A TECHNIQUE FOR MEASURING THE BEHAVIOR OF A NAVIGATIONAL BUOY*

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Summary A prototype instrumentation package has been designed and fabricated to furnish quantitative information about the stability of an ocean navigational buoy. A total of fourteen electro-mechanical transducers were included in the package to yield attitude, acceleration, and mooring chain tension information about the buoy. By utilizing a six channel telemetry data system and a 4-channel command telemetry system, continuous data from selected sets of transducers were recorded and used to determine the types, sensitivities, and ranges of instrumentation best suited to this application. The number of telemetry channels chosen represents the "best guess" number required in the final program which will consist of five separate instrumentation packages. By integrating the two telemetry systems in the prototype unit, a flexibility of operation was realized that yielded large amounts of useful data at a minimal cost.

Introduction Navigational aids are used to assist a navigator in determining his position or course, and to warn him of dangers or obstructions. The stability of a buoy as an aid to navigation is of importance in payload design and in the calculation of the probability of detection of the aid in given sea conditions. Buoys provide information by shape, color, markings, and by more sophisticated devices such as beacon lights, bells, and radar reflectors. These latter devices are designed to be effective within a given motion envelope. If the buoy motions exceed this envelope, the utility of the aid will be reduced and the probability of detection and recognition will be decreased.

A buoy widely used today is the Coast Guard standard 8x26 type shown in figure 1. The number is indicative of the size of the aid which measures 8 feet in diameter and 26 feet

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in length. When placed in the water the position of a buoy is constrained by a mooring chain attached to a massive concrete sinker. The weight of a single buoy system, including the buoy, mooring chain, and sinker, often exceeds ten tons. Because of the extreme environmental conditions experienced by the buoy, corrosion of the color coded exterior, marine fouling of the chain, and physical damage to the active devices on board are common. To correct these problems, the Coast Guard employs a fleet of specially equipped ships called buoy tenders. Each buoy system is serviced annually by a tender at which time the entire system must be removed sufficiently from the water to be inspected and any necessary repairs made. Normal service also includes checking the position of the buoy and replacement of the battery packs and light bulbs.

In addition to this type of annual maintenance, every lighted buoy is taken ashore at three year intervals for a complete overhaul. The equipment and manpower required to perform these dangerous and time-consuming tasks account for a sizeable portion of the Coast Guard budget.

In an effort to reduce the maintenance cost involved with aids to navigation, the Coast Guard is considering the use of a new series of buoys constructed of plastic materials. These buoys exhibit better anti-corrosion characteristics and weigh one-third of the system they are designed to replace. This would greatly simplify the maintenance performed by the tender by increasing the length of maintenance intervals, reducing the size of the handling equipment, decreasing crew size, and allowing for a safer operation.

The obvious unknown about these new buoys is their stability, that is, how do the motions and excursions compare to those of the currently used standard 8x26. To determine a quantitative value for this stability, the Coast Guard engaged the Transportation Systems Center to develop and fabricate an instrumentation and data handling system which could be used to evaluate various configurations of buoy systems.

In this paper, the physical parameters to be measured will be discussed as will the mechanical transducers chosen for the prototype unit. Specific attention will be focused on the telemetry system used to command the instrumentation into operation and to transmit the data to a ground based recording station. A qualitative discussion of the results of the prototype conclud6-the report. Model studies of three systems have previously been performed by Lockheed Space and Missiles Division and an attempt will be made in the future to correlate these studies with actual ocean data.

Stability Parameters To accurately describe the stability of a buoy, the following parameters were chosen to be measured:

(a) Heave Displacement - the vertical displacement of the buoy center of gravity caused predominately by wave action. A small shallow buoy would be expected to closely follow the wave action while a heavier deep draft structure would be much less effected. It is desired to know the heave characteristics of navigational buoys which would lie between these extremes.

(b) Heave Rate - the time rate of change of vertical displacement. This parameter will be used with the displacement to generate a transfer function defining the buoy heave motion as a function of the sea state.

(c) Neutral pitch angle - the average angle of tilt of the buoy center line from local vertical. A neutral pitch angle other than zero would indicate a prevailing wind, current, asymmetrical mooring or a combination of all three.

(d) Neutral roll angle - an angle similar to the neutral pitch angle but about an orthogonal axis.

(e) Pitch Excursions - the amplitude of the motions about the neutral pitch angle.

(f) Roll Excursions

(g) Pitch Rate - time rate of change of pitch excursions.

(h) Roll Rate

(i) Mooring line tension - the tension in pounds of the mooring chain including the static weight of the chain and the dynamic change caused by varyin sea states.

It is useful at this stage to introduce an example illustrating the importance of the above measurements. Consider a small buoy equipped with a flashing light and a radar reflector mounted on the superstructure. The heave motion is important in order to specify the type of radar target presented. That is, how high above the mean water line in heavy seas should one expect to detect a target, and for what length of time will the target be visible? Now assume the divergence half-angle of the beacon light beam is 3° and a small boat is approaching at night in the pitch plane of the buoy. If the buoy has assumed a neutral pitch angle of 4°, and the sea is calm it will be virtually useless and the probability of the boat detecting the aid is near zero dependent upon the light intensity. However, if a wave motion developed which caused the buoy to pitch back and forth about this 4° neutral pitch angle with a maximum amplitude of 2°, this probability is increased because the buoy attitude would be within the 3° limit more of the time. In general the length of typical mooring chain is three to five times the depth of the water in which it is used. Each link is constructed of 1 1/2" diameter steel and is 10 inches long by 6 inch wide. Two hundred feet of this chain weighs in excess of three tons. It is felt that the chain is oversized and the Coast Guard is considering the use of wire or even nylon rope to replace the bulky chain. The tension measurements will help clarify the issue.

Data on the above parameters, in addition to benefitting the navigator, will also enable the Coast Guard to determine the type of aid best suited to the conditions that prevail in a given sea location. Optimization of the light and target characteristics, superstructure design, chain length, and sinker size may also be based on this data resulting in an increase in the probability of detection of navigational aids.

Transducers in the Prototype Unit To measure the parameters specified above, electromechanical transducers were chosen to interface with the telemetry system. The selection of the transducers was governed by accuracy, frequency response, power requirements, weight, size, expected life, and, of course, cost.

Heave motion characteristics were furnished by miniature potentiometric accelerometers having a range of ±5 G's and a flat frequency response from zero to twenty hertz. One accelerometer was mounted with the sensitive axis parallel to the buoy centerline, while an additional unit was placed in each of the arbitrarily chosen pitch and roll planes. Using the pitch and roll data from other transducers, the output of the three accelerometers was vectorily summed and the vertical and horizontal components of the total acceleration calculated. Integration with respect to time of the vertical acceleration data yielded vertical velocity or heave rate, while an additional integration resulted in displacement information. Three additional potentiometric accelerometers were included to form force couples in each of the pitch, roll, and yaw axes to determine the angular accelerations. For comparison purposes, a variable reluctance type accelerometer of range ±1 1/2 G's was also placed parallel to the buoy centerline as a reference for judging the potentiometric devices.

Two types of transducers were chosen to measure angular excursions of the buoy. Pendulum inclinometers with potentiometric outputs in the ±45° range were placed in the pitch and roll axes. Due to the inherent sensitivity of these instruments to lateral accelerations, their use was restricted. To "smooth" the inclinometer data in the presence of lateral accelerations, direct current vertical gyroswere used. The gyros chosen were unique in that vertical alignment was obtained only in one axis while the other axis erected to the angle of the instrument case. For this reason, two gyros were included in the prototype to yield vertically referenced information in both the pitch and roll axes. Finally, a load cell using a strain gage bridge was inserted into the mooring chain to furnish tension data. The range of this device was 0-20,000 pounds with a maximum tensile strength comparable to that of the mooring chain.

The instrument package in its weather-proof enclosure is shown in figure 2, and a bottom view of the instruments and electronics is shown in figure 3. The total system, with exception of the ground based antennas, is depicted in figure 4. Included in this view are the instrument package, buoy antennas, load cell and cable, control console and stripchart recorder.

Electronics Figure 5 is a block diagram of the electronic aspects of the instrument package. The prime power is supplied by a 3000 ampere-hour lead-acid battery pack. Power is routed directly to the command receiver and signal decoder through which four separate command functions may be initiated. The command system which is activated at all times draws a quiescent load current of 110 milliamperes. Because of the relatively large current drains the gyro motors were assigned separate command functions. Each motor would draw about a current of 1 ampere at start which after a period of 2 minutes would fall to a value of 1/2 ampere. A third command function was used to activate the telemetry transmission system. This is a standard FM-FM system using the first six IRIG proportional subcarrier channels. The last command function was used to activate a rotary stepping switch in which sixteen possible inputs were sampled in various combinations through the first five subcarrier channels. The output of the tension cell was differential as well as low level therefore it was permanently assigned to channel six. Because most of the transducers had a potentiometric readout it was essential that the applied voltage be closely regulated. This was done using a small self-contained hybrid cermet thick film unit. With a 5 volt output the regulation was better than ±0.07% for a 10% input voltage change over an extreme input voltage change of 22 to 32 volts the regulation was better than ±0.25%. This feature permitted direct zeroing of the system as well as a means of monitoring the battery voltage. To zero the system a regulated mid-range voltage was applied via the stepping switch to all of the voltage controlled oscillators while the subcarrier discriminators at the ground station were adjusted for zero output. In another position of the stepping switch a voltage proportional to the battery voltage was applied to one of the voltage controlled oscillators. By comparing the discriminator output with the zero setting, the actual battery voltage was easily discernible.

The ground station equipment was quite standard with the possible exception of the gravity bias unit. This unit simply added corrective voltages in series with the discriminators on certain channels at the time they were used to monitor the vertical accelerometers. The magnitudes of these voltages were set to just bias out the one G acceleration of gravity thus centering the outputs about the zero point. This was a definite convenience in recording data for all of the readings were now compatible. In the cases where a strip chart recorder was used this permitted the sensitivity to be changed without having to readjust the zero point centering of the pens. With some twelve possible combinations of inputs this feature proved to be a decided advantage during the data runs.

The buoy antennas which were visible in figures 1 and 4 are of the simple quarter wave ground plane type. Vertical polarization was used because buoys are generally free to rotate about their mooring point. The vertical field strength patterns of these antennas is approximately 90 degrees which is considered sufficient to provide coverage with even the most extreme excursions of roll and pitch occuring.

The ground based antennas which were not shown are standard yagis with unidirectional gains in excess of 9dB. The horizontal field strength patterns of these antennas with vertical polarization is in excess of 35 degrees. This pattern was selected to permit simultaneous coverage of a group of five buoys, which are the conditions that are planned for future tests.

The present tests were conducted with transmitter powers in the 1 to 2 watt range. These levels are also expected to provide a very adequate margin of safety in any future tests, since the propagation path will be along a direct line of sight over water for distances less than one half mile.

Prototype Testing and Data Reduction The purpose of the prototype unit was to determine the types, sensitivities, and ranges of instrumentation required to adequately measure the stability parameters, to evaluate the command and data transmission systems for use on future units, and to illustrate the methods of preliminary data reduction. Laboratory tests were conducted in addition to dockside evaluations. In the lab, the prototype was placed in an oven and heated to 120°F for three hours. Subsequently, the unit was placed in a food freezer at 0°F for three more hours. During these tests, the command functions, transducers, and data transmission system operated successfully. As an endurance test, the entire system was run continuously for 24 hours. Again, no malfunctions occurred. Finally, the components to be secured to the buoy were given submergence and water spray tests with the environmental integrity of the case proving satisfactory. It is interesting to note that while the prototype case was indeed water tight, “breathing” of air occurred as a result of temperature changes within the case. Since the air in the buoy environment would contain a considerable content of moisture and salt, an effort was made to minimize this “breathing”. The volume of air drawn in to the case was directly proportional to the free volume in the case. By custom forming blocks of plastic foam with a hot wire cutting tool, and securing them in the case, the free volume was reduced 80%. Assuming a 100% relative humidity of the air surrounding the buoy and the cyclic temperature changes, a quantity of silica gel dessicant packets were included to offer six months of protection in which the relative humidity inside the case would remain less than 40%, the value in most general purpose labs.

The dockside tests were conducted at the Coast Guard Station in Curtis Bay, Maryland. The 8x26 buoy shown in figure 1 was outfitted with the load cell, instrument package, antennas and associated cabling. The ground station equipment was set up in an enclosure about one fifth of a mile from the buoy but still afforded visual examination of the buoy motions. A modified mooring system was constructed for these tests and used to impart heave motion to the buoy and also to vary the tension sensed by the load cell. This was accomplished by “threading” a wire rope attached to the load cell on the buoy, through a sinker on the bottom of the bay and returning the free end of the rope to the pier. Sufficient forces were developed by pulling on this rope with a tractor. Angular excursions were imparted by two men riding the buoy and simultaneously shifting their body weight and also by a rope attached to the superstructure held by a third man on shore. The entire series of dockside test were recorded on movie film with synchronization of events via walkie-talkies.

In order to obtain the clearest picture of the data with a minimum amount of invisible processing such as digitizing equipment, the prototype package was analyzed using analog stripchart recordings of the continous data. While this method is most tedious, it best represents the raw data. The final deployment of five similarly outfitted buoys will most likely require a more automated data handling system but specifications of this system are yet to be determined.

Conclusions The tests of the system validated the operation of the telemetry and data reduction techniques and determined the ranges of transducers that would yield more accurate measurements. Specifically, the buoy accelerations in this test seldom exceeded one-half G and a reduction in the instrument range is indicated. Because of this small range, the use of potentiometric devices may also be questioned. Placement of the package on the buoy is also critical. If the unit is not placed at the center of rotation of the buoy, tangential components of angular accelerations dominate the output of the accelerometers located in the pitch and roll planes. These tangential components similarly affect the pendulum inclinometers dictating that a center of rotation placement is much preferred.

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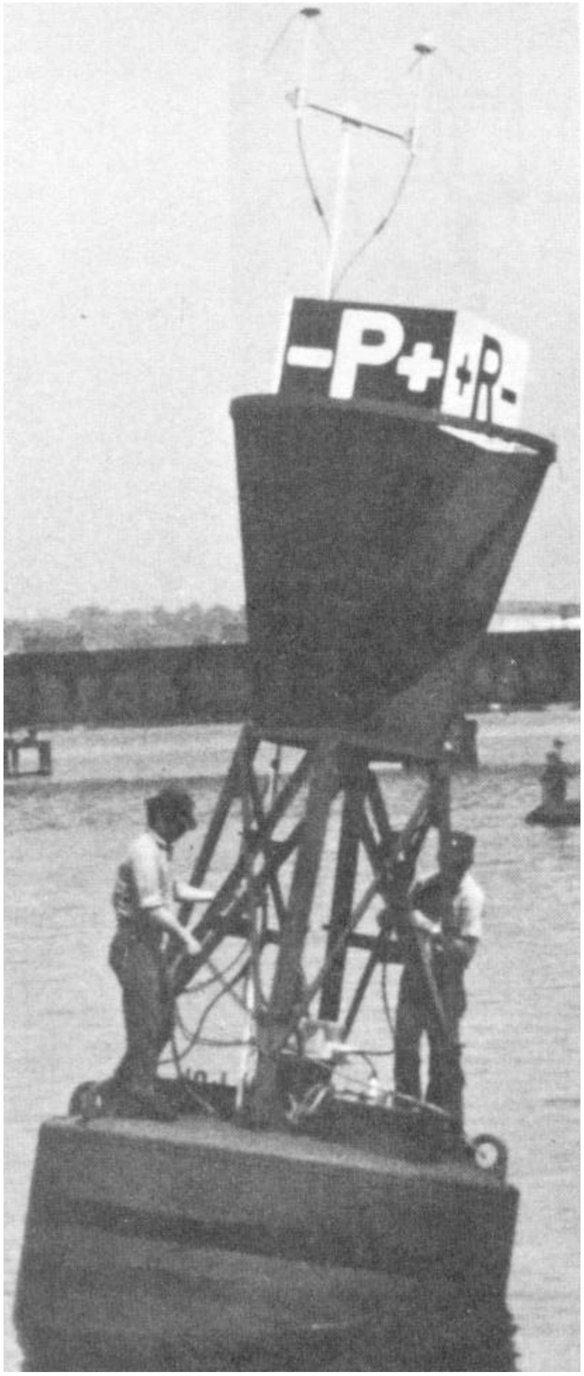

Fig. 1 - Standard Buoy Outfitted with Test Equipment

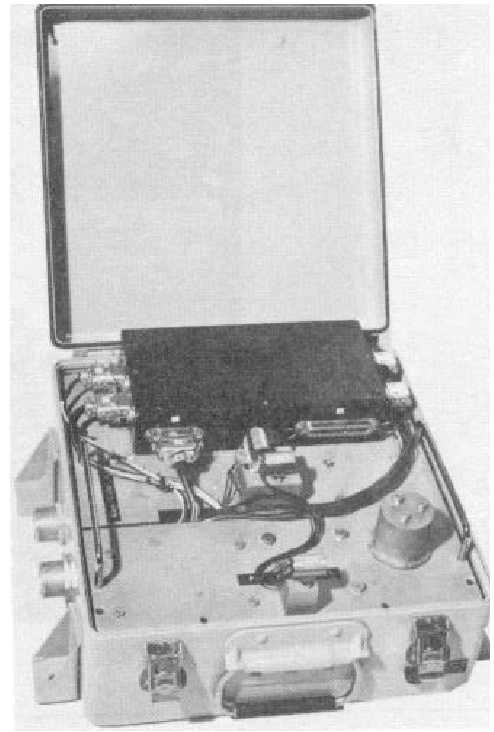

Fig. 2 - Instrumentation Package Top View

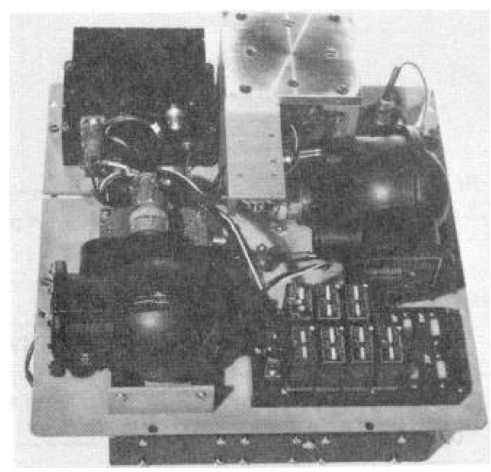

Fig. 3 - Instrumentation Package Bottom View

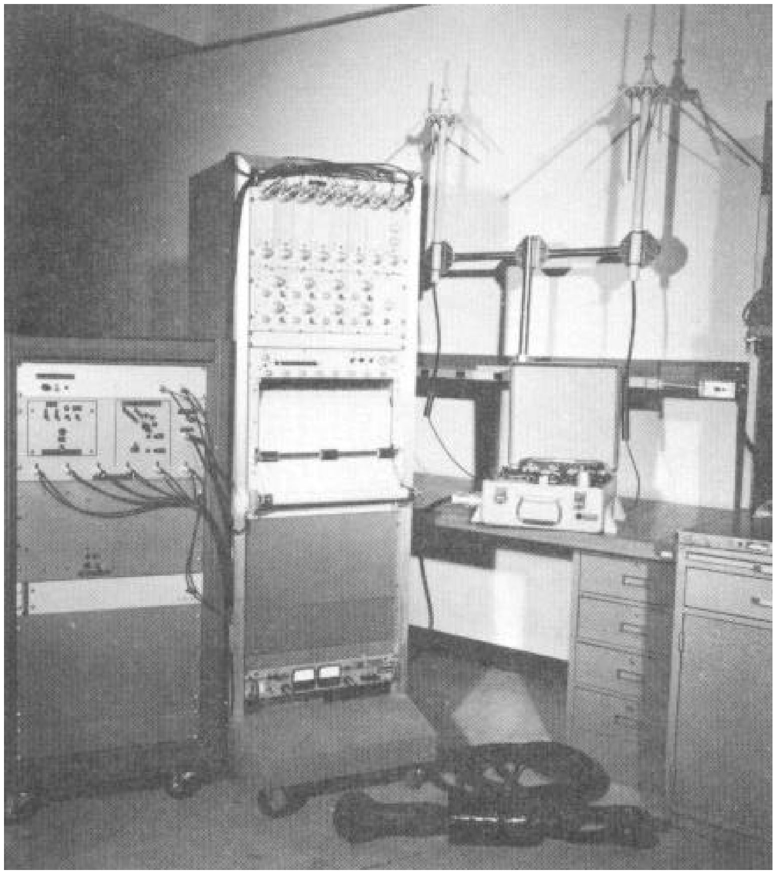

Fig. 4 - Buoy Instrumentation, and Ground Station Equipment

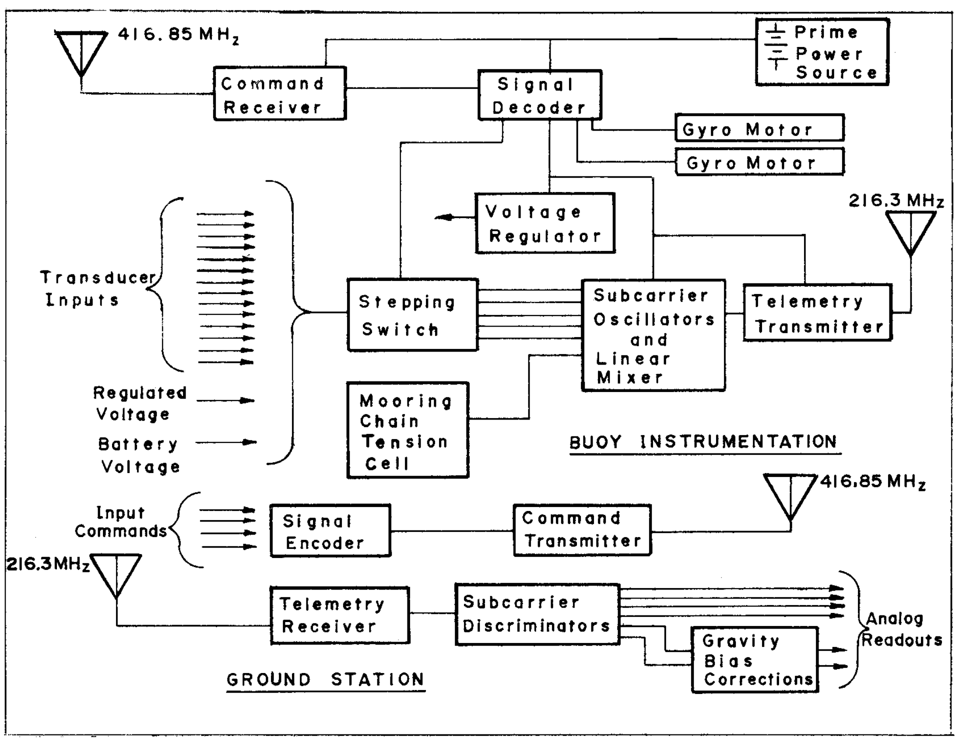

Fig. 5 - Block Diagram of the Electronic System