# APPLICATION OF AUTOMATION
# IN THE STUDY AND PREDICTION OF TIDES
# AT THE FRENCH NAVAL HYDROGRAPHIC SERVICE

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The considerable development of the applications of electronic computations during the years following the war, and the appearance on the French market of powerful computers have urged the Naval Hydrographic Service to seek a solution, more reliable and less complicated, to the various problems allied to the study and prediction of tides.

Since 1954 electronic computation has been applied to the harmonic analysis of tidal observations, using the least square method.

From 1957 onwards the Service has devoted much time to making the production of the Tide Tables as automatic as possible, as this constitutes the basic work of the Tidal Computation Bureau.

Up to the present time the following advantages have been obtained :
— The actual calculation is now more rapid and more reliable.
— The result appears in tables showing times and heights of high and low waters in their final form (that is, as they appear in the Tide Tables) needing only to be reproduced on zinc by photoengraving for printing in offset.
— The detailed verification formerly necessitated by the use of typesetting has now disappeared : its character has been changed : the simplification is great.

However, at the present time, no modification of the conventional formulas of calculation for these tables has been made. The methods formerly used for manual computation have simply been transferred to the electronic computer. There could be no question of changing all at the same time, and without sufficient study, the theoretical data, the formulas, the method of computation, the manner of presentation and of printing the Tables without risk of delaying the date of issue and of eventually jeopardising the accuracy of the tidal predictions.

Experience has shown that this prudence was wise, for the development of the automatic computer to its present (1962) form has taken several years longer than expected.

For the future, however, as the way of automation is opening it is considered wise to plan cautious modifications to present methods of

analysis and prediction with the aim of improving the quality and the extent of the predictions given in the Tide Tables.

Moreover it is noted that various national hydrographic services have now entered the field of automation concerning tidal prediction.

For a number of years, Germany, for example, has handled certain problems of harmonic analysis through the use of the punched-card method. In the United States automatic recording of information furnished by the Tide Predictor has been achieved.

A Meeting held at the Headquarters of the Naval Hydrographic Service in Paris from 23 November to 2 December, 1961, by the Committee on Tides of the International Association of Physical Oceanography concerned itself in fact with the use of automatic computation in dealing with problems relating to tides.

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The Tide Tables published by the Naval Hydrographic Service are in two sections :

Volume  I :   French Ports
Volume II :   Foreign Ports [*]

The method of calculation differs from one volume to the other, but the presentation of the Tables is the same.

### I. — Publications for French Ports

All predictions are derived from the tidal conditions in Brest.

The times and heights of the tide in this port are obtained by using the formula of LAPLACE (1799) adapted for calculation by Ingénieur Hydrographe CHAZALLON (1839). This formula is sufficiently well-known to make it unnecessary to consider it in detail [**].

The formula is moreover relatively simple and its calculation by an electronic computer presented no particular problems.

It seems necessary, however, to emphasize the complexities shown in producing Volume I, for it is not limited to the " Brest Calculations " alone.

Once the predictions relative to this port have been obtained those of sixteen other ports of reference in the coastal regions of the English Channel and the Atlantic can be appropriately deduced by means of a method of correlation (Concordances). It is no longer a question of actual calculation but of reading four correlated tables empirically established between these sixteen ports and Brest : two of these tables concern the times and heights of High Water, and the remaining two the same data for Low Water.

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[*] Volume II is essentially concerned with the principal ports of French Overseas Hydrographic Surveys.
[**] See A. COURTIER (1934) : *Données numériques concernant les marées des Côtes de France* (Numerical data concerning the Tides of the French Coasts).

The book also furnishes tables of hourly predictions of the height of the tide at Le Havre which were formerly obtained by means of diagrams with the aid of a transparent template bearing characteristic tidal curves of various ranges. For the moment the electronic computer first works out the times and heights of High and Low Waters for Le Havre. It then uses the Table for finding the height of the tide between High and Low Water. (Publication No. 580 A [*] of the French Hydrographic Office, which contains data for Le Havre). This results in a cross-interpolation which gives better information than by the previous graphical method.

In 1964 the Tide Tables, Volume I, will also contain hourly height predictions for St. Malo. These will be calculated electronically from the numerical values given by the standard tidal curves for this port.

Lastly the computer produces the times and heights of High and Low Waters in their final table form thus obviating the necessity to re-copy. This is probably one of the *major contributions* of electronics in the production of Tide Tables.

This production is performed very accurately at a speed of 600 lines per minute, and is set out in a very suitable form, provided particular care is given to the choice of paper and the inking of the type on the tabulator. It is only necessary to superimpose on each table of figures a grill traced on a transparent film in order to obtain the final copy for the photoengraver, after making a slight reduction in size.

In short, the work of the computer begins with the interpolation of the astronomic elements at the times of the moon's transits, and it continues to the final tabulation of the predictions through the calculation of formulas, numerous settings, changes of time, harmonic calculations, application of the correlation method, computation of curves, etc.

A year's prediction concerning 17 ports is handled by a large machine manufactured by the I.B.M. Company in slightly under half an hour, which is a most satisfying economy in operation.

## Volume II. — Foreign Ports

A certain number of ports listed in this volume have a tide of a mixed type or one with a large diurnal inequality (for example those of the central Viet-Nam coast) so that computation by the use of harmonic analysis methods has been necessary from the beginning.

For a long time the matter for publication had been arrived at by processing the tidal curves obtained by the Tide Predictor. Then it became customary to read the information directly from the machine at the moment it appeared on the dials in order to avoid the actual plotting of the curves and their subsequent analysis.

[*] 580 A and B. *Table des hauteurs d'eau pour les côtes françaises de la Manche et de l'Atlantique* (Tables of Tidal Heights for French Coasts on the English Channel and the Atlantic).

télétype

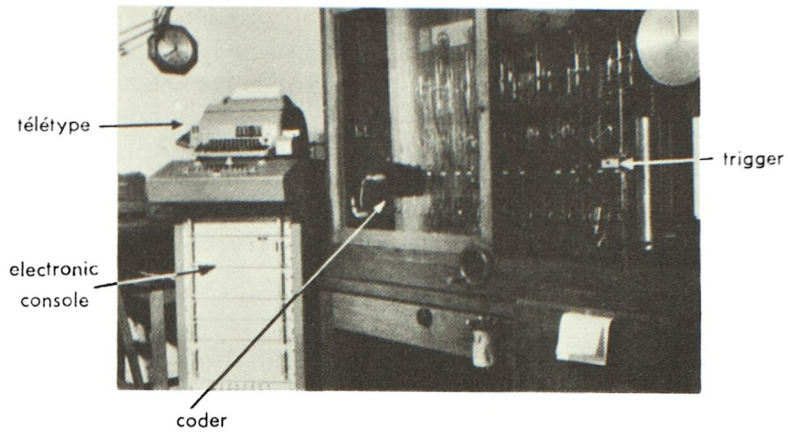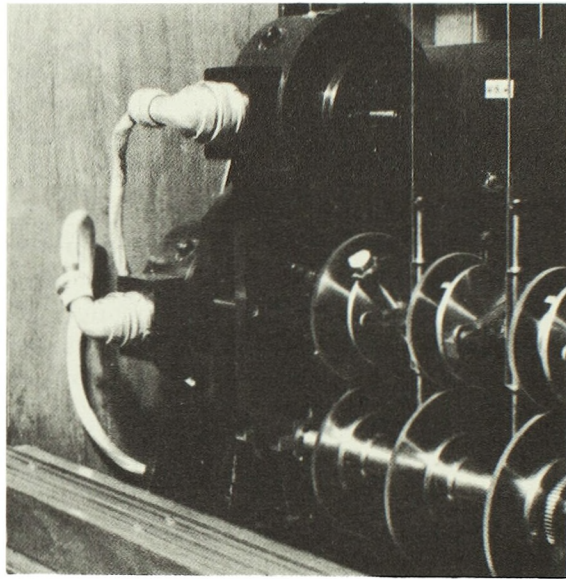electronic
console

trigger

coder

FIG. 1



FIG. 2

In fact, the operation was composed of two stages :

(a) A sampling of the times of High and Low Waters on the "derivative curve", when the recording stylus passed the average level of the curve, the instrument being stopped at each time of high and low water.

(b) The reading " in passage " of the height of the high waters, and the corresponding low waters, on the actual tidal curve, the instrument being in continual operation.

As the two volumes of the Tide Tables will henceforth be printed in offset by photoengraving on zinc it is necessary to type the Prediction Tables for the Foreign Ports in their final form, an operation which, with trained personnel, could be carried out during the operations (a) and (b) mentioned above.

To pass to the " automatic " production of Volume II, it would obviously have been attractive to proceed to a direct electronic computation, followed by a tabulation of the results. However this solution could not be considered owing to the relatively long time taken to make the computation necessary to determine the maximum and minimum values of the tidal curve. Actually the elegance with which Lord KELVIN resolved this problem on his Tide Predictor makes it easy to forget the real mathematical problem. Furthermore it proved practically impossible to render directly automatic both at the same time the readings of the hours and those of the heights on the Tide Predictor of the Hydrographic Service — an out-dated apparatus not designed for such a purpose. As a result it has been necessary to restrict the use of this apparatus to automatic readings of the times of high and low water by reference to the times when the derivative curve crosses the zero, and to obtaining by electronic computation the corresponding heights of the tide and in addition the tabulation of the predictions. The computation time of 4 heights a day per port is relatively negligible, as the production of the entire tables assumes only the computation of about 700 000 cosines.

The following are some details on the realization of automatic readings of the times of High and Low Water.

One complete rotation of the main shaft of the Tide Predictor corresponds to the interval of time of a mean day. Without too much difficulty it was possible to install a photo-electric counting device of moderate size at the end of this shaft, allowing at any moment electronic readings of the actual value of the angle of rotation of the shaft, in revolutions (days) and 1/1 000 of revolutions with an effective precision of 1/1 000 of a revolution, or ± 1.4 a minute.

The photo-electric counter is interrogated each time the recording stylus of the Tide Predictor covers a photo-electric cell, set opposite a punctual light source, at the average level of the derivative curve.

This photo-electric counter and " trigger " controls a tele-type machine by means of a comparatively small electronic device which receives and transforms the coded signals representing the times of high and low water.

On the writing surface of the tele-type machine can generally be read for each day 5 groups of 3 figures similar to the following :

254      002      252      510      758

The first group of three figures indicates the day; the others the times of the successive high and low waters in 1/1 000 of a day : that is to say in this case : —

00ʰ03ᵐ      06ʰ03ᵐ      12ʰ14ᵐ      18ʰ12ᵐ

On a punched tape the tele-typer apparatus also reproduces as it receives them the times, in 1/1 000 of a day, of the high and low waters in a special five-channel code, for which each figure is always represented by a combination of three punches. The punched tape allows the introduction of the data into an electronic computer which effects the calculation of the heights and gives the predictions in table form.
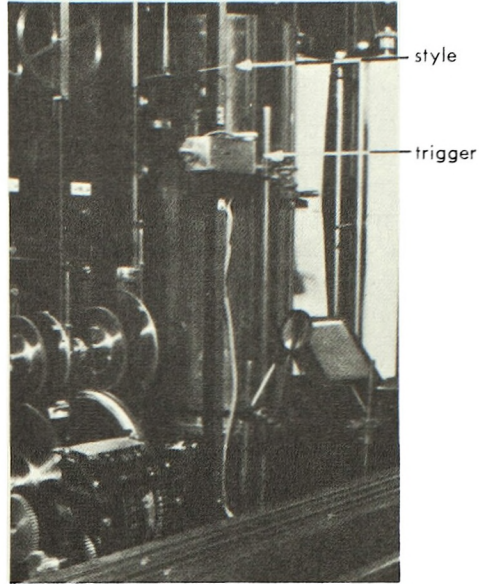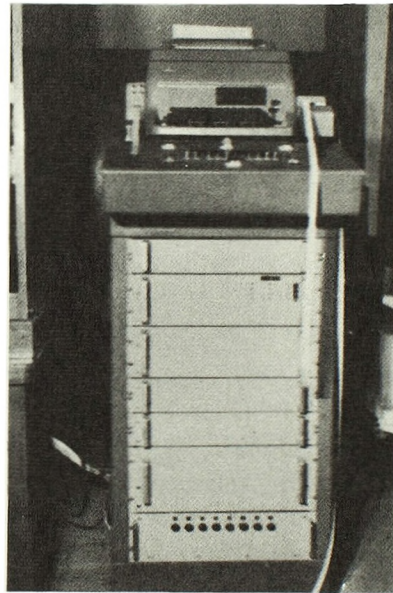
style

trigger

Fig. 3



Fig. 4

### New developments of the work of the Computation Bureau
### of the Tidal Section

The electronic Computer and associated Tabulator being practically immune to all functional errors simplifies to an enormous degree the various verifications incumbent on the Tidal Section.

It is, however, necessary to point out that at the present time the lightening of work has not become an actual fact but has remained
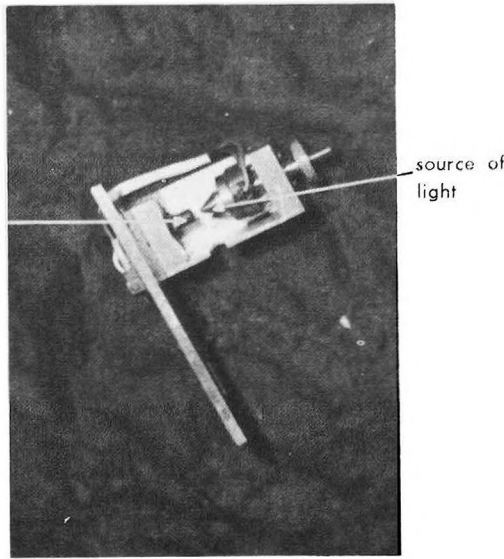
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FIG. 5

theoretical, for a considerable amount of the time has been required for checking the accuracy of the programmes of computation and tabulation.

Recently the tabulation programme had to be re-started following the adoption of chronological order in the predictions in the Tide Tables. Similarly, the construction and adjustment of the electronic equipment of the Tide Predictor by the Electronics and Automation Company of Courbevoie (Société d'Electronique et d'Automatisme de Courbevoie) have occupied a large amount of time.

Each year the Computation Bureau of the Tidal Section must proceed by various stages to the preparation of Tide Tables for three consecutive years. The problem becomes complicated if the method of production for these three years is not the same and this naturally occurred during the transition period of these changes.

In the future, as the various programmes become perfected, the advantages of electronic computation and the final tabulation of the results will become particularly noticeable and the gain of time will be considerable. It will then become possible to give positive thought to the improvement of the predictions themselves in a much more efficient way than in the past.

With this in mind it would be useful to revise the list of harmonic constants of many ports, by increasing their number and the accuracy of their determination, beginning with longer periods of accurate observations and a more elaborate method of harmonic analysis.

The aid of electronic computation will be equally important in this field of harmonic analysis of observations, whatever the method of obtaining them (the least square method, selective combinations of hourly heights, or the classic methods).

The Tidal Section has just taken delivery of an electronic computer of a moderate rate of calculation but highly accurate. Various developments concerning harmonic analysis are now in progress.

The improvement of predictions can be expected in future years to render the method of " concordances " by reference to the tides in Brest obsolete, at least for certain portions of the Atlantic or Channel coasts where its application is unsatisfactory as, for example, in the region between the Loire and the Gironde where the slack water curve is distorted owing to the presence of Over tides or Compound tides.

The prediction by means of harmonic analysis will doubtless necessitate the use of some shallow water constituents which do not exist on the Tide Predictor of the Hydrographic Service. It will probably be well to substitute a purely electronic computation for the analogical calculations of the Tide Predictor.

It still remains to be developed an electronic method of computation for finding the times of high and low waters through the derivative curve, and this constitutes the real problem to be solved for the direct calculation of maximum and minimum water levels. Research in this direction is being continued.

The presence at the Hydrographic Office itself of a computer capable of leading work of this nature to such good ends is full of promise.