A Great Brass Brain

A Unique Engine, on the Accuracy of Which Depend Millions of Dollars and Thousands of Lives

By C. H. Claudy

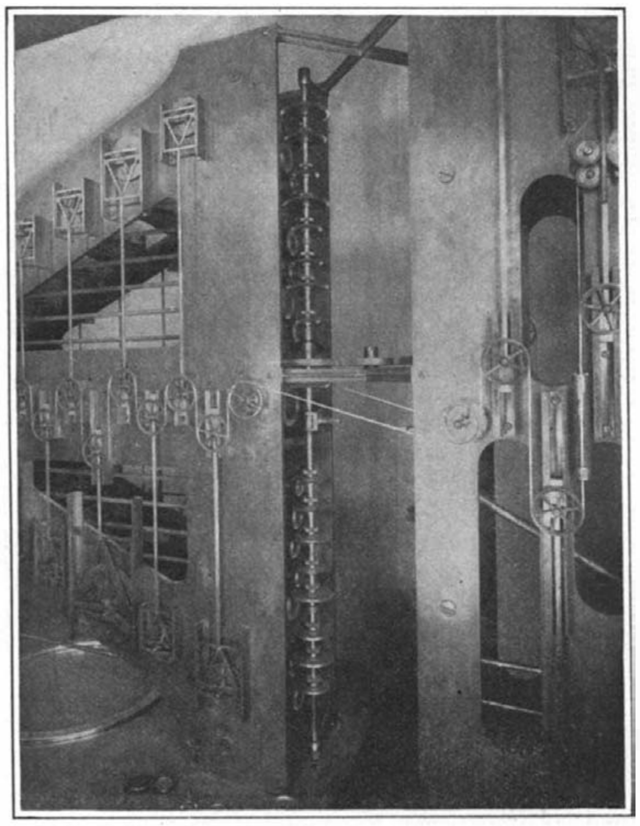
ROGER BACON, man of letters and of science, who lived in the thirteenth century, is supposed to have manufactured a brazen head or android, which spoke and revealed "dreaded secrets of the past and future." But no brass brain has come down to the present day from antiquity which can even think, let alone articulate through a brass mouth.

But a mechanism, built for these United States of ours, can truly be called a "brass brain," in that it does the mathematical calculations which would otherwise require a hundred flesh and blood brains to do; and if it does not actually articulate its results, at least it indicates them plainly enough, not only by dials, but by writing them down. Still more does it claim kinship with that ancient and fabled brass brain of Bacon's, in that it, too, foretells the future, though no "dread secret" does it make known.

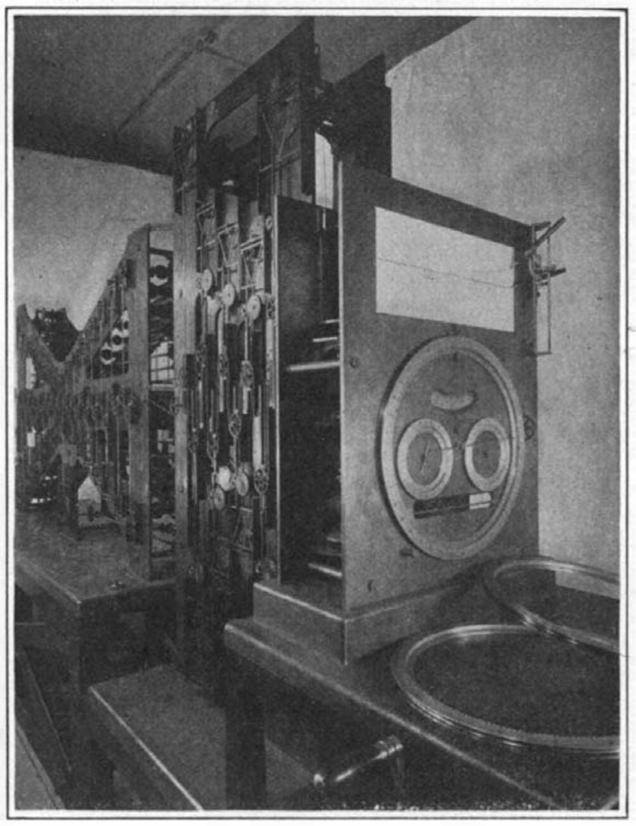
This introduction may seem fanciful—it is sober fact. The machine is known as the United States Tide Predicting Machine, Number 2. It is in daily operation in the United States Coast and Geodetic Survey at Washington. Its work is nothing less than the predicting of the times and heights of high and low tide, a year in advance. Its mechanism is of brass and steel, its house a huge mahogany and glass case, and its tender one observer, who does but sit and turn a crank until it stops, then copies off on paper the reading of several dials, and later removes from the machine a roll of paper on which is plotted the tidal curve for the particular spot along the coast, the tides of which have been predicted.

Every year the United States issues a fat book of Tide Tables, primarily for the use of its navy, and secondly for the use of all who go down to the sea in ships. This book of Tide Tables gives the time to the minute and the height to the nearest tenth of a foot of every high and low tide during the year for seventy of the great world seaports, and by means of an auxiliary table, the same information for 3,000 other places.

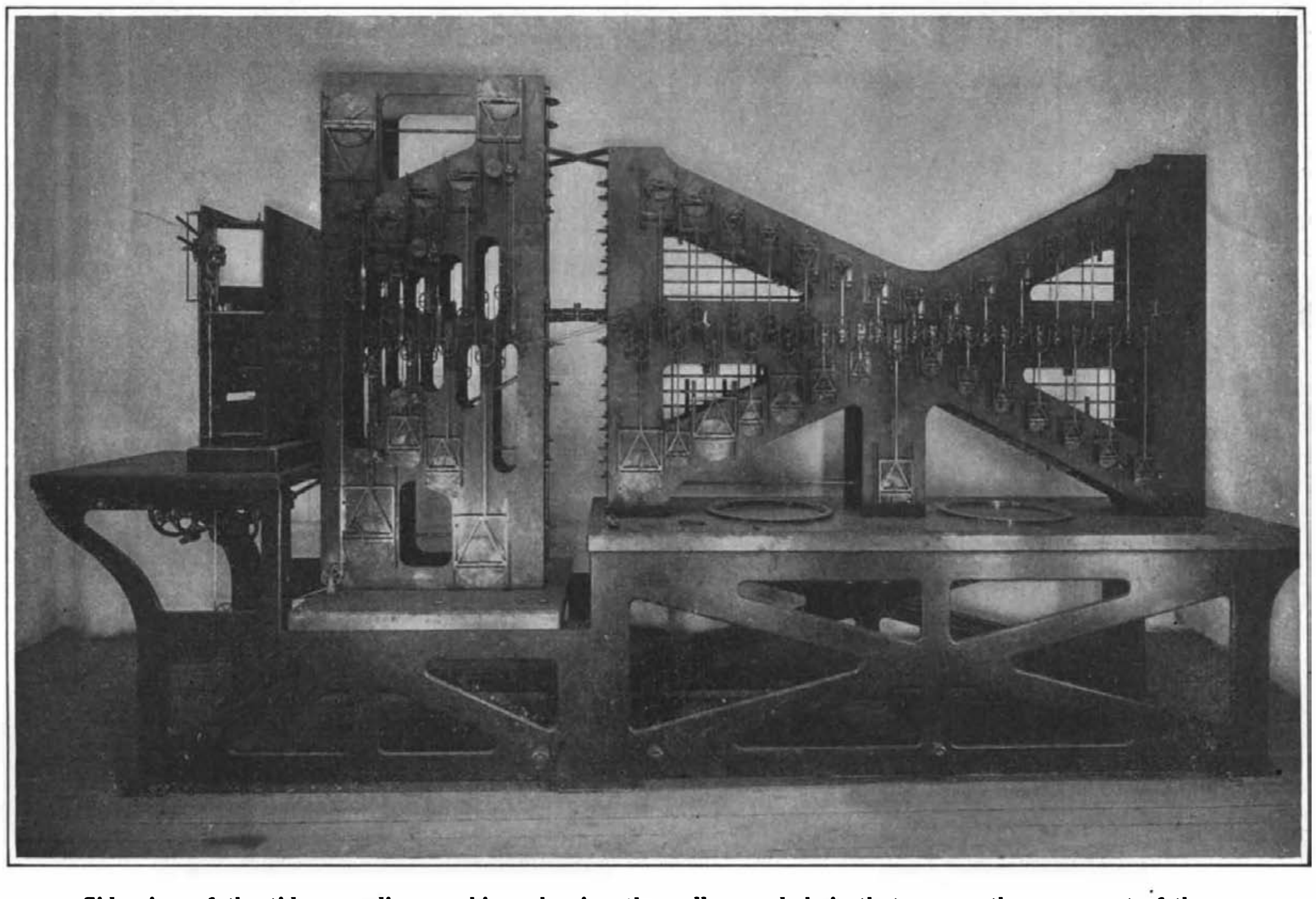
It is essential for the mariner to know when tide is high and when low, and the magnitude of the tide. The safety of his ship and the lives of all on the vessel may depend on that information being accurate and reliable. So that when it is a question of predicting for some day in the future, just when high water will be reached in New York harbor, or when low tide will occur in the Golden Gate, and just how high or how low the tide may be, you can be very sure that the machine which prophesies is an accurate if complicated machine.



Where tidal component differences are gathered together.



Front view, showing controls, dials and tidal curve plot.



Side view of the tide recording machine, showing the pulleys and chain that govern the movement of the pen.

That it is a wonderful machine may be imagined. It has over 15,000 parts, but so carefully is it made that lost motion is reduced practically to zero. Unlike the human brain, this one of brass cannot make a mistake. How wonderful this is, it is difficult to conceive without some knowledge as to how a tide is actually produced and how it would be predicted by the use of pencil and paper alone—the oldest way known, and also the longest and least accurate.

As most people know, the tides are the names we give to those periodical risings and fallings of the ocean which occur daily. They are produced by the action of the force of gravitation between the sun and moon and earth. The tides are thus the result of forces which come under observation of the astronomer, and it is astronomical data which is used in predicting a tide.

If the earth was a perfect sphere, covered all over with water to a uniform depth; if the earth went around the sun in a circular path with the sun in the center and the moon went around the earth with a perfectly uniform motion and if sun, moon and earth were always in the same plane, tide prediction would be a simple matter of mathematics; the heights of a tide for all ports in any one latitude could be made together.

But the earth is *not* a perfect sphere, it *isn't* covered with water to a uniform depth, it has many continents and islands and sea passages of peculiar shapes and depths, the earth does *not* travel about the sun in a circular path, and earth, sun and moon are *not* always in line. The result is that two tides are rarely the same for the same place twice running, and that tides differ from each other enormously in both times and in amplitude.

For many years tide predictions were made entirely by manual and mental labor, and because of the complication of the matter, but few of all the causes which enter into a tide were considered in actually predicting how high a tide would be, and when it would be in flood.

But Sir William Thompson, now Lord Kelvin, revolutionized matters when he devised what he termed a system of "harmonic analysis." It is evident that if a pencil be made to rise and fall as the tide rises and falls, on a vertical sheet of paper which moves under the pencil, a curve will result. It is also evident that if a sufficient number of observations are made to get rid of those tides which are late or early because of wind, or high or low because of freshets on land, the remaining tide curves, if averaged, will bear a definite relation to the actual tidal causes. Sir William Thompson found that he could analyze these tidal curves.

He began by imagining a fictitious sun, which moved evenly in a circular path about the equator at a uniform speed. The real sun doesn't move that way at all. But the theoretical sun, being a figment of the imagination, did as it was told. To this obedient sun was added another sun which moved differently, and still another moving still differently, and so on, until a very respectable number of imaginary suns were circling about the earth. These suns were all so calculated that the sum total of their attractions and movements equaled the sum total of the attractions and movements of the real, sure enough sun! Instead of having one sun in an irregular number of positions and distances, Lord Kelvin imagined a number of perfectly regular suns, which did what they were told as to unvarying motion, but which, when combined, equaled our own irregular sun.

The same thing was done for the moon; and behold a whole lot of definite, regular, undeviating mathematical factors, all together equaling the puzzling irregularities of our real sun and moon, but separately so well behaved that they could be used all the time as components of a mathematical equation which would demonstrate a tide.

All the most important of these theoretical suns and moons, or components of the tides, as they are called, were computed by Sir William Thompson and extended and improved by Sir George Darwin, brother of the great Darwin. Since that time, these components of the tide have been computed for practically all the important tide stations in the world and are common property.

It didn't take Sir William Thompson long to figure out that if harmonic analysis could predict tides from data gathered from an observed tidal curve, then the components which could be extracted from a given position of sun, moon and earth ought to be able to be put into a tidal curve. From this was but a short step to actually making the first tide machine, which took account of but ten components of a tide, but actually plotted a predicting tide curve.

This first tide predicting machine was followed at intervals by four others, two for England, one for France and one for Brazil. But conceiving a tide machine is one thing, making one practical, another, and all the various machines failed to take account of any great number of tidal components. Then came Prof. William Ferral of our own Coast Survey, who, in 1881, designed a tide predictor which was used by the Coast Survey for twenty-seven years. It was the first tide predicting engine to show on dials on its face the time of day, time of year, height of tide, etc. Instead of producing a tidal curve, it required only that an observer copy off the data to have it ready for the printer. All the other machines had traced curves from which a calculator had to work, digging out, literally by its roots, the data in numbers, from the curve in front of him.

The underlying principle of all these tide predicting machines has been the same—the summing up mechanically of a number of different motions, actions and reactions. The means is a slender chain, passing over pulleys, each of which is mounted on a shaft or crank. The crank is adjustable, so that it can be made more or less eccentric with the shaft itself. The degree of eccentricity represents the amplitude of the particular component (or imaginary sun or moon) of the tide under consideration. When the machine is operated, the various cranks revolve, and the chain which passes over them all is pulled upon by some and allowed to become slack by others. The movement of the end of the chain, then, becomes the sum of all the movements of all the components in the machine, each represented by a crank, adjustable on a dial.

By attaching the end of the chain suitably to a pen, and by having a moving sheet of paper beneath the pen, the machine traces the tidal curve. The principle of this mechanical summation is illustrated in the diagrammatic sketch, in which five component slides are shown. Reference to the photographs will show how these are operated; an adjustable steel crank-pin on each disk or wheel works in a horizontal slide in a light steel frame, an extension member of which terminates in a pulley, *C*, *D*, *E*, *F*, and *G*. Passing over and under these pulleys is the steel chain of the apparatus, one end of which is fixed (*A* in the diagram) and the other end of which is suitably connected with a movable pen *B*, which plays against a ribbon of paper that passes beneath it.

If we suppose the disks 1, 2, 3 and 4 in the diagram are fastened and stationary, and imagine a counterpoise weight connected to the chain beyond the pen *B*, then it is obvious that if the disk 5 revolves and at the same time the ribbon of paper passes from right to left under the pen, a true harmonic curve will be produced as in the line *ZZ* (of course the curve will be a solid line in practice; dotted lines are here used for clarity).

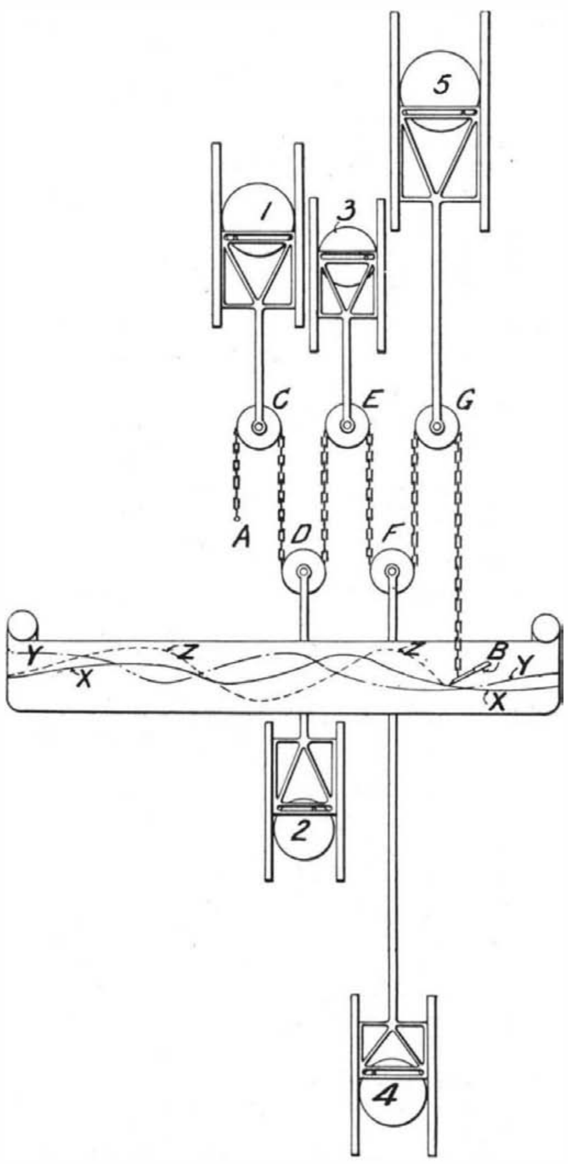
If now we suppose the disks 1, 2, 3, and 5 to be fixed and immovable, and disk 4 to revolve, another type of curve will be produced on the moving sheet of paper, as in the curve *YY*.

Now if disks 1, 2, and 3 be kept fixed and immovable, but disks 4 and 5 are permitted to revolve, then the curve traced upon the paper will be the sum of the two curves *ZZ* and *YY*, as shown in *XX*. If all five of the disks revolve, then the resulting curve will be the sum of all their curves individually.

If each disk in its speed of revolution represent the effect of motion of a lunar or solar component of a tide, and each crank on each disk is set so that its distance from the center represents the amplitude of such motion, then each disk, crank and slide truly represents a factor of a tide—the effect of one of the fictitious moons or suns, the sum total of the motion of which expresses the tide itself.

The Ferral machine was wonderful and accurate for a while. But it wore badly with years of use, its slender shafts were not sufficiently rigid to keep an error of torsion out of the results, and it was decided after twelve years that a new machine, better and quicker, more accurate, and more reliable, should be made.

Mr. E. G. Fischer worked upon the Ferral machine. Later he became Chief of the Instrument Division of the Survey. When it was decided to build a new machine, it was to Mr. Fischer that the authorities turned. He designed a new machine, and after the plans were accepted, went to work. Only such time as could be spared from the regular work of the Instrument Division was put into the new machine, which was fifteen years in building. But now it is finished, and stands forth as the most remarkable, most accurate and most complete machine of its kind in the world. It takes account of thirty-seven factors or components of a tide. It is truly American in its design, for not only does it do what all the foreign machines have done, plot a tidal curve by pen and ink, but it does also what the Ferral machine did—presents the results on dials for visual reading. It not only gives the times of high and low tide, but shows by a time line on the tidal curve sheet the hours, so that the state of the tide at *any* time can be readily computed.



How the curves are summed up mechanically.

The machine is entirely automatic, once it is set. The observer sits at the end, and turns a crank. When it will turn no farther the hands point to the day, the month, the hour, the minute, and the height in tenths of a foot of the tide. Pressure of a button in the crank releases it, and the next stop indicates the same data for the next tide. All the time the machine is doing this it is also tracing out the tidal curves, which are filed away for reference, so that should any question arise as to the figures as the operator takes them down, the machine need not be reset to get them over again; reference to the tidal curve will show all that the machine has shown.

The machine is two sided; one side has the tidal fluctuations to care for, the other, the time, so that when the prediction is made, it is complete. The copy, as it is made from the machine by the observer, goes directly to the printer, ready to be set up and printed.

Mr. Fischer strove long for some scheme by which a mechanical means of summation could be obtained which would eliminate a chain. Always he came back to it as the most practical. Every single thing about this wonderful machine was made by the Instrument Division (castings for the base are excepted) save the chain, which is fine chronometer chain, imported from England. To be sure that it was properly stretched, and worn and smooth in its actions, Mr. Fischer ran it in an endless belt form, over dozens of pulleys of all sizes, on the walls of his workshop, driving it eight hours a day by electric motor for months and months. It was bent in every link, not hundreds, but thousands of times, until, when it was put in the completed machine, it had done all the wearing possible.

As an instance of the extreme accuracy of the machine, Mr. Fischer told the writer of some tests which were made of it.

"We picked out two stations for these tests," said Mr. Fischer, "which we believed would most thoroughly test the machine because of the complicated nature of their tides. These stations were Aden, Arabia, and Hong Kong, China. For Aden we used thirty-five components of a tide and for Hong Kong thirty-three.

"We started the predictions at the beginning of a year and ran the machine until it had predicted the tides for almost the whole year at both these places. Not until then did we take a reading. Then we read the prediction for a given day. When we compared this reading, which had come after the machine had had a chance to add up infinitesimal errors through a year's predictions, with that of the most careful and accurate human calculation, we found a maximum error of 0.02 of a foot for the Aden tide, and 0.06 of a foot for the Hong Kong tide."

To do the same work in the same time, taking in the same number of factors or components, would require one hundred men. One wonders whether they would be anywhere near so accurate as the great brass brain.

The machine bears upon its face, by order of the Superintendent of the Coast and Geodetic Survey, the legend "Designed and constructed by E. G. Fischer." It is a monument not only to those men who went before—Lord Kelvin and Prof. William Ferral—but to the gentleman whose profound knowledge of mathematics, skillful ability in instrument work, and cleverness as a designer, made possible the greatest and most remarkable calculating engine in the world.

The Quantum Theory of Energy

THE old controversy so beloved of the Greeks as to whether matter is continuous or discontinuous is in our day definitely resolved in favor of the latter view. It is true that the ultimate particles of matter are considered to be something in the nature of local modifications of the ether, but nevertheless, matter as matter has a discrete structure. This tendency to atomize has now been imported into the conception of energy. At first sight it would seem that energy is something necessarily continuous, but it is found that this assumption leads us into serious difficulties. It is by examining the phenomena of heat and light radiation from bodies that scientific men have been led to adopt the remarkable hypothesis which postulates an atomic structure for energy.

When, by a process of strict reasoning from certain fundamental and well-established principles we arrive at an expression for the amount of radiant energy emanating from a hot body and existing in a unit volume of the ether, we have two very astonishing results. In the first place, experiment shows that the total amount of energy existing in a unit volume of the ether is distributed among the rays of different wave lengths in such a way as to be a maximum for a certain wave length (depending on the temperature) while our theoretically obtained expression does not admit of a maximum. In the second place, according to our formula the total quantity of energy would be infinite, a result which cannot be admitted. Planck, the great German physicist, was accordingly led to consider a radiating body as made up of a number of small bodies called resonators, the energy of which varies in a discontinuous manner. The total energy possessed by any resonator (which might be an atom of sodium, for example) at any time must be a whole multiple of some fundamental unit of energy. The atom of energy in any case depends upon the frequency of oscillation of the resonator and is, indeed, simply proportional to it. This very strange theory enables a formula to be obtained for the quantity of energy per unit volume of the ether due to radiation which agrees with experiment, possesses a maximum, and gives a finite value for the total quantity of energy. It was discussed before a distinguished audience at the last meeting of the British Association and promises to be of great importance in many branches of scientific investigation.