MEASUREMENT OF TEMPERATURE ON BOARD SHIPS

BY NILS RUSSELTVEDT

(Manuscript received 20th January 1936).

A. AIR TEMPERATURE

The measurement of air temperature at ordinary ship's stations has hitherto been rather deficient. Dr. Rudolf Lütgens 1) thus found errors of up to 7° C in the meteorological observations taken on board the «Pangani». These errors and experience from elsewhere led him to the conclusion that «falls sie nicht von einem Fachmann unter Beobachtung aller Fehlermöglichkeiten gemacht sind, nicht zu brauchen sind».

It may also be mentioned that Finn Spinnangr **) in 1930 studied the temperature measurements on a voyage with S/S «Bergensfjord». The observations were here not so bad as on the «Pangani», but errors of 1—2 degrees were found.

The investigations show that the heating of the ship makes it very difficult to get good results with an ordinary thermometer screen on board. Use has therefore been made of several small screens put up in different places, so that one of them should always have a sufficiently favourable position for measurement. The result, however, has not been satisfactory, the reason being that the screens were placed too far away from the rail and the influence of the heat from the ship thereby rendered unavoidable.

We might set up two screens, one on each side of the bridge and fix them to the rail in such a manner that they reach beyond the ship's side into the free air. The screen on the windward side would then be exposed to an air stream free from all influence from the ship, and here we could then measure the true temperature. Such an arrangement, however, would be relatively costly. It would also cause various difficulties. The screens would easily be smashed or even carried away by the waves, and the thermometers would soon get wet in rough sea and storm, and then indicate wrong temperatures.

To save the screens we could make an arrangement so that they could be pulled in in rough weather. It is, of course, not necessary always to observe the temperature outside the rail. When the wind force on the ship (the apparent wind) is a moderate breeze or more, the air temperature may with sufficient accuracy be measured inside the rail to the windward side, and, with higher wind forces, we may obtain the true temperature still more remote from the rail. As a general rule, we may say that the greater the wind force, the more abeam the wind is coming, and the higher the thermometer is fixed above the deck, the farther from the windward rail the true air temperature can be measured.

Such transportable thermometer screens are, as mentioned above, costly, and demand great attention on the part of the observer. It may be supposed, however, that such an arrangement is the best one for large ship's stations equipped with thermographs and hygrographs.

Sling thermometers and aspiration thermometers have been used on board by scientists, but have not found general use at sea. The sling thermometer has not been used because it is difficult to handle on board during rolling, wind and sea. The reason why Assmanns aspiration psychrometer has not been more employed at ship's stations, is, certainly, that up to now it has been an expensive and delicate instrument, with which it is difficult to make observations, and one which can easily be damaged.

It is clear, however, that an aspiration thermometer is in principle the ideal instrument for

---

*) Archiv der Deutschen Seewarte XXXIV Jahrgang 1911. 8. 13 und 67.

**) Norsk Tidsskrift for sjøvesen, juli 1930.

measuring the temperature at sea. When not in use, it may hang indoors, being thus protected from the wear and tear and from the damage, that outdoor instruments are always exposed to on board. And when it is to be used, it can be taken to the windward side of the bridge and used there in air, that has not been warmed by the ship.

An aspiration thermometer for use at an ordinary ship station has, however, to be solidly constructed, so that it can endure the rough treatment to which it is often exposed on board. The thermometer must further have an easily discernible mercury column and a simple and clearly marked scale, so that it can be easily read.

During the Winter of 1931—32, experiments were made with this new type of aspiration thermometer, and the two first instruments were ready for use in the Spring of 1932. They were as soon as possible tried on board a ship in open sea. The trial turned out so favourably that it was determined to equip some large steamers with the instrument.

The thermometers were made with rather much lag — a quality which was then reckoned to be an advantage for the accuracy of reading. When the exposure is finished, the observer must take the instrument close to the ship's side or even inside the rail in order to read it, and then a sensible instrument would adopt the temperature of the place of reading (on the bridge) before the observer could get time to read it.

The lag, however, is in other respects a drawback. Thus the small rate of variation is a great inconvenience to the observer, because it is often a heavy job to hold the instrument out from the ship's side for 4—5 minutes. Every arrangement that could shorten the time of adjustment and at the same time conserve the accuracy of observation is therefore welcome. The best arrangement would be if we could work with great sensibility during the exposure and with much lag during the reading. During the Winter of 1932—1933 experiments were made to construct an instrument of this quality, and the problem was solved by putting a valve in the upper part of the air channel. By means of this valve we may lead the air stream past the thermometer, when the instrument is desired to be sensible, and stop the air current when the instrument is desired to be lag.

Instrument description.

Fig. 1 shows the aspiration thermometer in its present form. The drawing to the right shows it seen from outside (from the front), the drawing to the left shows it partly in section. ⓓ is the aspirator capsule. This is provided with a large mobile hoop ⓑ for the suspension of the instrument and a key-shackle ⓒ for winding up the clockwork movement. On the side of the capsule there is as usual a little window through which we may control the rate of the clockwork. ⓖ is the fan (stippled) and ⓕ is a screen for protecting the fan. ⓘ is the valve. This is constructed like an ordinary lock valve fitted to the valve tube ⓗ. It is kept in an open position by a spring and is shut by pressing down the valve shutter Ⓚ with the ring finger. The dotted part shows the valve shut. The part fully drawn shows it in the usual open position. ⓞ is a screen tube destined to protect the thermometer and to serve as conductortube for the ventilation air. It is provided with two

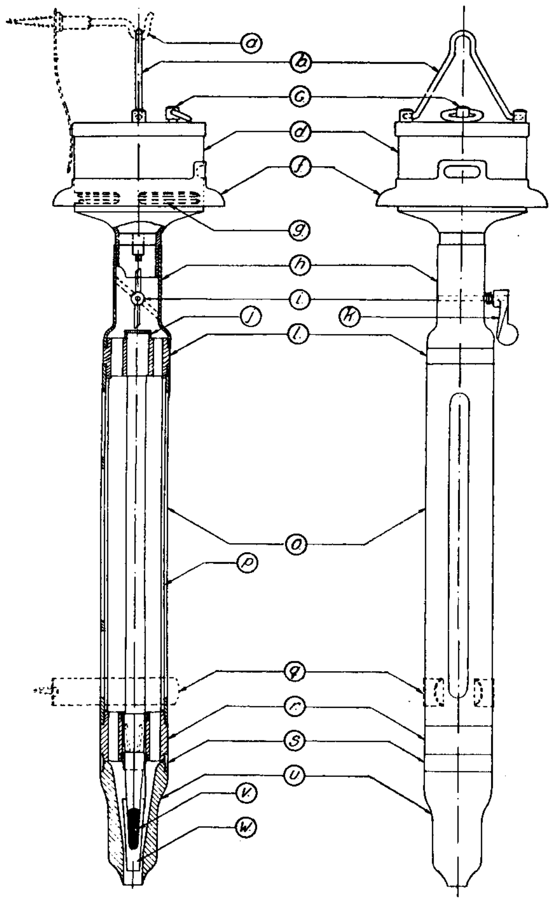

Fig. 1.

apertures, 1 cm broad, 16 cm long, and opposite each other for reading the thermometer in translucent light; one of the apertures is seen in the front of the drawing to the right. A tightfitting glass tube ⓟ placed inside the tube serves as a window in the apertures. ⓛ and ⓡ are two insulating connecting pieces of turbonite, internally provided with channels for the ventilation air and bores for the thermometer. Ⓢ is a metallic ring, coupling the exterior protecting tube or muzzle piece ⓤ to ⓡ. ⓤ is a white ebony-like substance (bakelite), which insulates well. ⓦ is the interior protecting tube. It is made of thinly crome-nickel-plated brass plate. Ⓥ is the bulb. The stippled parts ⓐ ⓠ is the suspension arrangement. The upper part of it consists of a hook ⓐ and a spring. The hook is screwed to the wall and serves as hanger for the instrument. The spring is to parry possible bumps against the wall. ⓠ is a vice-like bracket screwed to the wall at a suitable distance below ⓐ and serves to fix the instrument below. The aspiration thermometer was made by C. A. Ljungmann & Søn, Oslo.

The effect of the valve.

The ratio between the rate of variation at shut and open valve is on an average 1/20. For quite calm air the relation lies generally somewhat below this amount, in wind above the same.

The muzzle of the protecting tubes ⓤ and ⓦ is comparatively narrow, so that the exchange of the air this way is rendered difficult when the valve is shut.

If the valve is used before the massive parts near the bulb have adopted the air temperature (for example by rapid measurement of the temperatur, see below), the thermometer must be read quickly in order to avoid the effect of the radiation from the massive parts in the neighbourhood.

Determination of the lag constant.

The lag of an instrument is usually given by the lag-constant K *). In order to determine this constant we observe how quickly the thermometer changes from one temperature T_0 to another temperature T_1. During the transport of the instrument from air of the temperature T_0 to air of the temperature T_1 the valve is shut in order to avoid the stand of the thermometer changing during the transport. If the thermometer t minutes after the temperature change, shows a temperature T, we get the exponential equation:

$$C_t = C\,e^{-\frac{t}{K}} \tag{1}$$

where $T_0 - T_1 = C$ and $T - T_1 = C_t$. From this equation we get:

$$K = \frac{t \log e}{\log C - \log C_t}$$

We might also determine the rate of variation $\frac{dT}{dt}$ and have then according to Newton's law of refrigeration:

$$C_t = K\frac{dT}{dt} \tag{2}$$

or

$$K = C_t \bigg/ \frac{dT}{dt}$$

The lag of the aspiration thermometer is to some extent dependent on the wind velocity and the position of the instrument in relation to the wind, so that it is less when the muzzle is held against the wind than when it is held perpendicular or in the direction of the wind. K below is given only for calm air. The value of K is also to some extent different for the different instruments, but for calm air and full ventilation (55—65 seconds per one revolution of the springbox) it has the approximate value of $K = 40$, when t is reckoned in seconds.

Methods of observation.

1. We shall find an expression for the time t_h that the thermometer needs for changing $\frac{T_0 - T_1}{2}$ degrees (the time of dimidiation). We then introduce $C_t = \frac{1}{2}C$ in equation (1), and get:

$$t_h = K\frac{\log 2}{\log e} \tag{3}$$

For the value $K = 40$ this equation gives $t_h = 28$ seconds.

If we call the temperature which the termometer shows at the time t_h for T_h, we have:

$$T_0 - T_h = \tfrac{1}{2}(T_0 - T_1)$$

and find:

$$T_1 = T_h - (T_0 - T_h) \tag{4}$$

---

*) See for instance «Lehrbuch der Praktischen Physik von F. Kohlrausch.

When we have determined t_h, we can by means of this equation determine the air temperature T_1 in a very easy way. The procedure is as follows: The fan is put into motion, and the instrument is brought with the valve open to the place where the air temperature is to be measured. Then the valve is shut, the temperature T_0 is read, and the valve is opened again. After a time t_h, the valve is shut, and the temperature T_h is read. The air temperature T_1 can then be found by mental calculation by means of formula (4).

2. We are to find an expression for the time t_d that the thermometer needs for changing $\frac{10}{11}(T_0 - T_1)$. We then introduce $C_t = \frac{1}{11} C$ in equation (1), and get:

$$(5) \qquad t_d = K \frac{\log 11}{\log e}$$

For $K = 40$ this equation gives $t_d = 96$ seconds.

If we call the temperature that the thermometer shows after the time t_d as T_d, we have:

$$T_d = T_0 - \tfrac{10}{11}(T_0 - T_1)$$

and find:

$$(6) \qquad T_1 = T_d - \tfrac{1}{10}(T_0 - T_d)$$

When we let the air current pass the thermometer in t_d seconds, this convenient formula can be used to determine the air temperature T_1. This method (the decimal-method) is a little more troublesome than the dimidiaton-method, because the thermometer has to be exposed for a longer period; but it gives a greater accuracy.

3. The direct method. It is possible to obtain good temperature observations without any calculation at all, viz., if the observer before the real exposure makes arrangements so that the temperature of the thermometer does not differ more than 1° C from the true air temperature. After an exposure of 2 minutes outside the rail, the thermometer will then show the true air temperature with an error of less than 0°.1 C.

The accuracy of the measurement.

1. The dimidiation-method: If we put $C_t = \frac{1}{2} C$ in equation (2), we get:

$$\tfrac{1}{2}\mathrm{C} = K \frac{dT_h}{dt_h}$$

and if this equation is solved with reference to dt_h we get:

$$(7) \qquad dt_h = dT_h \frac{2K}{C}$$

For $K = 40$ we get $dt_h = dT_h\ 80/C$ and find:

$$dt_h = 0.4 \text{ for } C = 20°,\ dT_h = 0.1$$
$$dt_h = 4 \text{ for } C = 2°,\ dT_h = 0.1.$$

If C is large we must read the time in fractions of seconds in order to obtain an accuracy of 0°.1 in T_1; if C is small, however, an error in t_h of several seconds is required to cause an error of 0°.1 in T_1.

If we differentiate equation (3) we get:

$$dt_h = dK \frac{\log 2}{\log e}$$

If we put this value of dt_h in equation (7) and solve, with reference to dK, we get:

$$(8) \qquad dK = dT_h \frac{2K \log e}{C \log 2}$$

If as above we put $K = 40$, $dT_h = 0{,}1$, we get: $dK = 12/C$.

For $C = 20°$ we then find $dK = 0.6$ and for $C = 2°$ we find $dK = 6$.

Thus for large values of C the error in K must be less than 1 if the error in T_1 is to be below 0°.1. For small values of C the coefficient K can have an error of several units before the error in T_1 attains a value of 0°.1.

As experience shows that variations of 5—6 units in K often take place by wind the result is:

When C is large the dimidiation-method is not convenient, but if C is small, the method can be used.

2. The decimal-method: If we put $C_t = \frac{1}{11}$ C in equation (2), we get:

$$\frac{1}{11} C = K \frac{dT_d}{dt_d}$$

and this equation solved with reference to dt_d gives

$$(9) \qquad dt_d = dT_d \frac{11\,K}{C}$$

If as before we put $K = 40$, $dT_d = 0.1$, we get:

$$dt_d = \frac{44}{\mathrm{C}}$$

For $C = 20°$ we then get $dt_d = 2$ seconds and for $C = 2°$ we get $dt_d = 22$ seconds.

As we see, no great accuracy is required in the determination of time, even for large values of C.

Differentiating equation (5) we get:

$$dt_d = dK \frac{\log 11}{\log e}$$

If we put this value for dt_d in equation (9), we get:

$$dK = dT_d \frac{11\,K \log e}{C \log 11}$$

If, as before, we put $K = 40$ and $dT_d = 0.1$, we get:

$$dK = \frac{18.4}{C}$$

For $C = 20°$ we then get $dK = 0.9$ and for $C = 2°$ we get $dK = 9.2$.

The result is that the decimal-method is better than the dimidiation-method.

Observation.

When the aspiration thermometer is out of use it ought to have its place in the chart room or another suitably heated room, and it ought always to hang in its suspending arrangement (see above). It must not be taken out before it is to be used. The procedure with observations is as follows:

The instrument is wound up and brought from its indoorplace to the windward side of the bridge, the valve is shut, and the temperature T_0 is read. The instrument is then kept at arm's length outside the end of the bridge, the muzzle being directed downwards (as shown in fig. 2) and against the wind. As quickly as possible the valve is opened, and the exposure takes place. After t_h or t_d seconds have elapsed, the valve is shut, the thermometer is taken inside the rail, and the temperature (T_h or T_d) is read. The temperature T_1 of the air is then calculated in accordance with formula (4) or (6).

Which formula is to be used will depend on the temperature difference C and the accuracy of the observation.

If, as before, we put the limit of accuracy to 0°.1 the rule will be as follows: For $C \leqq 2°$ both the dimidiation-method and the decimal-method can be used. For $2° < C \leqq 3°$ only the decimal-method ought to be used.

If the difference between the indoor and the outdoor temperature is greater than 3°, we must bring the temperature of the instrument nearer to the air temperature, so that we get $C \leqq 3°$, before we make the real exposure. This can be done in the following way: 6—7 minutes before the time of observation, we wind up the instrument and hang it in a suitable outdoor place. In order to do this as conveniently as possible, we can place an ordinary suspension arrangement on each side of the chart room so far to the side of the bridge as the sea spray permits. The suspension arrangement on the windward side should be used. After about 5 minutes, the instrument is taken down, wound up again, and exposed as described above for t_h or t_d seconds.

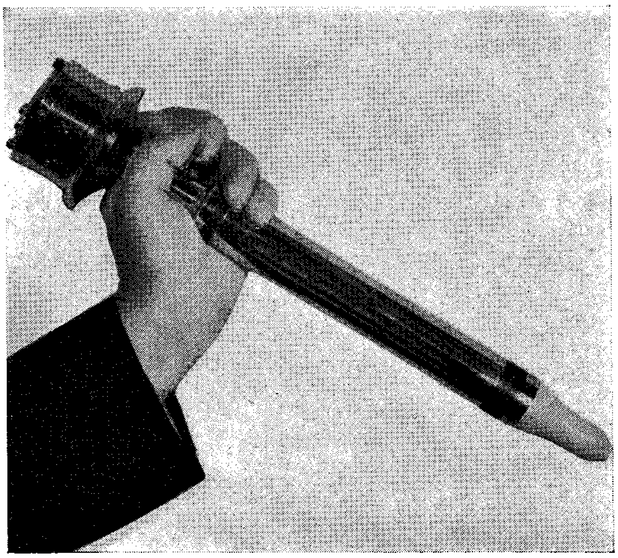

Fig. 2.

When the measurement is finished, the instrument is taken in, wound up and put into its indoor place. The instrument is wound up in order to «run dry».

Control.

The instrument must be controlled from time to time. It is thus necessary often to control that the rotation time of the spring box has not changed. Further, we ought to take the instrument from a cold room to a warm one or conversely, in order to try whether the methods for measurements described above give an accurat value for T_1 or not.

If the ventilation has changed, new values of t_h or t_d must be determined.

B. TEMPERATURE OF THE SEA SURFACE

The procedure for determination of the surface temperature has been to take a bucket of sea water and measure the temperature of the water with the aid of a mercury thermometer fitted in a wooden or metallic protecting tube. As this observation work, especially on board large ships of great speed, may be rather troublesome, we have of recent years tried to find other observation methods.

Some years ago we began to take measurements in the keel water of the ship's engines. On the above-mentioned voyage with «Bergensfjord» Spinnangr *) made use of an arrangement similar to that generally used on board for determination of the temperature of the condenser water, viz., a thermometer fitted in a metallic tube screwed in where the temperature is to be measured. The whole tube was made of brass and screwed into the top of the centrifugal pump for the keel water, with the bulb part (the exposed part) fully in the water. This part is thus, when the engines are in motion, washed by the fresh sea water streaming in. In order to make the conductivity as good as possible, the space between the bottom of the tube and the thermometer bulb was filled with metallic fillings. The obtained conductivity was, however, not satisfactory and it was, therefore, desirable to use mercury as a heat conducting medium instead of metallic filling. Then, however, a brass tube could not be used, because the brass is attached by the mercury. To avoid this difficulty, stainless steel was used in the exposed part of the tube, and after the right sort of steel had been found, a very good tube, practically unassailable by mercury and sea water was obtained.

We have now several years of experience with these tubes. In a few cases a little rust has been observed, but this, on closer examination has appeared to be loose rust transported by the sea water from elsewhere.

Instrument description.

The instrument consists in its present shape of a mercury thermometer graduated in 1/5 C° fitted into a metallic tube the upper part of which is of nickel-plated brass, the lower part of stainless steel. Fig. 3 A shows the instrument in vertical section, Fig. 3 B shows the part ⓓ in horizontal projection. ⓔ is the above mentioned tube of stainless steel. ⓓ is a nut of nickel-plated brass thread and bolted to ⓔ and serving as bolt head when screwed tight. ⓒ ⓖ is the mercury thermometer. ⓑ is a protecting tube of nickel-plated brass ginged to the upper end of ⓔ. It is provided with two apertures for reading the temperature. ⓐ is the tube-formed brass lock for protecting the upper part of the mercury thermometer. ⓗ is a spiral spring destined to protect the bulb ⓖ from bumps against the tube bottom.

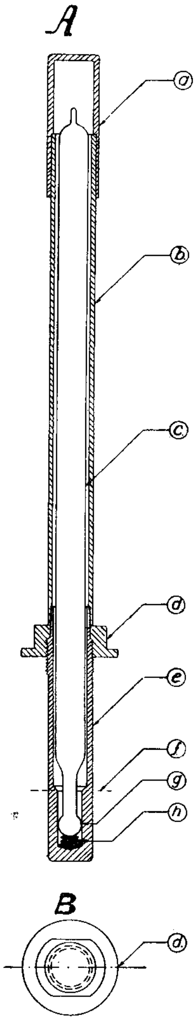

Fig. 3.

Mounting. When the hole for the tube has been bored and threaded, a packing is put under ⓓ, and ⓔ is screwed on. In order to prevent extraneous things from entering the tube ⓔ during this work, we ought to screw off the tube ⓑ and put a cork into the opening. When ⓔ is screwed tight, the spring ⓗ is put into its place, and mercury is filled in until the level ⓕ. For this purpose about 6 cm^3 of mercury is required.

Sensibility. In streaming water the measuring arrangement has a lag-constant of about 13. Thus its sensibility is greater than that of the aspiration thermometer (lag constant 40).

If, instead of mercury, we use water as a heat conducting medium in ⓔ, K has a value of about 40. We can thus get usable observations with sea water instead of mercury.

The mercury thermometer employed, has, exposed in an air current with a velocity of 2—4 m per/sec., a lag constant between 60 and 80, and exposed in streaming water, a constant of about 5.

---

*) See «Tidsskrift for sjøvesen». juni 1930.

Printed July 10, 1936.

Differentiating equation (5) we get:

$$dt_d = dK \frac{\log 11}{\log e}$$

If we put this value for dt_d in equation (9), we get:

$$dK = dT_d \frac{11\, K \log e}{C \log 11}$$

If, as before, we put $K = 40$ and $dT_d = 0.1$, we get:

$$dK = \frac{18.4}{C}$$

For $C = 20°$ we then get $dK = 0.9$ and for $C = 2°$ we get $dK = 9.2$.

The result is that the decimal-method is better than the dimidiation-method.

Observation.

When the aspiration thermometer is out of use it ought to have its place in the chart room or another suitably heated room, and it ought always to hang in its suspending arrangement (see above). It must not be taken out before it is to be used. The procedure with observations is as follows:

The instrument is wound up and brought from its indoorplace to the windward side of the bridge, the valve is shut, and the temperature T_0 is read. The instrument is then kept at arm's length outside the end of the bridge, the muzzle being directed downwards (as shown in fig. 2) and against the wind. As quickly as possible the valve is opened, and the exposure takes place. After t_h or t_d seconds have elapsed, the valve is shut, the thermometer is taken inside the rail, and the temperature (T_h or T_d) is read. The temperature T_1 of the air is then calculated in accordance with formula (4) or (6).

Which formula is to be used will depend on the temperature difference C and the accuracy of the observation.

If, as before, we put the limit of accuracy to 0°.1 the rule will be as follows: For $C \leqq 2°$ both the dimidiation-method and the decimal-method can be used. For $2° < C \leqq 3°$ only the decimal-method ought to be used.

If the difference between the indoor and the outdoor temperature is greater than 3°, we must bring the temperature of the instrument nearer to the air temperature, so that we get $C \leqq 3°$, before we make the real exposure. This can be done in the following way: 6—7 minutes before the time of observation, we wind up the instrument and hang it in a suitable outdoor place. In order to do this as conveniently as possible, we can place an ordinary suspension arrangement on each side of the chart room so far to the side of the bridge as the sea spray permits. The suspension arrangement on the windward side should be used. After about 5 minutes, the instrument is taken down, wound up again, and exposed as described above for t_h or t_d seconds.

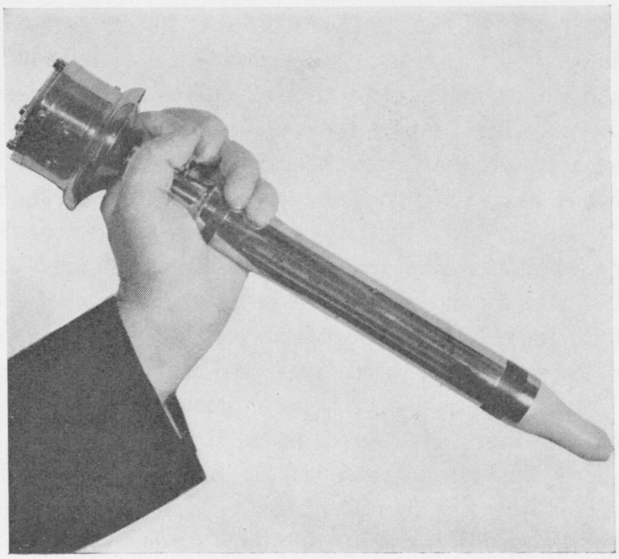

Fig. 2.

When the measurement is finished, the instrument is taken in, wound up and put into its indoor place. The instrument is wound up in order to «run dry».

Control.

The instrument must be controlled from time to time. It is thus necessary often to control that the rotation time of the spring box has not changed. Further, we ought to take the instrument from a cold room to a warm one or conversely, in order to try whether the methods for measurements described above give an accurat value for T_1 or not.

If the ventilation has changed, new values of t_h or t_d must be determined.

B. TEMPERATURE OF THE SEA SURFACE

The procedure for determination of the surface temperature has been to take a bucket of sea water