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# Floating Ice Thickness and Structure Determination — Heated Wire Technique

René O. Ramseier and Robert J. Weaver



**TECHNICAL BULLETIN NO. 88**

*(Résumé en français)*

INLAND WATERS DIRECTORATE,  
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## **Abstract**

The thickness of floating ice is one of the most important general parameters to be measured for many applications in the fields of transportation, engineering and climatology. The requirement for accurate thickness information, with details on the ice structure, led to the development and use of the heated wire ice thickness gauge. Once installed, the gauge provides a means of making in-situ thickness measurements on fresh and salt water ice quickly and accurately. This report describes the measurement methods of determining ice structure from readings obtained, and details of construction of the gauge complete with engineering drawings.

## **Résumé**

L'épaisseur des glaces flottantes est l'un des paramètres généraux les plus importants à mesurer à diverses fins dans le domaine du transport, du génie ou de la climatologie. À cause de la nécessité de mesures précises de l'épaisseur de la glace et de détails sur sa structure, on a développé un appareil fondé sur le principe du fil chauffé pour mesurer l'épaisseur. Une fois installé, celui-ci permet de mesurer sur place l'épaisseur de la glace, en eau douce ou salée, et ce avec rapidité et précision. Le texte qui suit décrit la méthode qui sert à déterminer la structure de la glace d'après son épaisseur et donne tous les détails de la construction de l'appareil de mesure, avec illustrations techniques.

# Floating Ice Thickness and Structure Determination — Heated Wire Technique

René O. Ramseier and Robert J. Weaver

## 1. INTRODUCTION

The thickness of floating ice is one of the most important general parameters to be measured for numerous applications in the fields of transportation, engineering and climatology. In the past, measurement of ice thickness was obtained by drilling or cutting a hole through the ice. Such a measurement does not give direct information on the structure of the ice cover, which is required in many of today's applications. To obtain the necessary structural information an ice core must be removed from the ice cover and carefully examined. Both the drilling of a hole and coring are time-consuming, cumbersome efforts. Often ice thickness measurements are required throughout the winter, entailing repeated measurements at a designated station, or at a number of locations, as recorded in the St. Lawrence River (Transport Canada, 1973). The second and subsequent measurements have to be made in the vicinity of the first one because a refrozen hole does not give a satisfactory new measurement. Undue inaccuracies may occur, since a river ice cover can be locally highly irregular. The large number of stations to be measured in the St. Lawrence River makes the task time-consuming and costly, since most of the stations are only accessible by helicopter. With the appearance of a number of remote sensing techniques, both in the active and passive microwave regions, measurement of ice thickness and structure is becoming more exacting and demanding.

A new system was designed to give a quick and accurate measurement of ice thickness after installment. It had to provide basic structural information such as the amount of secondary and superimposed ice and the depth of snow, with a minimal amount of measuring equipment. In addition, the equipment and measurement procedures had to be simple enough so that any person with a minimal amount of instruction could fulfill the task. Finally, the gauge should be of low cost so that it could be discarded if necessary after one season of use. Similar gauges with a heated wire have been used before, notably by the U.S.S.R. (Butyagin, 1965) and by Lazier and Metge (personal communication, 1972).

## 2. ICE THICKNESS GAUGE

Figure 1 shows the ice thickness measuring gauge that was developed by members of the Floating Ice Section. It consists of a painted wooden stand; a flange to accommodate the threaded end of a bent pipe; a heated wire, the length dependent on the local ice thickness; a handle and a weight connected to the top and bottom of the hot wire respectively; and an insulated conduction wire terminating at a plug coming from both ends of the hot wire. Figures 8, 9 and 10 are the engineering drawings, which include a list of materials. A cost analysis is given in Appendix 2.

The two variables which may affect the thickness gauge are the total ice thickness accumulations of secondary and of superimposed ice. The first will affect the length of the hot and electrical wires, and the second, the height of the stand. For example, if the measurement is located in an area of heavy snow accumulation, with a large accumulation of superimposed ice probable, then the height of the stand would have to be increased. The measurements of the gauge in Figures 8, 9 and 10 were determined for the St. Lawrence River.

## 3. METHOD OF MEASUREMENT

The gauge is installed after the ice is thick enough to support a man or the means of his transportation (snowmobile, air cushion vehicle or helicopter). Care should be taken not to disturb the snow where the measurement is going to be made. Loose snow will be blown away by the effects of the air cushion vehicle and the helicopter. If snow is present at the time of installation, the footing of the gauge should be placed on the ice surface. The hole created in the snow cover can be filled with loose snow after the installation has been completed.

### 3.1. Installation (Fig. 2)

1. Once the site or station has been located, a hole is drilled through the ice with a drill, such as the ring drill



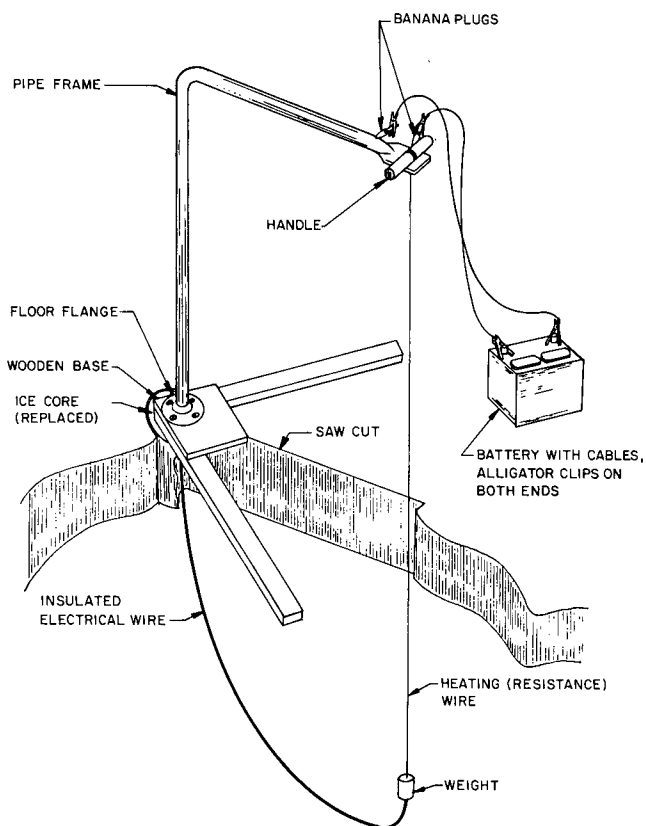


Figure 1. Ice thickness measuring gauge with a heated wire.

(Ramseier and Weaver, 1975) or the SIPRE drill. The core is required for an initial structural analysis to locate the boundaries of secondary and superimposed ice and to obtain a reference to thickness of the ice cover as a check of the initial measurement (Fig. 2a). The diameter of the hole should be 0.075 m or greater to facilitate structural analysis and the cutting of the slit.

2. A vertical 0.30-m slit is cut in the ice cover with a hand saw, starting at the hole (Fig. 2b).

3. The weight of the preassembled gauge is then lowered through the hole. The heated wire is pushed through the slit, and the electrical wire remains in the hole.

4. The previously examined ice core is then replaced in the hole and the wooden stand is placed on top (Fig. 2c).

5. The wooden base is then nailed to the ice to prevent any shifting of the gauge, and slush and snow packed around it to freeze and secure it.

6. A measurement is made, as described in the following section.

7. Necessary entries are logged on the Ice Report Form.

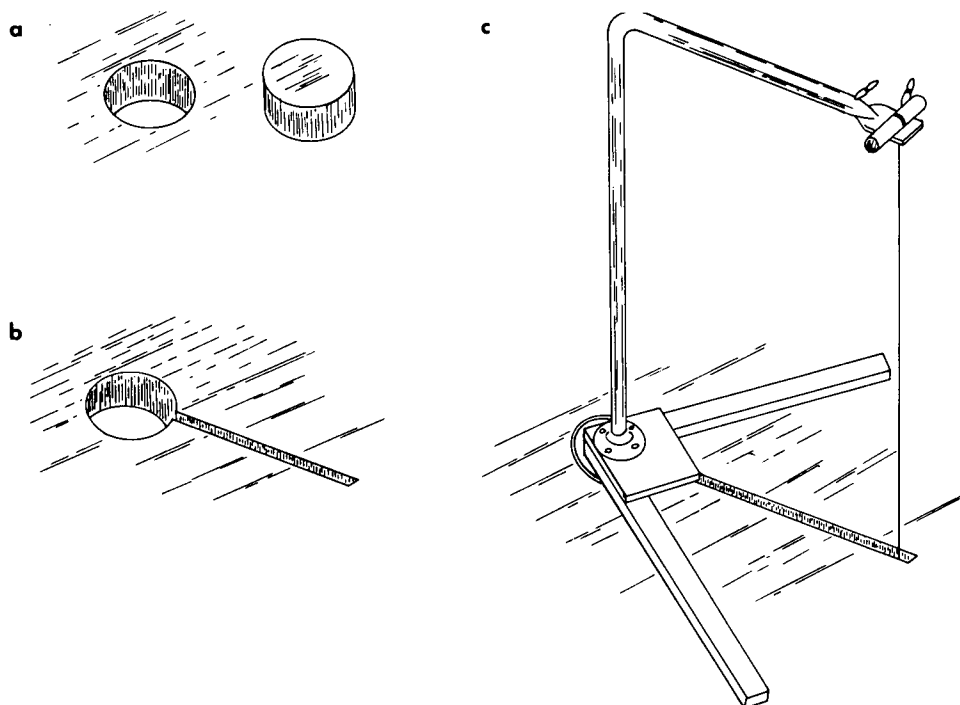


Figure 2. Installation of ice thickness gauge: (a) cutting hole through the ice cover with drill; (b) cutting slit in ice cover with hand saw; (c) installing gauge.

### 3.2. Ice Thickness Measurement

Figure 3 illustrates the measurement procedures described in this section. The equipment required is a metric tape or metre stick and a power source, such as a 12-volt dc battery or an 80-watt Honda generator. To make an ice thickness measurement, these steps are followed:

1. Connect the plugs to the power source.
2. Measure the depth of snow at a number of locations and make the entries on the form under snow thickness at S1 to S6 (or as many entries as necessary to represent the local snow conditions).
3. The initial measurement has been separated into case (a) and case (b).

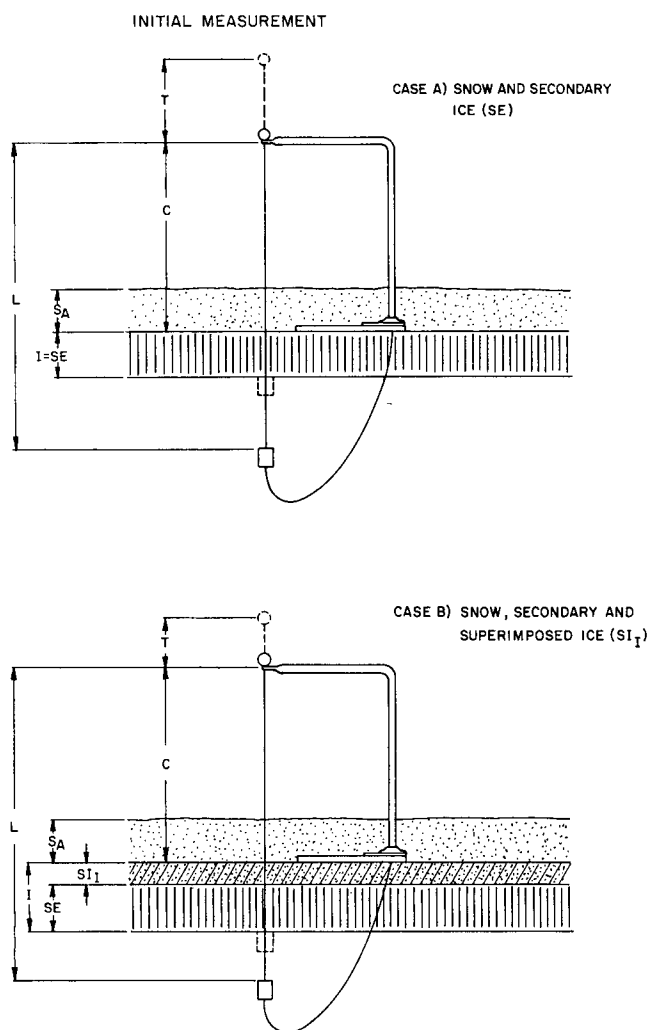


Figure 3A. Measurement of ice thickness. Initial measurements. Case (a), secondary ice only; case (b), secondary and superimposed ice.

Case (a)—Examination of the ice core reveals that there is no initial superimposed ice ( $SI_1=0$ ). One then measures the distance  $C$ , which is a constant, and the distance  $T$  by pulling the handle upwards till the weight stops at the ice-water interface. As soon as measurement  $T$  is made the handle is released to prevent the weight from sticking to the underside of the ice cover.

Case (b)—There is some initial superimposed ice ( $SI_1 \neq 0$ ). Measurements proceed as in case (a).

4. The routine measurements have been separated into case (a) and case (b) analogous to the initial measurements.

Case (a)  $SI_1=0$

Case (b)  $SI_1 \neq 0$

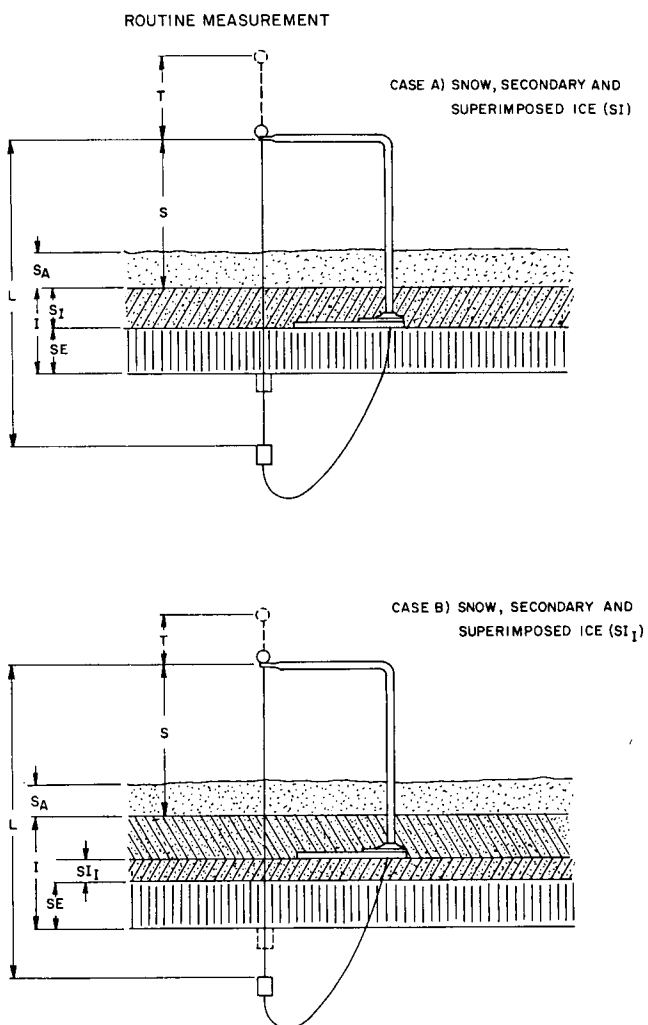


Figure 3B. Measurement of ice thickness. Routine measurements. Case (a), secondary ice only; case (b), secondary and superimposed ice.



5. After the handle has been released, the weight should pull the heated wire down. Then the plugs should be disconnected from the power source.

6. Check that the necessary entries have been made on the Ice Report Form.

### 3.3. Ice Report Form

To facilitate the data gathering and reporting of the results a form was prepared (Fig. 4). The top box contains the information for the initial measurements. The various symbols are defined as follows:

Station	Station number
Position	Station latitude and longitude
Chart No.	Hydrographic chart number
Date of Installation	Date of initial gauge installation
Time	Time of initial gauge installation
SI <sub>I</sub>	Initial superimposed ice thickness
SE	Secondary ice thickness
I	Total ice thickness

L	Length of heated wire
C	Height of stand above ice surface at time of installation
$\theta$ Air	Air temperature
$\theta$ Wat.	Water temperature (optional)
$\theta$ Sur.	Snow or ice surface temperature at air-material interface (optional)

For the routine measurements the information is recorded below. Under the heading of "Ice Thickness," the symbols are defined as follows:

T	Distance from handle to stand reference (See Fig. 3)
S	Distance from handle to SI (superimposed ice) surface
I	Total ice thickness (Eqs. 5, 8, 13)
SI <sub>T</sub>	Total superimposed ice thickness (Eqs. 12a and b)
SE <sub>T</sub>	Total secondary ice thickness (Eqs. 3, 6, 11a and b, 14a and b)

ICE REPORT 197		STATION :		DATE OF INSTALLATION:		TIME:	
POSITION: LAT.		SI <sub>I</sub> =		L =		$\theta$ AIR =	
LON.		SE =		C =		$\theta$ WATER =	
CHART NO:		I =				$\theta$ SURFACE =	

DATE TIME	$\theta$ AIR	$\theta$ WAT	ICE THICKNESS					SNOW THICKNESS							GENERAL REMARKS  ICE CONDITIONS	
			T	S	I	SI <sub>T</sub>	SE <sub>T</sub>	SI	S2	S3	S4	S5	S6	S <sub>A</sub>		

Figure 4. Ice report form.

Under snow thickness, space is provided for six snow depth measurements (S1 to S6). The last column,  $S_A$ , designates the average snow depth in the vicinity of the station. For six measurements the average would be:

$$S_A = \frac{(S1 + S2 + \dots + S6)}{6} \quad (1)$$

Under "General Remarks, Ice Conditions" unusual features should be recorded, such as water on the ice surface, slush under the snow cover or grey areas representing bare snow ice. Large cracks or ridges should also be mentioned.

### 3.4. Computation of Ice Thickness

To calculate the total ice thickness  $I$ , the secondary ice thickness  $SE$  and the superimposed ice thickness  $SI$  formulas have been combined for the two cases with or without superimposed ice, and for the initial and routine measurements.

#### Initial Measurements

Case (a)  $SI = 0$  (See Fig. 3A).

The total length of the heated wire is given by

$$L = SE + C + T \quad (2)$$

The amount of secondary ice  $SE$  is given by

$$SE = L - (C + T) \quad (3)$$

This result should check out with the direct measurement of the ice core thickness.

Case (b)  $SI \neq 0$  (See Fig. 3A).

Again the total length of the heated wire is given by

$$L = I + C + T \quad (4)$$

Solving for the total thickness,

$$I = L - (C + T) = SE + SI_i \quad (5)$$

The secondary ice thickness becomes

$$SE = I - SI_i \quad (6)$$

Since all these quantities were measured initially, the calculations should provide a check on the measurements.

#### Routine Measurements

Case (a)  $SI = 0$  (See Fig. 3B).

The total length of the heated wire is given by

$$L = I + S + T \quad (7)$$

Solving for the total ice thickness,

$$I = L - (S + T) = SE + SI \quad (8)$$

The constant  $C$  is given by

$$C = SI + S \quad (9)$$

and the amount of superimposed ice becomes

$$SI = C - S \quad (10)$$

Solving Eq. 8 for the amount of secondary ice and using the result of Eq. 9,

$$SE = I - SI \quad (11a)$$

or

$$SE = L - (S + T) - SI \quad (11b)$$

Case (b)  $SI \neq 0$  (See Fig. 3B).

The total length is given by Eq. 7 and the total ice thickness  $I$ , by Eq. 8. The distance between the original surface and the reference point on the gauge is given by Eq. 9 from which the amount of superimposed ice formed since the initial installment of the gauge can be calculated with the help of Eq. 10. The total amount of superimposed ice is then given by

$$SI_T = SI + SI_i \quad (12a)$$

or

$$SI_T = C - S + SI_i \quad (12b)$$

where  $SI$  is obtained from Eq. 10 and  $SI_i$  from the initial value measured. The total amount of ice is given by

$$I = SE + SI_i \quad (13)$$

and the total amount of secondary ice is

$$SE = I - SI_T \quad (14a)$$

or

$$SE = L - (T + C + SI_i) \quad (14b)$$

The results of these calculations can then be entered in the Ice Report Form in the appropriate columns.

## 4. EXAMPLES OF MEASUREMENT

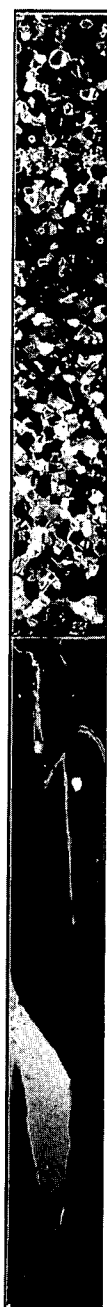
### 4.1. Ice Structure

The initial ice layer that forms under static or dynamic conditions on a body of water is called the primary layer (Ramseier, 1970). All the ice that forms below this layer is secondary ice, which is produced either by growth or by deposition of frazil, slush or ice floes. The ice that forms above the primary layer by flooded snow or rain is called superimposed ice (Michel and Ramseier, 1970). Since both form under completely different conditions, it is important to keep them separate. At air temperatures below freezing, the secondary ice grows parallel to the heat flow direction. The superimposed ice

THICK  
SECTION



THIN  
SECTION



SECTIONAL  
VIEW



SNOW ICE

COLUMNAR  
ICE

SCALE

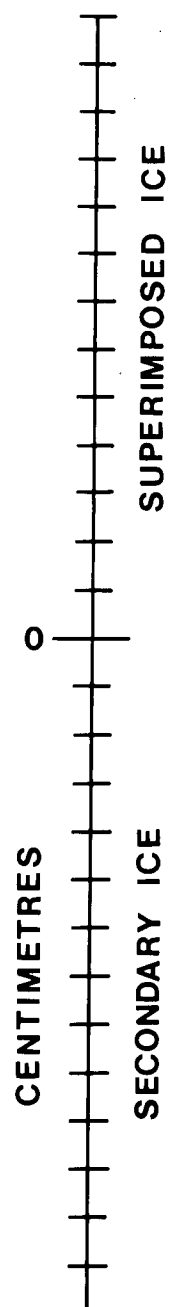


Figure 5. Structure of ice.

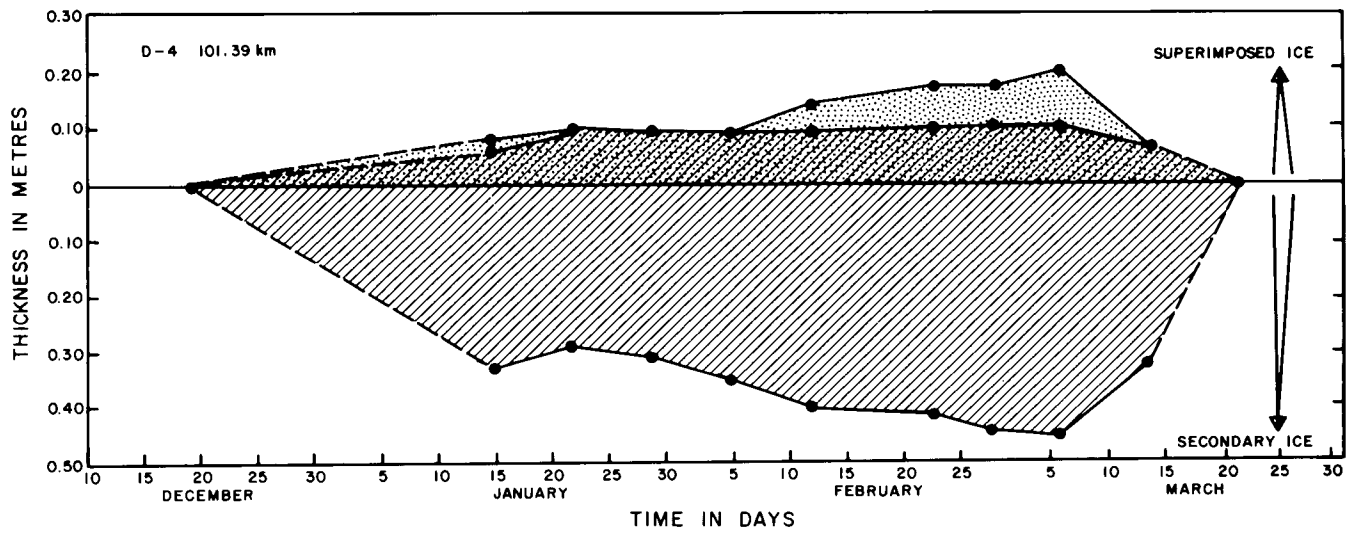


Figure 6. Thickness profile for station D-4.

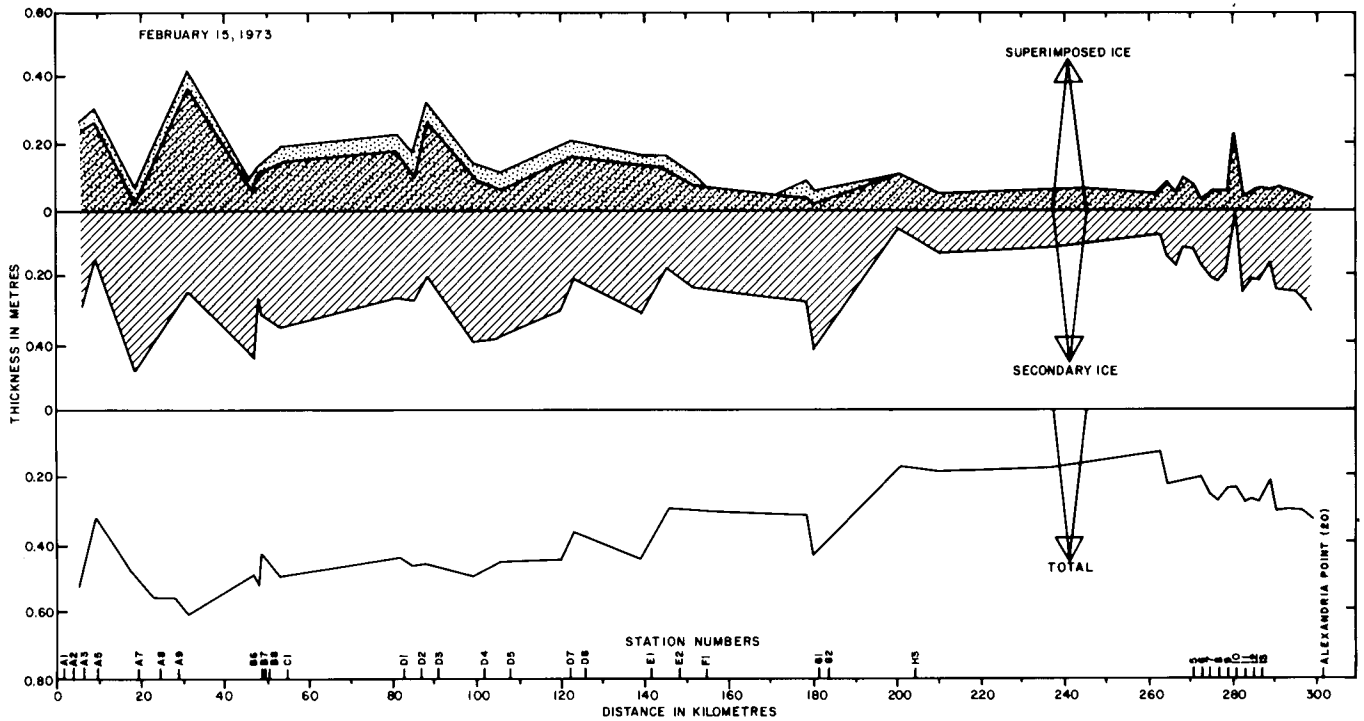


Figure 7. Longitudinal ice thickness profile of river for February 15, 1973.

eventually forms because of the accumulation of predominantly solid precipitation in the form of snow. The snow may be fully or partly flooded by water coming through cracks in the ice cover and causing the formation of snow ice.

To locate the primary ice layer boundary, i.e., the boundary between secondary and superimposed ice, a good rule of thumb is to take the interface between cloudy and clear ice. An example is shown in Figure 5. The thick section illustrates a core as extracted from an ice cover, and is what the observer would see. The boundary in question is indicated on the schematic core. In general this will suffice. To be certain where the primary layer is located a thin section has to be prepared (Fig. 5). The preparation requires a large amount of work and equipment. The ice thin section mounted on a glass plate was photographed between crossed polarizers. This method reveals the individual crystals from which an accurate assessment of the structure and texture can be made (Michel and Ramseier, 1970).

#### 4.2. Ice Thickness Profile

An example is given in Figure 6, which shows a station thickness profile taken during the winter of 1972-73 at kilometre 101.39 (D-4) in the St. Lawrence River. Figure 7 shows a longitudinal river ice thickness profile for February 15, 1973, for a total river length of 300 km. The variation in ice thickness is very pronounced (Transport Canada, 1974).

### 5. WORKING EXPERIENCE AND ECONOMICS

The gauge, as described here, has been used successfully by a number of agencies during the winters of 1972-73 and 1973-74. The St. Lawrence Seaway Authority in Brossard, P.Q., installed over 40 gauges along the navigation channel of the river between Montreal and Lake Ontario in 1972-73. During the previous winter, when they were using the techniques described in the introduction, it took them two days to make their measurements (Transport Canada, 1973). With the same number of stations and using the heated wire technique, it took them only one day to make the measurements (Transport Canada, 1974).

The Department of Transportation and Communications (Ontario) also used the gauge successfully in a joint study in Barrett Bay, Wolfe Island (Dickens and Ramseier, 1973). The object was to measure ice thickness to evaluate a bubbler system for the Wolfe Island Ferry.

The Floating Ice Section used the gauges in the Seaway between the Thousand Islands Bridge and Lake

Ontario, where over 20 gauges were serviced by air cushion vehicles during the winter of 1972-73 (Transport Canada, 1974). The work was easily completed in four hours instead of the two days required the year before to determine the ice thickness by the technique of coring ice samples (Transport Canada, 1973).

The saving in time and expenditures amounted to at least 50 per cent over previous years for the same program. Based on this saving, it became possible to incorporate an airborne FM radar program, (Venier *et al.*, 1975), using the Canadian Coast Guard helicopter stationed in Prescott, for measuring the ice thickness between Montreal and Lake Ontario. In effect, the ground measurements of ice thickness are to be used during the winter of 1974-75 as the "ground truth" for the FM radar.

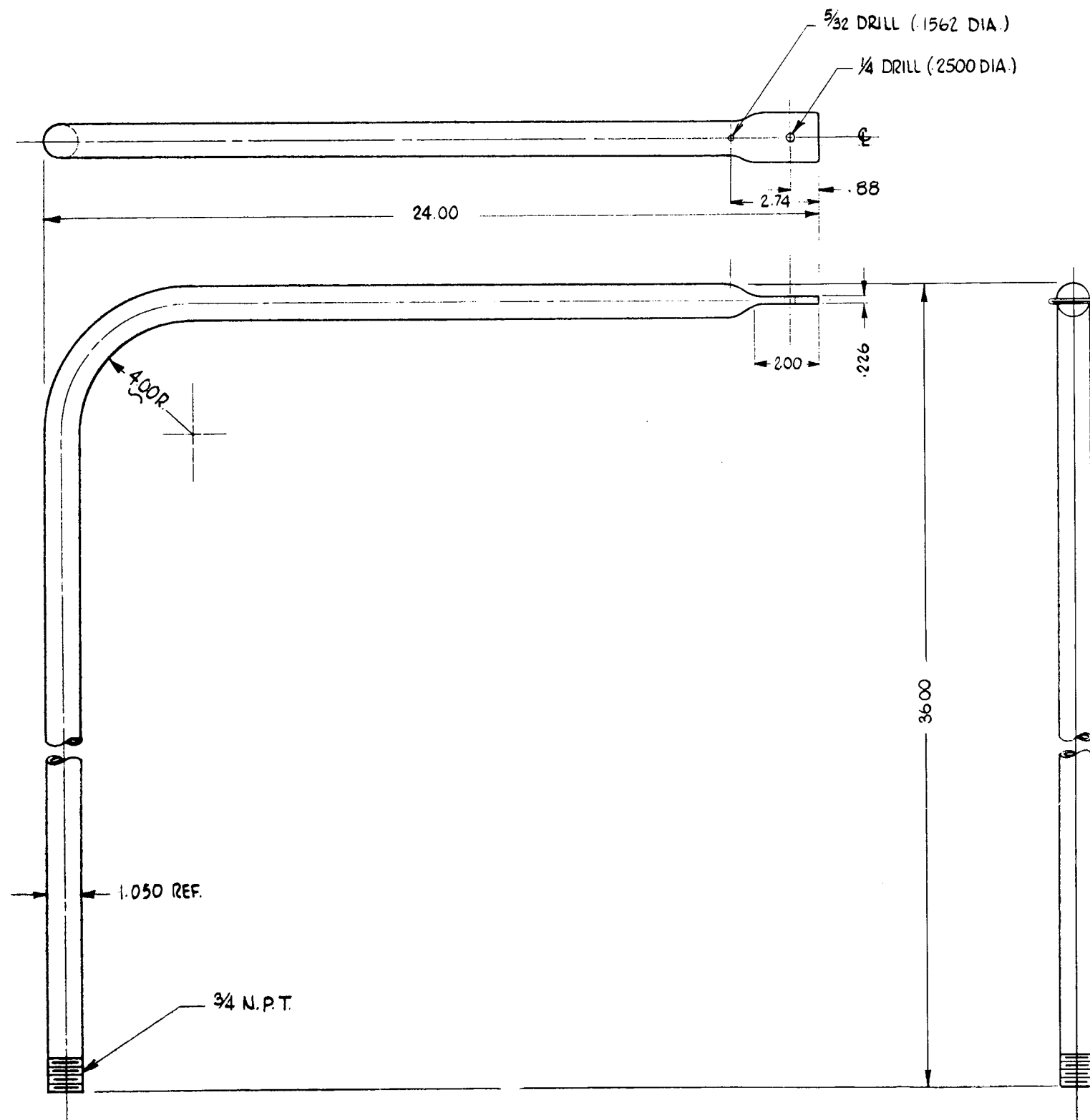
### ACKNOWLEDGMENTS

We would like to thank Mr. G. Forget and his crew at the St. Lawrence Seaway Authority in Brossard for having done an excellent job of measuring ice thickness in the St. Lawrence Seaway. This would not have been possible without the help of Mr. Bill Blair and Mr. Frank Reynolds of SLSA, Cornwall, who encouraged the use of the gauge.

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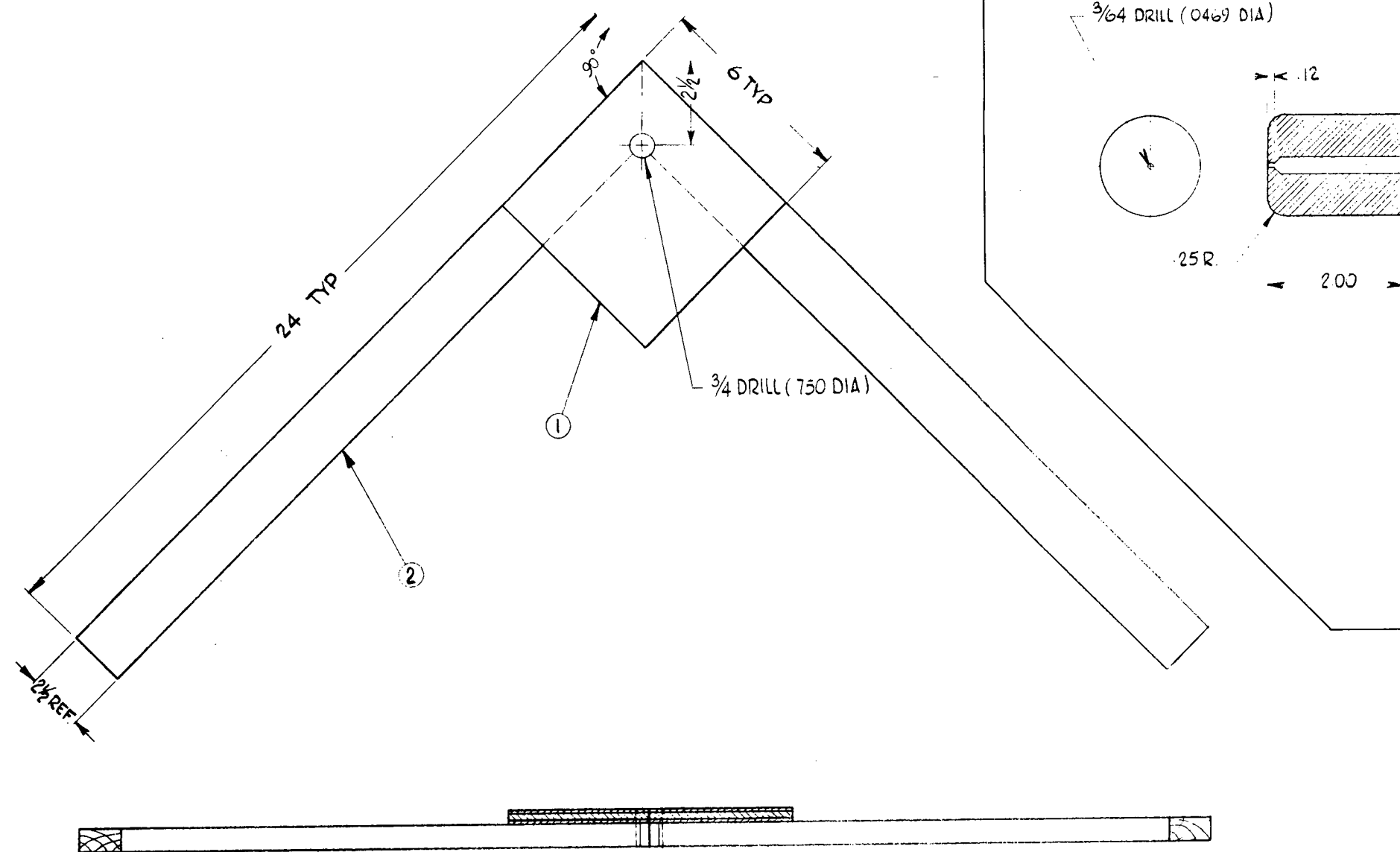
NOTES: 1) REMOVE ALL BURRS & SHARP EDGES.

REVISIONS			
SYMBOL	DESCRIPTION	CHECKED	DATE

QUANTITY REQUIRED		ITEM	PART NUMBER	NAME	DESCRIPTION	SPECIFICATION
17-D378-1		T STACHIN	17-D378-1	17-D378-1	PIPE, SCHED 40 3/4 NOM. STL. BLACK	
APPROVAL		DATE		UNLESS OTHERWISE NOTED DIMENSIONS ARE IN INCHES TOLERANCES ON FRACTIONS DECIMALS ANGLES SURFACE FINISHNESS		
17-D378-1		17-D378-1		SCALE		
DEPARTMENT OF THE ENVIRONMENT ENVIRONMENTAL MANAGEMENT SERVICE INLAND WATERS DIRECTORATE						REVISION SYMBOL
FIS ICE-THICKNESS MEASURING DEVICE FRAME						17-E 377
DRAWING NUMBER						17-D378
SHEET						OF SHEETS

Figure 9. Ice thickness measuring device frame.





3/64 DRILL (.0469 DIA)

1/2

1/2 DIA REF

1/4 DRILL (.2500 DIA)

25 R

200

NOTES: 1) REMOVE ALL BURRS & SHARP EDGES

BAR, ROUND 1/2 DIA CRS

QUANTITY REQUIRED	ITEM	PART NUMBER	NAME	DESCRIPTION	SPECIFICATION
1	1	17-B380-1	T. STACHOW 2 JAN 74 CHECKED 10-10-74 SECTION SUPERVISOR ENGINEER APPROVED 10-10-74	DEPARTMENT OF THE ENVIRONMENT ENVIRONMENTAL MANAGEMENT SERVICE INLAND WATERS DIRECTORATE FIS ICE-THICKNESS MEASURING DEVICE WEIGHT	REVISION SYMBOL NEXT ASSEMBLY DRAWING NUMBER 17-E 377 17-B380 SHEET 1 OF 1 SHEETS

NOTES: 1) ITEM 1 TO BE SECURELY FASTENED TO ITEM 2 WITH ITEM 3

QUANTITY REQUIRED	ITEM	PART NUMBER	NAME	DESCRIPTION	SPECIFICATION
1	1	17-D379-1	T. STACHOW 2 JAN 74 CHECKED 10-10-74 SECTION SUPERVISOR ENGINEER APPROVED 10-10-74	DEPARTMENT OF THE ENVIRONMENT WATER MANAGEMENT SERVICE INLAND WATERS BRANCH FIS ICE-THICKNESS MEASURING DEVICE BASE	REVISION SYMBOL NEXT ASSEMBLY DRAWING NUMBER 17-E 377 17-D379 SHEET 1 OF 1 SHEETS

Figure 10. Ice thickness measuring device weight and base.

## APPENDIX 1

### NORTHERN AND SEA-ICE APPLICATIONS OF GAUGE AND NECESSARY DESIGN CHANGES

The resistance wire (Ni-Chron) works well in applications in fresh water where little heat is lost through conductivity. Unfortunately, the opposite is true in sea-ice applications where high loss owing to conductivity will result in inefficient heating. Therefore, it is necessary to use an insulated resistance wire and to provide a waterproof connection at the resistance wire — insulated wire junction. Such an insulated wire is available (see Appendix 2—cost analysis).

Another difficulty experienced in northern applications would be associated with the large total ice growth over one winter. To install a gauge with a resistance wire

long enough to measure the maximum ice thickness would result in a poor arrangement for initial ice conditions. Error in measuring the distance from the stand to the handle, or the possibility of breaking or kinking the wire could render the gauge useless. A solution may be to install two or more gauges per measurement site with the resistance wire cut to increasing lengths to cover the minimum to maximum ice thickness conditions. One-metre differences in wire length would provide manageable lengths to measure, and once the gauge weight was frozen into the ice sheet the next gauge with the longer wire length could be used, and so forth, until maximum thickness conditions prevailed.

## APPENDIX 2

### COST ANALYSIS FOR ICE THICKNESS GAUGE

Description	Cost/100
Metal stand—formed and drilled at machine shop	\$ 360.00
Wooden base—cut and assembled by DOE—1 x 3—#1 pine and ¼" GIS Fir Ply	100.00
Resistance wire—80/20, 21 G Nichron wire	6.00
Insulated wire—#18 AWG Test Prod Wire #8899 Black	48.60
Metal weight—manufactured at machine shop	120.00
Banana plugs—Johnson #108—red and black plugs	56.00
Handles, solder, hardware and paint	224.00
Labour—1½ hrs. @ \$4.00/hr. per gauge	600.00
	<hr/> \$1,514.60

Approximate cost per gauge based on a 100-lot price is \$15.15.

Note: *Arctic Gauge*—Insulated resistance wire is available from the Claud S. Gordon Co. "Xactglo" is a miniature metal-sheathed metal-oxide insulated heating wire.

Manufacturer: Claud S. Gordon Co.,  
5710 Kenosha St.,  
Richmond, Illinois.