SALIENT FEATURES OF THE DESIGN OF A NEW TIDE-PREDICTING MACHINE

by Douglas L. PARKHURST
Chief, Instrument Division, U.S. Coast & Geodetic Survey

IHB Note. — Mr. Douglas L. PARKHURST, former Chief of the Instrument Division of the U.S. Coast and Geodetic Survey, died suddenly at his home in Bethesda, Maryland, on 12 October 1959, shortly after he submitted this article for publication.

Mr. PARKHURST was born 25 May 1893 at Amherst, New Hampshire. He was graduated from the Worcester Polytechnic Institute, Worcester, Massachusetts, in 1915 with a B. S. degree in mechanical engineering. His long career in the Bureau dated from May 1923 when he entered duty as a mechanical engineer at the age of thirty years. He had already served six years in other government positions.

His contributions to the development and refinement of instrumental equipment of the Coast and Geodetic Survey have been many and varied. He was the first Chief of the Instrument Section which was subsequently elevated to the level of Instrument Division. This vital aspect of Bureau operations was expanded and developed under his direction and as a result of his great inventive genius. His record comprises the development and refinement of new and improved equipment used throughout the surveying profession.

The Parkhurst theodolite which bears his name is one of his most noteworthy developments. In addition, he developed the vertical collimator, geodetic level rod, a photographic process for graduating geodetic level rods, the sounding engraving machine, plane-table alidade, seismograph recorder, tide gauge, a signal lamp for night surveying, and station markers. He also proved his inventiveness in patenting an electric time switch, a fuse for hand grenades and mortars, a horizontal-angle indicator, and an artillery bore-sight instrument.

Upon his retirement, Mr. PARKHURST left a highly trained, modern organization of thirty-eight employees who carry on the highly important work of providing the operational activities of the Bureau with the best possible instrumental equipment.

He had published various articles on scientific instruments and equipment in technical and scientific magazines. In 1950 he was awarded the Department of Commerce medal for meritorious service in recognition of his many contributions to the development of instrumental equipment. His place is secure among the many renowned scientists and engineers whose unselfish and devoted service to the Bureau and the Nation over a period of fifteen decades has contributed to the enviable heritage of the Coast and Geodetic Survey.

It is nearly 100 years ago that the first mechanical method for predicting the rise and fall of the tide was devised by Sir William Thompson

(Lord Kelvin), in 1872, although the idea had been suggested in 1845. Several such machines were designed and built by the British between 1872 and the early 1900's, and in 1882 the first American predictor, designed by Professor William Ferrel of the Coast & Geodetic Survey, was built by Fauth and Company of Washington, D.C.

This machine was used until 1910 when a second machine, designed and built cooperatively by Dr. R. A. Harris and Mr. E. G. Fisher, both members of the Coast & Geodetic Survey staff, was completed in the Bureau's shop and put into service.

This new predicting machine was far more elaborate and comprehensive in its action than any such device previously constructed anywhere, having a total of 78 component units, representing 37 harmonic constituents of the tide-producing force due to the sun and moon. An innovation was provided for drawing a trace on paper representing the predicted stages of the tide with respect to time. These and numerous other features, plus design and construction with a view to long, trouble-free operation by use of the best materials and construction techniques then available, resulted in a machine that has amply justified its maker's efforts, the predictor having been used continuously for 49 years. It is still in good condition with only minor repairs having been required to date.

However, these same 49 years have seen tremendous advances in the kinds and qualities of materials that are available, and improvements in the mechanical arts make possible accuracies in the forming and finishing of machine parts undreamed of in 1910. Experience in the operation of the tide predictor has indicated various desirable changes which would improve its operation and convenience, consequently, these and other considerations led to the decision by the Coast & Geodetic Survey to undertake the design and construction of a new machine which would be up to date in every respect.

An important consideration was the factor that not only are all the predictions for the U.S. and its possessions performed by this one machine, but a number of other governments rely upon the U.S. to make predictions for them as well, consequently any accident which would render the predictor inoperative for a prolonged period would be a serious matter. It was evident that a second machine was needed to provide insurance against such possible shutdown.

The problem of acquiring a new predictor had been under consideration for some time but funds had never been available for construction by contract nor did it seem likely that they would be in the near future. This led the writer to suggest to Captain H. E. Finnegan, then Chief of the Division of Tides and Currents, that we undertake the construction of the machine in the Instrument Division's shop using such funds as the two divisions might have that could be assigned to the purchase of parts and materials; the work to be performed by our instrument makers as opportunity permitted. This, we realized, might be a rather long drawn out project, but better that than no progress at all.

We presented this plan to the Bureau management, who wholeheartedly approved the idea, and immediately made available sufficient funds for purchase of the special gearing required for the machine's operation.

The matter of the type of machine to be built was thoroughly discussed by the technical staff, and the decision was finally made to follow the mechanical principles of the older predictor, redesigning various elements in keeping with modern materials and practices, and incorporating the modernizing features indicated by our experience with the older instrument. This type appeared to be materially less expensive than others, and the reliability of its design had been proven through long service.

The purpose of this article is to describe the new machine, which is about 75 % completed at this time, and emphasizing the features which are major improvements over the older predictor.

Beginning with the base, the rise of welding as a method of construction led to the adoption of a base made as a weldment of structural steel. Cast iron had been used originally, but today proved to be not only very costly, but difficult to obtain as a specialty. By using steel the base was materially lighter and decidely less expensive. The main body of the base consists of a heavy structural channel, machined on the back surface, with supporting legs of large-diameter steel tubing. Feet of steel plate are provided, all assembled as a unit by welding. The front end of the base is also of steel angles and plates, carefully machined and bolted together.

The side plates, upon which are mounted the gearing and other moving elements, are made of specially rolled and leveled naval leaded brass alloy, to provide dimensional stability and ease in machining. Stability is particularly important because of the many bearings and other elements which have to be closely fitted and aligned.

The gearing, which determines the movements of the various elements, may be considered to be the heart of the instrument. There are 244 gears, mostly of the bevel type, and hardly any two pairs are alike in size and number of teeth.

The new gears are of stainless steel, with teeth generated to true form, so that contact on all gears is across the full width of the tooth, and movement is pure rolling. As many of these gears must be releasable, for turning with respect to the shaft when adjusting the predictor, a clutch mechanism is built in.

The machine has a rather elaborate system of stainless steel shafting, and modern ball bearings have been used throughout to reduce the frictional load to a minimum.

One of the most decided departures in design from that of the older predictor is in the components. These are alike in principle, although varying considerably in size and in some details of arrangement. The component consists essentially of a crank, a crosshead, a tubular stem and an epoch dial.

The cranks, which are located at each end of a gear-driven shaft have an adjustable crankpin, so that the *throw* of the crank may be set to conform to the requisite amplitude, as derived from observational data obtained at the station for which predictions are to be made.

The crankpin engages a slot in the crosshead, another element of the component, imparting a reciprocating motion to it, the amount of travel varying with the setting of the *throw*.

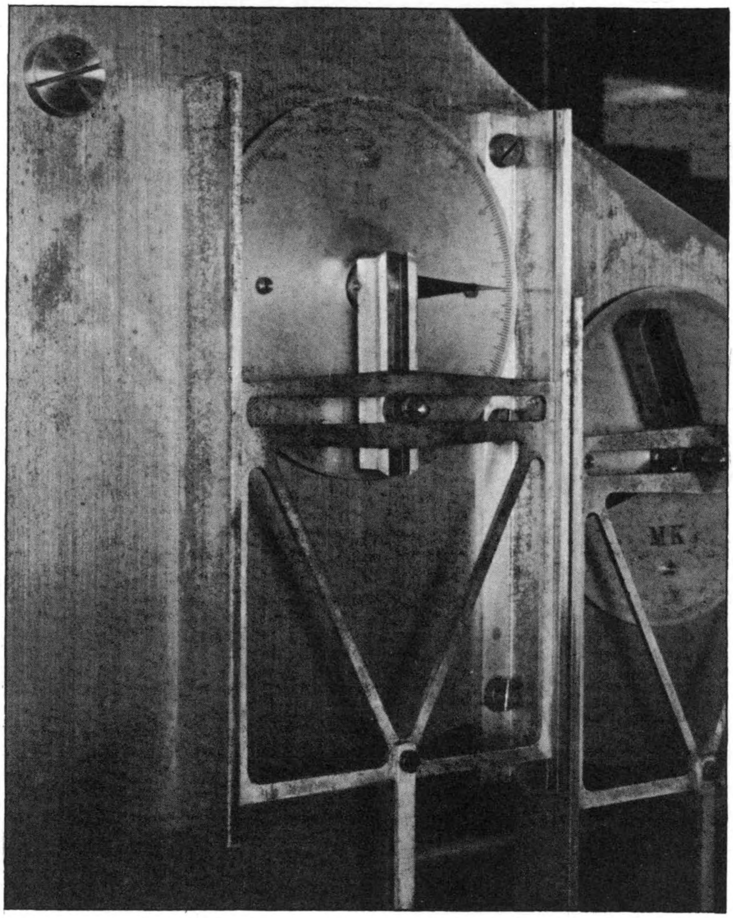

Fig. 1

To the crosshead is permanently attached a tubular member, whose length depends upon the particular component and its location on the machine. This tubular element carries a free-turning pulley, or sheave, at its lower end, over which passes the summation chain, which in turn actuates time- and height-indicating and recording mechanisms.

The accuracy of action of the gearing and the units of the components determines the overall accuracy of the tide predictor. Every effort has been made to achieve lasting perfection in the design and construction of these parts.

Beginning with the crank (fig. 1), in the 1910 machine, no positive mechanical means was provided for exact setting of the throw. The crankpin element was loosened, slid along a slot in the crank, and then clamped. With this method exact positioning requires considerable care, as the act of clamping may disturb the setting. In the new crank (fig. 2), which is largely made of stainless steel, the pin element is moved to its correct position by a long lead screw, which holds it in place during clamping.

In the 1910 machine, emphasis was upon keeping the mass of the reci-

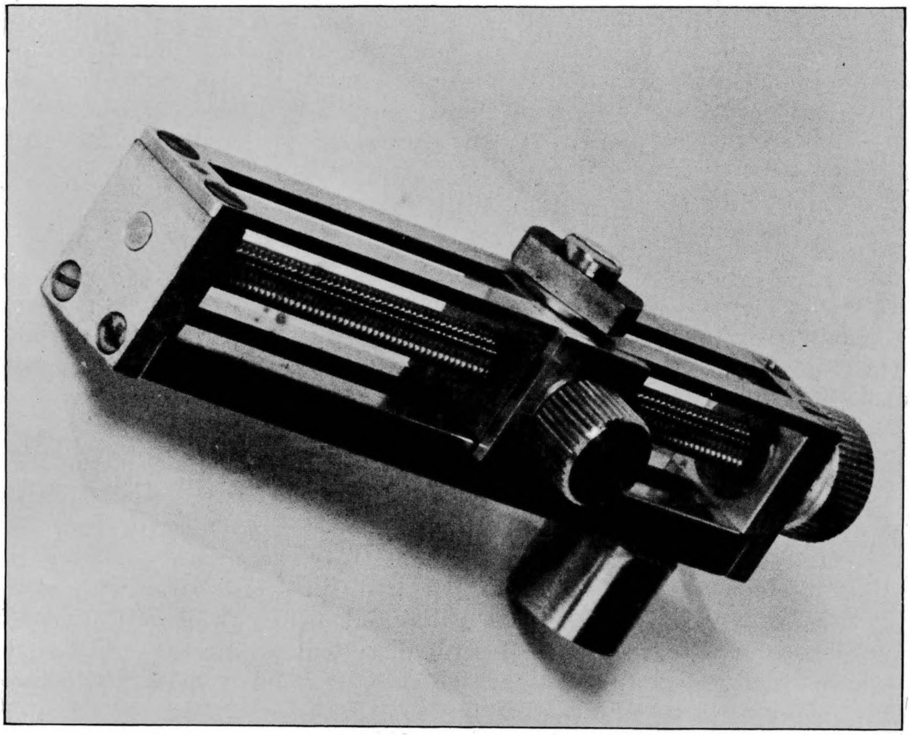

Fig. 2

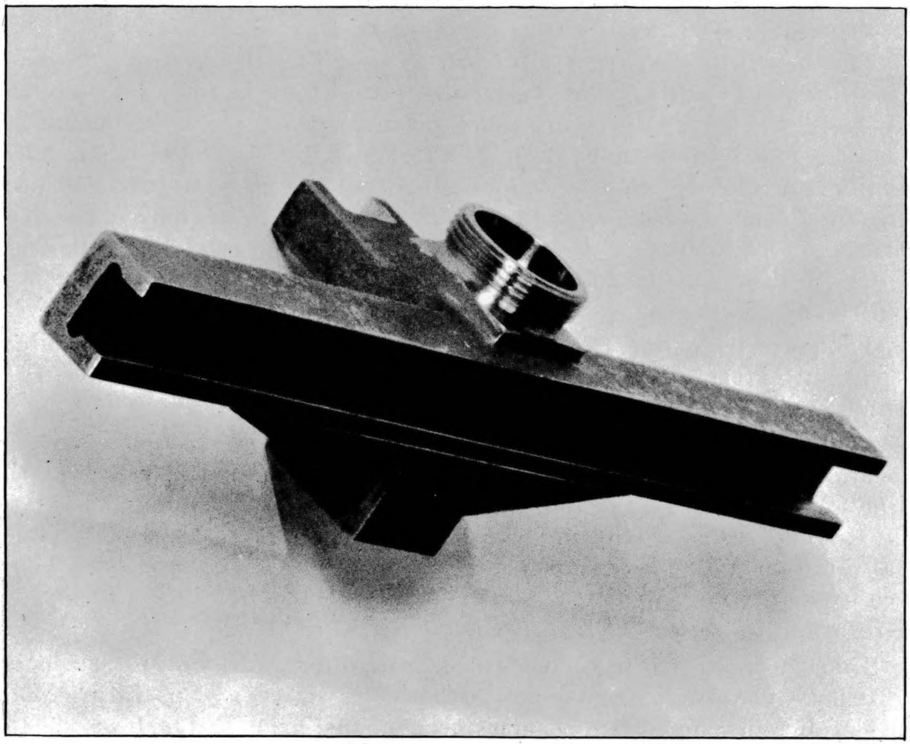

Fig. 3

procating parts of the component at a minimum, and one of the principal elements was the crosshead (fig. 1). This was formed from thin sheet steel, laboriously cut away to a rather flimsy grillwork pattern by drilling and hand filing. As there were 78 of these crossheads, their manufacture by this method was slow and costly. The raceway for the crankpin had to be carefully cut to size, with the bearing surfaces held closely to parallelism, and normal to the line of motion of the component.

In the new machine, the crosshead (fig. 3) is a precision casting of stainless steel. Castings made by this method can be held closely to size; only a comparatively small amount of machining is required, such as boring the central hole for assembling the tubular stem, and grinding the parallel surfaces of the crankpin raceway. All are machine-tool operations. With this method of construction, assembling the tubular stem so that it is normal to the crankpin raceway was no problem.

In the 1910 predictor, the crosshead, and that portion of the stem carrying the summation wheel, runs in slotted guide bars mounted on the frame of the machine. The slots must be carefully aligned in order that there shall be no binding in the movement. This was another tedious and costly job which has, to a considerable extent, been done away with in the design of the present machine. The guiding element is a smoothly ground stainless-steel rod, over which the tubular stem is carefully fitted, the assembly being attached to the machine by brackets. Any tendency towards binding is easily overcome.

One additional component change was made and while this is of a minor nature, it adds materially to the operator's convenience when setting the machine.

The epoch dials on the 1910 predictor were of silvered brass, fastened to the side plate, with a pointer attached to the shaft, sweeping around the dial. Lack of contrast, growing more pronounced as the silver tarnished with age, made these dials difficult to read. Consequently in the new machine the dial is made of anodized aluminum alloy, the background being dyed black, with lines and figures in white. The anodized finish is permanent, the color fast and excellent contrast. The relation of dial and pointer is reversed, the dial being mounted on the shaft, turning past a fixed reference line.

The entire component is easier to build and assemble to the machine; its parts are sturdier, and setting and reading are easier than in the 1910 predictor.

Changes are planned for the recording end of the machine, such as relocating the large dials and sweep hands, presently mounted on the face of the machine, behind the face plate with windows cut through to expose only those portions of the dials which are to be read. This will reduce to a minimum possible confusion in reading. Consideration is also being given to the use of mechanical counters in place of dials, which will present the information to the operator in linear form.

Takeoff shafts will be incorporated to permit attachment of such automatic data-recording mechanisms as may be selected at a future date, considerable development of such mechanisms being carried on at the present time.

The present designers and builders are following the precepts of their predecessors, by using the best materials and methods available and constructing the machine with the highest degree of skill at our command. We hope, and fully expect, to complete a machine which will be as representative of today's design and manufacturing capabilities as did the 1910 predictor in its day.