SOME RECENT SYSTEMS DEVELOPMENT
BY U.S. COAST AND GEODETIC SURVEY

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Systems Development plays a major part in the research and development programs of the U.S. Coast and Geodetic Survey. The general purpose of this phase of research and development is not only to develop new means of collecting data at sea and on land, but to collect oceanographic and geophysical data more efficiently, and to process these data more rapidly. Another purpose, equally important, is to develop higher quality in instrumentation measurements through calibration and standardization.

Of the systems thus far developed by the Coast and Geodetic Survey that shall be discussed, all are beyond the planning stage and have been laboratory and field tested; some are in the test and evaluation stages; and in such cases where redesign is indicated, the program has not been completed.

Hydrographic Data Processing

The U.S. Coast and Geodetic Survey, as with many other hydrographic agencies, found that the rate of collecting survey data far exceeded the means of processing, thus resulting in a large backlog of data.

In 1959, the U.S. Coast and Geodetic Survey initiated a study program through which the processing of data could be kept abreast of the data collection and thus help reduce the backlog. Briefly this program aims :

(*a*) To reduce all hydrographic data collected on the ship to punched-paper tape while the survey is being conducted.
(*b*) To provide means of converting data from sounding volumes of completed surveys to punched-paper tape.
(*c*) To provide means of adding data, such as tides, (not available at the time of the survey) in a suitable form for machine processing.
(*d*) To process these data through a land-based computer.
(*e*) To plot the smooth sheet by means of a high speed precision plotter.

Two systems have been developed to record the shipboard data. One is called the Automatic Hydrographic Digital Logger; the other is known as the Semi-automatic Logger. The Automatic Logger is connected directly to all the sensors necessary on a survey vessel — the clock, echo sounder and navigation system being the most important. The logger is programmed to read all these sensors at prescribed times and present these data on an electric typewriter which also has a built-in punch-paper recorder. In addition to the punched tape, a typewritten record is made of all data as they are recorded. These recordings are used to plot the boat sheet during the survey operation. Supporting information can also be entered on the typewriter keyboard.

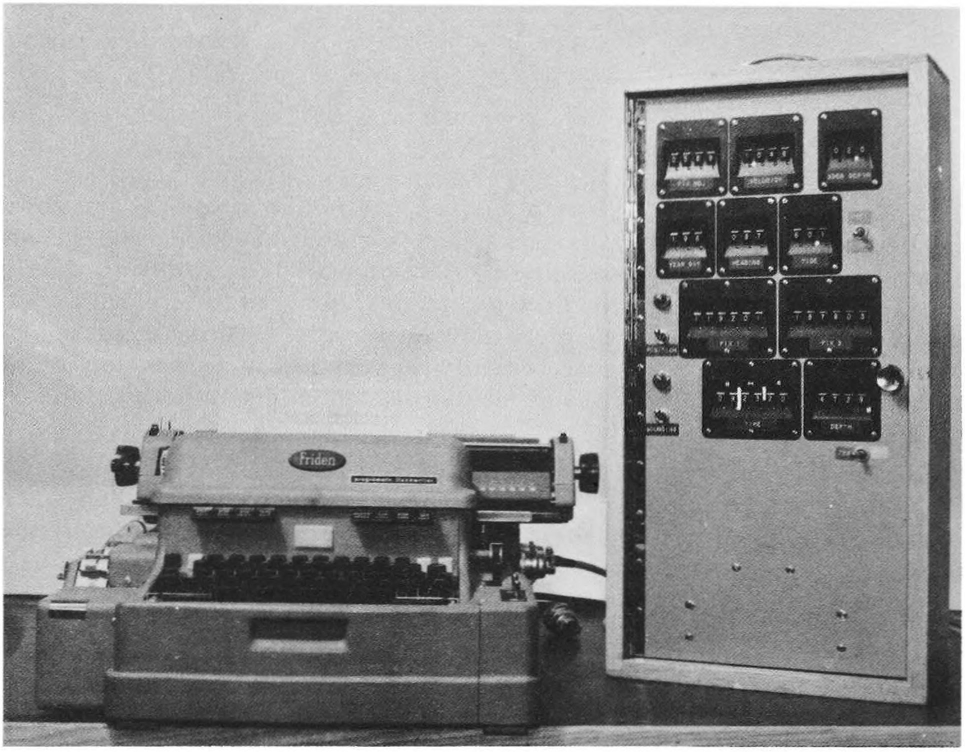

FIG. 1. — Semi-automatic Logger. The parameter board on the right is for entry of hydrographic data. Other supporting data may be entered on the flexowriter keyboard or from the tape reader on the right. The flexowriter in addition to printing all entries contains a paper tape punch, appearing on the left.

The semi-automatic logger, figure 1, is far simpler and less expensive. It requires that all data be entered by controls on its front panel, called the parameter board. When using the survey technique employed by U.S. Coast & Geodetic Survey, time and echo sounding values are the most frequently entered variables, position and position-identifying numbers being entered about one fifth to one tenth as frequently. Readout is on demand. When the sounding switch is pressed, only time and the sounding values are recorded. When the position switch is pressed, all values on the parameter board are recorded. There are interlocking circuits to prevent operator error in neglecting to advance time and position numbers. Only switches, relays and stepping switches are used in this logger. Recordings are on an electric typewriter with attached paper punch similar to that used on the automatic logger.

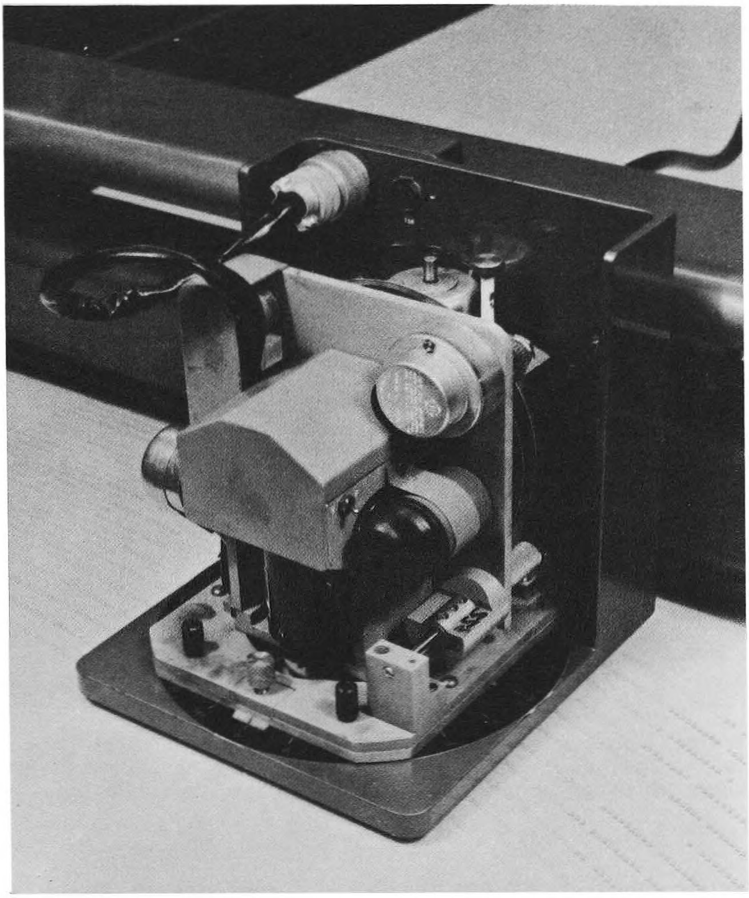

FIG. 2. — Plotter Head. The head may be orientated to print at any angle.

Data from the survey ships in the form of punched-paper tape and a copy of the printed data are sent to a central plotting area, which is now located in Washington, D.C., but will be located in Seattle, Washington, and Norfolk, Virginia.

There are two principal components in the plotting area, an IBM 1620 computer and a Gerber precision plotter, figures 2 and 3. The paper tape is fed into the computer and appears at the computed output processed on IBM cards. The computer corrects sounding data and computes the position data in a suitable form for the projection used in plotting. The conversion of tape to cards was selected because cards are easier to edit than tape. These cards are then put into a reader which operates the plotter.

The plotter is capable of plotting sheet sizes up to 45 by 60 inches. It will print up to four-digit figures in two type sizes. There is a choice of printed symbols, plus a stylus which pricks an inked hole through the paper.

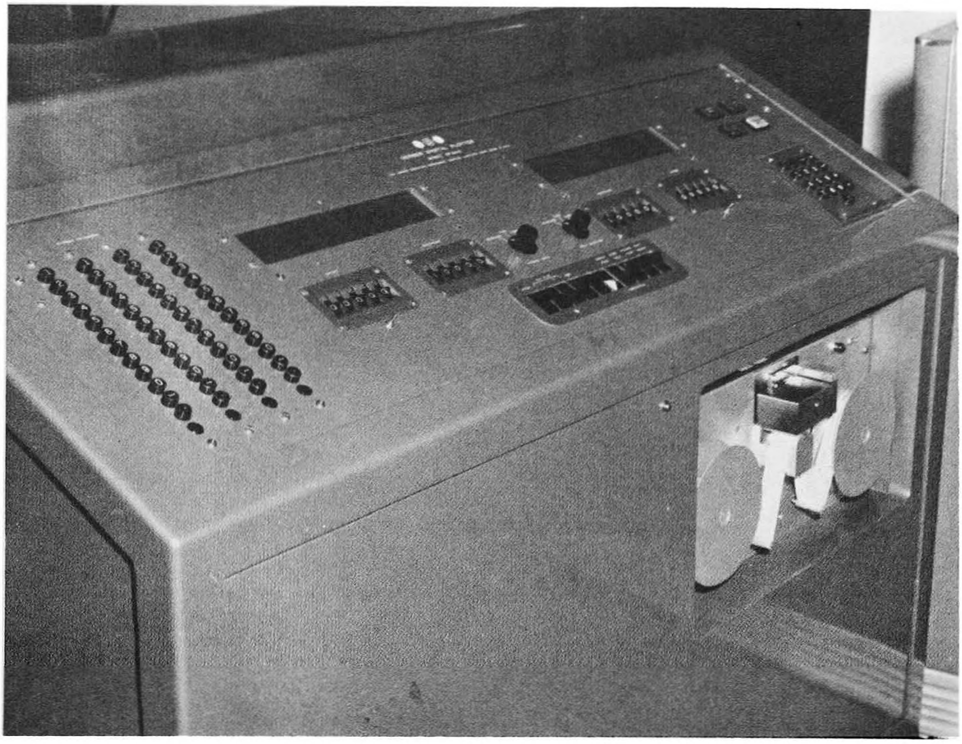

FIG. 3. — Plotter Control Panel. Controls on the left manual operate the printer head and those on the right position the head. The plot may be off set in both X and Y. Also, the plotter scale may be multiplied up to 10. Paper tape data input or card input may be used.

The accuracy of printing has been demonstrated to be within five thousandths of an inch over the entire plotting area. The plotting speed is about four seconds for a four-digit number and, roughly, proportionately less for smaller digits.

One Coast Survey ship has been using the Automatic Logger for two survey seasons. During the last survey season, all data were recorded on punched tape. It is planned to machine plot all the data from these surveys. Figure 4 is an example of part of a machine-plotted survey.

Semi-automatic loggers, now on four Coast Survey vessels, were used experimentally for a few months at the close of the 1963 survey season. It is planned to use them more extensively in the 1964 season. Besides being less expensive, the semi-automatic logger has other advantages over the automatic system. It may be used for editing purposes to cut new tapes when correcting or adding data. This logger has also been used to convert completed surveys into a form suitable for machine processing. There is a considerable saving in time and energy to convert data from a sound volume into punched-paper tape, compared with hand plotting.

While many of the instrument problems have been resolved, problems still remain in the processing of data and in cartography. Another year may be required before the computer-plotting systems are fully operational.

About the same period of time will be required to automate all the major survey vessels. It is difficult to predict when all survey parties, large and small, will have their data recorded in machine form.

Two new oceanographic vessels, now under construction, will have a complex logging-computer system. All data such as hydrographic, oceanographic, magnetic, gravity, and meteorological will be in a form for machine processing, or processed data will appear at the output of its computer. Allowances are being made for logger-computer failure by use of an alternate recording system to store data until the logger-computer is once more operational.

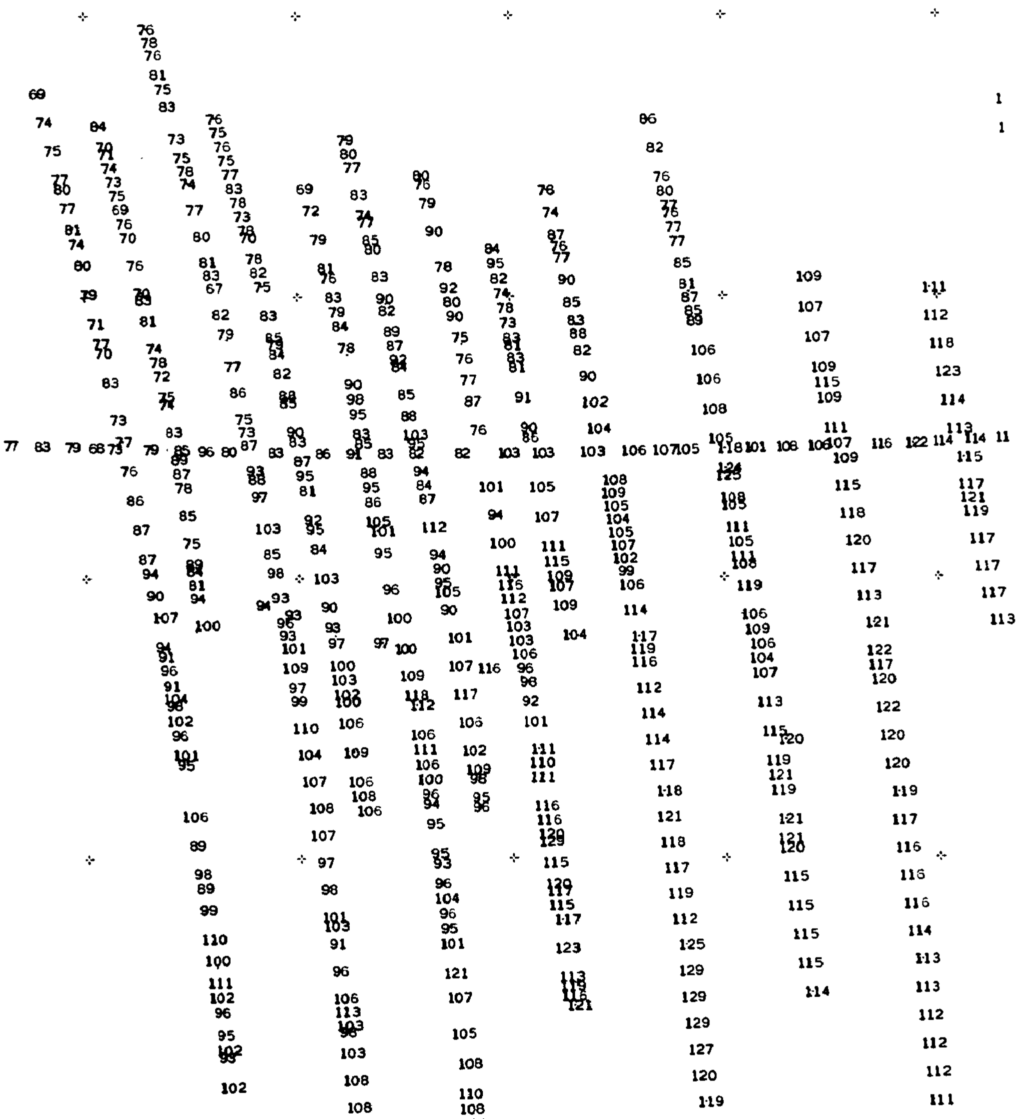

FIG. 4. — Smooth sheet machine plotted.

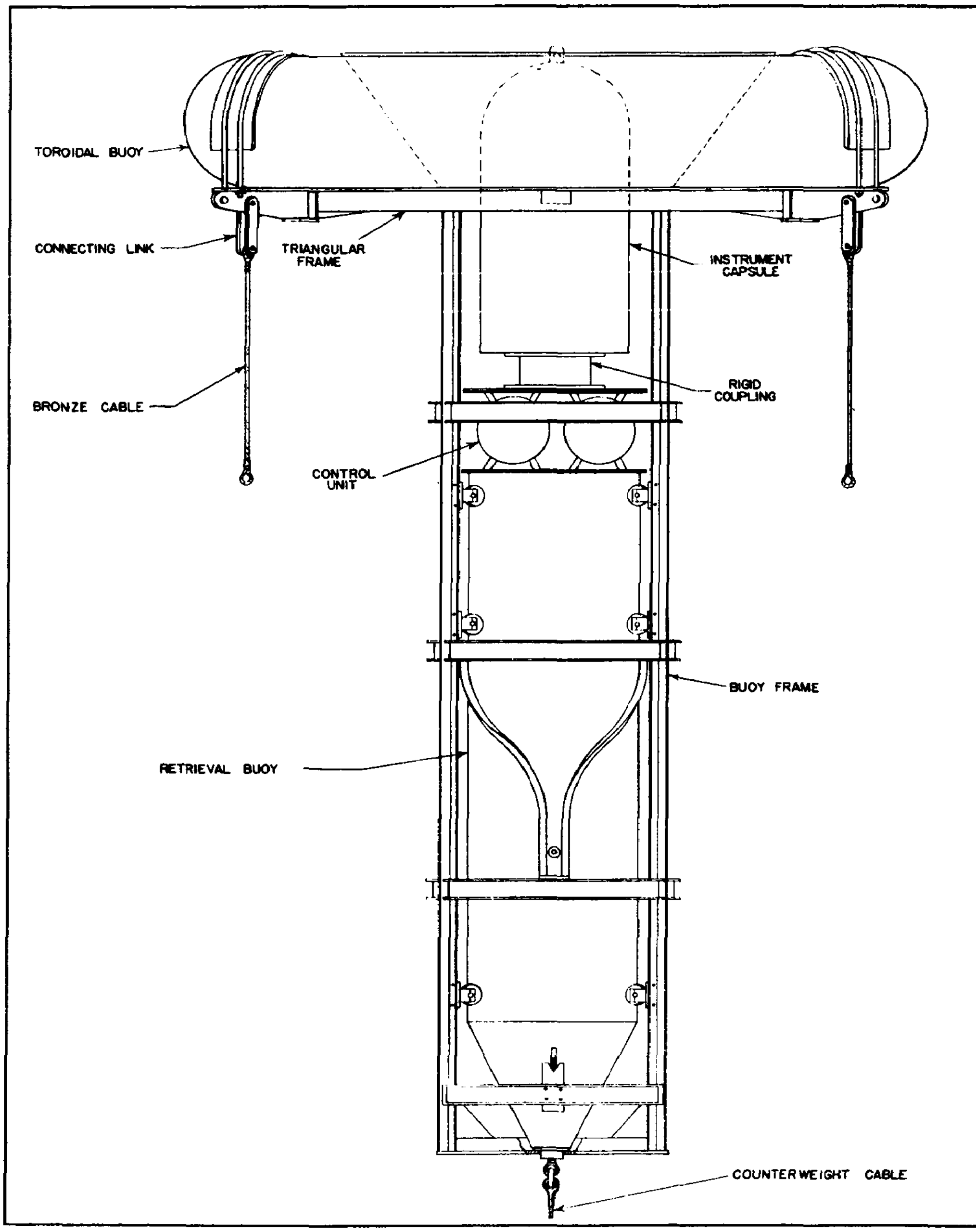

FIG. 5. — Stable Platform.

Stable Platforms

The Coast and Geodetic Survey has just completed the second phase of a three-step program to evaluate stable platforms at sea. Such platforms, when properly instrumented, can be of considerable value in collecting oceanographic and other data over long periods of time. Such data might be prohibitively expensive or impossible to collect by means of ships. Much of these data can be used to support the vessels' oceanographic program.

Some measurements, in order to be useful, must be made on a platform which remains fixed, in the ocean space, regardless of environmental changes; the measurement time variations of the components of the earth's magnetic field being an example of one of the most critical.

There is little disturbance by the sea surface activity at depths greater than 100 feet below this surface. It was decided that the stable platform package was to be tested in this region. Consideration was first given to bottom measurements but was set aside for these reasons, the difficulties in instrumentation when measuring tides and waves in deep water; also, magnetic measurements at the bottom may not be typical of those near the sea surface and such a system does not easily provide for intermediate measurements between the sea surface and the bottom.

The first test of the stable platform program was made in relatively shallow water of 500 feet. All the instruments aboard the platform were intended to measure the platform stability. The platform was stationed about 100 feet below the sea surface by means of three-way anchoring system 120 degrees between the legs.

This system can be considered as being an assembly of three parts : the anchoring system, flotation part, or buoy, and the instrument capsule. The instrument capsule nests into a socket in the buoy and may be brought to the surface and returned to the buoy at will. Figure 5 is a picture of the buoy.

The first instrument capsule contained a single component magnetometer recorder and mutually perpendicular level vials. The magnetometer was intended to indicate rotation of the platform and the level vial indicated tilt. All this information was recorded on strip chart recorders. The magnetometer readings were correlated to those of a magnetometer recording on a nearby island. No means for measuring the vertical motion of the buoy was provided at this time.

Results of these tests indicated that the platform remained stable in tilt and rotation to better than one degree in this water depth, and under the moderate sea conditions encountered. These results were sufficiently encouraging to advance to the second phase of the program—that is, to place a more completely instrumented stable platform in deeper water and to study the motion of the platform as a function of time.

Next the platform was stationed about 100 feet below the sea surface in 4 200 feet of water. The new instrument capsule contained, in addition to a magnetometer and level system, a pressure tide gage and an inverted echo sounder intended to measure both tides and surface waves. In addition, it is possible to record on the surface; most of the data being recorded in the capsule below. It is also possible to orientate the magnetometer and

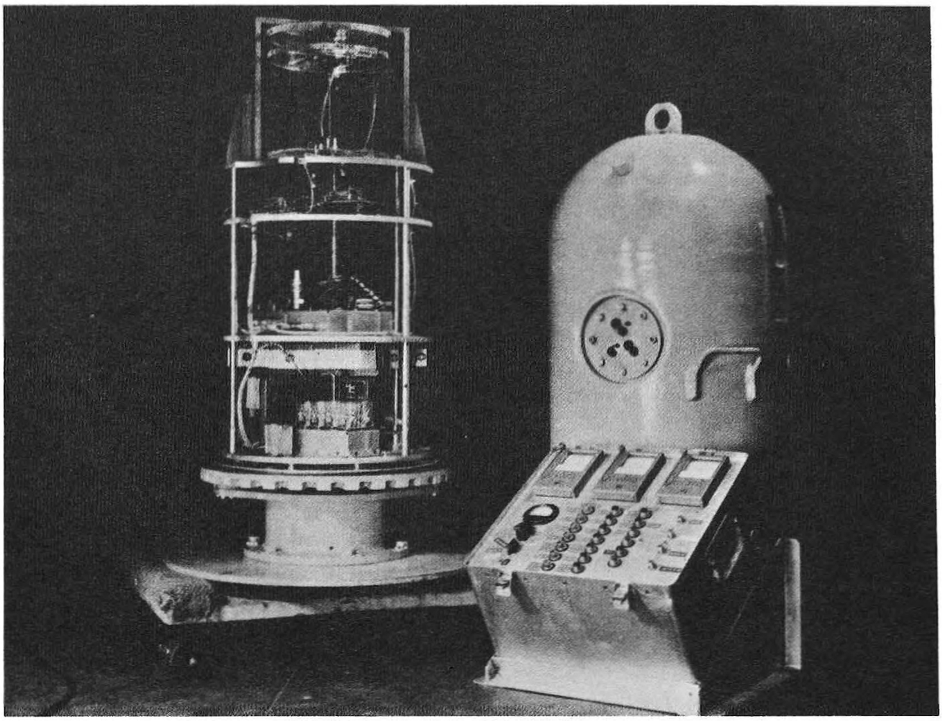

FIG. 6. — Instrument Capsule. Experimental instrument capsule used on the stable platform. This unit contains a magnetometer and electronic levels. The surface control unit — on the right — used in the initial adjustment of the submerged unit and surface monitoring.

change the sensitivity of the levels from the surface. Thus, it is possible to monitor the data without recovering the instrument capsule.

The results of the deep water tests were equally encouraging. During the test period it was learned that the platform rotation did not exceed $\pm$ 1/2 degree, nor the tilt more than $\pm$ 1/2 degree.

There are indications that the vertical motion of the buoy is slight by the very good correlation between tide measurements made from the platform to that of a predicted tide in this area.

While the system was in operation for over two months, very little long-term data were obtained because of the failure of the fiberglass, polyurethane-filled float which saturated under continuous pressure. Tests were also made with single and two-wire anchoring systems in 4 200 feet of water. Such anchoring systems are not sufficiently stable for magnetic observations, but reasonably good tide and wave records were made from these platforms.

The final phase of this program calls for stationing a platform in 2 000 fathoms of water. It is to have a three-component magnetometer, tide and wave sensors, temperature and current measuring devices. Tsunamic wave detection is also being considered as part of this program. It is hoped also to learn more of the platform behavior under severe storm conditions. In previous operations surface wave heights were not known to exceed ten feet.

Offshore Tide Gages and Wave Measurements

Most of what is known about offshore tidal behavior is predicted from tide measurements on the continental shore lines and on ocean islands. USC & GS has a program to develop offshore tide gages to add to the general scientific knowledge of such waves and, in some cases, to improve the accuracy of hydrographic surveys.

For the past year and a half a pressure tide gage has been under test which seems to meet accuracy requirements as a bottom recorder instrument to depths of 1 000 feet. The present program does not call for a system development for a bottom sensor in deeper water because of the promising results in the measurement from the stable platform. The instrument to be described was also part of the instrumentation on the stable platform.

An effort has been made to keep this system as simple and rugged as possible. It was made up largely of off-the-shelf components. The design novelty is in the method of obtaining an expanded scale within the linear range of the transducer.

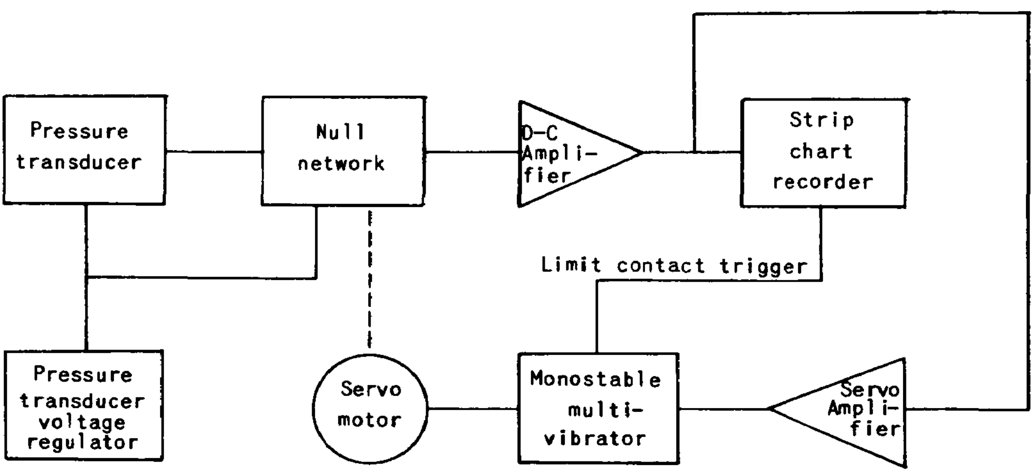

Fig. 7. — Block Diagram of Offshore Tide Gage.

With reference to the block diagram in figure 7, this system functions as follows : a high quality strain gage transducer, arranged in a bridge circuit, supplies its signal to a highly stable DC amplifier which in turn drives a strip chart recorder. At the high and low scale of this recorder are limit switches. These switches, through the proper circuits, drive a small motor which turns a potentiometer, generating a voltage to cancel the transducer output voltage so that the amplifier input is essentially zero. This voltage is referred to as the bucking bias.

With some foreknowledge of the approximate tide range the amplifier gain is set to give a range on the recorder which will include this predicted tide range value. As an example, if the tide range is expected to be 6 feet, then the scale range could be made 10 feet. As the gage is lowered, the recorder moves to the upper limit of its scale; and when the limit switches

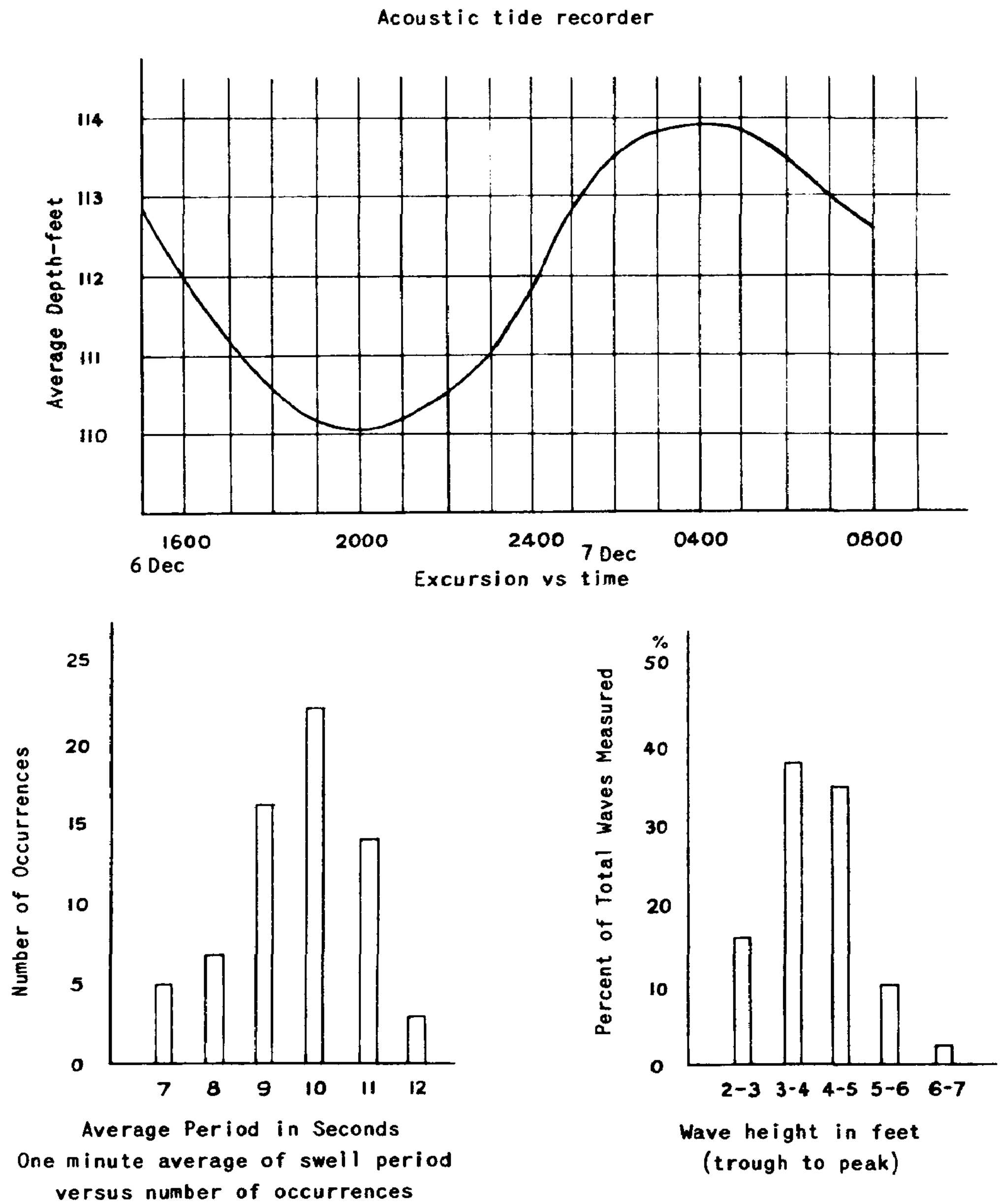

FIG. 8. — Measurements of tides and surface wave characteristics from the stable platform in 4 200 feet of water.

close, the bucking bias is applied to bring the recorder back to about center scale. Thus, the recorder will give a sawtooth record of 5-foot increments (continuing the above example) until the bottom is reached. The system is then in balance. The system is now ready to record tidal changes.

There is a surface control circuit to adjust and monitor the operation during the lowering and while the gages are on the bottom. A second surface pressure transducer has been used to remove the variations due to barometric pressure. The circuit arrangement is such that the final tide reading is corrected for barometric pressure. However, in the interest of simpler circuitry, barometric observations are most often made on the ship when it is operating in the area and corrections applied as a later processing.

This gage is presently designed to operate for a period of 50 days. It has been tested in the Chesapeake Bay, on the stable platform, and in the Atlantic Ocean.

During the 1964 season it is planned to run simultaneous tests from three gages in 30 feet, 200 feet, and 750 feet.

As a companion project an inverted echo sounding system was assembled, as a comparison to the pressure system, in depths that do not exceed 200 feet. An inexpensive graphic recording echo sounder was modified for this purpose.

The principal modifications were to the paper drive speed and keying mechanism. A precise programming clock was added to turn the instrument on at a prescribed time for a fixed period. For tidal measurements it is only necessary to sample for about 20 seconds every 15 minutes, thus conserving paper and power. The acoustic frequency is near to 200 kilocycles, which gives a narrow beam for the transducer size.

This inverted echo sounder has advantages over the pressure system in that it may also be used to measure surface wave heights. This was accomplished by reprogramming the timer to remain on for a period sufficient to allow several wave patterns to appear before the shut-down period. The paper speed was greatly increased, so the characteristics of the wave form can be studied. It is also possible to extract the tidal information from these wave records. The combined graphs in figure 8 show wave measurement and tides from the stable platform which was stationed in 4 200 feet of water. The bar graphs illustrate wave heights and periods over the period of observation.

The next wave and tide system planned for the stable platform will use transducers with total beam width of about 4 degrees to give a better delineation of the wave shape. An attempt will be made to distinguish this direction of wave patterns by means of multiple directed beams.

Echo Sounding

Two development projects in echo sounding by the U.S. Coast and Geodetic Survey are : the modernization of shoal water echo sounding instruments, and systems developments for accurate deep water sounding.

The specifications for the shoal water instruments are generally as follows :

(*a*) To operate from 115 volts 60 cycles.

(*b*) An optional built-in tuning fork dc to 60 cycle converter supplied from 12 volts or 24 volts dc.

(*c*) When using converter the frequency, and hence the stylus speed accuracy, to be better than 0.005 percent. Tuning fork may be easily replaced by a plug-in module which permits adjusting stylus speed to correct for velocity of sound in water.

(*d*) Choice of acoustic frequency of 20 kilocycles for general sounding, or 200 kilocycles for more accurate bottom delineation in shoal water. This is accomplished by the exchange of plug-in transmitter and receiver units and transducer.

(*e*) Depth range to 250 feet or fathoms in 6 phases.

(*f*) Rugged construction and a large safety factor in the design of all electronic circuits, and simplicity in adjustment and operation. The stylus to be a long continuous wire adjusted in fixed increments by means of a knurled feed screw.

(*g*) May be used with either magnetostriction or barium titanate transducer. All older C & GS ships have permanently installed magnetostriction transducers. There is a choice of four types or sizes of barium titanate transducer to best suit the size and mission of vessels.

The construction of a prototype was contracted, and careful evaluation tests made on this model. Minor changes were necessary between the prototype and production models. This instrument is now designated as the DE 723. In the past two years over 30 of these instruments have been used in survey operations. With the exception of minor difficulties, most of which are now corrected, they have proven to be a very satisfactory survey instrument.

It is not difficult to sound in water less than two feet below the transducer. It is also not unusual to obtain soundings in water of depths between 700 and 1 000 fathoms.

With the conventional deep water echo sounder it is difficult, if not impossible, in some areas of rugged bottom, to determine the water depth under the vessel. Such sounders have small transducers compared with the wave length of the acoustic frequencies being transmitted, which results in a broad beam pattern. Because of this broad beam the echo signals bounce back from a wide area of the bottom and present such a confusion on the fathogram as to mask the true depth necessary for charting.

To narrow the transducer beam requires a transducer that is large compared with the wave length of the acoustic signal being radiated. To reduce the wave length by increasing the acoustic frequency reduces the depth capability of the sounder because of the increases in attenuation of sound with frequency. Some compromise is usually required between increased transducer size and selected frequency.

Narrowing the beam of the transducer requires means of keeping the beam directed toward the sea bottom as the ship rolls and pitches.

A two-part development program was started in 1962 to improve deep sea soundings. The first part of this program was for the development of a system employing a large transducer mechanically stabilized to the vertical by a control signal from a gyro sensing unit. This is known as the Mechanically Stabilized Transducer. The second part of the program called for a transducer fixed to the ship's bottom, the beam of which is stabilized with a vertical gyro by proper phasing of the signals and to form the elements of this transducer. This is known as the Electrically Stabilized Transducer.

The Mechanically Stabilized Transducer is a disk type, five feet in diameter. It is supported by a large steel shaft which is secured to the back face of the transducer. On the end of the shaft is a ball knuckle riding in a housing. A system of oil-actuated rams moves the transducer to keep its beam patterns always pointing down.

A gyro is used for the vertical sensing element which operates the rams through amplifier and an oil pump system. Stabilization is for motion of the vessel of 20 degrees roll or pitch.

This transducer is intended for use in the C & GS new Class I oceanographic vessel. The transducer will be built into a flooded enclosure just aft of the bow. The bottom of the enclosure will have an acoustic window to give a smooth flow of water past this part of the vessel.

The system operates at a frequency of 20 kilocycles. For this size transducer the total beam width is less than six degrees at the 10 d.b. down points. Five kilowatt pulses are delivered to the transducer. The outer half of transducer elements is fed at half power to improve the side lobe characteristics. For a sea state 4, computations indicate sounding to 4 000 fathoms is possible over most bottom areas. Deeper soundings should be possible under more favorable conditions.

The receiver and transmitter are part of the system design. The transmitter is all solid state and employs silicon-controlled rectifiers in its output stage. The output pulse is in CW form and can be controlled in length from a nominal 2 mili-seconds. Transmitter output power can be controlled from a few watts to 5 kilowatts. This control will be used in place of a receiver gain control. The receivers' gain is preset and fixed. Solid state amplifiers are also used throughout the receiver.

The transducer has been completed, and laboratory and barge tested. It is now ready for installation. Sea trials are scheduled for fall or winter of 1964.

The design of the Electrically Stabilized Transducer is less conventional than the mechanically stabilized unit. The transducer is made up of two parts, the transmitting and receiving units, and is called a crossed beam design. The beam of each of these transducers is wide in one direction and narrow in the other. Such a beam pattern is accomplished by having the unit long compared with its width. The transmitting and receiving parts of the transducer are arranged on the ship's bottom in the form of a T. Thus, the wide and narrow part of the beams of each part are at right angles to each other. There is then only a small area on the bottom common to both beams.

The receiving part of the transducer runs athwart ships, while the transmitting part is just aft of the receiver unit and runs fore and aft. Thus, the receiver beam is narrow in the fore and aft direction, while the transmitter beam is narrow athwart ship. Beams from each unit are stabilized to the vertical only in narrow dimension.

Twenty groups of three magnostriction elements are used in the transmitting unit, while 40 barium titanate elements are used in the receiving unit. Each part of the transducer is eight feet long and about 18 inches wide. They extend about 9 inches below the hull. Fairing is built around the unit in such a way as to reduce friction and noise and turbulence, harmful to the transducer operation.

Signals from the transmitter divide into 20 phase shifters which, in turn, are each connected to an element of the transmitting part of the transducer. These phase shifters are actuated by the vertical stabilizing gyro. When this transducer is tilted by reason of ship's motion, the phase of the signals is advanced in those elements in the high end of the transducer with respect to the phase of these elements in the low end. Thus, the beam swings in a direction so as to keep its narrow dimension toward the sea bottom. Similar action takes place in the receiving part of the transducer. Thus, the area common to both beam patterns remains directly under the vessel.

The effective beam pattern is 4.5 degrees. The transmitting frequency is 12 kilocycles. 100 watts of power is delivered to this two-center transducer element. The power is progressively reduced on the elements going outward from the center. This is to improve the side-lobe characteristics. Computations indicate the system will not be depth limited except under severe sea conditions.

Included in the system are the transmitter and receiver. Provisions have been made at the receiver's output for digital recording as well as graphic recording.

This system was installed on the ship *Surveyor* in January 1964. Sea trials were conducted in February. Tests were conducted in an area which is difficult to sound with conventional echo sounders due to the nature of the bottom.

Automatic Magnetic Observatory

The Coast and Geodetic Survey maintains 10 observatories continously recording the earth's magnetic field. All recordings are made on photographic film which require careful but tedious manual-scaling.

Through various stages of experimentation a magnetometer has been developed which may supplement or even replace the instruments now used in these observatories. The general characteristics of this instrument are:

(*a*) Measures the absolute value of the magnetic field and its direction so that any desired component can be computed.

(*b*) Is an absolute instrument. Does not need standardizing as the presently used system.

(*c*) All readings appear in digital form on punched-paper tape for machine processing.

(*d*) Data is in a useful form for telemetering.

A Rubidium sensing element is placed in the center of a Helmholtz coil system. The coil system consists of two pairs of coils arranged to have perpendicular fields at their center, as shown in figure 9.

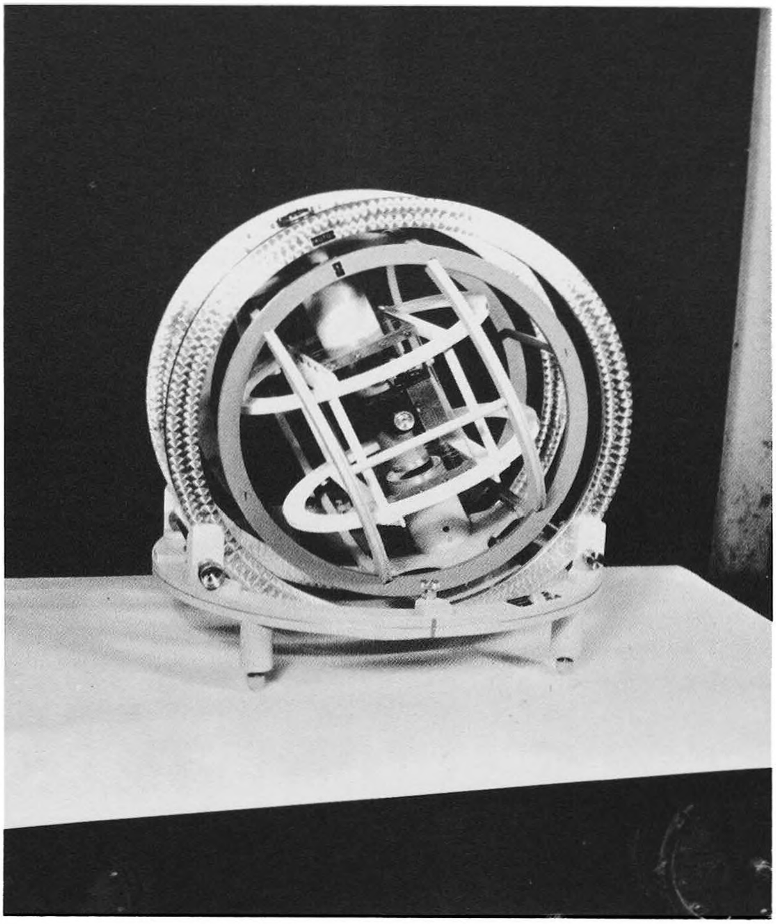

Fig. 9. — Helmholtz coil used in the Automatic Magnetic Observatory. The sensing element can be seen in the center of the system.

As an initial step in setting up the system at an observatory the coil system is carefully adjusted so the total force vector of the earth's field is mutually perpendicular to the fields of the Helmholtz coils. The steps to accomplish this will not be described.

A programming circuit is set to make five readings in rapid order. First the total field is measured (no currents in the coils), a known current is then reversed through the same coils for the third reading; the fourth and fifth readings are from the second set of coils in a manner just described. One complete set of readings may be made in 20 seconds and the instrument is idle during the remainder of each minute. The current through the Helmholtz coils produces a field at nearly right angles to the earth's field and the magnetometer sensing unit measures the resulting field. Effectively the earth's field appears to be moved first left, then right, then up and then down. With these readings on punched-paper tapes applied to a programmed computer, the components of the earth's magnetic field are derived, as well as other data such as the K indices.

Various experimental models have been in operation in observatories over the past two years. Production models are now being completed. It is planned eventually to add the automatic units to all Coast and Geodetic Survey observatories. The first production units are to be used in new observatories now under construction. At one of these observatories the equipment will operate unattended and telemeter its information over telephone wire to two or more universities and to a scientific instrument company.