National
Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

National Oceanography Centre

Research & Consultancy Report No. 56

An inventory of tide prediction machines

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2016

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DOCUMENT DATA SHEET

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PUBLICATION DATE
2016

TITLE
An inventory of tide prediction machines.

REFERENCE
Southampton, UK: National Oceanography Centre, 71pp.
(National Oceanography Centre Research and Consultancy Report, No. 56)

ABSTRACT

This report provides an update to two 'inventories' made many years ago of tide prediction machines (or 'Kelvin machines'). It provides a list of all the machines that were made between the late-19th and mid-20th centuries, up until the 1960s when the advent of digital computers in tide table production made these remarkable analogue computers redundant. Photographs and brief descriptions of each machine are given. It will be seen that most of the machines still exist, and many are displayed in museums around the world, where they can be inspected by people interested in the history of tidal science.

KEYWORDS:

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An Inventory of Tide Prediction Machines

Introduction

Tide Prediction Machines (TPMs) were analogue computers that simulated the rise and fall of the ocean tide as a sum of sinusoidal motions of a number of individual tidal components (or 'constituents'). Each constituent had a particular angular speed (ω), amplitude (h) and phase (g). The values of h and g were 'programmed' into the settings of wheels on the machine, with each wheel rotating at a rate proportional to the angular speed of the constituent, and the tape (or 'band', usually made of nickel) wrapping around the pulleys attached by vertical rods to the horizontal channels on each wheel, serving to sum up all the constituents as shown below.

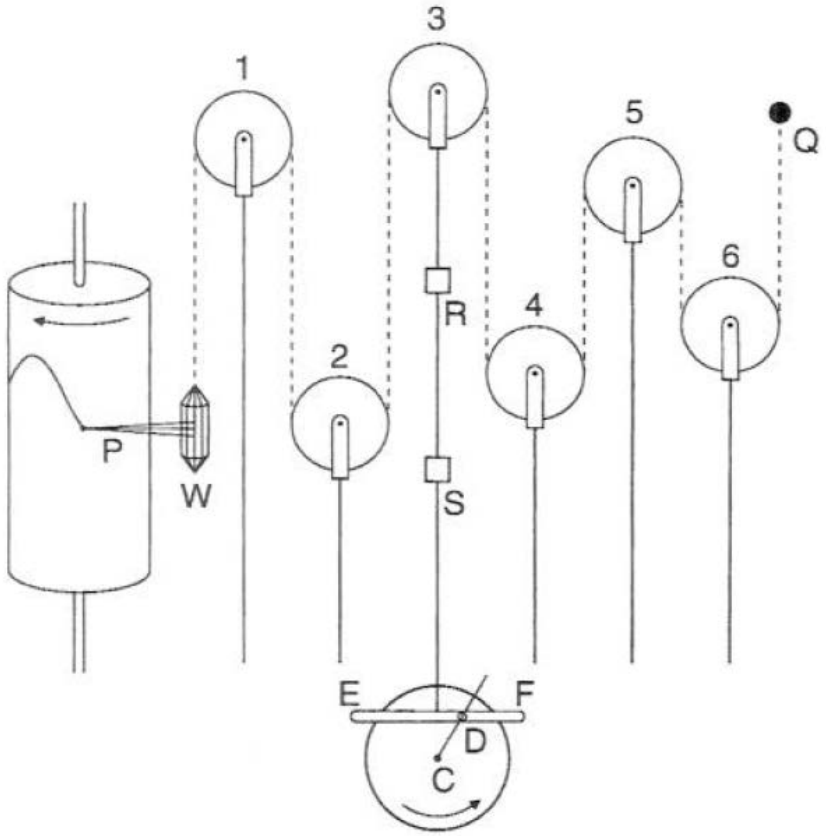

Figure from Cartwright (1999) showing the circular motion of a wheel (representing one constituent) with centre at C and a radial arm with a knob at D that slides along a channel EF. The channel is fixed to the end of a vertical rod RS, so the circular motion of D is converted into a vertical sinusoidal motion of RS and of pulley 3 with an amplitude CD. This motion causes the end of the band at W to be pulled up or down by twice the vertical motion of pulley 3. Contributions to W also occur for all the other wheels (for the other constituents). So the band, the other end of which is fixed at Q, serves to sum up the contributions from each wheel and plot the total at P. This is highly schematic, but while each machine had different mechanical design the principle was the same.

In other words, the machines attempted to calculate the total tide h_{total} at time t as follows:

$$h_{total}(t) = \sum_{1}^{N} h_i \cos(\omega_i t - g_i)$$

where h_i, g_i and ω_i are the amplitude, phase and angular speed of constituent i, and $\omega_i = \frac{2\pi}{T_i}$ with T_i its period. The periods T_i correspond to the main lunar and solar frequencies which contribute to the tide. Most of them have values around either 12 or 24 hours (semi-diurnal and diurnal tides), some have smaller values (shallow-water tides) and a few have values up to a year (the long-period-tides). The two largest constituents in many parts of the world are called M2 , with a period of 12 h 24 min (the main semi-diurnal tide from the Moon with a period of half a lunar day), and S2 , with a period of 12 h (the main semi-diurnal tide from the Sun with a period of half a solar day). The total number of constituents used by a particular machine will vary from 2 (for the Kelvin prototype called TPM-KP2 below) to 62 (for the machine called TPM-S16 below).

An interesting question at this point is where the amplitudes and phases used by the machines came from in the first place. The answer is that they came from analysis of existing sets of measurements by tide gauges at ports around the world. A separate note is available on how tidal analysts such as Arthur Doodson derived these parameters (called 'harmonic constants') in the years before digital computers came along.

The Inventory

The intention here is not to give a description of the ocean tide (there are text books available for that e.g. Pugh and Woodworth, 2014), nor the history of tidal research (e.g. Cartwright, 1999), nor even to discuss TPMs in great detail (Cartwright, 1999 gives a general explanation; chapter 9 of Hughes, 2005 contains a good history of the machines and of the individuals involved). Our objective is simply to update the two inventories that have been made previously, and to give a little background to each machine, and add some information on where these interesting machines, that were made redundant with the advent of digital computers, might now be found.

Only about 30 TPMs were ever made (apart from prototypes) but most survive in museums located around the world. While they all worked according the same principle of summing components to obtain the total tide as described above, the mechanical design that went into the construction of each machine is very different, and in some cases is very difficult to now understand; it is rather like having to understand how complicated watches made a century ago once worked.

The first inventory of TPMs was made by the International Hydrographic Bureau in 1926 (IHB, 1926). This was a collection of sets of information provided by the machine owners at the time. A second inventory was made by Günther Sager, a distinguished German oceanographer (Wikipedia, 2015). Sager published several books and his "Gezeitenvoraussagen und Gezeitenrechenmaschinen" published in 1955 contains a Chapter 3 listing the TPMs that he knew about and gives some technical details of each one. It is known that Sager corresponded with Bidston Observatory (the then Liverpool Observatory and Tidal Institute, LOTI) and received help in the compilation of the machines by its Director, the eminent tidal scientist and expert on TPMs, Arthur Doodson.

Sager's list contains 25 entries. He did not include the prototype machines of Kelvin, presumably because they were never used for operational tidal predictions. In addition, there were a couple of omissions such as the Australian TPMs. His book was published in 1955, just as the production of the machines was coming to an end, but there were still at least three to come along (the Japan, Indonesia and Burma Doodson-Légé machines TPM-X3, X4 and X5). In addition, he did not include the smaller portable TPMs that were developed for military and hydrographic surveying purposes; we have listed the portable machines we know about, although there may be some we have missed, and as far as we know they were not a great success and so never became as well-known as the larger machines.

Consequently, our inventory is only slightly larger than Sager's. For each one, we show photographs and provide some brief information, some of which is based on IHB (1926) and/or Sager (1955). The information starts with the manufacturer's name and date of manufacture, and date of refurbishment up to the time of Sager's book. Sometimes, when a machine was refurbished, extra constituents were added. For example, the 20 (24) constituents shown for TPM-S2 indicates that 4 extra constituents were added in the refurbishment in 1891.

We give each machine a code number such as TPM-S20, indicating that the machine was number 20 in Table 2 of Sager (1955); TPM-KP1, indicating Kelvin's first prototype; TPM-X1, indicating a machine that was not in Sager's 1955 inventory; or PTPM-1, indicating the first Portable Tide Prediction Machine. A summary of the machines is given in the present Table 1.

Although, as mentioned above, it is not our intention (or capability) to provide many technical details of these machines, it is worth pointing out that most of them can be listed under a small number of headings, with each list corresponding to a particular manufacturer with its own machine architecture. The invention of the TPM is usually credited to Sir William Thomson (Lord Kelvin) and all TPMs are sometimes called 'Kelvin machines'.[1] However, a heading of 'Kelvin type' applies to the set of machines made mostly in Glasgow (also in London and Basingstoke) by companies that were associated with Kelvin or, after his death, continued to carry his name. These 'Lord Kelvin Tide Predictors' are referred to further in Table 2.

A heading of 'Légé type' or 'Roberts-Légé type' or 'Doodson-Légé type' applies to the later machines, designed or supervised by Edward Roberts or Arthur Doodson, and manufactured by the London company of Alexander Légé who made an extensive range of different scientific equipment over many years. The two architectures are quite different and they both retained their distinctive styles for over a century. The 'Légé type' machines tended to be more solid in construction, with moving parts for the harmonic motion made in steel instead of brass, and therefore more expensive.

Although there were important TPMs constructed in Germany and the USA, the majority were designed and manufactured in the UK. Of the 33 machines in Table 1(a), 25 of them were made in either London, Glasgow or Liverpool. In addition, the UK was the only country to export TPMs to other countries. The construction of the majority of the machines made after 1920 was supervised, one way or other, by Arthur Doodson. Therefore, it is not surprising, given the small number of

[1] The idea for TPMs was clearly not Kelvin's alone. For example, Rev. Francis Bashforth explained in 1881 ('Tide-predicting machines', Nature, 24, 53) how he had had an idea for a 4-component machine in 1845 (IHB, 1926; Hughes, 2005).

expert machine makers involved in this subject and the passage of time, that it is sometimes difficult to understand the many nuances involved in the construction and operation of these machines.

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Acknowledgements

I am grateful to Dr. Paul Hughes, formerly of Liverpool John Moores University, for many discussions about the history of tidal science in general and TPMs in particular. Dr. Nicolas Pouvreau of SHOM provided a lot of advice on the machines in France. Prof. Mauro Andrade de Sousa of the National Observatory in Rio was a great help in tracking down the machines in Brazil. The compilation of this inventory came about through collaboration between Steve Newman, Alan Bowden and others at National Museums Liverpool, Julie Ledder and other at the National Oceanography Centre (NOC) in Liverpool, and Valerie Doodson, Sylvia Asquith, Ian Vassie and others, all former employees of NOC, during the refurbishment in 2015 of two of the TPMs formerly owned by NOC and now owned by the National Museums Liverpool.

Table 1: (a) Inventory of Tide Prediction Machines

Sager No.	Extra No.	Kelvin Prototype No.	Name	Year Made	Country Made	Manufacturer	No. Constituents	Country Now
		TPM-KP1	Kelvin Model made for the BAAS	1872	UK	Messrs. White	8	UK
		TPM-KP2	Kelvin 2-Component Machine	1873	UK	L	2	UK
	TPM-X1		Koenings' 4-Component Machine	??	France	??	4	??
1			Kelvin's First TPM	1873	UK	L	10	UK
2			India Office Machine	1879	UK	L	24	India
3			British TPM No.3	1881	UK	KW	16	France
4			US C&GS No. 1	1882	USA	Fauth & Co.	19	USA
	TPM-X2		Australian TPM		Australia	A.Inglis	16	??
5			Roberts-Légé Machine	1906-1908	UK	L	40	UK
6			US C&GS No. 2	1894-1910	USA	US C&GS	37	USA
7			British TPM No. 4	1909	UK	KW	12	Brazil
8			Japan Kelvin Machine No. 1	1914	UK	KBB	15	-
9			German TPM No. 1	1915-16	Germany	Toepfer & Sohn	20	Germany
10			Argentina TPM No. 1	1918	UK	KBB	16	Argentina
11			Japan Kelvin Machine No. 2	1924	UK	KBB	15	Japan
12			Japan Kelvin Machine No. 3	1924	UK	KBB	15	Japan
13			Lisbon Machine	1924	UK	KBB	16	Portugal
14			Bidston Kelvin Machine	1924	UK	KBB	29	France
15			Brazil Kelvin Machine	1927	UK	KBB	23	Brazil
16			German TPM No. 2	1935-39	Germany	Aude und Reipert	62	Germany
17			Russia Doodson-Légé Machine	1945	UK	L	40	-
18			Norway Kelvin Machine	1947	UK	Chadburns	30	Norway

19			Madrid Kelvin Machine	1948	UK	KH	16	Spain
20			Bidston Doodson-Légé Machine	1950	UK	L	42	UK
21			Manila Doodson-Légé Machine	1950	UK	L	30	Philippines
22			India Doodson-Légé Machine	1951	UK	L	42	India
23			Siam Doodson-Légé Machine	1951	UK	L	30	Thailand
24			Argentina Doodson-Légé Machine	1952	UK	L	42	Argentina
25			German TPM No. 3	1952-55	VEB Karl-Marx-Werk	Germany	34	Germany
	TPM-X3		Japan Doodson-Légé Machine	1956	UK	L		Japan
	TPM-X4		Kobe Machine		Japan	?		?
	TPM-X5		Indonesia Doodson-Légé Machine	~1963	UK	L	30	?
	TPM-X6		Burma Doodson-Légé Machine	~1964	UK	L	42	Myanmar

Manufacturers: L = Alexander Légé & Co., KW = Kelvin and White, Glasgow, KBB = Kelvin, Bottomley and Baird, Glasgow, KH = Kelvin and Hughes, Glasgow.

(b) Inventory of Portable Tide Prediction Machines

Portable No.	Name	Year Made	Country Made	Manufacturer	No. Constituents	Number Made
PTPM-1	German Navy PTPM	Approx. 1940	Germany	Aude und Reipert	10	About 20
PTPM-2	British Copies	Approx. 1947	UK	Marine Instruments Ltd.	10	Unknown
PTPM-3	Doodson-Légé PTPM	Approx. 1956	UK	L	12	At least 12

Table 2: Lord Kelvin Tide Predictors

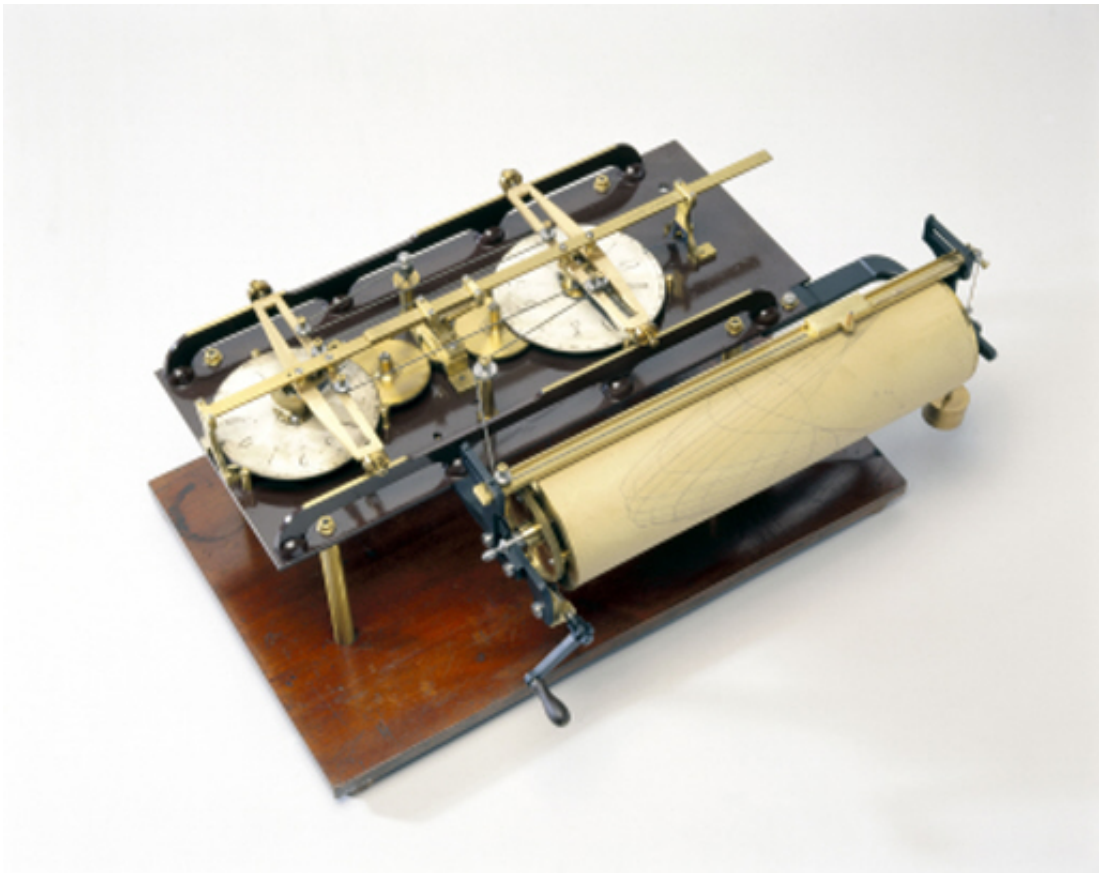
The machines made by the Kelvin companies carried plaques that gave the machine a 'Lord Kelvin Tide Predictor' number. This table provides a list of these machines.

Sager No.	Lord Kelvin Tide Predictor No.	Name	Comments
3	1?	British TPM No.3	Now in France. Needs a good photo of the plaque to confirm.
7	2?	British TPM No. 4	Now in Brazil. Plaque does not give a number.
8	3	Japan Kelvin Machine No. 1	Machine destroyed.
10	4	Argentina TPM No. 1	Plaque missing from the machine but almost certainly 'No.4'.
11	7	Japan Kelvin Machine No. 2	Photo of plaque available.
12	8	Japan Kelvin Machine No. 3	Photo of plaque available.
13	5	Lisbon Machine	Photo of plaque available.
14	6	Bidston Kelvin Machine	Now in France. Photo of plaque available.
15	9	Brazil Kelvin Machine	Photo of plaque available.
18	10	Norway Kelvin Machine	We assume this counted as 'Lord Kelvin Tide Predictor No.10', so that the Madrid machine was later considered by KBB as 'No.11'. The Norway machine was made by Chadburns and not KBB and does not have a plaque. But there is no other candidate for No.10.
19	11	Madrid Kelvin Machine	

TPM-KP1 Kelvin's First Prototype

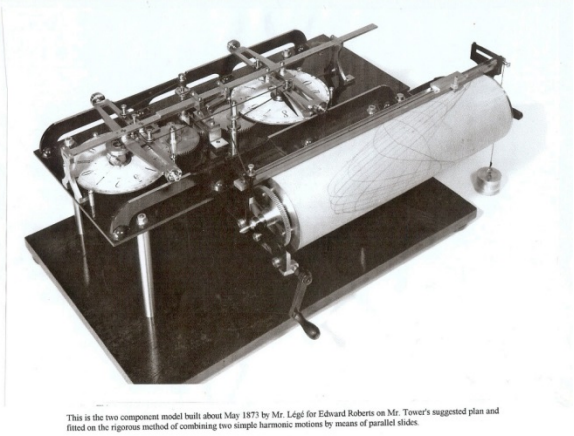
Kelvin's 8-component wooden-frame model of a tide predicting machine from 1872. This demonstration model, made by Messrs. White in Glasgow, was shown to the British Association to obtain funds for constructing a full-scale tide predictor. First, the tides at a particular port were observed using a tide gauge over an extended period of time. The motion was then analysed into simple components. The tide predictor would then be set by adjusting the pulley positions to imitate those components, and the resulting motion would predict the tides. [Adapted from the Science Museum web site].

TPM-KP2 Kelvin’s 2-Component Second Prototype



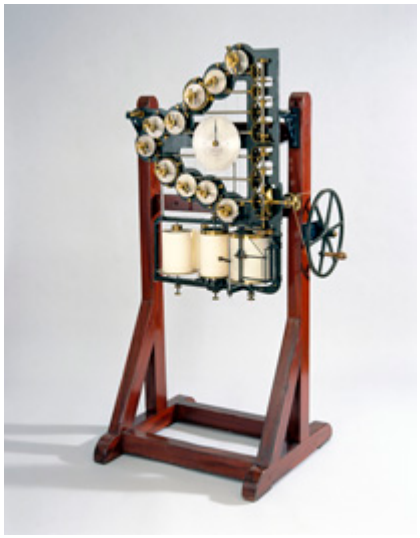
Kelvin's second tide predictor from 1873 made shortly before TPM-S1. The machine was designed by Roberts and made by Alexander Légé. It is only 10 inches across. The two dials seen on the machine are set from knowledge of the tide in a particular harbour. On cranking the handle, the machine calculates the harbour’s tide for up to a year in only four hours. [Adapted from the Science Museum web site. It is presently not on display at the Science Museum.]

Hughes (2005) states there was another 2-component model made by Roberts, at Kelvin’s suggestion, with the 2 components aligned vertically. This machine has not survived.



Photograph of the 2-component model provided by Mr. Gordon Roberts (great grandson of Edward Roberts).

TPM-S1: Kelvin's First Machine (British Tide Predictor No.1)



Left photograph from http://en.wikipedia.org/wiki/Tide-predicting_machine (A Wikimedia Commons image) and right photograph from the Science Museum web site.

Manufactured By: Alexander Légé and Co., London
Manufacture Date: 1873
Architecture Type: Unique
Refurbishment Dates (According to Sager): None
Refurbished Since Sager: None
Number of Constituents Simulated: 10
Features (According to Sager): Graphical recorder.
Original Operation Location: South Kensington Museum
Present Owner: Science Museum, South Kensington, London (2015)
Present Location: Science Museum, South Kensington, London
Present Working Condition: The machine is in a good general condition but not known if in working condition.
On Display to Public: Yes
Web Sites:
Notes:
This was the first operational TPM and was constructed by A. Légé and Co. to a design by Kelvin (Thomson). Expenses were covered by the British Association for the Advancement of Science

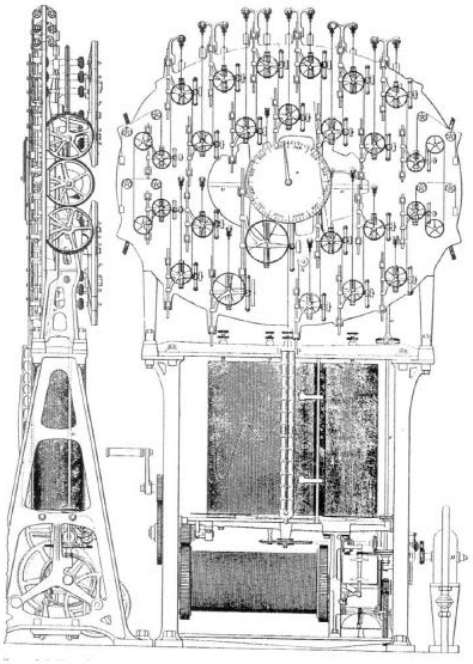
(BAAS) so the machine is sometimes called the British Association Machine. The basic design was Kelvin's but the gear ratios which determine the speeds of the constituents were worked out by Edward Roberts and the construction was supervised by him. The motions of the pulley axles had horizontal as well as vertical motions, which introduced small errors and all later machines had strictly vertical motions (Cartwright, 1999).

The accompanying plaque at the Science Museum says: "This, the first full sized machine for predicting tides, combined ten tidal components (one pulley for each component). It could trace the heights of the tides for one year in about four hours." The machine is described in an Evening Lecture by Lord Kelvin to the British Association at the Southampton Meeting, Friday, August 25th, 1882 (http://www.bartleby.com/30/16.html).

The 10 components were M2, S2, N2, K2, Q1, K1, L2, P1, M4 and MS4.

According to Schoffield (2006), an improved version was made by Kelvin a few years later(?).

TPM-S2: India Office Kelvin Machine (British Tide Predictor No.2)



India Office Machine
1877 made by A. Légé & Co.,
London to design of Edward
Roberts. 20 (later 24) constants.

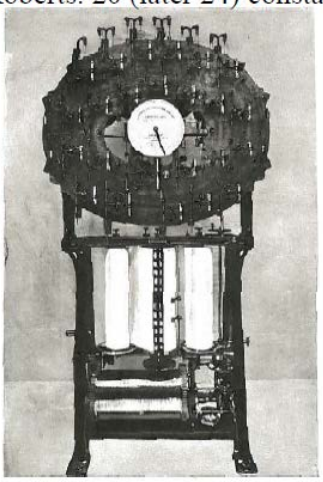


Fig. 8
Roberts or India Office Tide Predicting Machine

Photograph from Sumit Kumar Singh via Paul Hughes

Manufactured By: Légé and Co., London
Manufacture Date: 1879
Architecture Type: Unique
Refurbishment Dates (According to Sager): 1891

Refurbished Since Sager: None
Number of Constituents Simulated: 20 (24)
Features (According to Sager): Graphical recorder.
Original Operation Location: Survey of India, Dehra Dun
Present Owner: Museum of the Survey of India, Dehra Dun (2015)
Present Location: Museum of the Survey of India, Dehra Dun
Present Working Condition: Unknown. It is doubtful it is in working condition.
On Display to Public: By arrangement with Museum of the Survey of India, Dehra Dun
Web Sites:
Notes:
A plaque attached to the machine reads: It is an old 24 component tide predicting machine which was being used for predictions by the Survey of India till 1952. The machine, constructed in 1877, was the first Harmonic tide predicting machine of its kind and was kept in England and used for working out tidal predictions for the Indian ports for over 40 years. It was brought out to India and setup in Dehradun in 1921. By 1952 the machine had not only become too old but was found from experience to be too inadequate to yield the necessary accuracy in predictions for modern navigation. It was replaced in 1952 by a 42 component tide predicting machine.

For a detailed explanation of how this machine worked, see an article (un-named but presumably by Roberts) on page 447-448 (and figures) of the 19 December 1879 edition of The Engineer. There is also a detailed explanation in Chapter 8 of Eccles (1901).

Cartwright (1999) mentions that this machine was designed by Roberts himself, on contract to the India Office, and was originally known as the 'Roberts Tide Predicting Machine' but that name was later applied to the 'Universal Tide Predictor' of 1906 (TPM-S5).

In the refurbishment of 1891, the number of components was extended from 20 to 24.

The 24 tides were (according to Sager, differs a little to IHB 1926):

M2, N2, L2, nu2, mu2, S2, K2, 2N2, T2

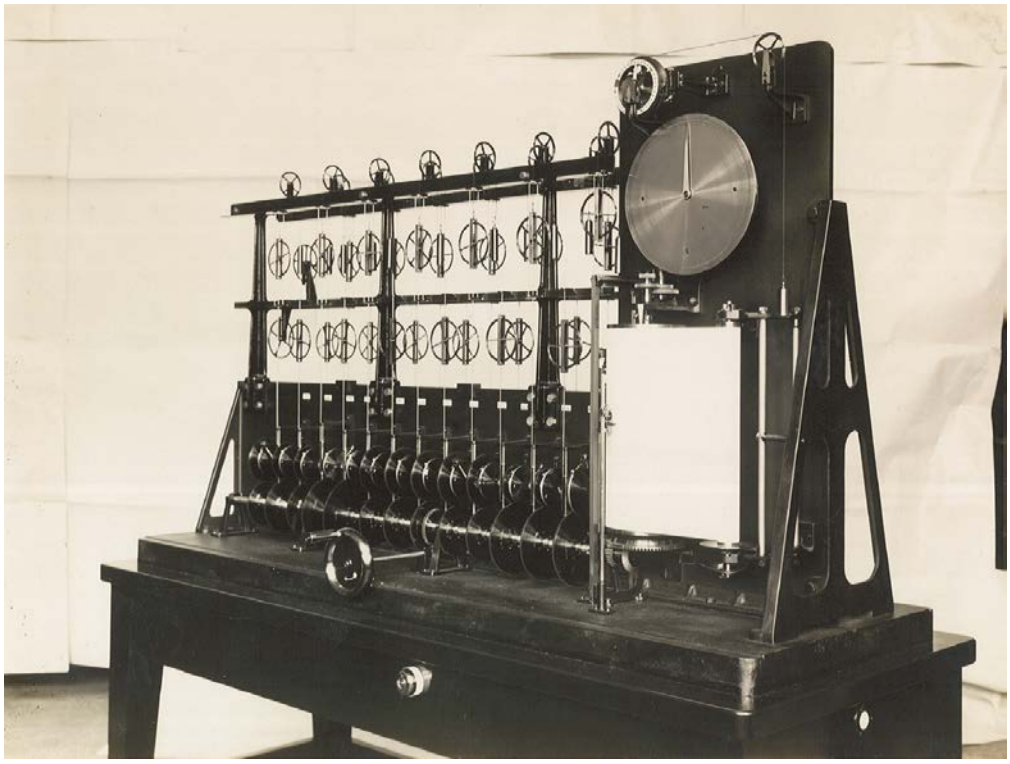
Q1, O1, I1, P1, K1, S1

M4, M6

2SM2, MK3, 2MK3, MS4, MN4,

Sa, Ssa

TPM-S3: British Tide Predictor No.3 – Now in France



Photograph provided by Dr. Nicolas Pouvreau (SHOM)

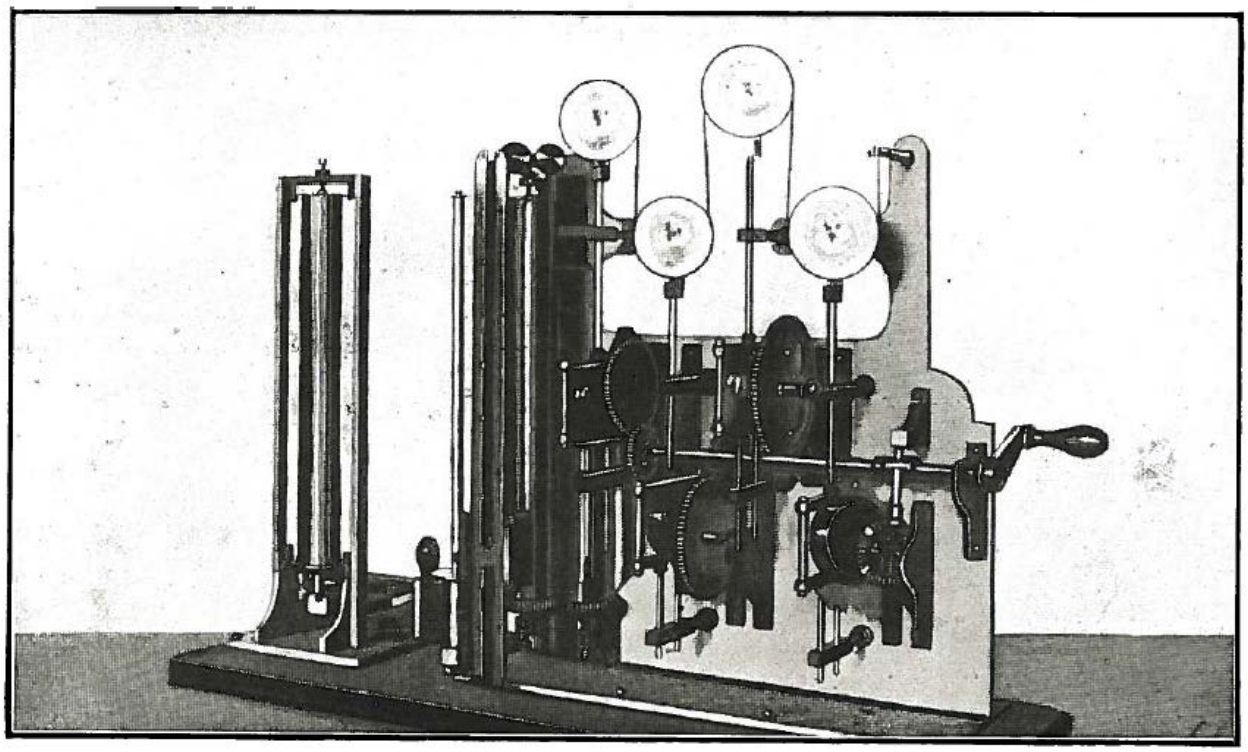
Manufactured By: Kelvin and White, Glasgow
Manufacture Date: 1881
Architecture Type: Unique
Refurbishment Dates (According to Sager): 1901
Refurbished Since Sager: None known of
Number of Constituents Simulated: 15 (16)
Features (According to Sager): Graphical recorder.
Original Operation Location: Paris
Present Owner: Musée des Arts et Métiers (et provient du SHOM) (2015)
Present Location: Musée des Arts et Métiers, Paris
Present Working Condition: Unknown.
On Display to Public: Unknown
Web Sites:
Notes: This was "Lord Kelvin Predictor No.3" and passed into the hands of SHOM in 1901 for application to the tides at French colonial ports (Cartwright, 1999). In the refurbishment of 1901, the extra component added was T2. It is described in French in:

http://cnum.cnam.fr/CGI/fpage.cgi?4KY28.131/459/100/607/0/0

The machine is catalogued at the Musée des Arts et Métiers as:
http://cugnot.cnam.fr:8000/SEARCH/BASIS/collec/internet/objet/DDW?W%3DDESIG+PH+WORDS+%27tide+predictor%27+ORDER+BY+DESIG/Ascend%26M%3D1%26K%3D23496%26R%3DY%26U%3D1

Dr. Nicolas Pouvreau pointed me to two posts on Twitter in March 2016 with photographs of the machine showing that it is still safely stored by the Musée des Arts et Métiers but probably not on public display.

TPM-X1: Koenings' 4-Component Machine



Photograph from IHB (1926)

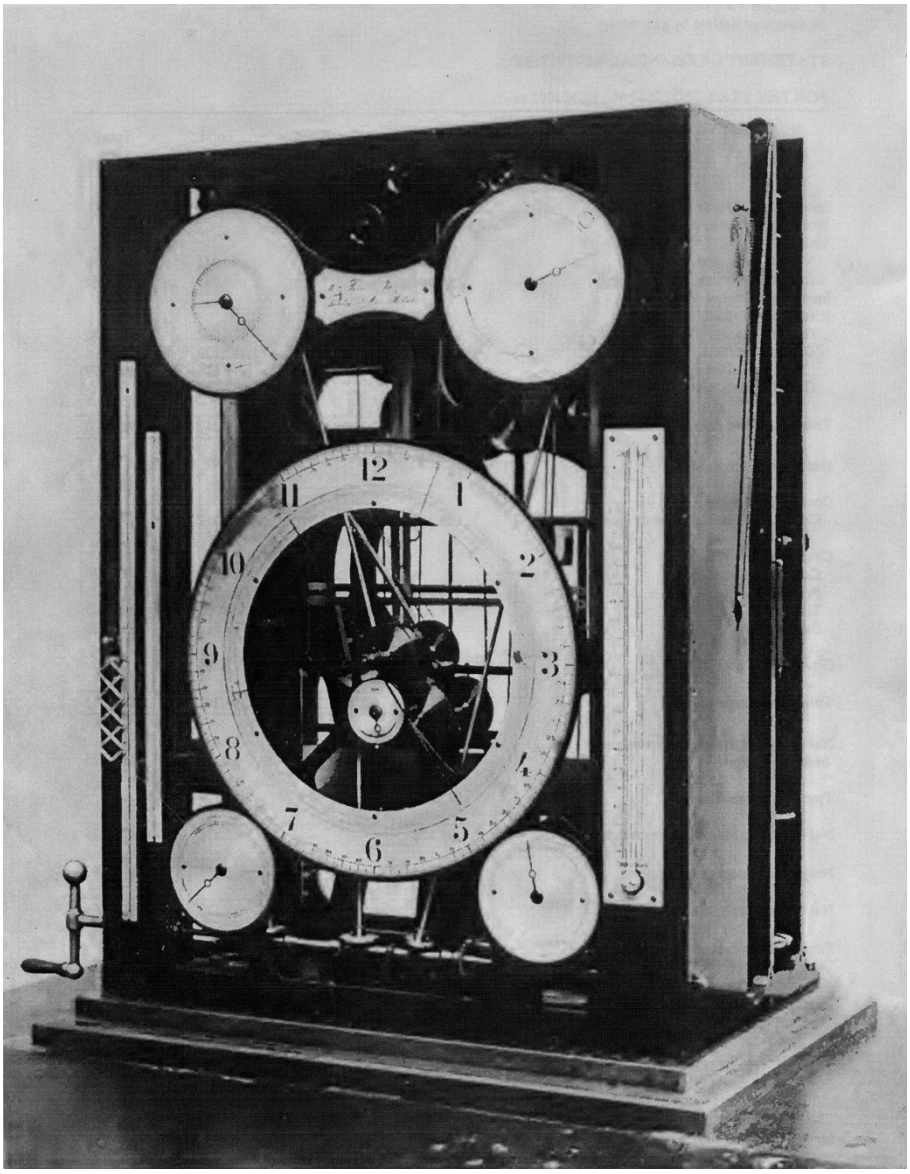
IHB (1926) mentions a 4-component machine constructed for demonstration purposes by Professor Koenings, Member of the Académie des Sciences.

However, this is probably a spelling mistake. There was a mathematician Gabriel Koenigs who was a member of the Academy of Sciences whose date of death (1931) would correspond to the date of the machine: http://www.academie-sciences.fr/academie/membre/memK.pdf. See also:

https://en.wikipedia.org/wiki/Gabriel_Xavier_Paul_Koenigs
http://fr.wikipedia.org/wiki/Gabriel_Koenigs
http://www-history.mcs.st-and.ac.uk/Biographies/Koenigs.html
http://www-groups.dcs.st-and.ac.uk/~history/Biographies/Koenigs.html
There is a Boulevard Gabriel Koenigs in Toulouse.

A less likely possibility is that this is a reference to Rudolph Koenig (1832-1901), the inventor of the tuning fork and many types of scientific instruments, especially those involving sound (https://en.wikipedia.org/wiki/Rudolph_Koenig). Koenig lived in Paris for most of his life. However, experts on Koenig at the University of Toronto and the Museo Galileo in Italy whom we have consulted did not know of any interest of Koenig in tide prediction machines.

TPM-S4: US Coast and Geodetic Survey, Machine No. 1



Photograph from http://en.wikipedia.org/wiki/Tide-predicting_machine

Manufactured By: Fauth and Co., Washington D.C.
Manufacture Date: 1882
Architecture Type: Unique
Refurbishment Dates (According to Sager): None
Refurbished Since Sager: None known of
Number of Constituents Simulated: 19
Features (According to Sager): Counter display.
Original Operation Location: Washington
Present Owner: Smithsonian National Museum of American History (2015)
Present Location: Smithsonian National Museum of American History
Present Working Condition: Unknown.

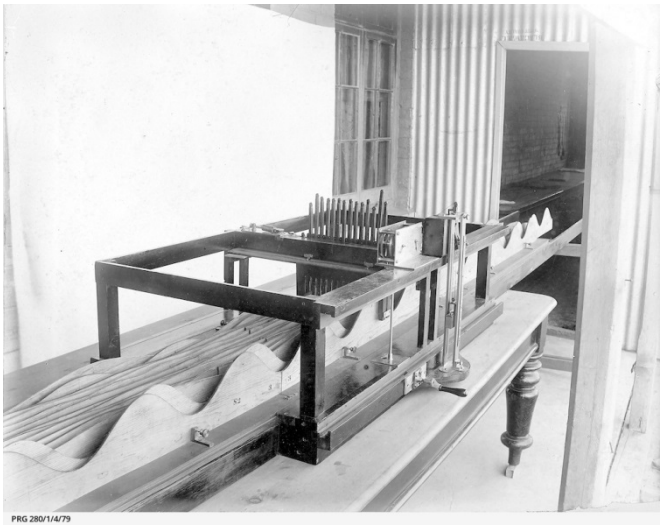
On Display to Public: It is not at the moment.
Web Sites: http://americanhistory.si.edu/collections/search/object/nmah_997047
Notes:

The US Coast Survey (from 1878 the US Coast and Geodetic Survey) commissioned Fauth & Co. to make this, in effect, first 'double-sided' machine to a design by William Ferrel (Cartwright, 1999). A double-sided machine computed the rate of change of the tide as well as the tidal height itself i.e. hw (cos wt + 90) as well as h cos (wt) – see further explanation for 'double-sided' in TPM-S20.

Unlike the other machines, this one did not have mechanisms for each frequency, but rather the differences of frequency with M2, and so was useful only for computing the high and low water turning points. Indeed, Ferrel called this the 'The maxima and minima tide-predicting machine'. Its different function meant that its design differed considerably from those of Kelvin and Roberts and it was very compact (24 x 12 x 18 inches).

Hughes (2005) says that this machine was used operationally between 1885-1914; IHB (1926) says 1883-1910.

TPM-X2: Australian Tide Predictor



Photograph from State Library of South Australia

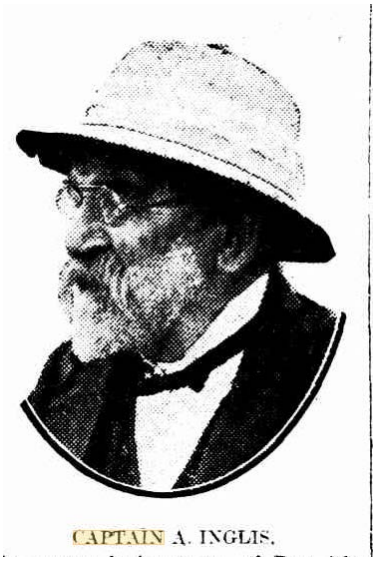
Manufactured By: Alexander Inglis, Adelaide Harbourmaster, Australia
Manufacture Date: 1897
Architecture Type: Unique
Number of Constituents Simulated: 16
Original Operation Location: Adelaide, Australia
Present Owner:
Present Location:
Present Working Condition:
On Display to Public:
Web Sites:
Notes:

This machine was invented in the years up to 1897 by Captain Alexander Inglis, Harbourmaster at Adelaide, Australia. It is described in Inglis (1898). It was designed to simulate 23 components of the tide although only 16 were used in practice. It was totally different in concept to the Kelvin and other machines included in this report. It used sinusoidal 'curves' or 'templates' each slotted into a horizontal box as shown in the photograph. The sinusoid of a template had amplitude and period in solar hours proportional to that of the constituent being simulated (for Port Adelaide or Port Darwin in particular).

The phases of each constituent were set by positioning the template horizontally within the box. The total tide was then calculated by moving a bar over the templates, at right angles to the templates as shown above, the bar having a set of plungers that made contact with the top of the templates, and each plunger having a pulley. A wire passed through the pulleys and so summed the total tide on a paper chart recorder.

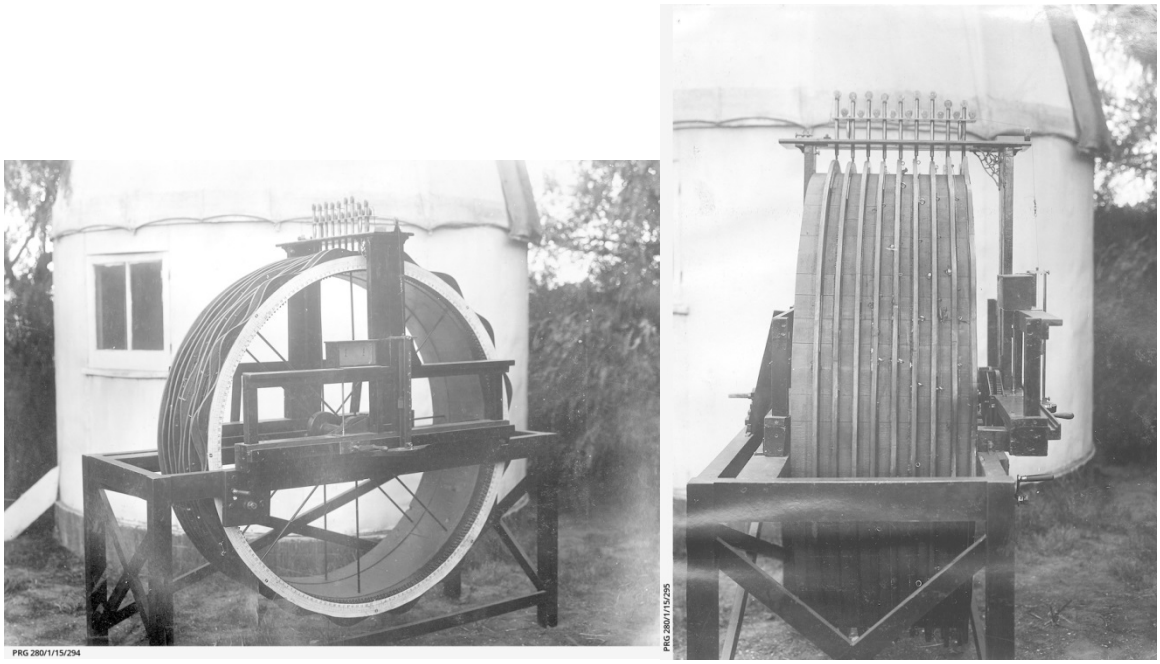
The harmonic constants (amplitudes and phases) for the tidal constituents at Adelaide, based on which the templates were made, were computed from tide gauge measurements during 1889 and

1893 analysed by Chapman and Inglis (1898). The clock and gears were made by Mr. O. Boettger of Adelaide but the rest of the machine (templates etc.) were made of wood and constructed by Inglis himself. Consequently, the machine was considerably cheaper than Kelvin machines (said to be perhaps 100 pounds compared to 3000).



Inglis was born in Banff in 1845 and was Harbourmaster at Adelaide for 34 years, retiring in 1915 having produced his tidal predictions for 17 years. He died in 1921. Following his death, the Adelaide Advertiser on 25 October 1921 reported an offer by Mrs. Inglis to donate his machine to the South Australia School of Mines. The School of Mines is now part of the University of South Australia but at the time it was part of Adelaide University. Professor R.W. Chapman, with whom Inglis worked closely, was an eminent scientist at the University and closely connected with the School. One suspects that Inglis received much of his inspiration from Chapman. After Inglis's death, no-one in Adelaide was in a position to carry on his work and tidal predictions for Adelaide were provided by the UK Admiralty. Information on Chapman can be found at https://www.adelaide.edu.au/library/special/mss/chapman/ .

The Adelaide Martime Museum also possesses 'tide reckoners' which appear to be some kind of tide table for particular years which were possibly also made by Inglis. Some background on tidal prediction at this time and further mention of Inglis can be found in Hughes and Wall (2007).



The second Inglis machine. Photographs from State Library of South Australia

The State Library of South Australia holds excellent photographs of the original Inglis machine and also a second machine with the templates arranged on a circle rather than in a horizontal box (http://collections.slsa.sa.gov.au/find/tide+prediction). If the sinuosoid for the template at the front of the above photograph is for a semidiurnal constituent, then the machine must have been capable of simulating about one week of the tide in one setting before requiring readjustment. (Clearly, an exact multiple of the periods of all constituents could not be fit onto a circle.)

This second machine appears to have had 9 constituents but it is not clear if it was ever used for practical predictions. Hughes (2005) states that it may have been made in 1918 with 11 components using parts cannibalised from the first machine. However, the photograph shows that it had only 9 components and 1918 would have been after Inglis had retired. In addition, parts from the horizontal machines could not have been usefully recycled for the circular second machine, apart perhaps from the clock and gearing. The 1921 Advertiser report suggests that only one machine existed at that time which one assumes was the original machine. It is unlikely they still exist although enquiries in Adelaide are ongoing. IHB (1926), rather disparagingly, called them 'approximate tide-predictors'. References on them include:

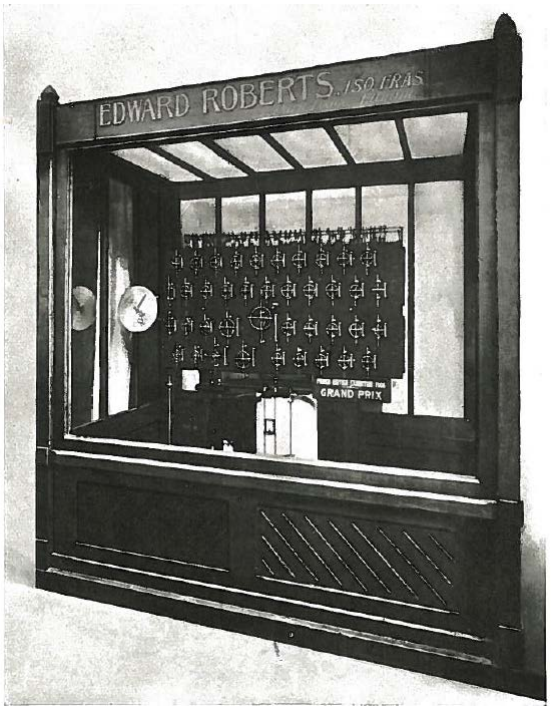
Chapman, R.W. and Inglis, A. 1898. The tides of South Australia. Report of the seventh meeting of the Australasian Association for the Advancement of Science held at Sydney 1898, pp.241-244.

Hughes, P. and Wall, A.D. 2007. The ascent of extranational tide tables. The Mariner's Mirror, 93, 51-64.

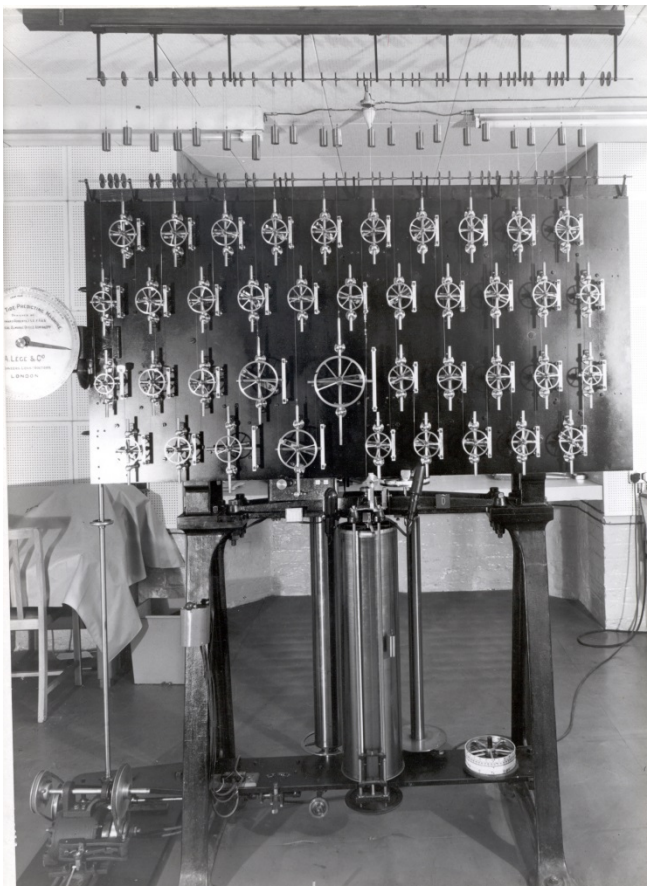
Inglis, A. 1898. The description of a new tide-predicting machine. Report of the seventh meeting of the Australasian Association for the Advancement of Science held at Sydney 1898, pp.239-241.

I am grateful to Mr. Lindl Lawton (Adelaide Martime Museum), Ms. Meredith Blundell (Port Adelaide Local History Library), Richard Venus of Adelaide (via Adelaide University), Dr. John Hunter (University of Tasmania) and Dr. Paul Hughes for information on Captain Inglis and his machines.

TPM-S5: Bidston Roberts- Légé Machine (British Tide Predictor No.5)



The Roberts machine at the 1908 Paris Exhibition.



Photograph from National Museums Liverpool. This shows the machine around 1966.

Photograph by Philip Woodworth. This shows the machine being refurbished May 2015.

Manufactured By: Légé and Co., London
Manufacture Date: 1906-1908
Architecture Type: Unique
Refurbishment Dates (According to Sager): 1929
Refurbished Since Sager: Refurbished at Bidston 1936 and by National Museums Liverpool 2015.
Number of Constituents Simulated: 33+7
Features (According to Sager): Graphical recorder. Counter display (later made addition).
Original Operation Location: In London, England by Edward Roberts.
Present Owner: National Museums Liverpool (2015)
Present Location: National Oceanography Centre, Liverpool
Present Working Condition: Only for demonstration purposes.
On Display to Public: By arrangement with NOC Liverpool.
Web Sites:
Notes:

This machine was designed by Edward Roberts, called the 'Universal Tide Predictor' and used for his own commercial work. It won the 'Grand Prix' of the Franco-British Exhibition of 1908 (Cartwright, 1999). It was transferred to Arthur Doodson at Bidston Observatory in 1929 at a cost of 753 pounds 15 shillings and refurbished by him.

Letters between the daughter of HWT Roberts (the son of Edward Roberts) and SHOM in 1929, after the death of HWT Roberts, show that the machine was offered to SHOM for 2000 pounds. The offer was clearly not taken up. Before HWT died much of the tidal prediction work for the Admiralty by the Roberts family, using this machine, had migrated to LOTI where the work was considered to be

more accurate. After HWT's death, Doodson was asked what should be done with the machine, and he suggested the Indian Government might take it, but anyway he considered it was worth 1000 pounds maximum depending on its actual condition. He was under the impression that the Roberts family wanted it to stay in the UK (but see above). A letter of 27/8/1929 from Doodson says the likelihood of a sale to India or France is small.

This is one of two machines (the other being the Bidston Kelvin Machine, TPM-S14) that was used for tidal predictions during World War II (see Parker, 2011).

The order of the constituents today, looking at the four rows of phase wheels on the back, is:

MN4	SK3	2SM2	2MS6	2SM6	MNS2	S1	S4	L2	T2	
2MK6	2N2	MS4	J1	M4	M6	M3	K2	Q1	P1	MK4
2MN6	MK3	NU2	MSf	2SN6	M2	K1	Ssa	N2	MSN6	
2MK3	Mf	Mm	MSK6	SN4	S2	Sa	O1	MU2		

i.e. this machine has 40 constituents, compared to 42 for TPM-S20. Of the 40, there are 6 which are on TPM-S20 but not on TPM-S5 (M1, OO1, MO3, M8, M10, M12) and there are 4 on TPM-S5 which are not on TPM-S20 (MNS2, SK3, 2MK3, 2SK6).

This list of constituents is identical to that in the LOTI annual report for 1936, except that shows MO3 instead of 2MK3. Presumably MO3 was replaced by 2MK3 at some point afterwards.

One puzzle we had in the course of this research is that the Paris 1908 photograph clear shows 40 wheels for 40 constituents. But both IHB (1926) and Sager suggest that the machine when originally constructed had 33 components and that 7 more were added when it was refurbished in 1929. IHB (1926) says:

"33 of which are actually geared up and vacant places for the gearing of the remaining seven components.."

And Sager (1955) says:

"it could take 40 tide gears, of which initially only 33 were built and the rest were intended for possibly to take into account shallow-water tides …. two decades later Chadburns made a number of improvements including ... changes to accommodate a nickel strip with a rectangular cross section, and finally the tide number was increased to 40".

And USCGS (1915) says much the same thing and lists the 33 constituents in its Table B.

Finally, a letter from Doodson dated 25/9/1929 says it was built with 33 constituents.

However, if the frame is inspected today, it does not appear to have had 33, with 7 added in some section stage. So we suspected that it must have been built with 40 from the start (hence the Paris photo) but only 33 were equipped with gears etc. Then it must have gone to Chadburns two decades later and the 7 were added into already-prepared positions.

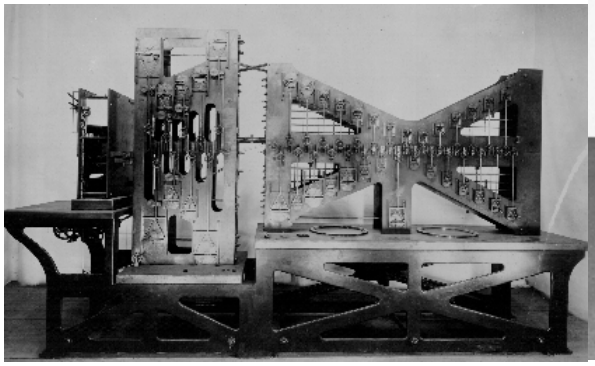
This puzzle was resolved somewhat when the LOTI annual report for 1936 was inspected again. That says that only 30 constituents were active from the 40 when first made, and 10 spaces were available. Chadburns now (1936) had added:

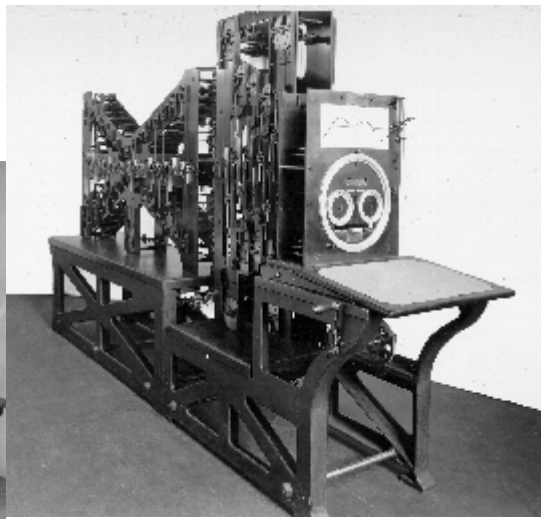
MNS2, SK3, SN4, MK4, 2MN6, MSN6, 2SN6, 2MS6, 2MK6, 2SM6 and MSK6 (note there are 11 in this list) and M8 was removed

which resulted in the machine we have today. The mention of 30 is not exactly the same as 33 but the general history is the same. So the photographs of a 40 component machine in 1908 are really of a 33 component machine with inactive wheels and gears for others added later.

Note also the changes made to the machine, between the 1908 and later photographs, above the chart recorder where there is an additional control wheel. There were also changes through its history in the motor used to control it.

TPM-S6: US Coast & Geodetic Survey TPM No.2





Photographs from http://tidesandcurrents.noaa.gov/predma2.html

Manufactured By: US Coast & Geodetic Survey, Washington
Manufacture Date: 1894-1910
Architecture Type: Unique
Refurbishment Dates (According to Sager): None
Refurbished Since Sager: See below
Number of Constituents Simulated: 37
Features (According to Sager): Graphical recorder. Counter display.
Original Operation Location: US Coast and Geodetic Survey, Washington
Present Owner: NOAA, Silver Spring, Maryland (2015)
Present Location: NOAA Science Center, Silver Spring, Maryland
Present Working Condition: The machine is in working order and is presently (September 2015) being cleaned and restored to remove or prevent any corrosion or deterioration.
On Display to Public: The NOAA Science Center in Silver Spring, Maryland is not open to the public full-time but there are several public events in the year when the machine is on display. Demonstrations are also provided on request for school and other groups.
Web Sites: As above.
Notes:

This machine was made, with many delays, by the US C&GS itself. The work was supervised by E.F. Fischer to a design by R.A. Harris, between which there was a dispute as to the credit (Cartwright, 1999). This was also a double-sided machine and a very accurate one and remained in use until 1966. It was known as 'Old Brass Brains'. There is an extensive description of this machine in USCGS (1915) and IHB (1926). Samuel Tierney (Science, 35, 306-307, 1912) points out that the machine was useful for solving general equations involving cosines, as well as for tidal prediction. Hicks (1967) provides a history of tidal prediction in the USA.

TPM-S7: British Tide Predictor No. 4 – Now in Brazil

This machine is now in the Museu Náutico da Bahia, Salvador, Bahia State, East Brazil. Photograph from Captain Rueben Bello Costa (Administrator, Museu Náutico da Bahia, Salvador, Bahia).

Manufactured By: Kelvin and White, Glasgow
Manufacture Date: 1909-1910
Architecture Type: Kelvin-type
Refurbishment Dates (According to Sager): None
Refurbished Since Sager: None known of
Number of Constituents Simulated: 12
Features (According to Sager): Graphical recorder.
Original Operation Location: The National Observatory, Rio de Janeiro
Present Owner: Museu Náutico da Bahia, Salvador, Bahia State, East Brazil.
Present Location: Museu Náutico da Bahia, Salvador, Bahia State, East Brazil.
Present Working Condition:
On Display to Public: Yes.
Web Sites:
http://revistamuseologiaepatrimonio.mast.br/index.php/ppgpmus/article/viewFile/211/187

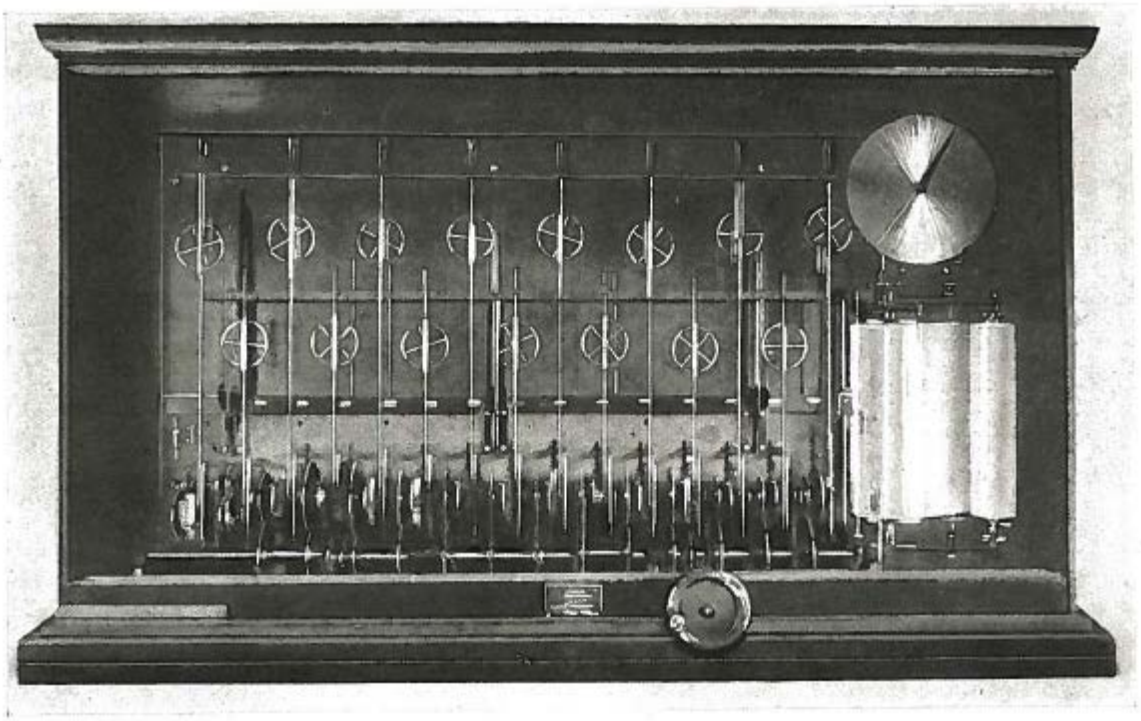
Notes: The original owner of this machine in Brazil was the National Observatory in Brazil. The above web document gives the information (with thanks to Captão-de-Fragata Rosuita Helena Roso of DHN): “The Astronomical Observatory of Rio de Janeiro acquired in 1911 a Predictor built by Kelvin Bottomley & Baird, of Glasgow, which, for reasons of economy, has only 11 waves chosen for the port of Rio de Janeiro, which, on the advice of Professor Darwin, were added two further long period tides, which could easily be added immediately, raising the number to 13…..”

Prof. Mauro Andrade de Sousa (National Observatory in Rio) tracked down this Kelvin Tide Predictor (originally 11 waves, augmented by 2 waves) on display in the Museu Náutico da Bahia, Salvador, Bahia State, East Brazil. It was the first TPM acquired by Observatório Nacional. Although it seems to have arrived in Rio in 1911, which is consistent with the above manufacturer date given by Sager, he

believes that its acquisition could have dated from a decade earlier, during the XIX century. That is because its original identification plate shows the instrument belonging to the “Imperial Observatório Nacional, Rio de Janeiro” while the Empire of Brazil ended in 1889. While it is almost certainly the same machine, this puzzle remains to be resolved.

The photograph above shows what appears to be a 12 component machine, consistent with IHB (1926) and Sager (1955), in spite of the 11-plus-2 information above. The machine has a plaque that confirms it was made by Kelvin and White but does not give a “Lord Kelvin Tide Predictor” number. The Kelvin and White name, instead of Kelvin, Bottomley and Baird, confirms it was made before the company name changed around 1911.

TPM-S8: Japan Kelvin Machine



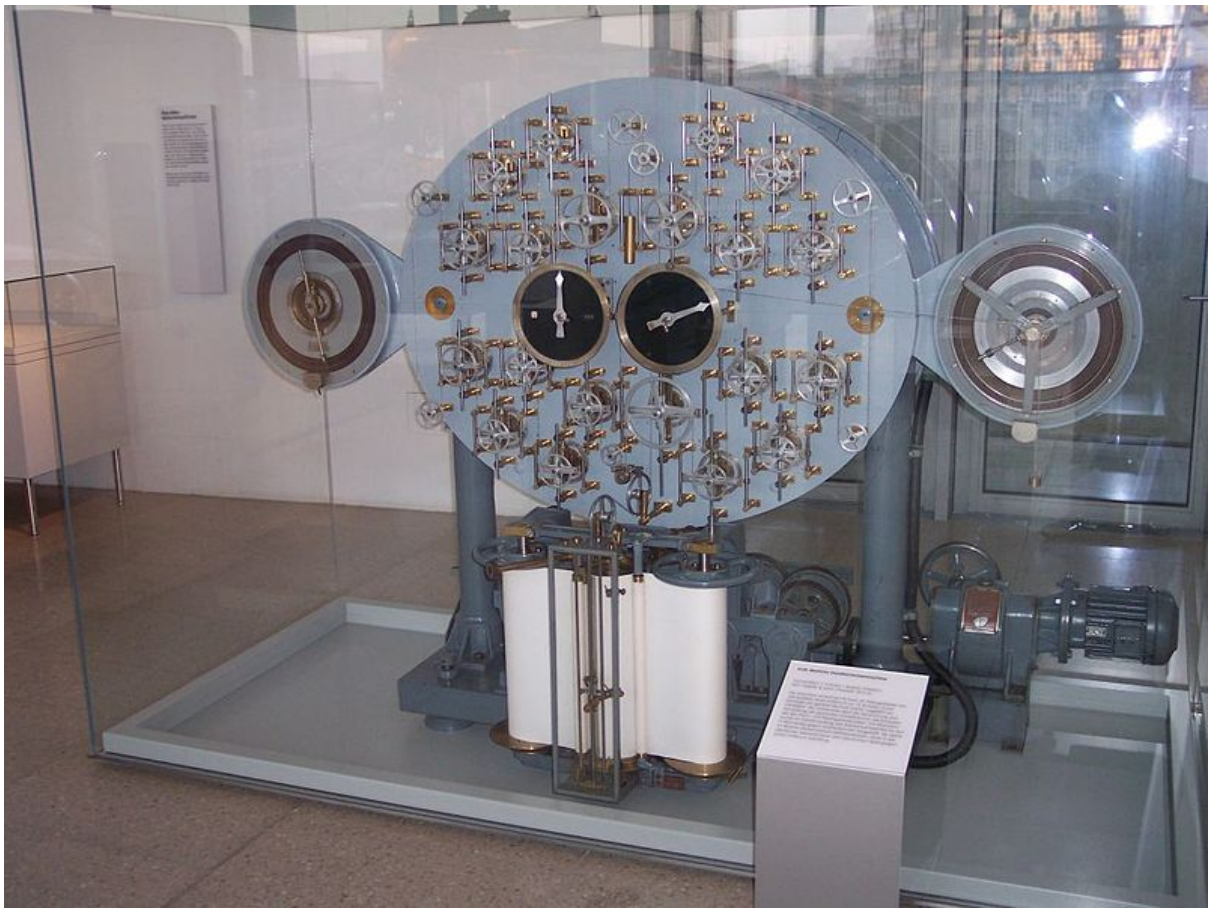
Photograph from IHB (1926)

Manufactured By: Kelvin, Bottomley and Baird, Glasgow
Manufacture Date: 1914
Architecture Type: Kelvin type
Refurbishment Dates (According to Sager): None
Refurbished Since Sager: Not relevant, see below
Number of Constituents Simulated: 15
Features (According to Sager): Graphical recorder.
Original Operation Location: Tokyo
Web Sites:
Notes:

Sager states “In 1914 the firm of Kelvin, Bottomley and Baird in Glasgow made a 15 component machine for Japan. As can be appreciated, the stability of the frame construction was increased by a horizontal drive for the tape. The construction was completed by being stored in a 1.9 m long and 1.1 m high glass cabinet. The machine was destroyed in 1923 as a victim of the Tokyo earthquake. [The Great Kanto earthquake of 1 March 1923.] The value of the tides for Japanese ports was discussed in the commissioning of the equipment given following the disaster [i.e. TPM-S11 and –S12] and by the provision to the Japanese Government of a German tidal abacus built during World War I.”

Note that this machine had no glass sliding doors, unlike the later TPM-S11/12.

TPM-S9: German Machine No.1

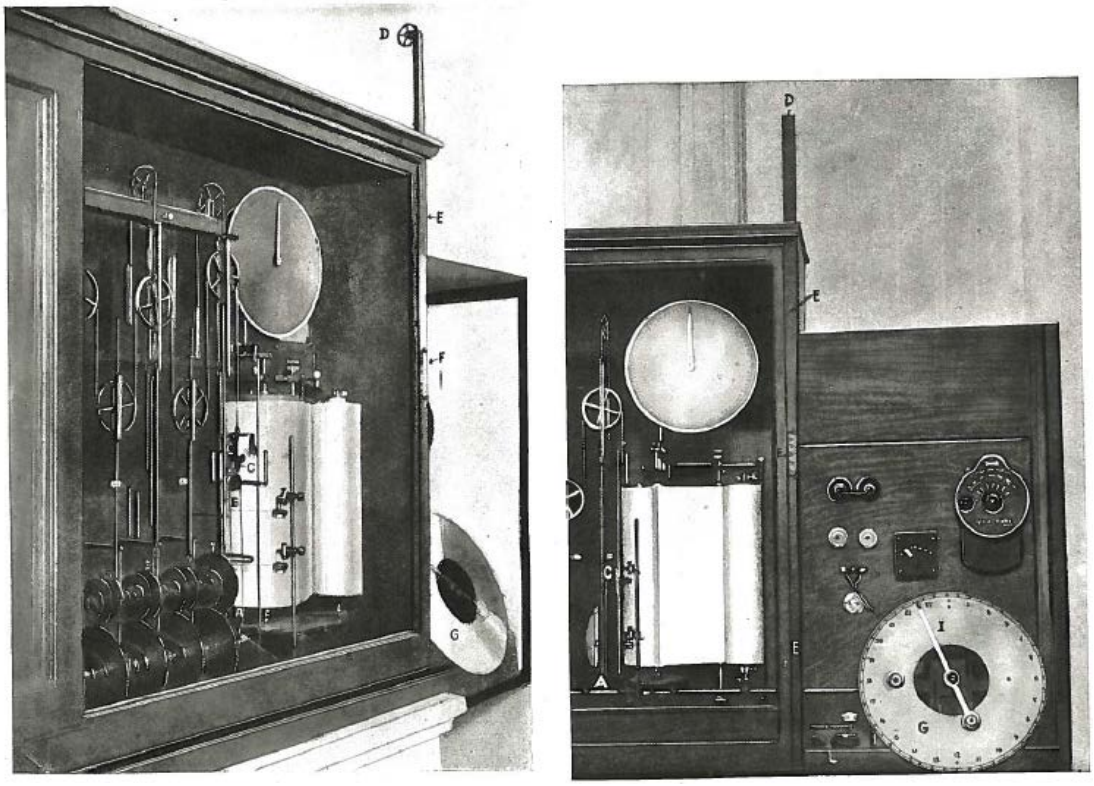


Photograph from http://de.wikipedia.org/wiki/Gezeitenrechenmaschine
(a Wikimedia Commons image).

Manufactured By: Toepfer und Sohn, Potsdam, Babelsburg
Manufacture Date: 1915-16
Architecture Type: Unique
Refurbishment Dates (According to Sager): 1931
Refurbished Since Sager: Unknown
Number of Constituents Simulated: 20
Features (According to Sager): Graphical recorder. Counter display. Printing unit (later made addition).
Original Operation Location: Hamburg
Present Owner: Deutschen Schiffahrtsmuseum, Bremerhaven (2015)
Present Location: Deutschen Schiffahrtsmuseum, Bremerhaven
Present Working Condition:
On Display to Public: Yes
Web Sites:
http://de.wikipedia.org/wiki/Gezeitenrechenmaschine
http://www.dsm.museum/
Notes:

This machine was designed by Heinrich Rauschelbach, who also designed the much larger second German machine (TPM-S16). According to Hughes and Wall (2007), it was based on the published designs for the Roberts India Office machine (TPM-S2). However, Cartwright (1999) claimed it was based on the USCGS machine No.2 (TPM-S6). This machine also had a double-sided construction.

TPM-S10: Argentina Machine No.1



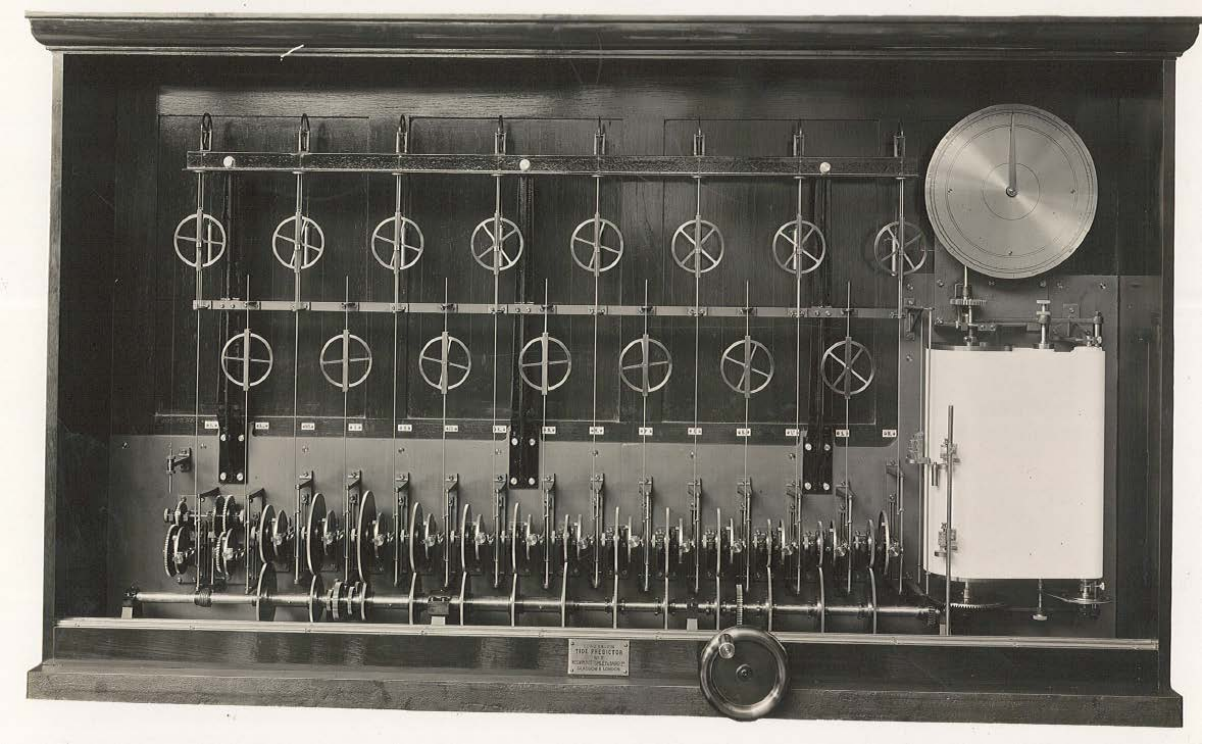
Photographs from IHB(1926).

Photograph by Hernan Niño Seeber (Servicio Hidrografia Naval)

Manufactured By: Kelvin, Bottomley and Baird, Glasgow (according to Sager, but see below)
Manufacture Date: 1918
Architecture Type: Kelvin type
Refurbishment Dates (According to Sager): 1920
Refurbished Since Sager: None known of
Number of Constituents Simulated: 16
Features (According to Sager): Graphical recorder. Counter display (later made addition).
Original Operation Location: Buenos Aires, Argentina
Present Owner: Argentine Naval Observatory (Observatorio Naval) (2015)
Present Location: Argentine Naval Observatory (Observatorio Naval) which is a component of the Servicio de Hidrografia Naval. The ON is located some 10 km from the main SHN offices in Buenos Aires.
Present Working Condition: Unknown
On Display to Public: Unknown
Web Sites:
Notes:

In contradiction to Sager, Cartwright (1999) suggested that this machine was made in Argentina to a design of Kelvin. However, a photograph of it provided by Dr. Nicolas Pouvreau (SHOM) contains a 'KBB' signature saying 'Argentine Tide Predicter … Portuguese … similar' which shows it was indeed made in Glasgow. From the photograph above, it is clear there was a 'Lord Kelvin' plaque on the front of the machine of the type shown for the Madrid machine (TPM-S19), which would have confirmed it was made in Glasgow. However, the plaque itself has been removed at some point. Ariel Troisi of the Argentine Hydrographic Office confirms that this machine was used for predictions up to mid-1953.

TPM-S11 and TPM-S12: Japan Kelvin Machines



These are two identical machines. The first is the “Lord Kelvin Tide Predictor No. 7” which we denote TPM-S11. An original photograph by KBB obtained via Dr. Nicolas Pouvreau.

The same machine (Lord Kelvin No. 7) today in the Maritime Safety Agency Museum in Hiroshima.

This is the “Lord Kelvin Tide Predictor No.8” that we denote TPM-S12. Photograph from the web site below.

Manufactured By: Kelvin, Bottomley and Baird, Glasgow
Manufacture Date: 1924
Architecture Type: Kelvin type
Refurbishment Dates (According to Sager): None
Refurbished Since Sager: None known of
Number of Constituents Simulated: 15 (Sager says 15 and 16 which must be incorrect)
Features (According to Sager): Graphical recorder.
Original Operation Location: Tokyo
Present Owner: Japan Coast Guard Academy, Hiroshima (TPM-S11) and National Museum of Nature and Science, Tokyo (TPM-S12) (2015)
Present Location: Japan Coast Guard Academy, Hiroshima (TPM-S11) and National Museum of Nature and Science, Tokyo (TPM-S12)
Present Working Condition: Unknown
On Display to Public: Yes (TPM-S12)
Web Sites:
see
https://www.kahaku.go.jp/exhibitions/vm/past_parmanent/rikou/Field_1/Detail_102.html
for TPM-S12.

Notes:

Professor Hiromichi Hashizume (Professor of Architecture at the National Institute of Informatics) informs us that there are at least three machines remaining in Japan:

(i) A Kelvin, Bottomley & Baird machine held and exhibited by the National Museum of Nature and Science, Tokyo. The machine was in service between 1930-1960 at the Japanese Central Meteorological Observatory (now called the Meteorological Agency). From the above photograph it clearly has 15 constituents. The plate on the machine says “Lord Kelvin tide Predictor”, the manufacturer's name and "No. 8". That machine we have denoted TPM-S12.

(ii) Another KBB machine held by the Maritime Safety Agency Museum at the Japan Coast Guard Academy, Hiroshima imported in 1924. Prof. Hashizume says it has 15 harmonic terms (and 5min resolution). This machine is the “Lord Kelvin Tide Predictor No. 7” as confirmed by photographs provided by Professor Toru Kajimura, Maritime Safety Academy. We have denoted this machine TPM-S11. It also clearly has 15 constituents.

(iii) The Doodson-Légé machine (1957) shown below as TPM-X3.

TPM-S8, -S11 and –S12 were very similar, the most obvious feature being that TPM-S8 did not have glass sliding doors on its frame.

Sager adds that “Both machines were completed in 1924 in Glasgow. They have 15 or [incorrectly] 16 components, which are housed in a glass cabinet that is protected against dust. Testing took place at the ‘Liverpool Tidal Institute’, which amongst others was doing comparative studies on the accuracy of the machine. The second machine was given a metal band that has been identified as the optimum form for mechanical summation of the harmonic movements of the tides. The drive is done by hand or by a small motor. One revolution of the recording drum corresponding to three days and the [paper] strip for the recording of the annual tidal curve has a length of almost 60 meters.”

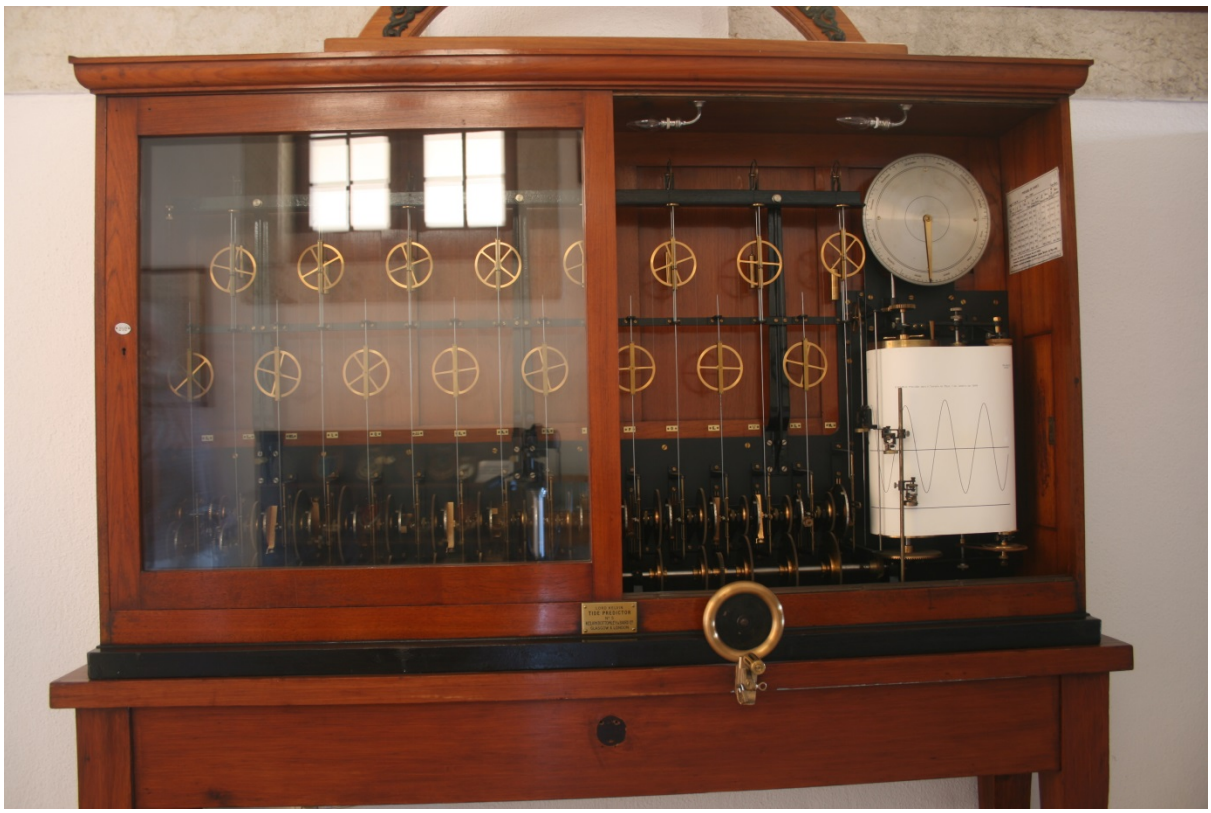
Note that the Admiralty Manual of Tides also states that the two 1924 machines had 15 and 16 components which is presumably where Sager got his incorrect information from.

But a letter from Kelvin, Bottomley and Baird in Glasgow dated 28 August 1925 to the authorities in Paris refers to a 15 component machine made for the Hydrographic Office in Japan and also a 15 component machine for the Central Observatory, Japan so it is clear that they were both 15 component machines. (Letter provided by Dr. Nicolas Pouvreau, SHOM).

The LOTI annual report for 1925 states that both machines were tested by the Institute prior to delivery to Japan. A ‘certificate of examination’ dated 29 May 1924 was provided by Doodson.

Professor Hashizume has also informed us that he has found an old harmonic analyzer of domestic (Japanese) make at Kobe University and has started an investigation of it. We have denoted that as TPM-X4.

TPM-S13: Portugal Kelvin Machine



Photograph from Milton Silva and Nuno Pereira da Costa,
Instituto Hidrográfico, Lisbon

Manufactured By: Kelvin, Bottomley and Baird, Glasgow
Manufacture Date: 1924
Architecture Type: Kelvin type
Refurbishment Dates (According to Sager): None
Refurbished Since Sager: None known of
Number of Constituents Simulated: 16
Features (According to Sager): Graphical recorder.
Original Operation Location: Lisbon
Present Owner: Instituto Hidrográfico, Lisbon (2015)
Present Location: In an exhibition in the lobby of the Library of the Instituto Hidrográfico, Lisbon
Present Working Condition: It is said to be 'in good condition'.
On Display to Public: Probably by arrangement with the Instituto Hidrográfico
Web Sites:
Notes:

Brass plaque reads "Lord Kelvin Tide Predictor No.5. Kelvin, Bottomley & Baird Ltd. Glasgow, London & Basingstoke". The LOTI annual report for 1925 states that the machine was tested by the Institute prior to delivery to Portugal.

TPM-S14: Bidston Kelvin Machine

The Bidston Kelvin Machine when at Bidston and (inset) Arthur Doodson (from Parker, 2011)

and now at SHOM in Brest (Photograph SHOM).

Manufactured By: Kelvin, Bottomley and Baird, Glasgow
Manufacture Date: 1924-25
Architecture Type: Kelvin type
Refurbishment Dates (According to Sager): None
Refurbished Since Sager: None known of
Number of Constituents Simulated: 26+3
Features (According to Sager): Graphical recorder. Counter display.
Original Operation Location: Bidston Observatory, Merseyside, UK
Present Owner: Service Hydrographique et Océanographique de la Marine (SHOM), France (2015)
Present Location: SHOM, Brest, France
Present Working Condition: The machine is in a good display condition.
On Display to Public: By arrangement with SHOM
Web Sites: www.shom.fr
Notes:

Brass plaque reads "Lord Kelvin Tide Predictor No.6. Kelvin, Bottomley & Baird Ltd. Glasgow & London".

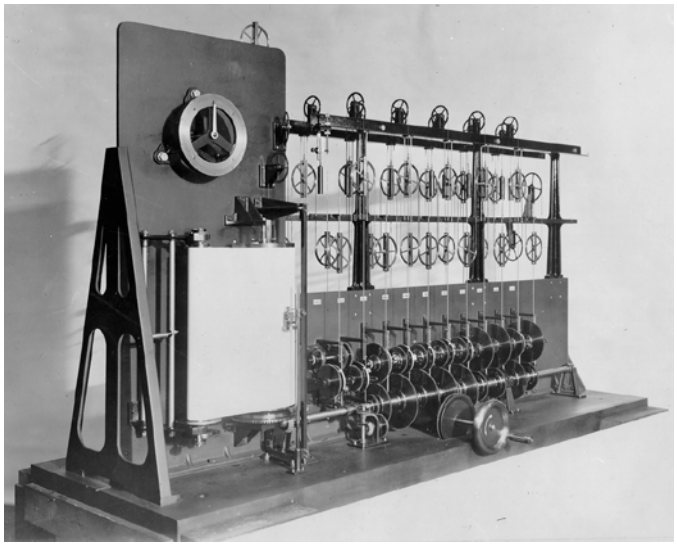
This machine was paid for by Charles Booth, of the Booth Shipping Lines, and by other ship owners for the Liverpool Tidal Institute, and its construction was overseen closely by Doodson. According to Scoffield (2006), the cost was 1,500 pounds, of which 300 was provided by the British Association for the Advancement of Science. A popular article by Doodson "A machine which works with the moon" describes how it works in an accessible way (in The Graphic, 14 March 1925, page 401).

The LOTI annual report for 1925 says that the machine differs from others made earlier by the same manufacturer in having more constituents, and in having the constituent pulleys arranged in two planes parallel to each other which allows for more constituents and adds strength. Constituents were:

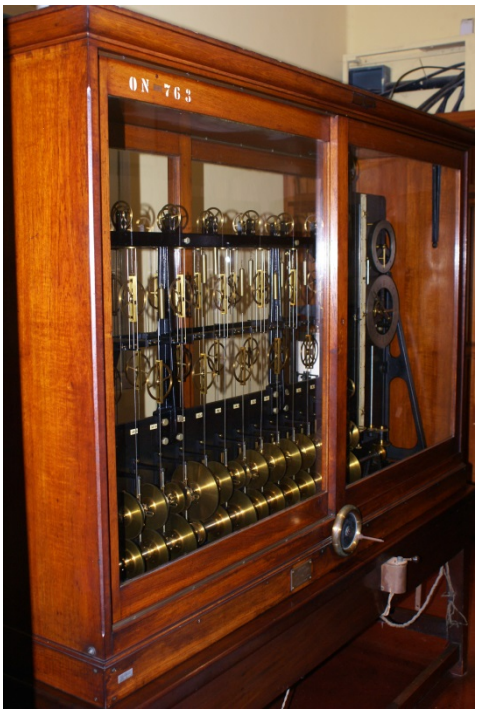
M2, S2, N2, K2, nu2, L2, T2, 2N2, mu2, 2SM2
K1, O1, P1, Q1, J1, S1
M3, MK3, 2MK3, M4, S4, MS4, MN4, M6, 2MS6, SMN6
and space left for 3 others.

This is one of two machines (the other being the Bidston Roberts-Légé machine, TPM-S5) that was used for tidal predictions during World War II (see Parker, 2011). The machine was transferred from Bidston to SHOM in 1950 and was operated first at the SHOM headquarters in Paris. It is now to be found at SHOM in Brest. The SHOM web site says it was used to calculate the tides of overseas ports. (Thanks to Nicolas Pouvreau and Guy Wöppelmann for their help finding information on the two machines now in France).

TPM-S15: Brazil Kelvin Machine



Photograph from http://tidesandcurrents.noaa.gov/predmach.html.



Photograph on left obtained from the web site below. That on right was taken in 2007 by Professor Mauro Andrade de Sousa, Observatorio Nacional, Rio de Janeiro.

Manufactured By: Kelvin, Bottomley and Baird, Glasgow
Manufacture Date: 1927
Architecture Type: Kelvin type
Refurbishment Dates (According to Sager): None
Refurbished Since Sager: None known of
Number of Constituents Simulated: 23

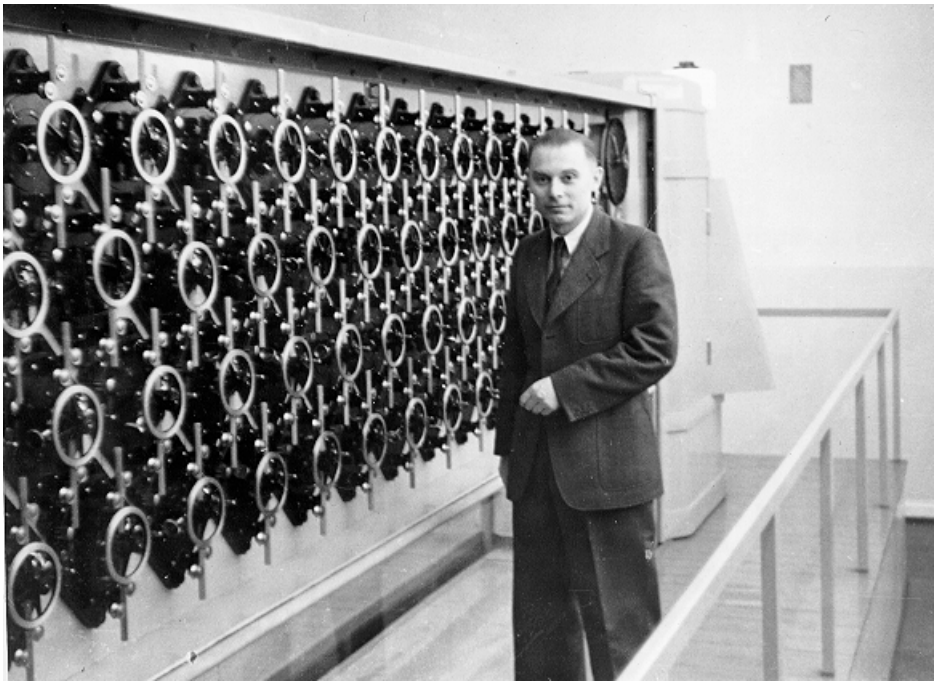
Features (According to Sager): Counter display.
Original Operation Location: National Astronomical Observatory, Rio de Janeiro
Present Owner: Museu de Astronomia e Ciências Afins – MAST, Rio de Janeiro (2015)
Present Location: Museu de Astronomia e Ciências Afins - MAST
Present Working Condition: Unknown
On Display to Public: Unknown
Web Sites:
http://revistamuseologiaepatrimonio.mast.br/index.php/ppgpmus/article/viewFile/211/187

Notes:

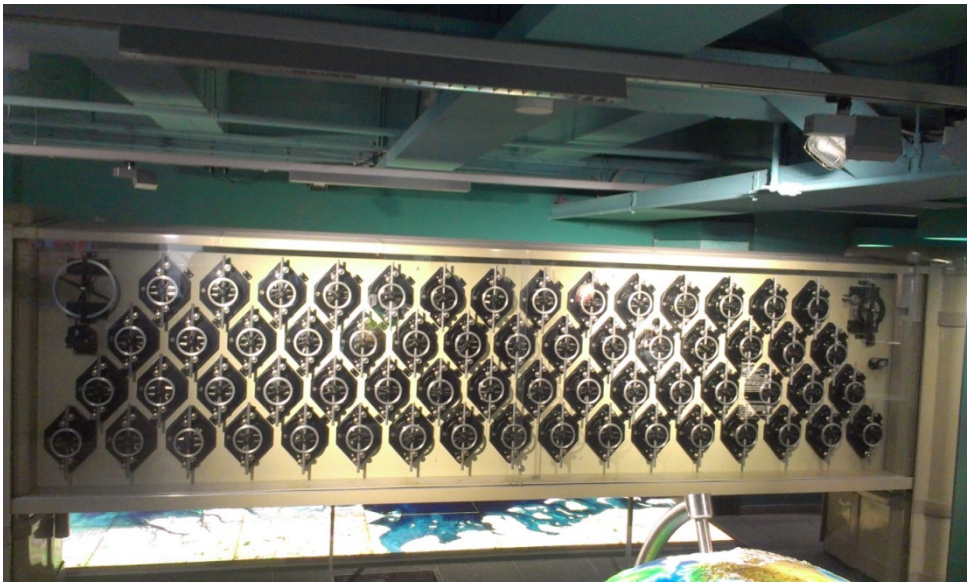
Part of the above web site reads (with thanks to Capitão-de-Fragata Rosuita Helena Roso of DHN):
"The funds for the acquisition of new prediction machine were released by Congress in 1926. The new instrument contains 21 [in fact 23] waves, can draw on a drum the curve any tide, with hours in cool weather, high and low tides. According to a proposed simplification by Dr. Alix de Lemos, and adopted for many years in the old instrument, rather than be limited to have traced the curve on the register cylinder, which is certainly useful on occasion, the stylus moves along a scale, where it parks itself at the moment low or high tide is achieved, whereas a stylus with divided drive allows reading of the day and the corresponding time, which is much more expedient….
…. It finally arrived in Rio in 1927....the device was used for predicting tides until 1967, when the service began to be performed with the aid of computers by the Directorate of Hydrography and Navigation of the Navy Department."

The LOTI annual report for 1926 states that the machine was tested by the Institute prior to delivery to Brazil. A photograph of its plaque taken by Prof. Mauro Andrade de Sousa of the National Observatory confirms that it is indeed the same machine (the Lord Kelvin Tide Predictor No.9, Kelvin, Bottomley & Baird Ltd., Glasgow and London).

TPM-S16: German Machine No.2



The German TPM No.2 and its designer Heinrich Rauschelbach (from http://tidesandcurrents.noaa.gov/predmach.html)



Photograph taken in 2014 in the Deutsches Museum, Munich by Chris Hughes.

Manufactured By: Aude und Reipert, Mechanoptik, Potsdam-Babelsberg
Manufacture Date: 1935-39
Architecture Type: Unique
Refurbishment Dates (According to Sager): None
Refurbished Since Sager: Unknown
Number of Constituents Simulated: 62

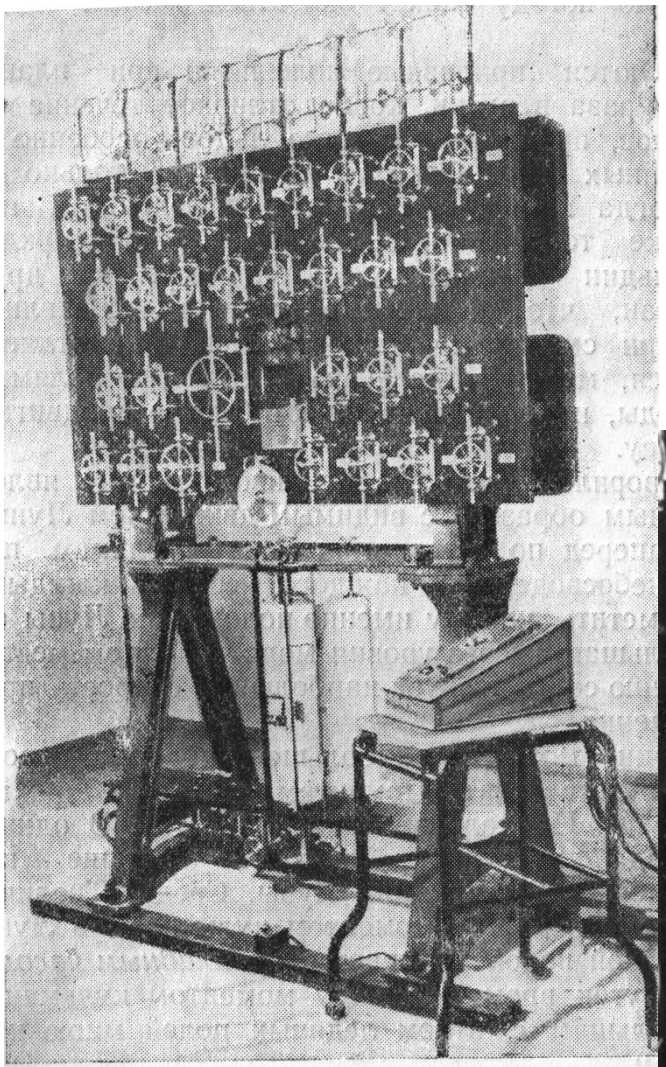
Features (According to Sager): Graphical recorder. Counter display. Printing unit.
Original Operation Location: Hamburg
Present Owner: Deutsches Museum, Munich, Germany (2015)
Present Location: Deutsches Museum, Munich
Present Working Condition: Not known for certain but looks in excellent condition.
On Display to Public: Yes.
Web Sites:
http://www.deutsches-museum.de/en/collections/transport/maritime-exhibition/tide-predicter/

http://de.wikipedia.org/wiki/Gezeitenrechenmaschine

Notes:

This tide prediction machine (Gezeitenrechenmaschine) was designed by hydrographic engineer Heinrich Rauschelbach (1888-1978). It weighed 7 tonnes and was the largest TPM ever constructed. It had a double-sided construction.

TPM-S17: Russia Doodson-Légé Machine



Машина для вычисления „Таблиц приливов"
(в Государственном океанографическом институте, в Москве)

Photographs made in the 1950s obtained by courtesy of Dr. Alexander Rabinovich.
They show the machine installed in Moscow and its operator Galina Sovershaeva.

Manufactured By: Légé and Co., London
Manufacture Date: 1945
Architecture Type: Roberts- Légé type
Refurbishment Dates (According to Sager): None
Refurbished Since Sager: Not relevant, see below
Number of Constituents Simulated: 40
Features (According to Sager): Graphical recorder. Counter display.
Original Operation Location: State Oceanographic Institute in Moscow from 1946.
Present Owner: The machine is known to have been destroyed (see below).
Web Sites: See

http://www.youtube.com/user/NOCSnews
and scroll to 'Tidal Prediction Machine Part II' for a film of the machine in operation (see notes below).

Notes:

(1) The lady in the photograph, Galina Sovershaeva, was for many years the person responsible for tidal prediction in Russia. As of 2013 she was still working at SOI.

(2) There is an exchange of correspondence from 1944, workshop assembly photographs and drawings of this machine in the archives of the National Museums Liverpool. It seems that this machine took a while to be completed and delivered. Alan Bowden of MMG suggests that the film mentioned above was shot immediately after the machine was assembled for a test run and that the person in it may be an employee (E.F.Elliot or the works manager) or a director of A. Légé & Co (one of the Jebson family). Doodson made notes and calculations regarding the resizing of the component wheels and bevel gears for this machine so that it would work properly. It is clear that Doodson spent an enormous amount of time on this machine and visited London at least 18 times to monitor its progress.

(3) In the letter from Doodson to the Norwegian Hydrographic Service of November 1945 (see TPM-S18) he states that the Russia TPM cost nearly 5,000 pounds.

(4) Dr. Rabinovic found a set of notes at the SOI to go with the above two photographs. The notes have some technical details. General information (which we have paraphrased here) is that the machine arrived in 1946 at the SOI having been ordered in 1941. Selection of the the manufacturer (Légé) was not accidental as the firm had made a good machine in 1907 for tidal predictions in Liverpool (i.e. TPM-S5). The SOI was an appropriate location for it as in the post-war years, the SOI was charged with prediction of tide and publication of navigational aids in the form of annual tide tables. Complex calculations were otherwise carried out at the Institute by hand. Work on predicting tides with the machine was carried out by two technicians. Maintenance was carried out by a mechanic. During operation, the machine made a melodic sound similar to the sound of bells. The machine was used for 23 years, but in early 1969 it was dismantled due to the introduction of electronic computers. The SOI offered the machine to the Polytechnic Museum, but it was refused, motivated by the fact that the machine 'is a monument to foreign science and technology, the museum is including only national exhibits'. As a result, the tidal machine was disassembled and thrown away.

TPM-S18: Norway Kelvin Machine

Photograph from Tor Tørresen, Norwegian Hydrographic Service.

Manufactured By: Chadburns, Liverpool
Manufacture Date: 1947
Architecture Type: Kelvin type
Refurbishment Dates (According to Sager): None
Refurbished Since Sager: None known of
Number of Constituents Simulated: 30
Features (According to Sager): Graphical recorder. Counter display.
Original Operation Location: Oslo, Norway
Present Owner: Stavanger Maritime Museum (2015)
Present Location: It was moved to Stavanger Maritime Museum from the Norwegian Hydrographic Service, Stavanger in July 2015.
Present Working Condition: Still in working condition.
On Display to Public: Yes.
Web Sites:
Notes:
The TPM used to stand in the entrance hall of the Hydrographic Service of the Norwegian Mapping Authority (Norges Kartverket) in Stavanger, but was moved to the Stavanger Maritime Museum in July 2015. It is in a glass case and is still working. The following information was provided by Tor Tørresen of the Hydrographic Service.

The Norwegian Hydrographic Service (Norges Sjokartverk) in Oslo ordered a 16 constituent machine in 1939 from Kelvin, Bottomley and Baird in Glasgow but the machine was not produced because of the war. After the war they instead ordered the above machine from Chadburns of Liverpool following advice from Doodson.

Copies of letters found include: (1) A letter from Doodson to NS in November 1945 saying that a Légé-type machine with 30 components like the Russian one (TPM-S17), ordered from Légé and Co., would be 2,750 pounds while a 20 component machine would be 2,150 pounds. Doodson stated that Légé and Co. would not quote for a Kelvin-type machine. He would also ask Chadburns to quote first for a Légé-type 'as that is less susceptible to wear' but a Kelvin-type would be cheaper. It is not clear if Chadburns ever quoted for a Légé-type.

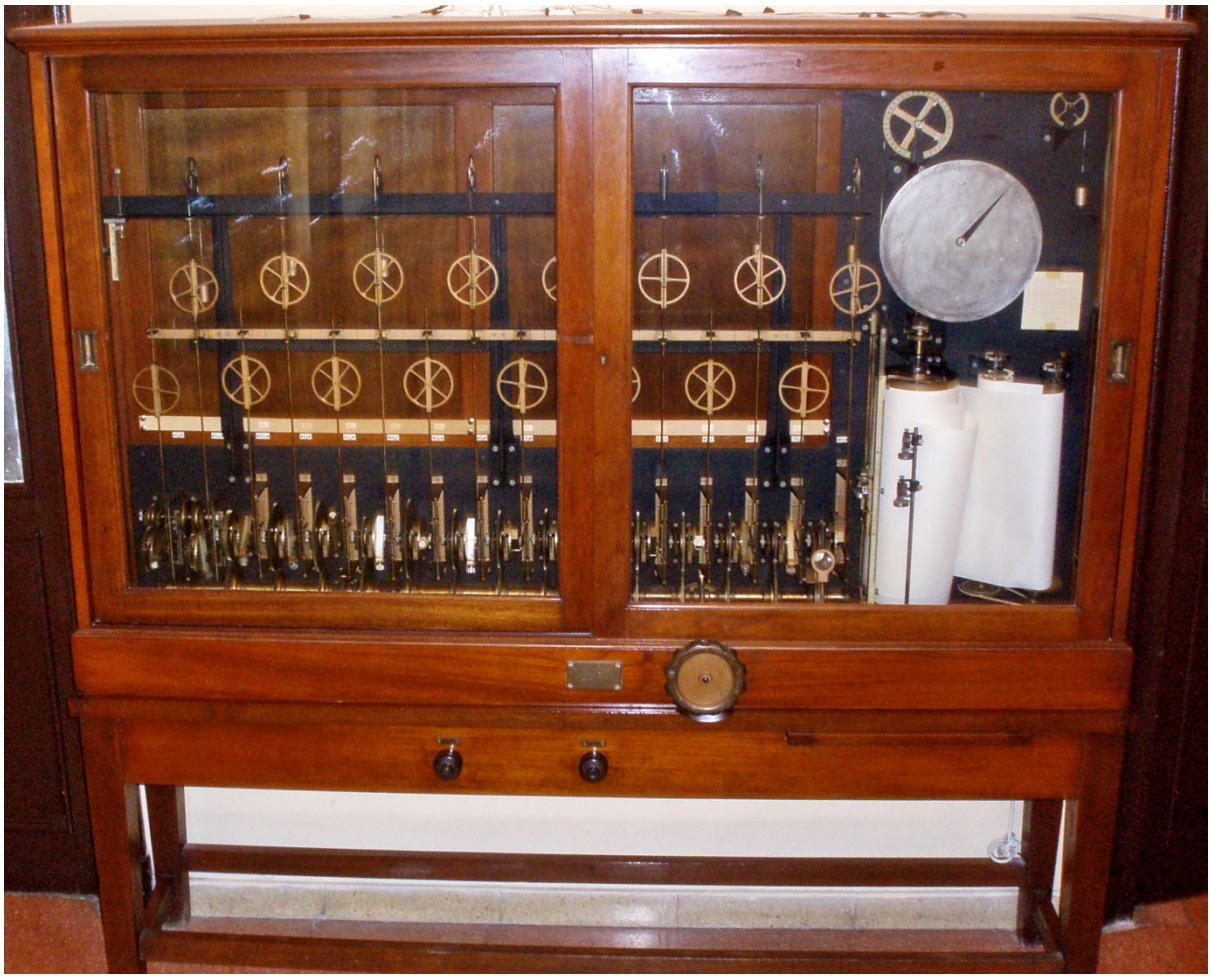
(2) May 1946, Chadburns letter to Norges Sjokartverk, quoting 1,800 pounds for a Kelvin-type TPM with 30 components 'to the specification of the Director, Liverpool Tidal Institute'.

(3) September 1946, Chadburns to Doodson, apologising for delays, and a letter from Doodson to NS to say that in the meantime he could do some Norwegian predictions for the NS himself.

The LOTI annual report for 1947 states that the machine was 'to a new design by the Director' (i.e. Doodson). It was tested by the Institute prior to delivery to Norway.

When the Madrid Kelvin machine (TPM-S19) was made by Kelvin and Hughes it was denoted the 'Lord Kelvin Tide Predictor No. 11' which suggests that they considered the Norway machine to be No. 10, even though it was not made by them but by Chadburns. This machine has no plaque as do the Brazil (No. 9, TPM-S15) and Madrid (No.11, TPM-S19) Kelvin machines.

TPM-S19: Madrid Kelvin Machine



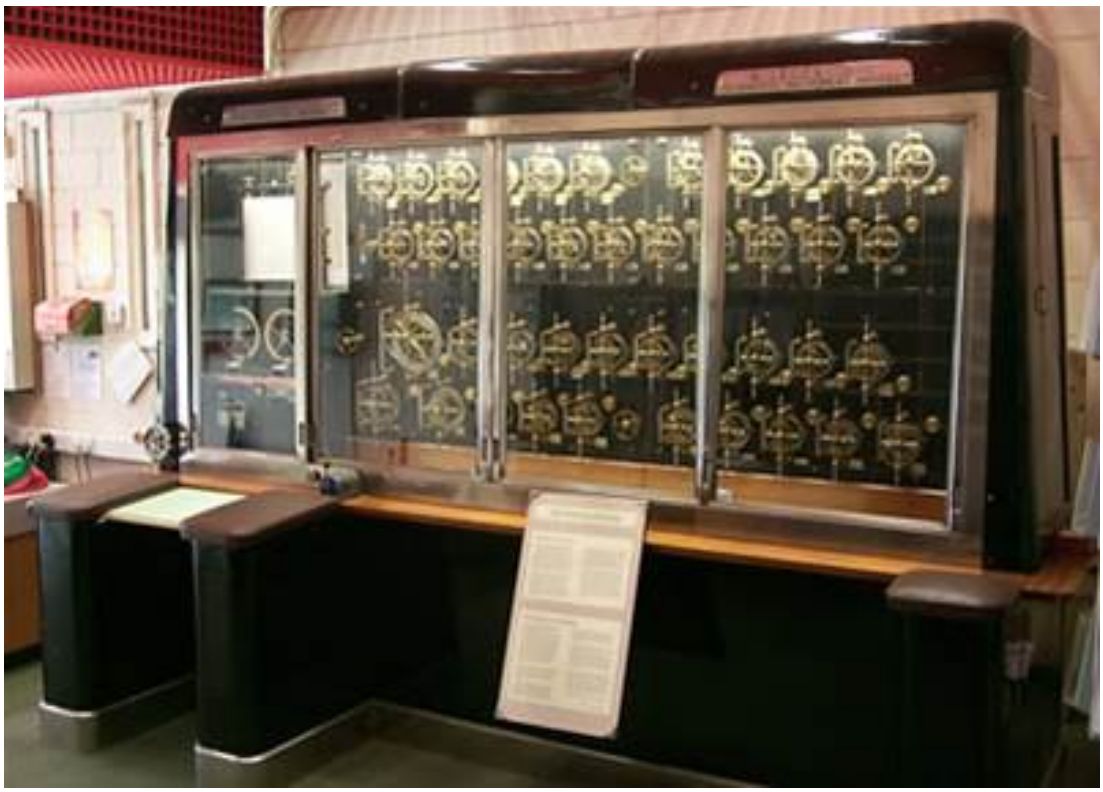
Photographs from Salvador Moreno,
Instituto Hidrográfico de la Marina, Cádiz (with thanks to Begõna Pérez, Puertos del Estado)

Manufactured By: Kelvin and Hughes, Glasgow
Manufacture Date: 1948
Architecture Type: Kelvin-type

Refurbishment Dates (According to Sager): None
Refurbished Since Sager: None known of
Number of Constituents Simulated: 16
Features (According to Sager): Graphical recorder. Counter display.
Original Operation Location: Madrid, Spain
Present Owner: Instituto Hidrográfico de la Marina, Cádiz (2015)
Present Location: Main building of the Instituto Hidrográfico de la Marina, Cádiz, Spain
Present Working Condition: Salvador Moreno remarked that 'it has not been seen working' but looks in good condition.
On Display to Public: No
Web Sites:
Notes:

Brass plaque reads "Lord Kelvin Tide Predictor No.11. Kelvin, Bottomley & Baird Ltd. Glasgow, London & Basingstoke"

TPM-S20: Bidston Doodson-Légé Machine



This photograph will have taken in the 1990s in the entrance of the reception area of Bidston Observatory, then called the Proudman Oceanographic Laboratory (POL). POL is now part of the National Oceanography Centre.

The machine undergoing refurbishment in Liverpool in May 2015 (Photograph Philip Woodworth)

Manufactured By: Légé and Co., London
Manufacture Date: 1950
Architecture Type: Roberts- Légé
Refurbishment Dates (According to Sager): None
Refurbished Since Sager: Refurbished in 2015 by National Museums Liverpool
Number of Constituents Simulated: 42
Features (According to Sager): Graphical recorder. Counter display.
Original Operation Location: Bidston Observatory, Merseyside, UK
Present Owner: National Museums Liverpool (2015)
Present Location: National Oceanography Centre, Liverpool, UK
Present Working Condition: The machine is in a good working condition suitable for demonstrations to the public etc.
On Display to Public: By arrangement with NOC, Liverpool
Web Sites:
Notes:

According to Scoffield (2006), the purchase of this machine was initiated when Arthur Doodson asked Mr. Jebson (Managing Director of Légé and Co.) to estimate the cost of a new machine with 35 or more constituents, either single- or double-sided. The funding of the machine was dependent on the disposal of the Bidston Kelvin machine (TPM-S14), which was completed when the latter was transferred to SHOM in France in 1948. The new machine was delivered to Bidston in December 1950 at a cost of 5,049 pounds.

The machine is described in some detail in Doodson (1951), page 89 of which implies that, when the machine was delivered in 1950, it was of single-sided construction but that the second side could be readily purchased if required. Sager's Table 2 also implies that it was single-sided, but that table was compiled in 1955 or before. We know that the machine now does have a double-sided construction, and did not acquire its second side until 1956 (Scoffield, 2006, page 176; ICOT annual report for 1956). Otherwise, this machine and the Argentina Doodson-Légé Machine (TPM-S24) are known to have been exact copies, the latter being double-sided when first made.

A double–sided machine was capable of simulating simultaneously the tidal height and rate of change of the height at any given time, due to the machine being a 'double-sided' one (i.e. in effect two machines). When the rate was zero, then that would be one of the 'turning points' (i.e. either high or low water), and the height and time could then read off. Single-sided machines had to simulate the rates and then be re-setup to simulate the heights at the times of the turning points, which was a lengthy procedure.

In this case, the front of the machine (as seen in the above photographs) had wheels and Vernier adjustments by which one could set up the phases and amplitudes of the constituents. A similar, in effect second, machine was accessed from the back with a set of wheels whereby one could set up the amplitude of the rate of change of each constituent. The component shafts of the front wheels were the same as for the back wheels so rotation at the front of the type H cos (wt + g) would be the same as the back where the amplitude, instead of being H, would be Hw and the phase, instead of

being g, would be (g+90), so as make the cosine into a sine (and so a rate). The 90 degree lag between back and front was included in the technical design.

In addition, TPM-S20 was the only one of the set of Doodson-Légé machines manufactured around 1950 to have had inner wheels (or 'dials') on the front of the machine for some constituents. These wheels were to accommodate calculations of the shallow water perturbations of the main tides according to an extremely complicated procedure described in the LOTI annual report for 1951 and later more fully in Doodson (1957).

The frame of the machine was made of aluminium, rather than steel as for TPM-S5. It was made at the same time as, and was identical to, the Manila machine (TPM-S21) apart from the number of constituents. The frame was assembled in four quarter-sections onto which the constituent wheels were attached in 4 rows (as seen from the front where both the amplitude Vernier screws and phase wheels were located):

Top row:	Sa,	Ssa,	Mm,	MSf,	Mf,	M4,	MS4,	MN4,	S4,	MK4,	SN4
2nd row:	M12,	M10,	M8,	M6,	2MS6,	2MN6,	2MK6,	2SM6,	MSN6,	MSK6,	2SN6
3rd row:	M2,	S2,	N2,	K2,	nu2,	mu2,	L2,	T2,	2N2,	2SM2	
Bot row:	K1,	O1,	P1,	Q1,	M1,	J1,	OO1,	S1,	MK3,	MO3	

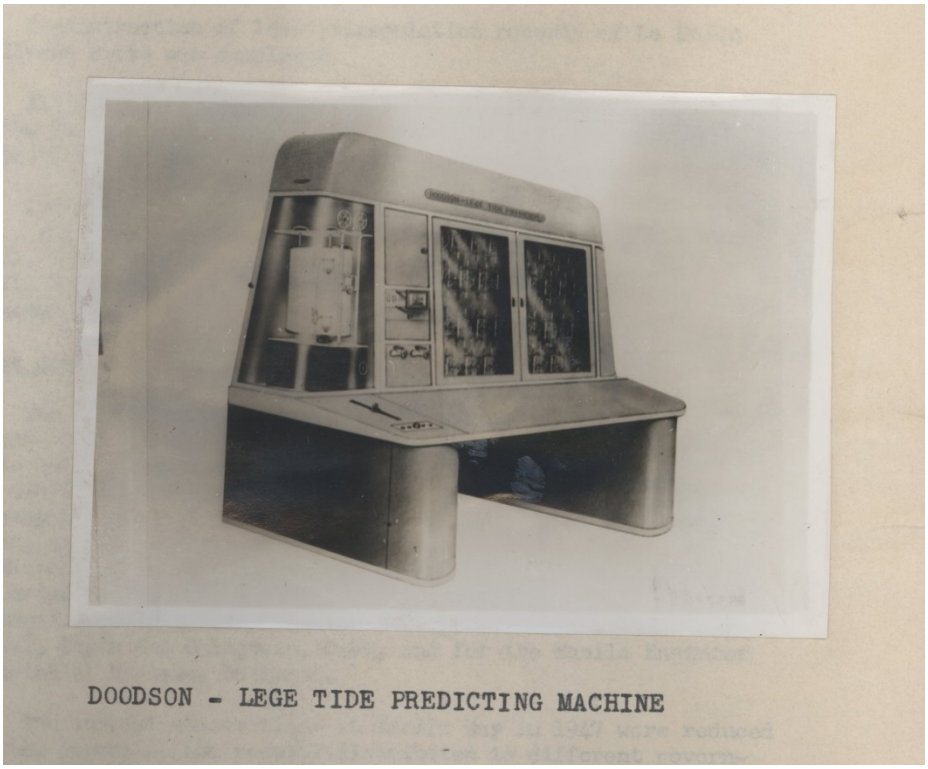
which is ordered by species (top to bottom) and in order of importance left to right, rather than the rather erratic ordering of the earlier Légé machines. The whole machine was enclosed in a steel case with sliding doors back and front. For more details, see Doodson (1951). It was of immense importance to Bidston Observatory, having provided predictions for up to 180 ports worldwide every year.

TPM-S21: Manila Doodson-Légé Machine

This photograph was taken in 2014 by Cdr. Rosalino delos Reye, National Mapping and Resource Information Authority, Hydrography Department, Manila.

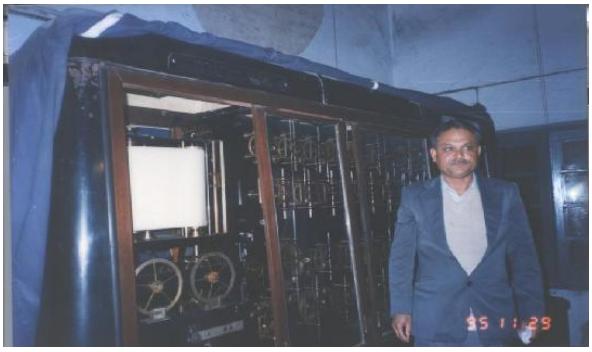
Manufactured By: Légé and Co., London
Manufacture Date: 1950
Architecture Type: Roberts- Légé
Refurbishment Dates (According to Sager): None
Refurbished Since Sager: None known of
Number of Constituents Simulated: 30
Features (According to Sager): Graphical recorder. Counter display.
Original Operation Location: Coast & Geodetic Survey, Manila, Philippines
Present Owner: National Mapping and Resource Information Authority, Hydrography Department, Manila, Philippines (2015)
Present Location: National Mapping and Resource Information Authority, Hydrography Department, Barraca Street, San Nicolas, Manila, Philippines
Present Working Condition: The machine is not in a working condition.
On Display to Public: The machine is an exhibit in the Museum of Hydrography Department
Web Sites:
Notes:
The original drawings for this machine are archived by the National Museums Liverpool.

A mystery is that the NOAA Picture Library has a photograph “Doodson-Lege tide predicting machine installed and used by the Philippine Coast and Geodetic Survey. Photo Date1949. Image ID: cgs01443, NOAA's Historic Coast & Geodetic Survey (C&GS)”, No. 1428 at http://www.photolib.noaa.gov/brs/cgind29.htm which has the look of a D-L machine but not quite the Manila machine e.g. the machine below shows only two doors.



DOODSON - LEGE TIDE PREDICTING MACHINE

TPM-S22: India Doodson-Légé Machine



The photograph on the left was taken in 1995 by Dr. Pat Caldwell, University of Hawaii Sea Level Center, during a GLOSS training course at Dehra Dun. That on the right was provided in 2016 by the Geodetic and Research Branch of the Survey of India.

Manufactured By: Légé and Co., London
Manufacture Date: 1951
Architecture Type: Roberts- Légé
Refurbishment Dates (According to Sager): None
Refurbished Since Sager: None known of
Number of Constituents Simulated: 42
Features (According to Sager): Graphical recorder. Counter display.
Original Operation Location: Survey of India, Dehra Dun, India
Present Owner: Survey of India, Dehra Dun, India (2015)
Present Location: Museum of the Survey of India, Dehra Dun, India
Present Working Condition: The machine was in a good working condition when inspected in 1995.
On Display to Public: Probably, by arrangement with the Museum of the Survey of India
Web Sites:
Notes:

From the available information in LOTI reports and from Doodson correspondence held by Mrs. Valerie Doodson, one concludes that this was a single-sided Doodson-Légé Machine. Otherwise it was a 42-component machine similar to TPM-S20.

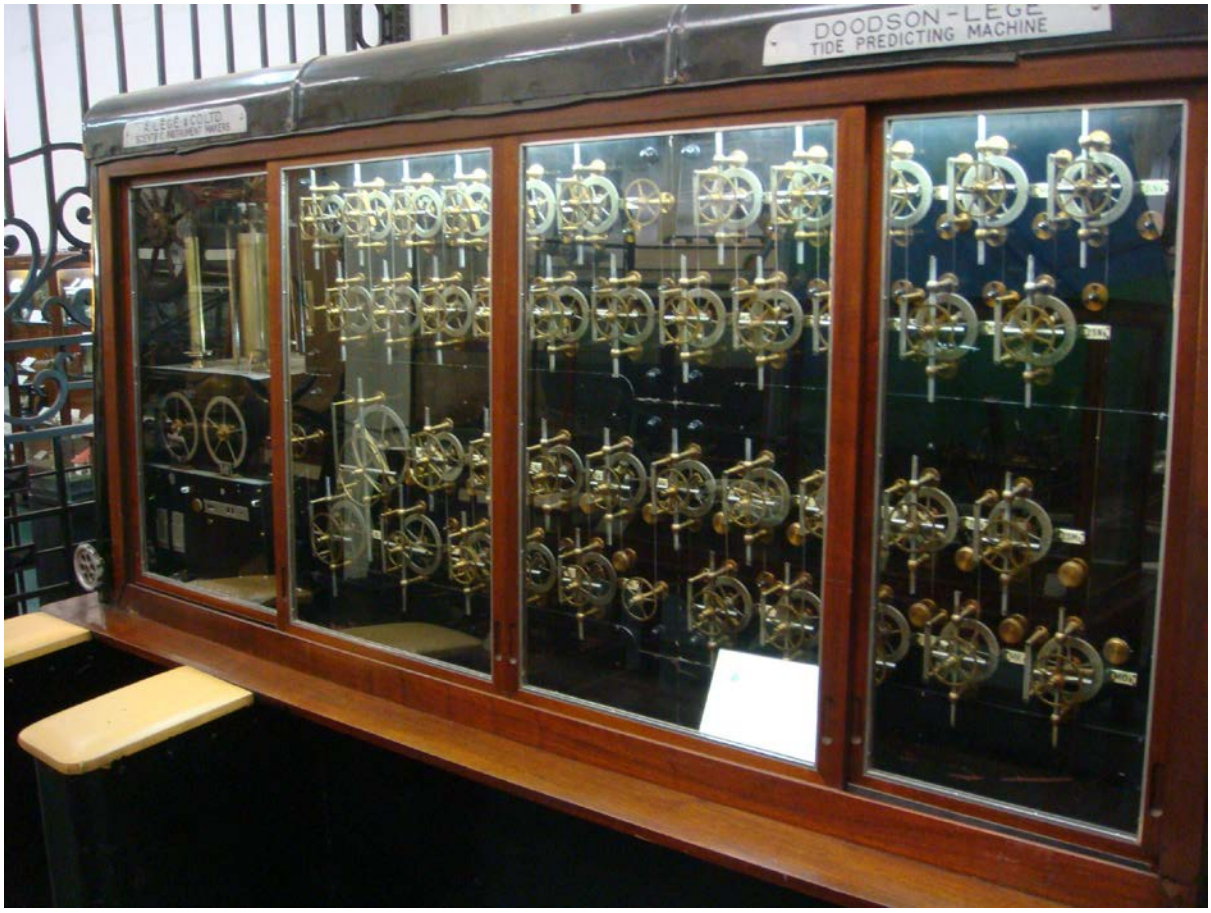
TPM-S23: Thailand (Siam) Doodson-Légé Machine

This photograph was taken in 2014 courtesy of Cdr. Supasit Kongdee, Royal Thai Navy.

Manufactured By: Légé and Co., London
Manufacture Date: 1951
Architecture Type: Roberts- Légé
Refurbishment Dates (According to Sager): None
Refurbished Since Sager: None
Number of Constituents Simulated: 30
Features (According to Sager): Graphical recorder. Counter display.
Original Operation Location: Royal Thai Navy, Bangkok, Thailand
Present Owner: Royal Thai Navy, Bangkok, Thailand (2015)
Present Location: Hall of Thai Hydrographic History, Royal Thai Navy, Hydrographic Department, Bangna, Bangkok, Thailand
Present Working Condition: The machine is not in a working condition.
On Display to Public: The machine is an exhibit in the Museum of the Royal Thai Navy Hydrographic Department, Bangkok
Web Sites:
Notes:
Before being shipped to Thailand, this machine was exhibited in the Dome of Discovery at the South Bank Exhibition during the Festival of Britain in 1951 as a particularly fine example of engineering. It is still maintained in an excellent condition although is no longer operational.

According to Admiral Tantigun, Royal Thai Navy, the machine was used last in 1977.

TPM-S24: Argentina Doodson-Légé Machine



Unknown picture source

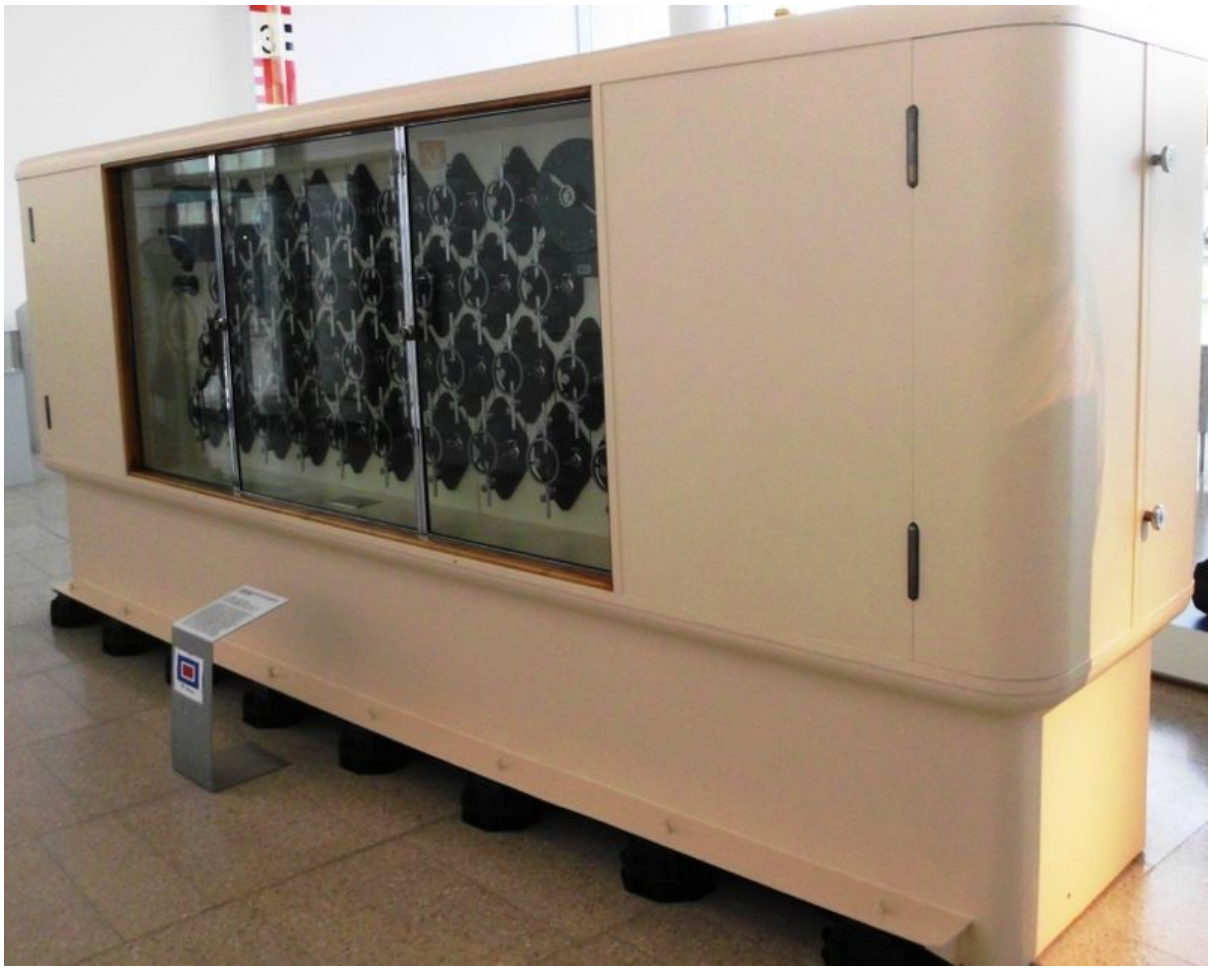
This photograph was taken in 2013 at the Museo Naval de la Nación, Buenos Aires (unknown source). It confirms where the machine can now be found; compare the metal screens in both pictures, behind the small sail-boat in the lower picture.

Manufactured By: Légé and Co., London
Manufacture Date: 1952
Architecture Type: Roberts- Légé
Refurbishment Dates (According to Sager): None
Refurbished Since Sager: None known of
Number of Constituents Simulated: 42
Features (According to Sager): Graphical recorder. Counter display.
Original Operation Location: Hydrographic Office, Argentine Navy, Buenos Aires.
Present Owner: Museo Naval de la Nación, Buenos Aires (2015)
Present Location: Museo Naval de la Nación, Tigre, Buenos Aires.
Present Working Condition: It is not known if the machine is not in a working condition.
On Display to Public: Yes.
Web Sites:
Notes:
This machine has a double-sided construction (as mentioned correctly by Sager). It is known to have been an exact copy of the Bidston Doodson-Légé Machine (TPM-S20), as mentioned in the LOTI report for 1952.

In addition to the standard mechanisms on the LOTI machines and others made at around this time to the same design, an electrically operated pen indicates on the graph of the tide height curve the times of high and low waters as given by the rear components and indicated directly by the time dial on the front of the machine (LOTI report for 1952).

The LOTI report for 1952 mentions that provision had been made for the use of the machine in the generation of shallow water corrections, but the additional dials on the Tidal Institute's own machine (see TPM-S20) had not been included. (The two parts of this sentence seem inconsistent, the machine would have to be inspected in Buenos Aires to see if the inner dials exist.)

TPM-S25: German Machine No. 3 (Gezeitenrechenmaschine der DDR)



Photograph from http://de.wikipedia.org/wiki/Gezeitenrechenmaschine
(a Wikimedia Commons image).

Manufactured By: VEB Karl-Marx-Werk, Postsdam-Babelsberg
Manufacture Date: 1952-1955
Architecture Type: Unique
Refurbishment Dates (According to Sager): None
Refurbished Since Sager: Unknown
Number of Constituents Simulated: 34
Features (According to Sager): Counter display. Printer unit. Double sided construction.
Original Operation Location: Rostock, East Germany.
Present Owner: Deutschen Schiffahrtsmuseum, Bremerhaven (2015)
Present Location: Deutschen Schiffahrtsmuseum, Bremerhaven
Present Working Condition: Looks to be in good condition.
On Display to Public: Yes.
Web Sites:

http://de.wikipedia.org/wiki/Gezeitenrechenmaschine
http://www.dsm.museum/

TPM-X3: Japan Doodson-Légé Machine

Photograph from web site below.

Manufactured By: Légé and Co., London
Manufacture Date: 1957
Architecture Type: Roberts- Légé
Number of Constituents Simulated: 42
Original Operation Location: Hydrographic and Oceanographic Department, Japan Coast Guard
Present Owner: Hydrographic and Oceanographic Department, Japan Coast Guard (2015)
Present Location: Hydrographic and Oceanographic Department Museum, Tokyo (see below)
Present Working Condition: See below.
On Display to Public: Yes
Web Sites:
http://museum.ipsj.or.jp/en/heritage/chokosuisanki.html

Notes:

The above web site reads: “The tide predicting machine was owned and operated by Japan Coast Guard to provide the tidal prediction information of the ports. This tide predicting machine was designed to automate such computations with 42 eccentric pulleys and a wire loop connecting them. Currently electronic computers are used for the purpose but the algorithmic basis remains unchanged. This is the latest, largest and retaining the best condition among a few tide predicting machines preserved in this country.”

It is not clear if this machine has the shallow-water wheels mentioned for TPM-S20, or whether it was single- or double-sided (the LOTI annual report for 1956 suggests that it was single-sided).

In the photograph there looks to be the spindle for attaching a missing height wheel (cf. TPM-S20) Maybe that has been lost.

The LOTI report for 1956 says the machine was ordered by the Maritime Safety Board of Japan. It was tested by the Institute prior to delivery.

Note that the IPSJ Computer Museum, Tokyo mentioned in the above web site is a ‘virtual museum’ and the machine is physically at the Hydrographic and Oceanographic Department (JHOD): MLIT Aomi Building, 2-5-18, Aomi, Koto-ku, Tokyo 135-0064, Japan

TPM-X4: Kobe Machine

Professor Hiromichi Hashizume (Professor of Architecture at the National Institute of Informatics) informs us that he has found an old harmonic analyzer of domestic (Japanese) make at Kobe University and has started an investigation of it. We have denoted that as TPM-X4.

TPM-X5: Indonesia Doodson-Légé Machine

In the 1963 annual report of the Liverpool Observatory and Tidal Institute (LOTI) there is mention of a 30 component machine made by Légé for the Indonesian Hydrographic Department. The Institute was testing it. The Indonesian Hydrographic Department reported that the machine was used for predictions from 1963-1987 when it was replaced by digital computers and is no longer on their inventory list. It seems likely that the machine has been scrapped.

TPM-X6: Burma Doodson-Légé Machine

Manufactured By: Légé and Co., London
Manufacture Date: Approximately 1964
Architecture Type: Roberts- Légé
Number of Constituents Simulated: 42
Original Operation Location: Burma Hydrographic Office
Present Owner: Myanmar Naval Hydrographic Centre (2015)
Present Location: Myanmar Naval Hydrographic Centre, P.O. Box 511, Yangon, Myanmar
Present Working Condition: See below.
On Display to Public: Not known
Web Sites:
Notes:

A letter dated 31/3/1961 in the archives of the Scientific Committee on Ocean Research (SCOR) (http://www.scor-int.org/Historical%20Documents/Tide_Gauges.pdf) mentions that the Burma Hydrographic Office wishes to acquire a 24 component TPM (a possible typing error with 42 components intended). In the 1964 annual report of the Liverpool Observatory and Tidal Institute (LOTI) there is mention of a 42 component machine being tested for Burma by the Institute.

The Myanmar Naval Hydrographic Centre (MNHC) has confirmed that they still have this machine. It was used for tidal predictions until 1990 although it is now not operational and is being made into a museum piece.

No LOTI reports after 1964 refer to TPMs, even the Institute's own, as digital computers were now becoming available. Valerie Doodson has mentioned that there may have been a 'China machine' also – to be confirmed.

PTPM-1: German 10-Component Portable TPM

German portable 10-component predictor on display in the Deutsches Museum, Munich in 2014 (Photograph Philip Woodworth). The caption to the exhibit reads:

Water-level computer
Aude und Reipert, Postdam-Babelsberg, around 1935

The water-level computer is a small tide-predicting machine. It is similar in function to the large tide-predicting machine, but only has 10 partial tides. Astronomer Heinrich Rauschelbach from the Naval Observatory in Wilhelmshaven proposed its design. The company Aude & Reipert manufactured 20 of these devices during World War II. The German navy used them to calculate water levels at sea in areas for which no calculations were available. Exact calculations were needed to lay mines off enemy coastlines.

It is mentioned in the book 'Sea-Level Changes' by E. Lizitzin (1974), page 211, wherein she says it was hand operated. The museum web site:
http://www.deutsches-museum.de/en/collections/transport/maritime-exhibition/water-level-computer/
has the same information as the above caption and mentions that its enormous expense (6000 Reichsmarks) was the reason only 20 were made.

PTPM-2: British Copies of the German 10-Component PTPM-1

The LOTI annual report for 1947 states that there was considerable interest in the small desk type of TPM with 10 components as used in the German Navy during the war (i.e. PTPM-1). It says that arrangements have been made for manufacturing them in Glasgow by Marine Instruments Ltd. (the new name for Kelvin, Bottomley and Baird) and the Institute will oversee the manufacture.

The 1948 report says that there had no further progress with this. It is not clear these machines were ever made.

PTPM-3: Légé-Made 12-Component PTPMs

THE DOODSON-LÉGÉ PORTABLE TIDE PREDICTOR

The LOTI annual report for 1956 states that it had been asked to design a 12-component machine for use by hydrographic offices and on survey vessels when approximate tidal predictions were required. Draft designs had been sent to Légé and Co.

The 1957 report states that 3 of these machines were being made by Légé and Co.

The 1958 report contains an extensive description of this machine, being 2 ft 9.75 in x 1 ft 7.5 in x 1ft 2.5 in and weight 95 pounds (!). Constituents are:

M2, S2,N2, K2, mu2, M4, K1, O1, P1, Q1, J1, MS4.

The report says that the three machines are expected for delivery to Canada in early 1959. The 1959 report says that one other was delivered to South Africa. The 1961 reports mention 6 more: 3 for

Indonesia, 2 for Brazil and one for the UK Hydrographic Department. The 1963 report refers to one for Italy.

One of the Brazil machines is now in the museum of the Diretoria de Hidrografia e Navegação of the Brazil Navy in Niteroi. That machine is identical to the above, with 12 components, but with nu2 and L2 instead of Q1 and J1, so it is likely that the choice of 12 was made depending on the country.

The DHN Brazil PTPM. Photograph by Lt. Cdr. Adriano Vieira de Souza.

NOC has copies of some drawings of these 'Lege Portable Predictors'. The dates on the drawings are 1957 which is consistent with the 1956 annual report. The drawings themselves are not very good. From Paul Hughes we know that that there is one 'in a green trunk' in the store of the Science Museum at Wroughton (Swindon).

Other PTPMs

It has been suggested occasionally that there was also a US PTPM but Dr. Bruce Parker, formerly at NOAA and who has researched tide prediction machines, does not know of any US portable machine.