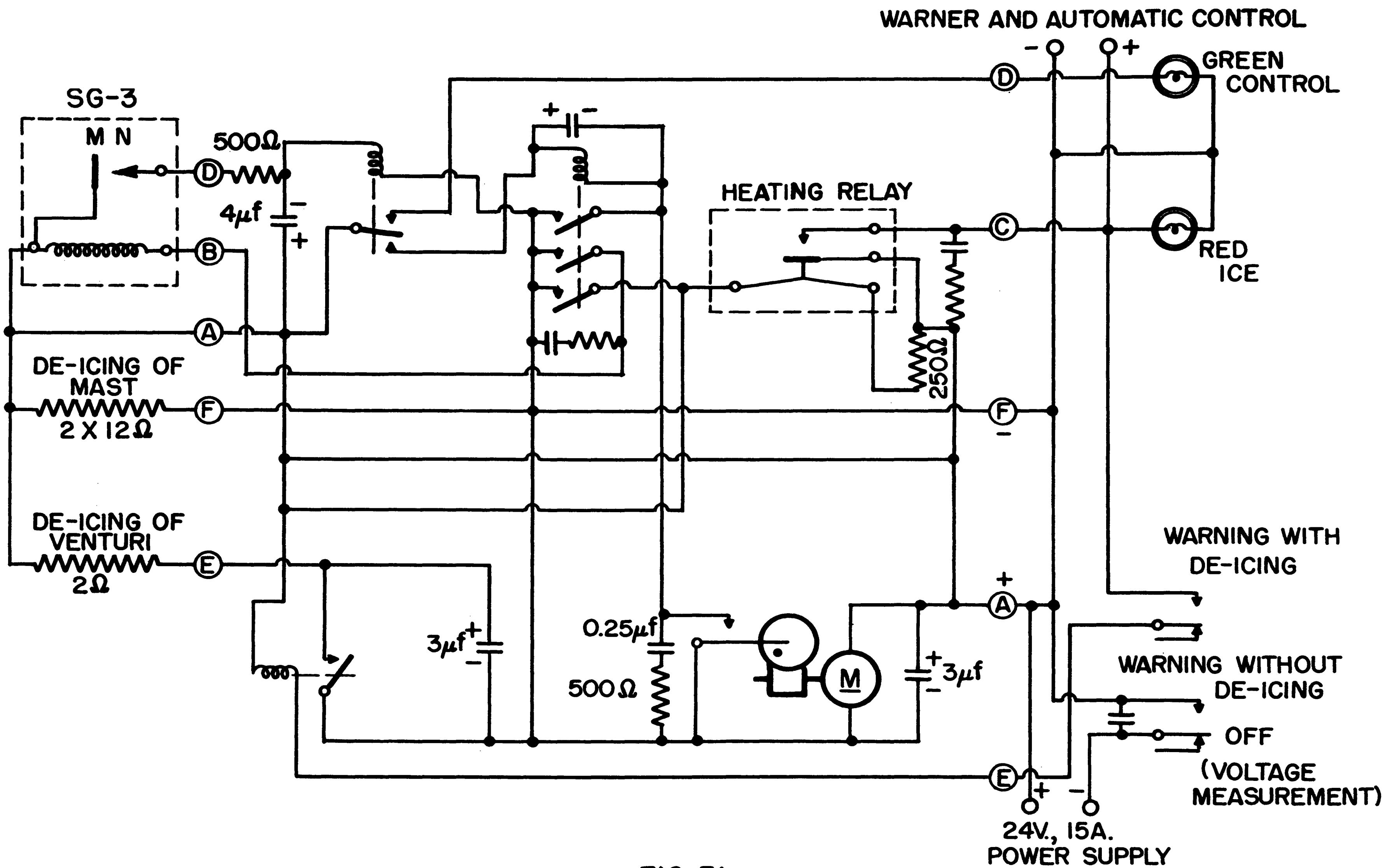


FIG. 31
WARNER OF ICING DANGER IG-22

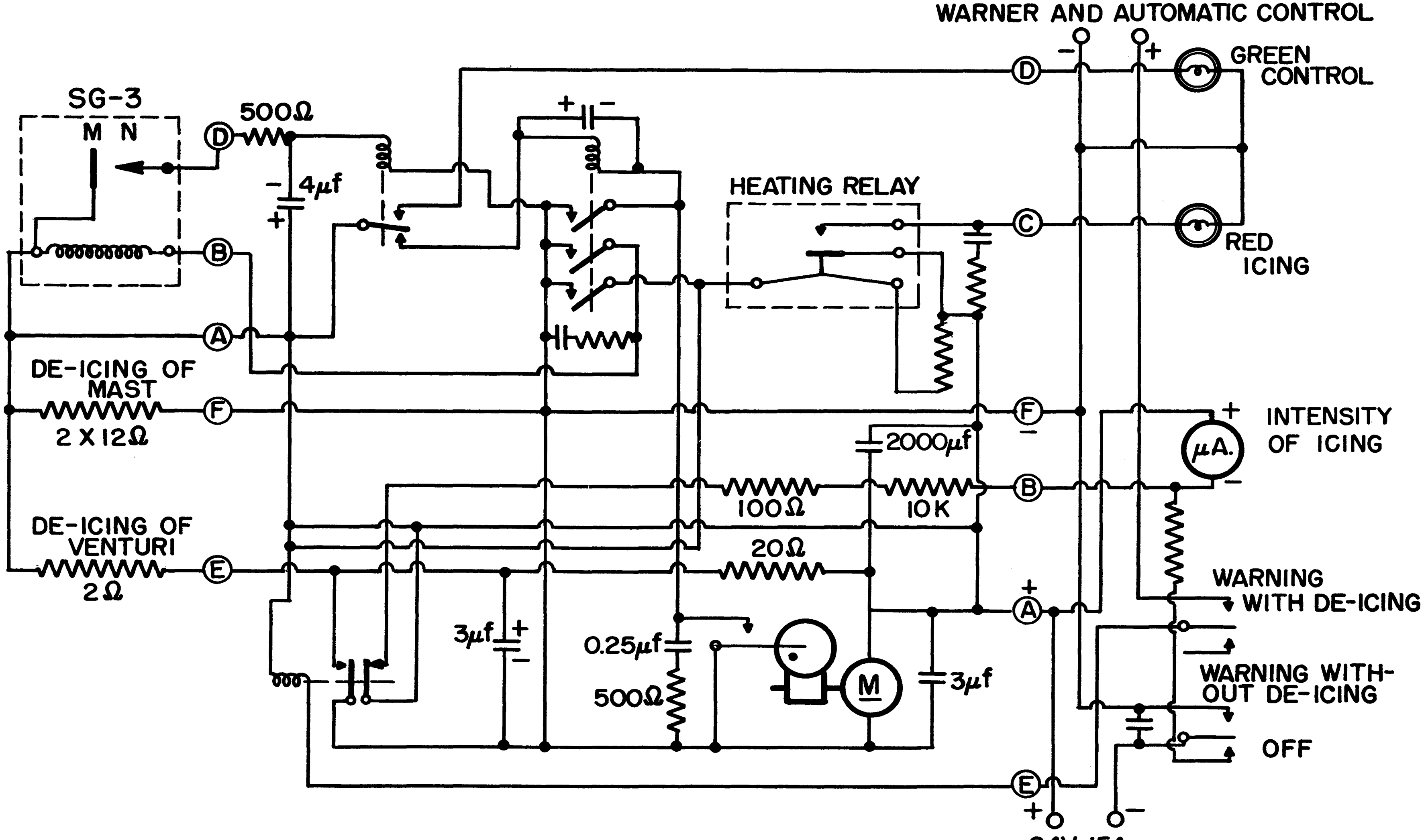


FIG. 32
WARNER OF ICING DANGER AND INDICATOR OF INTENSITY IG-22

CONCLUSION

This report shows the stage of development to which our prototypes for icing warners using a finger have been brought, one year after the conception of the first finger probe. If the large number of tests we have scheduled for natural winds, in the wind tunnel, and if flight during the coming winter season corroborate the results we have obtained up to now, we shall shortly dispose of the problem of warning and indicating instruments. These instruments will fill an existing need and will contribute to the safety of long-distance commercial flights, especially night flights.

Finally, we shall state for the benefit of those technicians who may be interested in this fact that 3,000 hours have been devoted in all to the study, the construction, and the testing of the instruments which we have described and of the thermal anti-icing power instruments which were built simultaneously and which will be described in another publication. This time, we think, is small in itself if one considers the numberous difficulties which have occurred at the present time (1945) and the very special situation at the Mount Lachat station.