PRECISE STATION-KEEPING IN DEEP WATER

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Ships at sea which are hove-to (have their engines stopped) do not remain long above any point on the bottom. They drift. This is because a ship presents a surface above the waterline against which the wind can press, and one below it against which the surface currents can exert a force. If they dangle a long cable through the deep water to the bottom as oceanographic ships commonly do, the drag forces on that cable may either speed up or retard the drifting motion. Generally however, the ship tends to move with the water that immediately surrounds it. And since the surface waters are almost always in motion in all parts of the ocean it is not an easy matter for a ship to maintain a fixed position with respect to the bottom. However, now there is a need for a no-drift ship which can do certain kinds of scientific and engineering work in the deep sea.

In oceanic depths (greater than 10,000 feet) two methods have been used to reduce the drift. One is to put out a sea-anchor--a sort of underwater parachute which presents a large drag surface to the relatively still water at depth. The other method is to anchor the ship. This has been done on a number of occasions but few ships have the need or the equipment to do it routinely. A remarkably light line will hold a ship. About 1950 an 800 ton ship of the Scripps Institution of Oceanography was first anchored in water two miles deep with a single strand of music wire not much more than an eighth of an inch in diameter; a few years later J. Y. Cousteau, the French oceanographer, used a light nylon line for the same purpose. The deep sea winch lines of oceanographic ships (3/16 to ½" cable) can be used for anchoring but this is seldom done; with a scope of as little as two to one (ratio of the length of anchor line to the depth of water) the ship does not hold its position very well. In the 13,000 foot average depth of the ocean a nominal yaw (swing on the end of the anchor line) of, say, 15^{o} means a horizontal ship motion of about 6,000 feet.

The simple fact is, ships have always been designed to move at sea, not to hold still. But now a very good reason exists to hold a ship in precise position above deep water. This is the need to drill holes in the ocean bottom for scientific purposes using more or less conventional oil well drilling equipment. Obviously the derrick ship cannot be permitted to move far from above its hole. Doubtless new forms of naval construction and deep sea mining operations will also require that a ship hold still or maneuver precisely.

The purpose of this paper is to propose a new, dynamic means of holding a large ship at an "epicenter"--a point at the sea surface above a predetermined fixed point on the bottom--within a reasonable tolerance. The tentative and rather arbitrary requirement is that the motion away from the epicenter must not exceed two percent of the depth of the water. In other words, a circle with a radius of 260 feet in 13,000 feet of water.

It might be possible to hold a ship within this circle statically by means of multiple mooring lines. In fact, a design for a six-point anchoring system has been worked out. (3) However, such anchoring systems have drawbacks which may not be readily apparent. For example, catenaries of steel cable five miles long, even though pre-stressed by winch tension and surface buoys, require support at a number of points along their length; otherwise the ship can move a considerable distance before the cable comes really taut. Multiple submerged buoys filled with gasoline could be used as supports but this would be clumsy and possibly dangerous to install. Neutral density fibers such as nylon have been suggested, as have coated magnesium and aluminum rod, because these would assume nearly straight lines, however these do not now look promising. Nylon, for example, will stretch more than 20% under substantial stress; besides it is expensive and may be attractive to sea life.

Other deep mooring problems have to do with uncertain holding ground of the bottom, corrosion, chafing, fatigue, and the requirement for special ships to place the gear. There would also have to be special buoys at the surface and special winches with tension-meters on the ship so that the tension could be adjusted to resist changes in the forces on the system. Moreover, the initial cost of the equipment and the expense of placing and retrieving it would be both large and irrecoverable.

A means for epicenter station-keeping is needed which does not depend on the advance placement of an elaborate mooring system at great expenditure of time and money. The method should require no great installation or operational expense and no substantial capital investment in items which have to be retrieved from the ocean when a site is abandoned. If the cost per station is small, a more flexible operation will be possible since the decision to change location will not be a major one.

These requirements could be met best by a ship equipped with a dynamic positioning system which would be composed of (a) position-marking taut-line buoys, (b) a constantly operating omnidirectional propulsion system. It would operate as follows: A ring perhaps a thousand feet in diameter of four to ten taut-line buoys would surround the proposed drilling site. The drilling ship, equipped with propellers capable of maneuvering it in any direction (sidewise, skewed, or in circles, as well as forward and astern) would move itself into position in the center of the buoy circle and maintain a position there for the duration of the job by applying the necessary thrust in the appropriate direction to overcome the constantly shifting winds and currents. A pilot on the bridge would guide the ship onto station by watching the ring of fixed buoys; however, once ship position is established, an automatic mechanism might be employed to sense position and control the propellers. No direct contact between the ship and the bottom would be needed.

Consider the elements of this system. First the position-marking buoys. The first deep-moored instrument stations were built by the author in 1951 in order to measure nuclear weapons effects far from land in the deep Pacific (1, 2). These stations consisted mainly of a 600 lb anchor, a mooring line of improved plow steel music wire 0.105" diameter (breaking strength 2150 lbs), and a buoyant cylinder that floated a hundred feet below the surface and kept a substantial constant tension on the wire. A lighted marker floated on the surface, connected by a short slack line to the underwater buoy. The slender music wire offered little resistance to the drag of the ocean currents and the underwater buoy is not believed to have swayed more than 100 feet from the vertical. These moorings have undergone development in the last few years and are now regularly used by oceanographers as reference points for surveys of currents and bottom topography. They are inexpensive (about $500 complete) and three or four can be placed by a small ship in a day. Thus a ring of marker buoys could be set about to mark a drilling site in about three days for less than $10,000. They would be regarded as expendable.

There are two kinds of maneuvering propellers (4) that can exert maximum thrust in any direction and either of them could be installed on a ship for precise station-keeping. These are the outboard type and the vertical axis or cycloidal type. The first, which is manufactured by Murray and Tregurtha of Quincy, Massachusetts, under the trade name "Harbormaster", is a very large version of the outboard motors used by pleasure craft. The torque of a motor is transmitted down a shaft, through a gearbox to a standard screw propeller.

The vertical shaft can be rotated 360° without recovery, and in so doing the direction of the propeller, and the thrust, can be controlled. As with all screw propellers, the efficiency at 100% slip (zero ship speed) is poor. Taggart (5, 6) has suggested that the addition of a Kort nozzle would increase the efficiency considerably in the low speed condition but this has not yet been tried. (A Kort nozzle is a short cylinder with a contracting section which leads the water to the propeller. The decrease in sectional area causes an increase in water velocity past the propeller and therefore an increase propulsive thrust at low speeds.)

Harbormasters are normally powered by individual diesel engines and come in several sizes to 600 HP, nominally producing about 20 lbs of thrust per horsepower at their most efficient speed. They have been installed on numerous special-purpose ships and barges, usually for the purpose of sidewise maneuvering in restricted waters. In deep-sea station-keeping there might be some difficulty in delicately controlling the direction and magnitude of the thrust. In order to hover over a point it might be necessary to quickly rotate the propeller through 180°. However, if used as opposing pairs, a small change in the thrust of either propeller would produce the desired effect.

The other propeller which produces omnidirectional thrust is the Voith-Schneider vertical-axis or cycloidal type. It consists of a turntable which is flush with the flat bottom of the ship and along whose perimeter are mounted four or six equally spaced vertical blades with hydrofoil sections. As the turntable is rotated, the blades trace out cycloids as the ship moves through the water. The angle of attack of each blade is regulated so that it has a sculling action on the fore and aft sides, a pushing action away from the direction of the ship motion and a feathered stroke as it travels with the ship. In the version made by J. M. Voith, a German company, engine speed and turntable speed are constant but blade pitch in any position is controllable. Thus it is possible to vary the speed from stop to full ahead in any direction almost instantaneously without having to accelerate any large mass of machinery. Usually the controls are so arranged that maneuvering is done directly from the ship's bridge (since no rudders are needed the engine controls are operated by the helmsman). Only a few Voith cycloidal units have reached the United States although over a thousand are in use in Japan and Germany. One exception to this is a German-built floating crane, the largest in the world (YD-171), which was captured by the allies in World War II and brought to the U.S. for use at the Long Beach, California naval shipyard. It is equipped with three 700 HP units individually powered by electric motors which make it self-propelled and completely maneuverable. With its great crane of structural steel, this structure is curiously similar to a floating oil derrick, although its hull is much smaller than that of a drilling ship.

The efficiency of vertical axis propellers does not seem to be as great as that of screw propellers at high free-running speeds. However, at lower speeds the two are about the same and for maneuvering or tugboat operations, the former is greatly superior. About 22 pounds of thrust per HP at 100% slip can be safely assumed. The Voith-Schneider units come in sizes up to 1250 HP--six blades 6 feet long on an orbit diameter of 12 feet that produce 26,000 lbs of thrust.

Now it remains to calculate how many propellers of what horsepower would be needed to hold a specific ship in position within a ring of buoys against the opposition of the elements. If the ship is required to remain on station in spite of two knots of surface current and 60 knots of wind, both from the same direction, the power required can be readily computed. Noted that a great advantage of being able to rotate the ship about a point and to apply skewed force is that the most favorable (bow on) aspect can always be presented to the winds and currents; it need never be broadside.

Robert Taggart and the author have calculated the kind and size of maneuvering propellers that might be used on two ships:

CUSS I, a YFNB 260 feet long, 48 foot beam, 10.5 foot draft, displacing 1,300 tons and equipped with a 98 foot drilling derrick, would require three Voith-Schneider 1250 HP vertical axis propellers (if they could be installed).

ARD 22 (a naval floating drydock 485 feet long, 81 foot beam, about 12 foot draft when displacing about 3,000 tons if fully equipped for drilling) would require four 1250 HP Voith-Schneider propellers to meet the stated conditions.

Actual tests at sea and experimentation with buoys, sensing devices, engine speeds, must be made in order to determine which of the many possible combinations for precisely holding over a point is most effective. A few days of practice by a pilot should make him very adept at station-keeping using manual controls. He could be assisted, and perhaps eventually replaced, by various optical, radio and sound-ranging devices which might be arranged to operate the propellers directly by means of a servo system. For example, a mechanism could be devised which would monitor the travel time of sound to and from underwater buoys at the major compass points and steer the ship so that it remained equidistant from opposite buoys.

Probably there would be an independent position-locating system, constantly checking on the one driving the engines, which would sound an alarm if the ship moved more than some specified distance from the epicenter. A shore based Raydist system might be used since it is said to be able to relocate a point within about 20 feet at distances to 200 miles from shore.

It appears that a ship equipped with these various devices could remain precisely on station for an indefinite period. If it can, this will be a great step in the direction of being able to do heavy work on the bottom of the deep sea-- a need which is barely beginning to be recognized.

References and Notes

1. Bascom, Willard, A Deep Sea Instrument Station, Scripps Institution of Oceanography, Reference 53-38, June 22 1953

2. Bascom, Willard, Deep-Sea Moored Buoy Instrument Stations. Aspects of Deep Sea Research, NAS-NRC Publication 473, 1956

3. Global Marine Exploration Company, Report to the Office of Naval Research on Deep Water Drilling Methods, October 1959

4. Gregory, John and Bascom, Willard. Unpublished notes on Various Maneuvering Devices for Ships, 1958-59

5. Taggart, Robert, Special Purpose Marine Propulsion Systems-Part I JASNE, August 1959

6. Taggart, Robert, Consultant's Report to the AMSOC Committee on Dynamically Positioning the Project Mohole Drill Rig, September 1959

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