NEW TIDE-PREDICTING MACHINES

Reproduced by kind permission of the Governing Committee of the Liverpool Observatory and Tidal Institute *from description given in the « Annual Report of the Institute » for the Year* 1950.

A principal activity during the year 1950 has been the supervision of the construction of the two tide-predicting machines referred to in the last Report. The 42-component machine for the Tidal Institute and the 30-component machine for the Coast and Geodetic Survey of the Republic of the Philippines were both completed at the end of December. These two machines have been constructed by Messrs. A. Légé and Co., of London, to the design of Dr. Doodson, who has closely supervised all details of construction. Both machines are to the same general design, differing only in the number and choice of components, so that the following description and photographs for the Tidal Institute machine apply in general to the Manila machine also. The construction of tide-predicting machines is continuing to be a major activity, for two other machines were in active preparation at the end of the year, a 30-component machine for the Hydrographic Department, Siam, and a 42-component machine for the Survey of India.

The general appearance of the Tidal Institute machine is shown by the photographs. It is completely enclosed in a steel case, with sliding glass doors back and front, designed to give easy access to the components. The doors have stainless steel frames and they slide in stainless steel frameworks. The machine is lit internally by fluorescent lights at the top and the bottom so that there are no shadows on the dials. The controls of the machine are on the left above a sliding desk with its upholstered side members. There is also a foot-control to the motor which runs the machine.

The 42 components chosen are as follows :

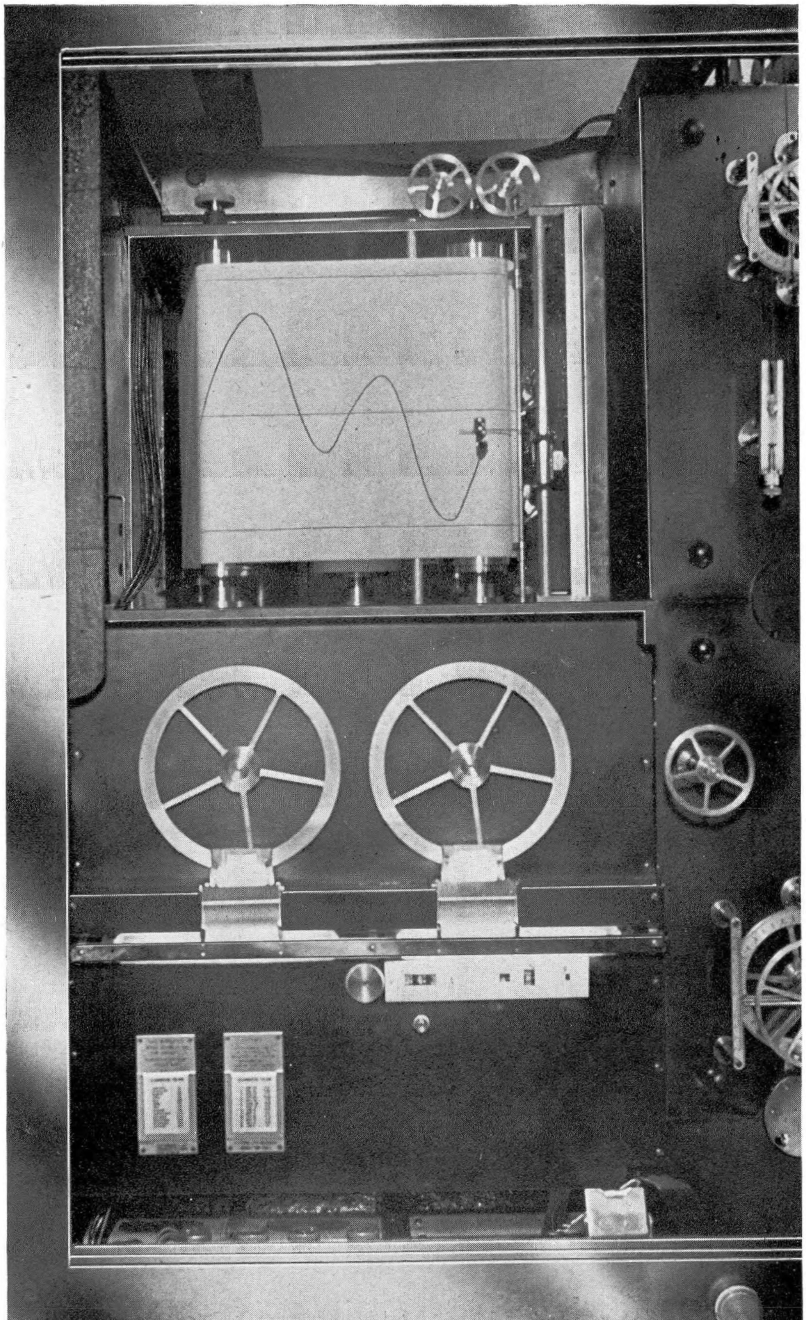
Top row : Sa, Ssa, Mm, MSf, Mf, M_4, MS_4, MN_4, S_4, MK_4, SN_4.
2nd row: M_{12}, M_{10}, M_8 M_6, $2MS_6$, $2MN_6$, $2MK_6$, $2SM_6$, MSN_6, MSK_6, $2SN_6$.
3rd row : M_2, S_2, N_2, K_2, ν_2, μ_2, L_2, T_2, $2N_2$, $2SM_2$.
Bottom row : K_1, O_1, P_1, Q_1, M_1, J_1, OO_1, S_1 MK_3, MO_3.

It may be noted that these are arranged in order of species (as indicated by the suffix) and in order of importance from left to right, which contrasts, with the somewhat erratic distribution in older machines. Very careful consideration was given to the choice of components in relation to the many types of problems of tidal prediction.Very special consideration was given to the problem of predicting tides in shallow water, but it may be noted that only one representative is given to each of the three higher species (M_8, M_{10}, M_{12}). It has been often stated by the Institute that if the eighth-diurnal constituents are important in shallow water then the tenth and twelfth diurnal ones (and even those of higher species) are likely to be nearly as important, and that in any case one representative of a species is quite insufficient to represent the tidal variations due to that species of tide. The three components referred to have been put on the machine for certain special purposes and they may be used with variations in amplitude and angle, made each day of tide by hand, when hourly heights are required. For the prediction of high and low waters the Institute will continue to use its special methods of correction and the needs of this method have been considered in choosing the constituents and in designing the machine in general.

By courtesy of the Liverpool Observatory and Tidal Institute

FIGURE I
The Doodson-Légé Tide Predicting Machine
General View

FIGURE I
Machine à prédire les marées Doodson-Légé
Vue générale



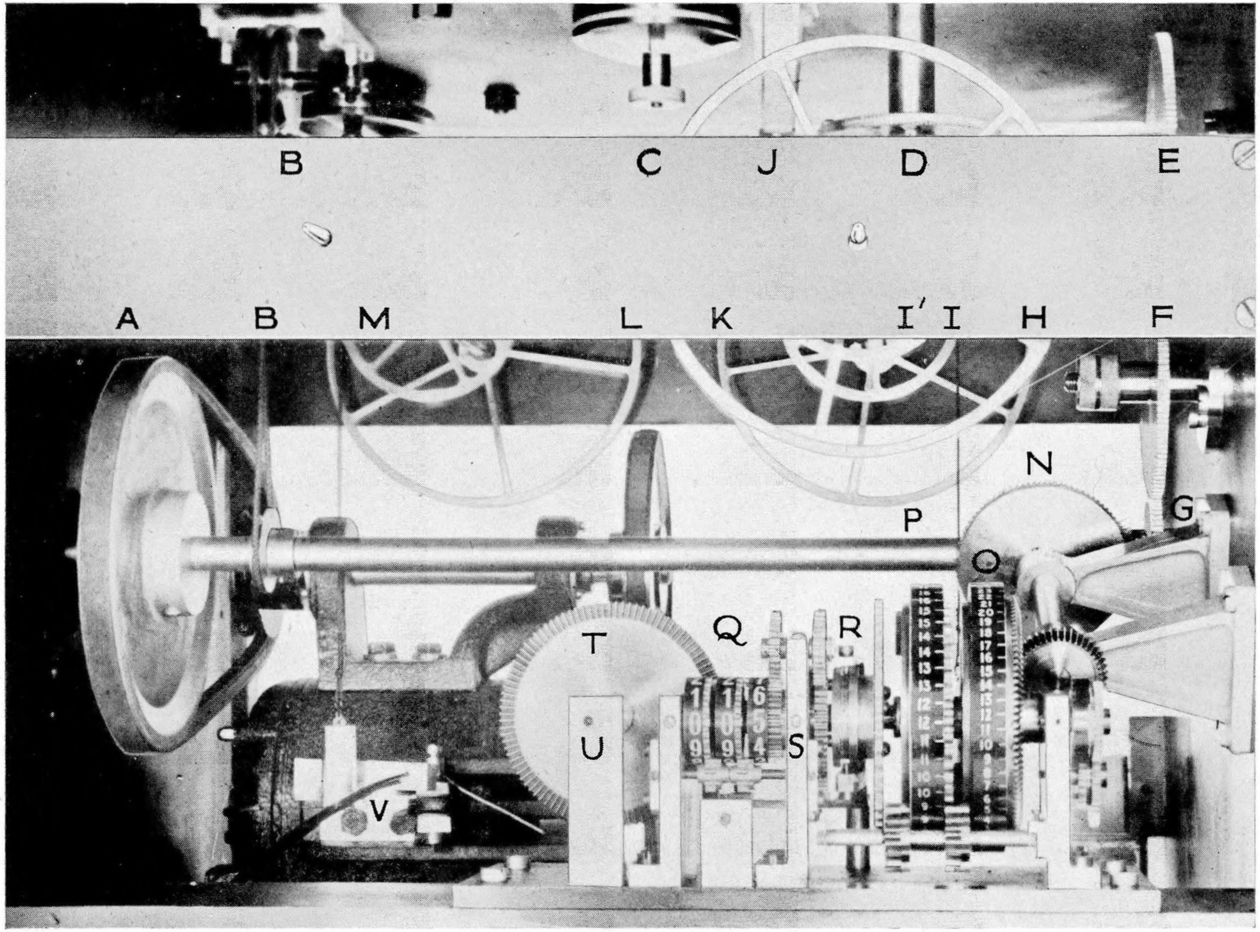
By courtesy of the Liverpool Observatory and Tidal Institute

FIGURE 2

General view of dials and chart

FIGURE 2

Vue générale des cadrans et de la feuille d'enregistrement



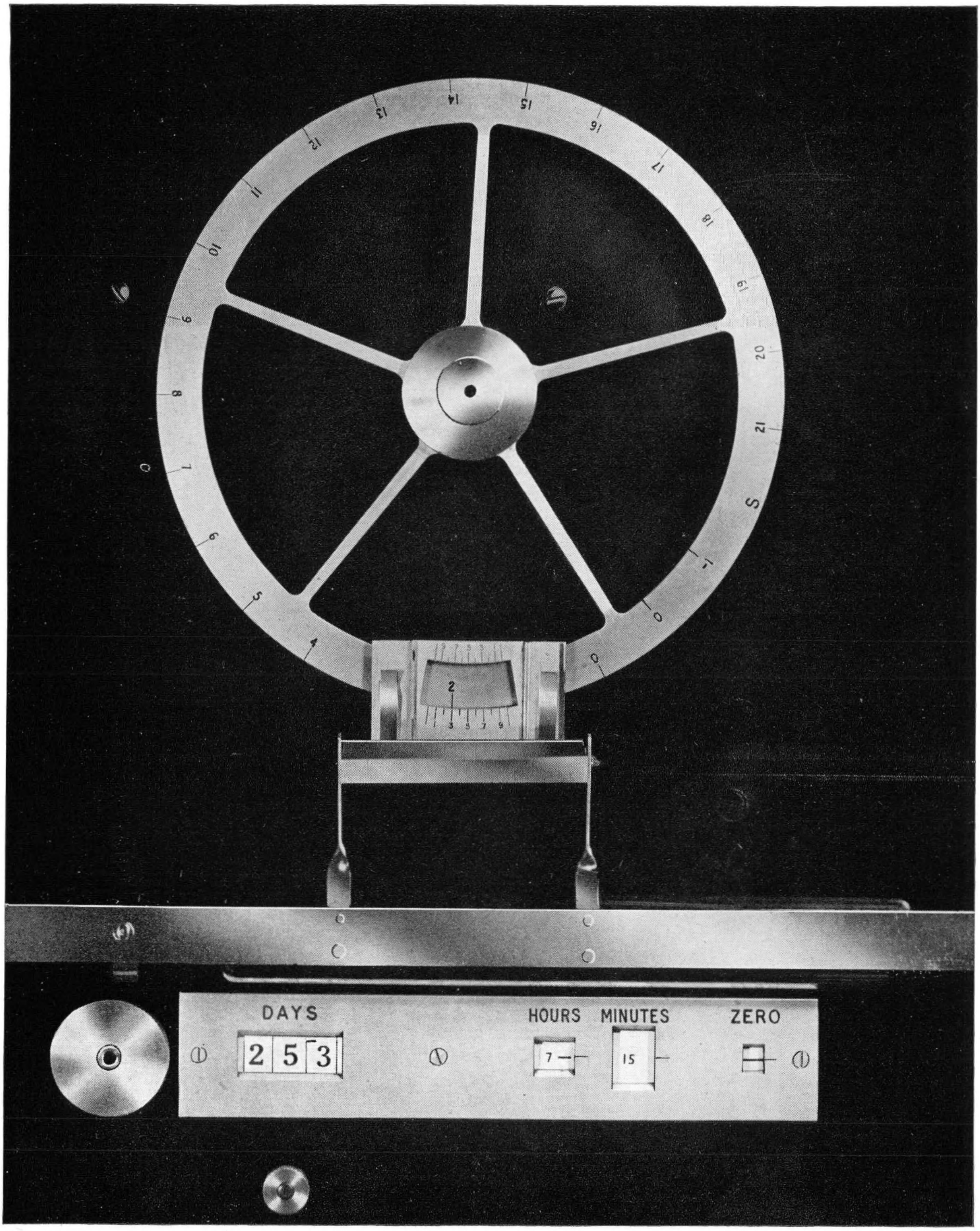
By courtesy of the Liverpool Observatory and Tidal Institute

FIGURE 3

Details of drives for machine dials, and chart

FIGURE 3

Détails du mécanisme d'entrainement des cadrans et de la feuille d'enregistrement



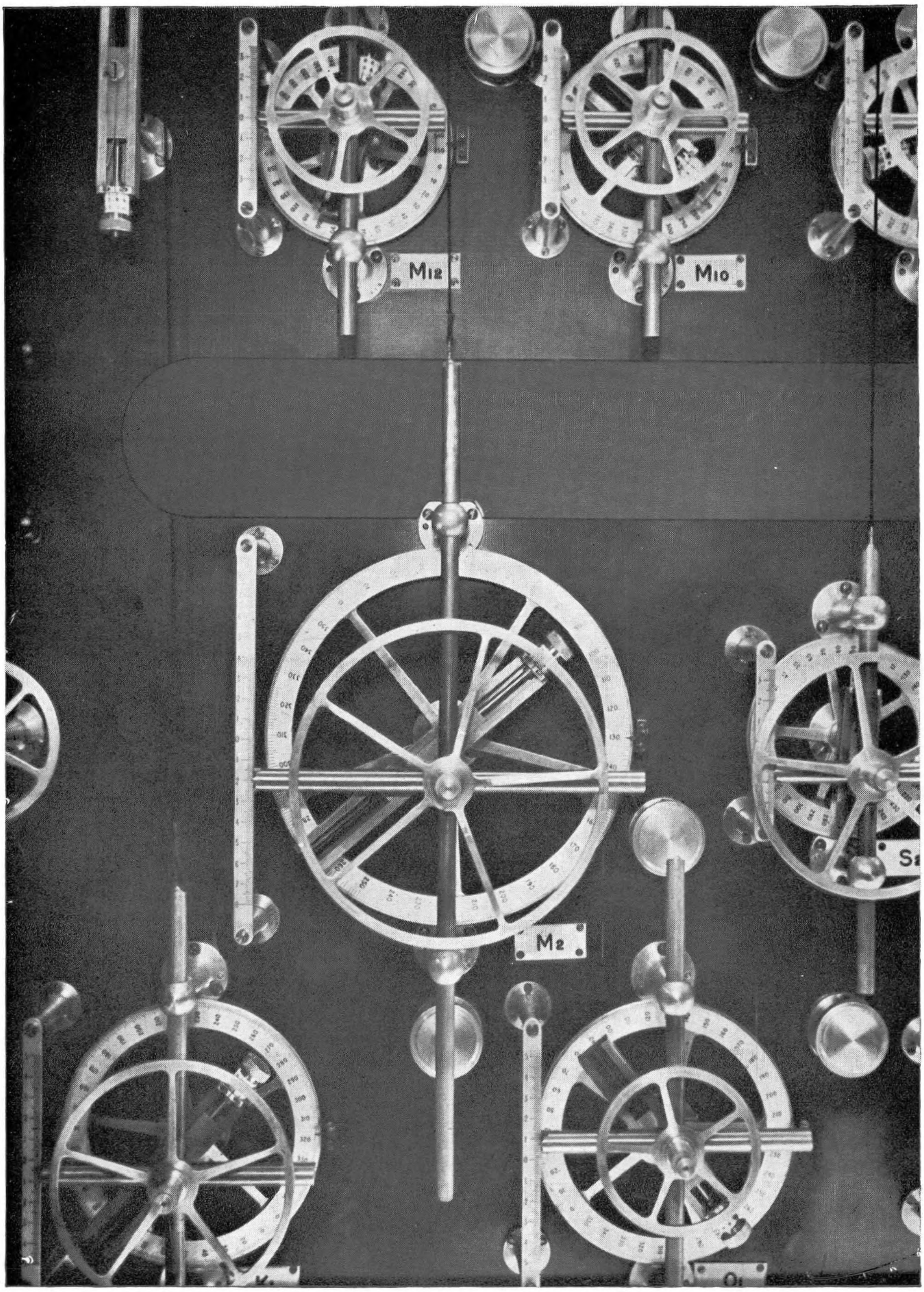
By courtesy of the Liverpool Observatory and Tidal Institute

FIGURE 4

Details of height-dial and day-dials

FIGURE 4

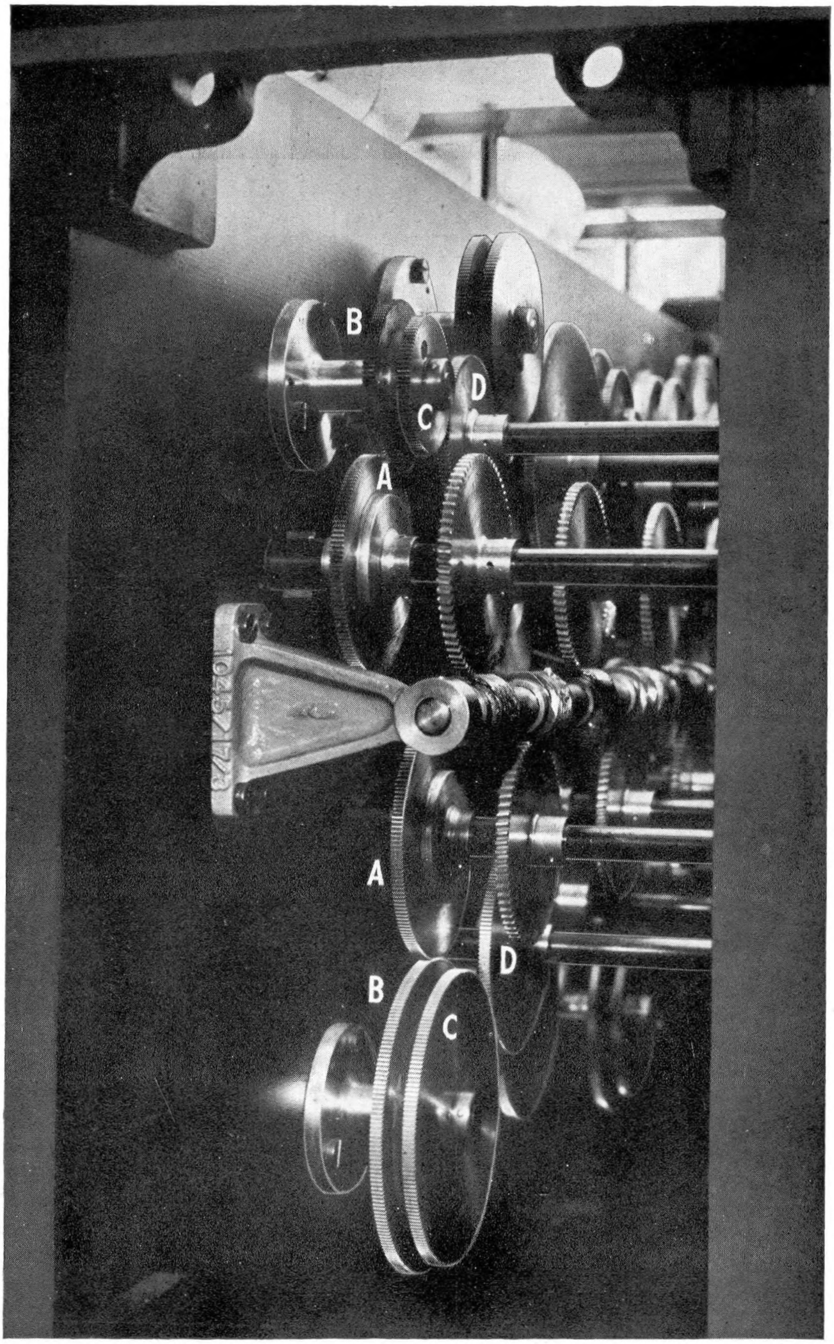
Détails du cadran pour les hauteurs
et des cadrans pour les jours



By courtesy of the Liverpool Observatory and Tidal Institute

FIGURE 5
Details of component

FIGURE 5
Détails des composantes



By courtesy of the Liverpool Observatory and Tidal Institute

FIGURE 6

Details of gears for driving component

FIGURE 6

Détails du mécanisme d'entraînement des composantes

THE DOODSON-LÉGÉ TIDE-PREDICTING MACHINE (42 COMPONENTS)

DESCRIPTION

The general appearance of the machine is shown in Figs. 1 and 2. Fig. 3 shows the recording part of the machine. Fig. 4 gives details of the drives in the motor-chamber behind the dials. A is the motor-driven belt-drive to the main shaft, from which there is a small belt-drive B upwards to the receiving drum for the chart. The friction control to the supply drum for the chart is shown at C. The pen drum is driven by the worm-wheel D through a worm on a shaft driven by the wheels drum is driven by the worm-wheel F can be released from meshing with E and G so that the pen-drum drive is freed from the machine drive. The height wheel H is driven by the wire shown below it on the right and on the same shaft are two wheels (I,I') of half the diameter of H, one of which (I,) carries the wire J upwards to the pen and the other (I) carries a cord for a counter-weight. On the same axle is also a wheel K similar to H and this is connected by a wire to a similar wheel L which drives the gradient-dial, and the wire is kept taut by a counter-weight on M. The minute dial (O) is driven from the main shaft at N, and from it is driven the hour-dial P and the day-dials Q. R is a sliding clutch which is operated by a lever-push at S and when the hour and minute dials are at zero the day dials can be released by this clutch sa that they can be returned rapidly to zero by the gear wheel T, operated by a knob on the shaft U. At V is seen the cable for the foot-control of the motor-clutch.

Fig. 5 shows in greater detail the outward appearance of the height-dial and the time-dials.The centre knob of the height-dial is a clutch so that when the amplitudes of the components are all at zero the dial can be rotated to indicate mean sea level and then be locked in position. To change the scale the knob is first removed. The subsidiary scale indicates decimals of a division and it can be removed by sliding upwards in the slot against the springs. There are several scales graduated -2 to 45, -1 to 21, -20 to 100 (or -2 to 10) for predictions of heights of tide, and -11 to 11, -60 to 60 for predictions of streams or harmonic shallow water corrections. Beneath the height-dial are the time-dials already described in Fig. 4. To operate the clutch for the day-dials the small knob below the day-dials is pushed in, and then the larger knob to the left is rotated.

Fig. 6 shows the details of the component for the principal constituent M_2. The clutch for it is to the right of the angle-dial, just above the vertical member of the cross-head for O_1. The clutch for K_1 is directly beneath the component for M_2, and that for O_1 beneath the component for S_2.

Fig. 7 shows the arrangement of the gear wheels driving the components for the upper rows of components. The first worm on the main shaft drives the worm-wheel immediately above it and on the same shaft is clearly seen the gear wheel A with its clutch. Immediately above this are the two associated wheels B and C on the stub axle, B being driven by A, and C driving D which is on the first of the top row of shafts. The second worm drives the end gear-wheels seen below the main shaft.

As compared with the old type of Légé machine possessed by the Institute, the most obvious change is that the angle dials are now on the front of the machine behind the amplitude blocks. This is a very great convenience as on the old machine the amplitudes had to be set on the front of the machine and the angles at the back. This was necessary, for the cone-clutches which connected the components to the gears, and which needed to be de-clutched when setting the angles, required the operator to pass his hand into the space between the two main plates. In the new machine the clutch is operated from the front of the machine, so that all controls are now readily accessible. The components are built up on four panels instead of the large panel previously adopted. This facilitates machining.

A special feature of the design, made possible by the alterations described above, is that it is now possible, if so desired, to place a complete set of amplitude units, with pulleys and wire, at the back of the machine. These can be attached to the component spindles and would be set at right angles to the front amplitude units so that the rear ones could be used to give the gradient (which is used for the determination of times, the gradient being zero at high or low water) while the front ones give the heights of high and low water. One advantage would be that times and heights would be run off together whereas when the machine has only the front units it has to be run once for times and a second time for heights. If so desired, however, the rear units can be added at any time, and since provision is made for this in the design it follows that any authorities who wish to have this fixture, and are prepared to pay for the extra cost, can have it without any modification of design.

The indicating and recording parts of the machine are just above the reading desk and there are two dials, the left-hand one for use with the gradient, whether obtained from the front or rear units, and the right-hand one for heights. The normal procedure is to stop the machine when the gradient is zero, and to read the time-dials which give the number of the day of the year, the hour, and the minute, by direct readings. This zero-position is atteined exactly, after stopping the machine, by a slight movement of the hand-wheel on the extreme left of the machine.

Both indicating dials can be changed very quickly according to the range of tide and the desired scale of indication. A single knob is removed and the old dial is then replaced by the new dial and locked into position by the screw. The dials are not graduated in decimals but at the bottom of the dial is a subsidiary scale which gives direct readings of the decimal values against the line for the unit values on the rotating dial. This follows the Institute's practice that the operator has not to follow a moving pointer on a fixed scale but maintains a steady look at a fixed position ; it is easier to read against a subsidiary scale for sub-divisions than to read finely divided divisions against a fixed mark. Another feature is that negative values are read off on a different radius from that of the positive values, and the marks are coloured red instead of black. The subsidiary scales slide in grooves for insertion and removal.

A graphical record can be obtained on half the main scale, but as the pens used are very fine there is no loss of accuracy. The effective width of the paper between the needle points is 25 cms., and the time scale is one cm. per hour. The drums are all very easily removable by pulling out the short top axles. The recording pen is a Uno-pen attached to a stiff wire which drops into a sloping tube so that the pen swings under a reduced gravitational force. The tube is mounted on a block which slides up and down a stainless steel rod. This carriage is a Légé design used in their recently designed tide-gauge, and it is very sensitive yet free from slackness. The datum-pens are also Uno-pens on the same principle as the recording pen and they can be moved up and down by screws, one turn per millimetre, so that very accurate setting is easily made.

The pen-drum is driven by gearing inside the space behind the indicating dials, and access to this space is obtained through a steel door at the rear of it. To disengage the drum it is only necessary to slide a gear wheel out of mesh. The adjustment for zero time on the drum is made by means of this detachable gear wheel with great ease and exactness. The paper is drawn round the pen-drum by needle points and the supply drum is controlled by a friction disc and spring. The storing drum for the used paper is driven by a belt from the main drive and there is a controllable provision by means of a friction disc and spring for the changing width of the roll. Access to the chart and drums is obtained through a door at the side, as well as from the front and rear.

A very important part of the design is that of the gears. The main driving shaft from the motor-chamber, behind the dials, drives from it a parallel shaft so that all the components except five are driven from one or other of these two starts, the exceptions being the five long-period components Sa to Mf, which are driven by a short subsidiary shaft by means of a worm. Each component is driven by means of a worm and worm-wheel ; some worms have one start, others two shafts, and some have three starts. The worm-wheels all have the same number of teeth. On the same shaft as the worm-wheel is the clutch, operated by the screw on the front plate. This operates the clutch by a tube on the axle, a pin in a slot in the axle, a rod in the axle itself, and the screw on the front face of the machine. The clutch affects gear A, and gear D is on the axle of the component itself. These two gear-wheels are connected together through gear-wheels B and C pinned together on a short stub-axle. Hence the speed of the components is proportional to (W × A × C) / (B × D), where A, B, C, D, give the number of teeth in each wheel and W is the number of starts in the worm. The positions of the various wheels can be adjusted so that no two components interfere with one another, but it is necessary also to ensure this by carefully choosing the values of A, B, C, D.

The computation of A, B, C, and D is a matter of great importance, as the choice is limited by considerations of space and ease of cutting of the teeth as well as by the accuracy of the speed. It was decided to limit the error of angle, after running the machine for a year of machine time, or about 9,000 hours, to $0^\circ.05$. For a semidiurnal component, with speed about 30° per hour, this involves an accuracy of one part in five millions, and for higher species of tide an even greater accuracy. The ordinary methods of computing gear ratios are useless for this class of work. The procedure adopted was to fix a limit of about 30,000 for A × C and B × D and to compute every possible ratio with errors less than that stated, and as a rule about 100 ratios per component were evaluated by a very rapid process. Then the numerators and denominators were factorized. In most cases, of course, very large prime numbers appeared and these cases had to be ruled out for mechanical reasons. As a rule some five or ten possibilities were left and a choice was made of these according to other considerations. Thus about 5,000 gear ratios were computed and factorized for this purpose.

The workmanship of the machine is excellent and Messrs. A. Légé and Co. have produced a mechanism which is very creditable to them. Thanks are due to the staff of the Dockyard at Birkenhead who prepared the strong concrete bed for the machine.