ELECTRONIC POSITIONING IN SWEDISH COASTAL HYDROGRAPHIC SURVEYS

(A report on operational trials primarily with the Hydrodist MRB 2 in 1961-62)

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INTRODUCTION

A study of the geological processes which have contributed to the topography of a country is of great value to hydrographic surveyors. The sea bed of Sweden, as well as that of other northerly countries such as Finland, Canada, parts of the United States, etc., was created by faults and by the action of the ice cap. An ice cap, 1 000 to 2 000 metres thick, covered Scandinavia during the last glaciation period, but was melted away about 8 000 years ago. During the slow movement over the country of these enormous ice masses, the topography was to a great extent sculptured even below the present sea level. When melting, the ice and the glaciers deposited huge masses of material of various types, among which were huge boulders several metres high. Another consequence of this enormous ice cap was the pressing down of the earth's surface which is now being compensated for by the continuous land uplift, in some parts of the country about 10 millimetres a year.

The waters around Sweden are generally characterized by relatively limited depths and a very rough bottom topography where the big boulders mentioned above are very common.

Sea routes along the Swedish coast very often pass through the archipelagos and over quite shallow areas, as do the fairways leading to harbours and industrial centres. As every decimetre of depth is of the greatest importance for the economy of the harbours, these very shallow and uneven archipelagos have to be surveyed very accurately. When taking into account that the Swedish coast is more than 2 500 kilometres long and partly covered by archipelagos several tens of kilometres wide, it is easy to see that surveying it is a long and time-consuming task.

Hydrographic survey work has been carried out in Sweden for more than 300 years, but obviously only a limited part of these results are accurate enough for the shipping of today. In fact, we can only fully rely on surveys carried out during the last three decades, as shoals or isolated boulders could easily have remained unnoticed during surveys before echo sounders were brought into use. As depths are generally shallow it is obvious that such mistakes could be very dangerous for modern ships with draughts of 12 to 14 metres. The old surveys are, however, very valuable for planning purposes.

In spite of the fact that the Hydrographic Department of the Royal Board of Shipping and Navigation has quite a large number of hydrographic survey vessels (twelve ships between 60 and 650 tons and about 50 survey boats), a re-survey with the most efficient methods used during the last decade would take about 70 years. For a rapidly developing modern country such a long period cannot be accepted and consequently the methods and techniques used in hydrographic operations were carefully analyzed in 1956 and 1957 in order to find possibilities to increase the productivity of survey operations. One very important problem was the positioning of ships and boats in a simpler and faster way which does not necessitate such fine weather and good visibility. In the offshore surveys a special Decca survey chain had been in use for 15 years and it was quite natural that we wanted to have something similar for shorter distances.

TRIALS WITH VARIOUS ELECTRONIC POSITIONING SYSTEMS

In order to meet the need for an electronic positioning system for shorter distances, we started investigations on what was already on the market and what could be expected to appear shortly. The systems were studied not only for accuracy, but also from the operational point of view. The Hydrographic Department has had the privilege of carrying out tests in close cooperation with the manufacturers of such equipment. The first trials were carried out in spring 1957 with a German invention called the Radio Log, manufactured by Atlas-Werke in Bremen. The Raydist system was studied in the U.S.A. in 1957 at Hampton Roads. In spring 1960 comprehensive accuracy tests were carried out with Hydrodist and Decca Hi-Fix in the archipelago of Stockholm where a dense high quality triangulation network made it possible to arrange reliable tests. The results of these tests have been published in the Supplement to the International Hydrographic Review, volume 2. In autumn 1961 the Canadian system Radan was tested in the same area.

OPERATIONAL TRIALS WITH HYDRODIST

The Hydrodist system was one of the systems fulfilling our accuracy specifications and its price was suitable for our financial situation. Its rather limited degree of automation was not considered to be a great disadvantage as we have no lack of staff, our shores are not inhabited and land communication is quite good. Thanks to the courtesy of the manufacturers, one Hydrodist set was placed at our disposal for practical trials which we wanted to carry out over quite a long period before deciding to purchase equipment. It is very important to know not only the accuracy when operated by skilled specialists, but also the reliability, practicability, etc. when the equipment is used by ordinary survey personnel.

Using Hydrodist on a routine survey

Due to the shallow water and the rough bottom topography, we normally have to run very close sounding lines. When the depth is less than 20 metres the interval between the sounding lines. When the depth is less than 20 metres the interval between the sounding lines is very often about 10 metres. Positioning by simultaneous readings of two sextant angles and immediate plotting is not advisable for such close spacing of sounding lines and consequently previous methods necessitated the placing of a large number of self-anchoring marker buoys all over the area. The very high accuracy of the Hydrodist system, even over quite long distances such as 40 kilometres, indicated that we could dispense with the rather time consuming work of placing marker buoys. It was realized, however, that reading distances on the Hydrodist and plotting them would take too long to be used for guiding the vessels along sounding lines as close as are often needed. Obviously the solution was to navigate along circular lines which meant that the light spot on one of the master instruments (the *circular master instrument*) on board the ship should be kept in a constant position by the helmsman; but for several reasons it was impossible to place that master instrument in front of him for direct observation. A special operator had to observe the instrument and give the information to the helmsman. It was, however, regarded as very important to cut down the time needed for the orders to reach the helmsman and also to arrange the system so that the helmsman received his orders continuously and not intermittently. In order to achieve this, a special component was added to the circular master instrument. This component makes it possible to show, in front of the helmsman on a special steering indicator, how far the cursor on the circular Hydrodist has been moved from the right position of the light spot on the cathode ray tube.

The operator of the other master station on board has to follow the light spot with his cursor but it was found to be rather tiring and this could affect the accuracy of the work. Consequently we added another component to that cursor, a motor with variable speed, and a contact giving a pulse for every full revolution of the cursor. Those pulses went to a special counter which could, for example, be set for five revolutions of the cursor (500 metres), and having counted that number of revolutions the counter gave a signal to the echo sounder to make a reference line on the echogram. As annotations are also made on the echogram about the circular distance, the time, etc., the echograms contain all information needed for a later evaluation.

A further advantage of the Hydrodist system as a result of its accuracy is that parallel-running boats can be used very well. The distance to the main vessel is maintained by a simple optical prism and a base on the ship. This parallel sounding multiplies the productivity of the survey team.

Preparation of survey base charts with circular lines

Survey charts are normally made on a scale of 1/10 000. The circular reference line system simplifies the preparation of the survey charts which is carried out as follows :

A series of master sheets have been prepared by engraving on plastic on a scale of 1/10 000 circles with radii up to about 70 kilometres. The interval between the circles is 50 metres. Assuming that the Hydrodist remote stations may be placed at any triangulation stations in the area, data are computed for the adjustment of the appropriate master sheets on a special grid base sheet. These computations are made in a big electronic computer so it does not matter if only a small proportion of the computer results are used in the survey operation. After having decided at which triangulation stations the Hydrodist remote stations will be placed, the appropriate circular master sheets are adjusted on the special grid by placing the corners with the help of the above mentioned computed values. After this, the pack of plastic sheets is copied, e.g. in a simple frame ozalid copying arrangement, and in less than 20 minutes a boat sheet is prepared with the double circular pattern on it. Consequently there is no great difficulty in changing the positions of the remote station for one reason or another.

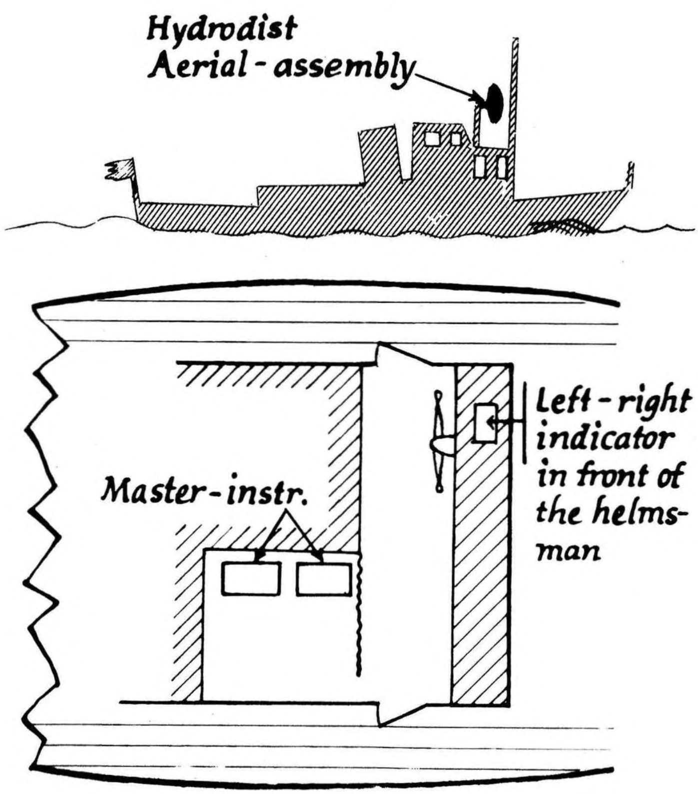

Fig. 1. — Position of antennae and master instruments on the 50-ton survey ship *Anden*.

Vessels used

In order to obtain reliable results, one of the ordinary smaller vessels was chosen for the work. The space in that vessel, an ex-minesweeper of about 50 tons displacement, was very limited, but after some correspondence with the manufacturer and much discussion the arrangement was decided as shown in fig. 1. To the same survey group were also alloted three heavy, as well as five light, fast motor launches.

The group was ordered to carry out a series of actual hydrographic surveys and use Hydrodist as completely as possible.

First survey

After installation of the Hydrodist equipment on board the *Anden* under the supervision of an engineer from the Tellurometer Co., the first survey was begun, i.e., that of the entrance channel to a big industrial plant on Lake Vänern (see fig. 2). In advance, suitable sites for the remote stations were visited and studied in detail as this was the first time this equipment was used. A great number of alternative points were chosen.

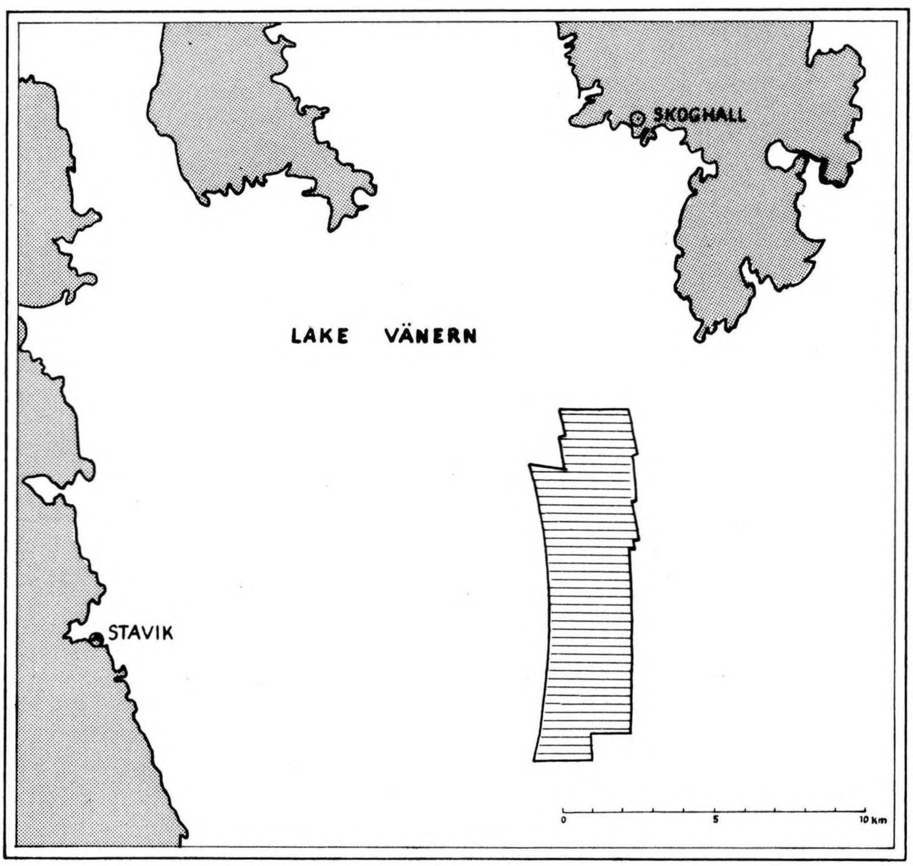

FIG. 2. — Survey No. 1.
Area surveyed and position of remote stations.

The survey area was sounded with a general sounding-line interval of 25 metres and, where it was found to be necessary, intermediate lines were run between these sounding lines so that the final distance between the lines in quite large areas was 12.5 metres. As can be seen from fig. 2, conventional positioning with sextant angles would have been quite difficult and time consuming due to the long distances to available shore fixes. In spite of the fact that it is a fresh water lake, the weather can be bad and the possibility of placing a system of reference buoys and keeping them in position for a longer period is limited.

The results of the operation were followed with very great interest. As expected, several difficulties arose, but it was possible to eliminate them one by one. However, some unforeseen technical faults caused trouble in connection with :

(*a*) electricity on board;
(*b*) certain weak points in the equipment;
(*c*) certain outside disturbances which could not entirely be explained.

Electricity on board

The Hydrodist needs direct current of very high quality. It must be almost completely free from alternating current components and the voltage must be very constant. In the beginning it was planned to use, for the master stations on board, current from the 24 volt supply of the ship, but that current was found to be unsuitable. Some experiments with electrical filters were quite successful, but in order not to delay the survey it was decided to use 24 volt accumulator batteries. Accumulator batteries were used for the remote stations and also a special charger which, when connected to the local power supply of 220 volts alternating current, transformed this current and delivered filtered 24 volt direct current. As there was, at the same time, a need for power for the VHF communication sets, the accumulators were too heavily loaded and gave some trouble.

Weak points in the equipment

Certain weak points were eliminated through minor modifications during operations. The antenna rotation system was not functioning very well and was far too slow. As that system has now been completely redesigned by us for our equipment (the manufacturers have modified their equipment in another way) there is no need to go into detail on that subject.

Another weak point, an electronic one, was the power pack in the master instrument which was the same as the one used in the tellurometer. The constant operation all day long was too heavy a burden for that type of power pack, but as this element has now been redesigned the number of breakdowns will certainly decrease considerably.

Outside disturbances

As the instrument works with a very low output effect it was very soon found that the atmospheric conditions had a great influence on the survey possibilities, but not on the accuracy. On several occasions very clear variations were found in the signal strength when the meteorological conditions changed. Fog and haze had a very unfavourable influence and sometimes rain completely interrupted the survey. In other similar cases there was no influence at all on the signal strength. Taking the carrying frequency into consideration, some of these disturbances may probably have resulted from refraction phenomena. In particular, this could be the explanation for the complete disappearance of signals during warm, calm days and very good visibility.

Bar checking

The sounding work had to be checked by mechanical means when the depth over a shoal near a fairway was critical for shipping. This mechanical checking was carried out with a suspended bar or a pipedrag and positioning was done in relation to marker buoys which had been moored immediately before by the ship using Hydrodist.

Due to the very high accuracy of the positioning during sounding work, it was found possible to limit the areas to be checked (the higher parts of the shoals) which saved a lot of work.

Second survey

This also took place on Lake Vänern. The position and the extent of the survey are shown in fig. 3. It is a further example of the difficulties which would be encountered and the time which would be wasted if the traditional method of positioning with a sextant were used. At that time the instrument operators (ordinary seamen) were better acquainted with their work and this resulted in a higher efficiency in parallel sounding. The only major interruption (2 days) was caused by a breakdown of a power pack. Certain disturbances occurred which were probably due to abnormal atmospheric refraction.

The northwestern part of the area was not covered by the remote station due to intervening forest land. An alternative position (marked with a circle in fig. 3) was used. A curious phenomenon was observed there. The signals disappeared completely within a narrow belt, a few hundred metres wide, at a distance of 6 kilometres from the remote station. On both sides of this belt the signals were clear and strong. This was probably owing to interference between direct and reflected signals.

Third survey

During a 10-day period successful trials were carried out, the object of which was to use the Hydrodist for measuring long geodetic ranges with a probable mean square error of about 0.5 metres. We wanted to check the position of the isolated island Gotska Sandön in the Baltic (fig. 4), 50 kilometres north of Gotland and about 90 kilometres from the mainland. As the maximum instrument height on shore was 45 metres and the distances were very long from the point of view of signal strength, it was

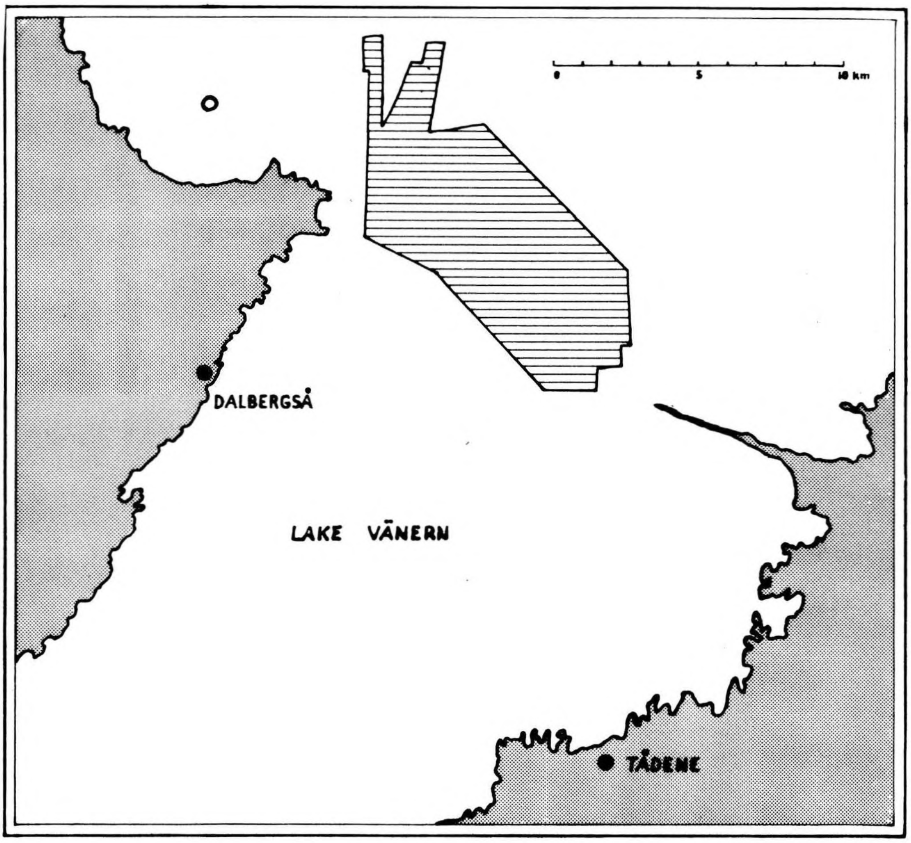

FIG. 3. — Survey No. 2.
Area surveyed and position of remote stations.

decided to try the line-crossing method. The master instruments were mounted as high as possible on a pilot ship which crossed the line between two remote stations several times. Every 20 seconds the distances to the remote stations were read simultaneously and the minimum sum gave the distance between these two stations. To find this minimum value, the sum distances were plotted on a graph and a smooth curve was drawn touching the plotted points. The minimum point gives the distance wanted. There were no difficulties in drawing the curve to touch the points but the irregular differences were about ± 2.0 metres. This may be because it is impossible to read A^+ and A^- values when the master instruments are moving; on stationary instruments both values should be read when highest accuracy is wanted.

In this way three distances (42-57 kilometres) were measured between a point on Gotska Sandön and three trigonometrical points on Gotland.

The greatest attention was, however, devoted to the survey of the line 88 kilometres long between Landsort lighthouse, south of Stockholm, and Gotska Sandön, where there had been no direct geodetic connection before, An attempt to use the line-crossing technique was not successful, probably due to meteorological conditions. Suddenly it was observed that the two

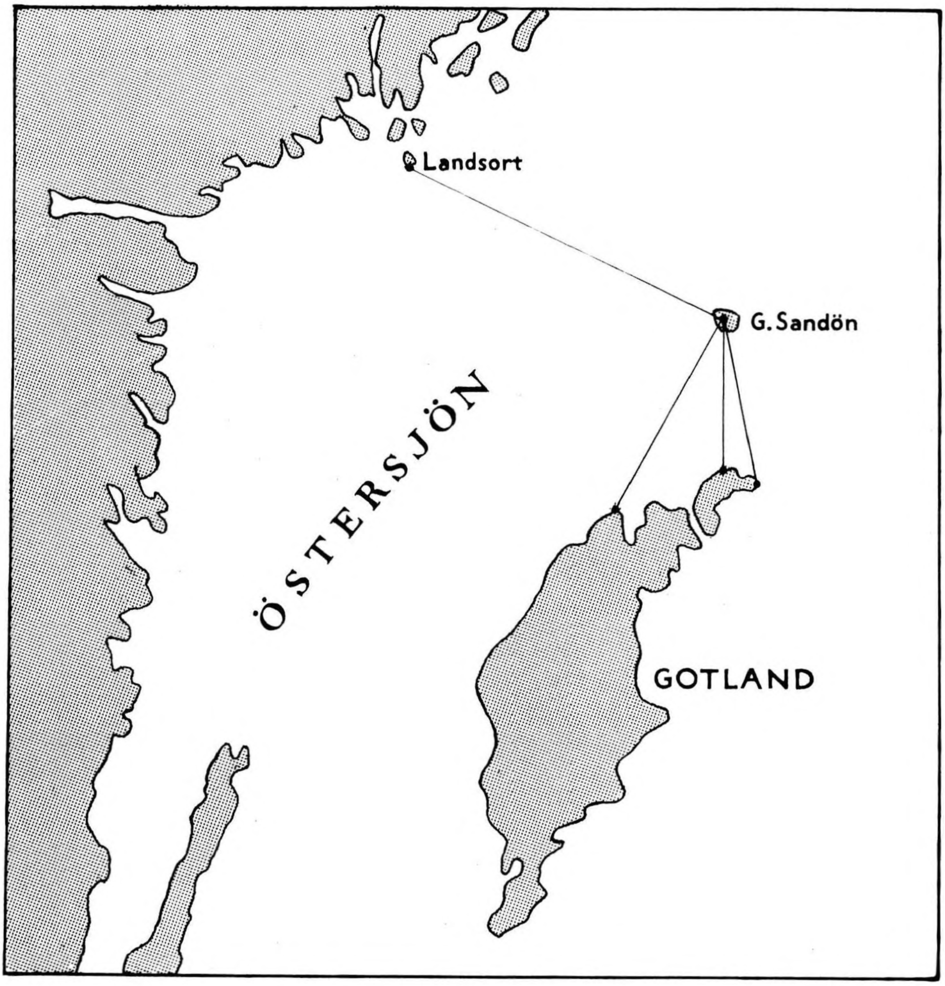

Fig. 4. — Survey No. 3.
Distances measured to determine the position of Gotska Sandön.

remote stations, 90 kilometres apart and placed only 45 metres above sea level, obtained VHF radiotelephone contact with each other in spite of the fact that they were below the radio horizon. Three hours later, the ship brought ashore one master instrument at Landsort lighthouse and a direct distance measurment to Gotska Sandön was successfully carried out. The incoming signal strength (automatic volume control reading) was very good (about 40-45 μA). This unique measurement was certainly a consequence of the particular meteorological conditions prevailing that day: a thin layer of dense fog just over the sea surface and reaching to about the level of the two stations on shore. An attempt at a similar measurement from another lighthouse the next day was not successful nor was an attempt with line-crossing.

The network made up by these observations, and also including previously made theodolite measurements from Gotland, was calculated and adjusted according to rigorous methods. The position of the island was moved 6 metres and the radial standard deviation of the survey was found to be ± 1.6 metres.

During this short expedition a transit traverse with sides of 800-7 000 metres was also measured around the island Gotska Sandön.

Fourth survey

The Fladen shoal, about 50 kilometres south of Gothenburg and about 20 kilometres offshore, was the next subject (fig. 5). Quite a large area

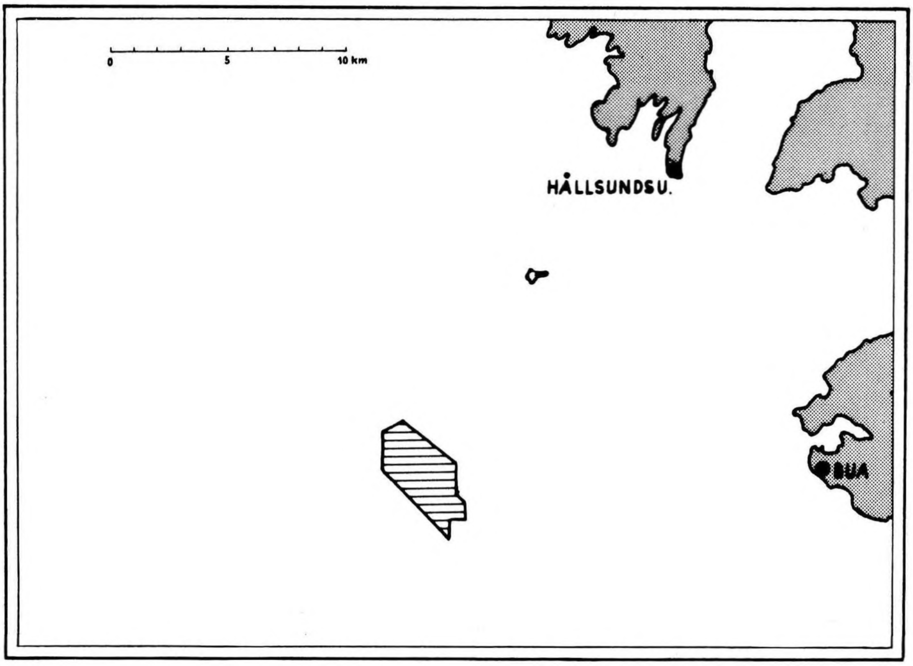

FIG. 5. — Survey No. 4.
Area surveyed and position of remote stations.

had to be closely sounded and a smaller one very closely sounded in order to obtain information for positioning and designing an offshore lighthouse (telescope building technique) in a depth of about 10 metres. Sextant positioning would have been very difficult and time consuming and a strong current would have hampered the use of reference buoys, etc. Just at the beginning of the work it was found that the Hydrodist was not functioning properly, i.e., the C-crystal in one of the instruments ceased to oscillate, which made it impossible to check the number of 1 000 metres. In spite of this, the work was carried out successfully. In one-and-a-half days the area was parallel sounded with a 25-metre and sometimes a 12.5-metre interval between sounding lines. A total of 400 nautical miles of sounding lines was recorded.

An intensive search for the defects in the instruments was immediately started by a team of electronics experts including the service engineer from the general agent; but it was not until a specialist from the Tellurometer

Co. had joined the team that a very well-hidden fault in a contact in the dipole antenna of one of the remote stations was found. Since the contact has been repaired and the instruments have been adjusted, the system has been working correctly thus far (August 1962). It was impossible to find out when this contact failure had occurred and as it decreased the signal strength to a varying extent it could have caused some of the troubles found earlier.

It should be mentioned that the troubles during the first part of the 1961 season caused the surveyors of that team and others in our organization as well as some members of the electronics team to ask for the immediate rejection of the Hydrodist system. We do not blame them for their reaction as we were sometimes quite close to rejecting it when we were faced with the capricious behaviour of the instrument. One day it worked efficiently, the next curious signal variations and disturbances occurred. Now everyone is glad we did not stop after the first half-season.

Fifth survey

The last task for the Hydrodist during the 1961 season was to sound two areas; the northern one was an area of 10 square kilometres (fig. 6) in the Sound between Denmark and Sweden, partly in Danish territorial waters. The interval between sounding lines in the northern area was 12.5 metres. Theoretically that means 800 kilometres of sounding lines, but in practice the distance covered was over 1 000 kilometres. In spite of rather bad weather late in the season and strong, changing currents, the northern area was sounded in two days with the Hydrodist working as perfectly as a chronometer.

Sixth survey

Just after laying up the survey ships, unforeseen problems occurred in the planning of a deep fairway to the new iron ore harbour in Lulea in the northern part of the Gulf of Bothnia. It was found to be important to obtain very detailed soundings over some 10-metre shoals where offshore telescope lighthouses were to be placed. Hydrodist, mounted provisionally on a lighthouse tender, was the only practical solution and only two days after this decision the sounding was started. That shows how transportable and easily installed the Hydrodist is. Although the C-crystal was not functioning because there were no spare parts available, and in spite of cold, bad weather (sometimes light snow), the rather extensive work was finished in due course.

Immediately after the last sounding line was finished one A-crystal broke down. We were afraid, quite naturally, that a crystal, just before a breakdown, could have introduced errors in the position finding on the last sounding lines, but discussions with the specialists from the Tellurometer Co. were reassuring as the instrument stops working if the error in the modulating frequency (A) deviates more than 200 periods. The distance errors corresponding to such a frequency error are negligible in hydrographic work.

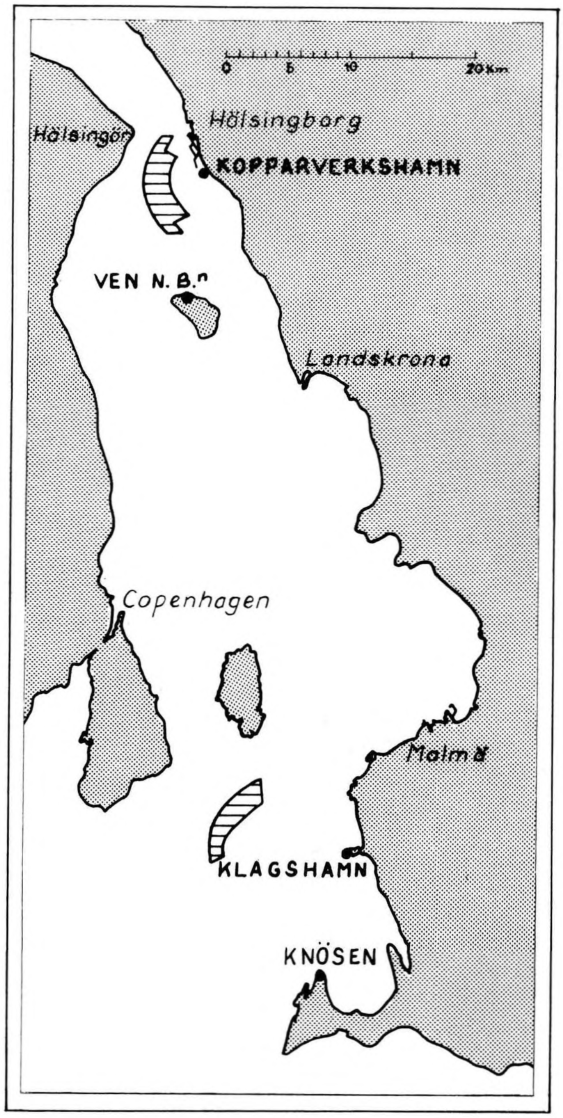

Fig. 6. — Survey No. 5.
Areas surveyed and position of remote stations.

CONCLUSIONS

From the comments above it is clear that this first Hydrodist survey season had its good and its bad points, but it should be emphasized that some of the weaknesses may be due to lack of experience in the detailed work and maintenance. The impression from the latter part of the season is, however, very favourable.

It must be borne in mind that there are two completely different causes of bad functioning:

(1) Faults in the instruments themselves: they had some weak points far below the normal sea-going standards for conditions of humidity, condensation and vibrations from diesels, etc.

(2) Disturbances caused by interference or unfavourable atmospheric conditions, to which the system was very sensitive due to the very low output effect.

In many cases it was difficult, perhaps due to our lack of experience, to determine from which of these two sources the disturbances came; but after more experience it will certainly be easier.

DEVELOPMENTS

Detailed studies and discussions with representatives from the manufacturers resulted in a modification programme aiming at a more reliable functioning of the apparatus. The possibilities of making the work on board less tiring, etc. were also examined and this resulted in the addition of some extra components. Some of the modifications were made by the manufacturer, some by the Swedish Hydrographic Department. The main modifications were:

The antenna system on board

For turning the antennae, synchros are used instead of motors in the Hydrographic Office's modification; the manufacturer has also modified the turning system but still uses motors. The system as modified by the Hydrographic Office allows a 540°-turn in 7 seconds which is found to be very important in practical work.

To avoid water condensation in the antenna domes an electric heater is installed.

The contacts in the coaxial cables from the instruments to the antennae have been really weak points and they have been reduced in number.

The antennae of the remote instruments

These instruments have been provided with bigger parabolic reflectors which considerably increase the signal strength.

The master instruments and their installation

The power packs have been placed outside the instrument boxes in order to increase the cooling. A spare power pack is mounted for immediate connection if one of the others breaks down.

The two master instruments are mounted on desks specially isolated from vibration which can easily be moved from one ship or launch to another. The controls and extra components are mounted on the panel of the desk (see fig. 7), e.g., the antenna rotation, the guiding part to the steering indicator and the motor control (if there is one) for the cursor on the cross-circle instrument, a counter for the signals which mark reference lines on the echogram, a counter with big figures (a slave instrument can be placed in front of the surveyor).

FIG. 7. — The instrument desks on board the *Gustav af Klint*.

The electricity is now taken from the ship's supply after certain precautions have been taken (filtering).

RECENT WORK USING HYDRODIST

During the present 1962 survey season two complete Hydrodist sets are in operation in Swedish hydrographic surveys. Both sets have functioned properly. Variations in meteorological conditions have caused certain variations in maximum ranges. Extensive surveys in the shallow Åhus Bay lasted about 2 months and about 24 000 kilometres of sounding lines were covered. At certain times two sets were in operation, the master instruments of one on board the *Anden* as during the previous season, and those of the other on board the 650-ton survey ship *Gustav af Klint* which carried 3 launches (this ship will be rebuilt next winter and will carry 8 launches) and also using 5 or 6 other sideboats from shore every morning when weather permitted.

In June and July 1962, the *Gustav af Klint,* with the Hydrodist equipment and assisted by two smaller survey ships, determined the fixed errors (land corrections) for the two new Decca navigational chains covering the Gulf of Bothnia and the Bay of Bothnia. In order to get excessive observations, theodolites were also in operation at the Hydrodist shore stations. In this way about 750 check points were very accurately determined by the *Gustav af Klint* using the Hydrodist; some of these points were as far as 70 kilometres outside the outer skerries. Using the sextant, the *Gustav af Klint,* another Swedish survey ship and some Finnish survey ships cooperating in this work determined 600 Swedish and 400 Finnish check points; each position was obtained by 5 angles. The extensive observation results were sent to Stockholm by telex and fed immediately into an electronic computer in order to find out if, for one reason or another, extra control points should be added in an area.

FURTHER DEVELOPMENTS

Analysis has shown that there might be some reason to use the combination of half a Hydrodist set (i.e. one master and one remote) and one theodolite or similar instrument.

If there is a breakdown at one of the instrument pairs in a complete set, a combination with a theodolite may be a good alternative.

If there is a rather narrow and long water area, a theodolite-type instrument may be moved along the shore, and bearings obtained which are corrected according to the distance to the ship (measured with Hydrodist) enable the ship to be directed along certain sounding lines. Tests have shown that this method works well.

The ship can also steer along a Hydrodist circle as usual but a theodolite observer at the side of the remote instrument tells the ship every time it crosses one of a series of geodetic bearings predetermined at suitable intervals.

The latter two methods make it possible for us to have more teams working at the same time with Hydrodist in our archipelagos.

It is, however, not possible to use the Hydrodist everywhere, in one or other of these ways, so it must be combined with various other survey methods. When it can be used, the Hydrodist, especially in combination with parallel sounding and using fast craft, increases considerably the productivity of our hydrographic surveys.