PHOTO 1

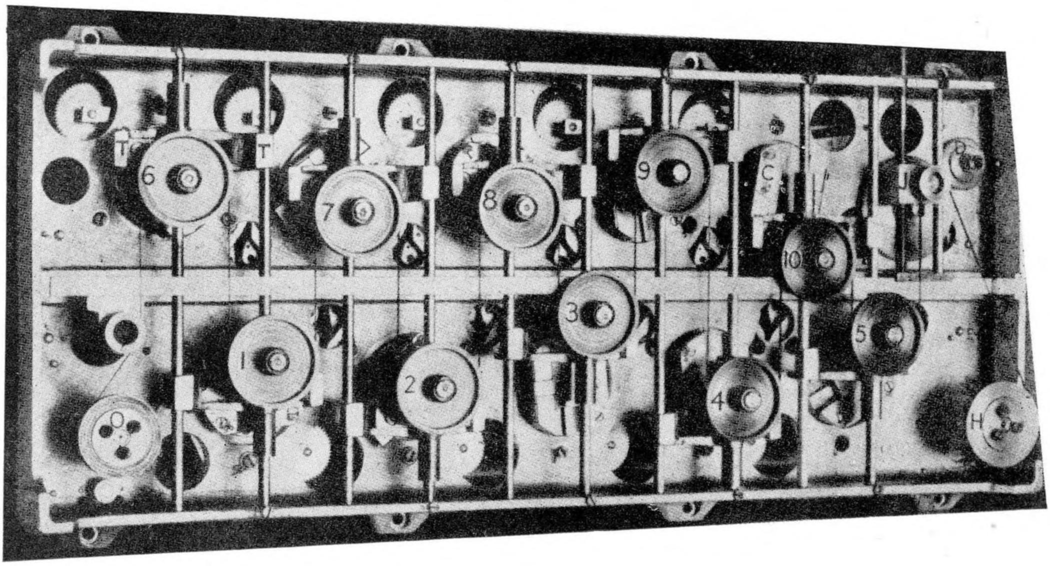
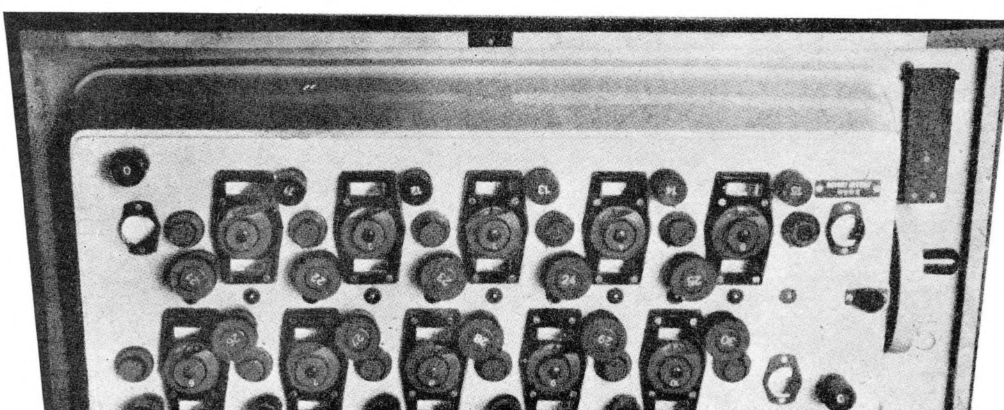


PHOTO 2



The portable Tide predicting Machine.

THE PORTABLE TIDE PREDICTING MACHINE

(Extracts from Description and Instructions relating to Portable Tide Predicting Machines designed and manufactured in Germany (*).

Communicated by the Hydrographer of the Navy, British Admiralty.
Hydrographic Department, Professional Paper N° 3, Part V, Tidal Branch, 1948).

In photograph I, a view of the lower half of the machine with the bottom plate removed, the numbers and letters stand for the following :

Pulleys are numbered 1-10 according to the knobs by which their amplitudes *fH* are set (*i. e.* the radius of the crank arm which can be moved in the slide on the face of the crank). The knobs numbered 1-10 are seen in photograph 2, the amplitudes *fH* are set on the circular scales below the knobs, segments of which can be seen on the side of the knob opposite to that on which the number is shown.

T and *T'* are parts of the *T*-piece to which pulley N° 6 is attached. The T-piece slides up and down the guides, one of which passes through the centre of the T-piece and the other through the extremity marked T'.

C is the crank which operated the T-piece to which pulley N° 10 is attached. The slide on the face of a crank can be seen most closely in that for pulley N° 5. When a pulley is in its high or low water position the slide on the face of the crank is parallel with the guides. At high water the T-piece will be near the outer edge of the box (see pulleys Nos 9 & 4) and at low water near the centre line of the box (see pulleys Nos 3 & 10). The cranks are set for angle by knobs 11-20 and 21-30. At any instant the angle of the crank operating pulley N° 1 will be equivalent to the sum of the angles on the scales adjoining knobs Nos 11 & 21 (see photograph 2).

O is the storage drum which is set by knob *O* (see photograph 2) to the height of mean sea level, as indicated on the scale below knob *O*. From this storage drum the wire passes a fair-lead to pulley N° 6, then round pulleys Nos 1, 7, 2, 8, 3, 9, 4, 10 & 5 to the zero adjuster *J* and finally to the spring drum *H* which turns the height scale (see photograph 2).

D indicates the time and date scales (see also the knob *D* and the adjacent scales on photograph 2). These scales are turned through gearing from the shaft but the date scale can also be independently set by knob *D*.

The handle which turns the shaft is on the right edge of the box (see photograph 2). The shaft itself is invisible as it runs beneath the plate in the centre line of the box.

The differential gearing which operates the cranks can be partly seen on the other side of the plate which divides the upper and lower halves of the box.

The functions of the machine are carried out as follows :

(*a*) A shaft, which is turned by the handle on the outside of the case, has a number of worms keyed to it, which, through differential gearing, drives a similar number of cranks. Each crank represents a constituent, and for one revolution of the shaft, a crank is turned through the appropriate number of degrees according to the speed of the constituent. It is possible to alter

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(*) Mechanoptik, Potsdam, Babelsberg, Turnstrasse, 18.

the position of the cranks without turning the shaft, so that all may be set to represent astronomical conditions at any instant. The astronomical arguments or positions to which the cranks must be set, are tabulated (Table supplied to holders of the tide predicting machines) for 0000 hours on each day of the year.

Two scales are to be seen through the window adjacent to the knob marked *D*. The shaft is turned by the handle so that the time scale, which is the lower of the two, is set to 0000. The upper scale is set by means of knob *D* to the date. The cranks are then set to the astronomical arguments for that date, by means of the knobs 21-30, the angles being shown on the scales adjacent to each of these knobs. Thereafter these scales will record the change in the angles as the shaft is turned, and the gearing is sufficiently accurate for the astronomical changes in a period of a month to be reproduced without appreciable error.

The angles shown on the scales at 0000 on a date at the end of this period, should be checked against the tabulated astronomical arguments for that date. If adjustments are made when these checks show them to be necessary, then the machine will reproduce the changes in astronomical conditions throughout the period of a year.

(*b*) Each crank has an arm, and a stud at the outer end of this arm projects through the horizontal slot of a T-piece. The T-piece is free to move only in a vertical direction, up and down on guide rods. As the crank arm rotates, the T-piece, which carries a pulley, rises and falls, reaching its maximum divergence from its mean elevation when the crank arm is at 12 or 6 o'clock.

The amplitude of any constituent varies from place to place and the arm of the crank must be adjustable, so that the vertical movement of the T-piece can be made proportional to the amplitude of the constituent at the place for which the tide is to be predicted. The radius of the circle, through which the stud on the crank arm travels, can be adjusted, for the crank arm can be moved in a slide on the face of the crank by means of a ratchet. The ratchets for each constituent are operated by means of the knobs 1-10, which are used to set the scales below the knobs to the amplitude fH.

The angle, $P = 360^{o} - g$, varies from place to place and it is possible to set the cranks to the appropriate angles, independently of any movement of the shaft. They are tabulated in the lists of harmonic constants and are set by means of the knobs 11-20 on the scales adjacent to the knobs. The angles set on these particular scales are not altered by movement of the shaft and in consequence the angle P can be checked at any instant.

> NOTE. — The crank and in consequence the T-piece and pulley are at their high water positions when the sum of the astronomical argument and the angle P, as shown on the appropriate scales, is equal to 360^{o}.

(*c*) The height of a constituent of the tide at any time is equal to $R \cos (nt - r)$. Where R is amplitude or semi-range of the constituent.

nt is the time at any instant, expressed as an angle ; *i.e.* the time "t" in hours multiplied by "n" the speed of the constituent in degrees per hour.

r is the time when high water of the constituent occurs, expressed as an angle.

The predicted height of the composite tide at any time, is equal to the sum of the heights of the constituents at that time.

On the tide predicting machine the displacement of a pulley from its mean position, at any time setting, is also equal to $R \cos (nt - r)$:

Where R is the radius to which the crank arm has been set.

$nt - r$ is the angular setting of the crank when the shaft is turned so that the time scale is set to the time "t" ($nt - r$ is equal to the sum of the astronomical argument at the time "t" and the angle P).

In order to predict the height of the tide as a whole, at any time, the machine must sum the displacement of the various pulleys from their mean positions. The mechanism for each constituent is arranged alternately on either side of the centre line of the machine. On each side the pulleys move outwards from the centre line as the constituents of the tide rise and inwards as the constituents fall. A wire from a drum is led over or under the pulleys to another drum with an internal spring. The length of wire between the two drums will vary with the positions of the pulleys, from an absolute minimum if all were at their nearest to the centre line, to an absolute maximum if all were at their maximum distance from the centre line.

The drum H operates the height scale, which records the movement of the drum as it winds wire on or off according to the resultant of the movements of the pulleys.

Instructions for using the portable tide predicting machine (German model).

Data for predicting at a particular port:

(*a*) The height of mean sea level (Z_0) above chart datum and the seasonal correction to Z_0.

(*b*) The harmonic constants fH and P for each constituent. In the list of harmonic constants H,the average amplitude or semi-range, is tabulated, this average value must be multiplied by a factor f whose value varies in a period of 19 years. The values of f for each constituent are tabulated for a particular year with the astronomical data.

P is the tabulated phase increment and is equal to ($360^o - g$), where g is the phase lag as given in Admiralty tide tables and methods of analysis.

(*c*) The astronomical arguments for each constituent as tabulated for 0000 on the commencing day of prediction:

Place the machine on a table with the handle on the right. For the purpose of illuminating the scales, connect a 24 volt battery to the plug on the left side of the machine. The switch operating the lights is on the front side of the machine. Spares for these 12 volt bulbs are stowed under the black cover on the wooden base of the machine.

Of the two scales below the window near knob D the lower scale is set to 0000 by turning the handle and the upper scale is set to the date by knob D.

(*a*) Apply the appropriate seasonal correction to Z_0 and set the scale under the window by the knob O, to the corrected mean level by means of knob O.

(*b*) Set the scales below the knobs 1-10 to the amplitudes fH of the constituents by means of these knobs. If the harmonic constants for any constituent are not available that scale must be set to zero by turning the appropriate knob in a clockwise direction until the pointer comes up against the stop. (If the knob is turned in an anticlockwise direction the pointer will eventually come up against the same stop but the amplitude will be set to 5.00 feet).

The mean level scale is graduated to 7.00 feet, the amplitude scales to 5.00 feet and the height scale to 13.00 feet. As a rough guide, it may be said that if the sum of mean level and the amplitudes set by knobs 1, 2, 6 & 7 is greater than about 12.00 feet, it is likely that the more extreme heights will be beyond the limits of the height scale. In that case corrected mean level and all the amplitudes *fH* must be halved before being set on the scales and the heights read off the height scale must be doubled.

Set the scales below the windows near knobs 11-20 to the angles *P* of the constituents, by means of those knobs. These scales must always be set by increasing the angles they happen to be reading, *i. e.* if it reads 10° and *P* is 360°, the angle must be increased by passing 180° and not decreased by passing 0°. This is done in order to take up the back lash. If the harmonic constants of any constituent are not available and the amplitude of that constituent has been set to zero, then the setting of *P* is immaterial.

(*c*) Set the scales below the windows near knobs 21-30 to the astronomical arguments for the constituents by means of these knobs. These scales must also be set by increasing the angles they happen to be reading. If the amplitude of a constituent for which the harmonic constants are not available, has been set to zero, then again the setting of the astronomical argument is immaterial.

The predictions will be in the time zone for which the harmonic constants are given.

The machine after the initial setting of the astronomical arguments can be used for predicting for a period of 15 days without any appreciable error. At the end of that period, when the time scale is set to 0000, the astronomical arguments on the scales 21-30 should be checked against those tabulated for that day and adjusted where necessary. At the same time, if the seasonal correction to mean sea level (Z_0) has changed in this period the new value of corrected mean level should be set on the appropriate scale.

Accuracy of predicting by the portable predicting machine.

The harmonic constituents of the portable tide predicting machine M_2 S_2 N_2 K_2 μ_2 K_1 O_1 P_1 M_4 MS_4 are those which are incorporated in most of the tide-predicting machines, (belonging to various countries) used to predict the Standard Ports in Tide Tables. In addition there are a large number of shallow water harmonic constituents which, to a varying degree, are incorporated in all of these machines. Even these shallow water constituents may be inadequate if these effects are particularly complicated, and extra non-harmonic corrections may have to be made to the predictions from the machine.

The portable tide-predicting machine has two shallow water harmonic constituents M_4 (set by knobs 9, 19 & 29) and MS_4 (set by knobs 10, 20 & 30). These constituents represent only the most simple shallow water effects and are quite inadequate foı those waters where the effects are complicated.

It is apparent from the foregoing that the same accuracy of prediction cannot be expected from this 10 component machine as from one with a great many more components.

Nevertheless because the machine embodies all the principal constituents, its accuracy can be adopted as being adequate for all ordinary navigational purposes. For special purposes the accuracy can be improved by applying certain modifications which are described in the following article.

Harmonic constants determined from 29 or 15 days analysis, to use with predicting machine.

In the harmonic analysis the lags of the constituents will be given as g, before they are used with the machine the lags must be converted to $P = 360^{\circ} - g$. These analyses will give the harmonic constants, g and H for all the constituents incorporated in the machine except μ_2. They are therefore, after converting g to P and H to fH, set on the machine for prediction by the normal procedure.

Inclusion of the effects of additional harmonic constituents.

In the Admiralty method of prediction only the four principal constituents are employed but the effects of a number of others are included by modifying the astronomical arguments and the amplitudes of the principal constituents. These modifications are based, not on the harmonic constants of those additional constituents as determined from analysis of observations but from the theoretical relationships of those minor constituents to the principal constituents. These theoretical relationships are true as a general average but may not be exact at any particular place.

A similar procedure can be adopted for modifying the astronomical arguments and the amplitudes of the constituents embodied in the portable machine, in order to allow for the effects of some of those constituents which are not included.

In the tables accompanying *Profesional Paper N° 3, Part V*, the modifications to certain constituents, for the effects of additional constituents, related to the moon's position in her orbit, are given in Table X. The constituent K_1 is modified for the effects of the constituents M_1 and J_1, the constituent O_1 for the effects of the constituent Q_1, the constituent M_2 for the effects of the constituents L_2 and $2\,N_2$ and the constituent M_4 for the effects of the constituent MN_4.

The modifications to certain constituents of the effects of additional constituents related to the sun's change of distance and declination are given in Table $Y\,1$. The constituent S_2 is modified for the effects of the constituent T_2 and the constituent MS_4 for the effects of the constituents MK_4 and MT_4.

The modifications to the constituent N_2 given in Table $Y\,2$ represent the effects of the constituent v_2.

The individual modifications referred to are small, but under certain astronomical conditions the aggregate may have quite an appreciable effect on the predictions.

The machine can be used also to facilitate prediction by the Admiralty Method, for it can be used to carry out the calculations of luni-hourly heights which are normally undertaken in Tables A and B of Admiralty Tidal Prediction Form *H. D.* 289 (*). If there are shallow water corrections given in Admiralty Tide Tables for the port, they must be applied to the uncorrected curve.

The luni-hourly heights predicted by machine will be more accurate than those calculated on Form *H. D.* 289 for the following reasons. In the Admiralty Method of Prediction the two semidiurnal constituents are combined into one component, according to their relationship at noon. In actual fact, their relationship is altering throughout the day and this changing relationship is accurately represented on the tide predicting machine. In the Admiralty Method the two diurnal constituents are also combined into one component, but they are more accurately represented on the machine as separate constituents.

(*) See : *International Hydrographic Review*, Vol. XXV, n° 2, Monaco, November 1948, p. 119.