AD-A265 553

...MENTATION PAGE

Form Approved
OMB No. 0704-0188

REPORT DATE: 5/93	3. REPORT TYPE AND DATES COVERED: TECHNICAL
4. TITLE AND SUBTITLE: THE DYNAMOOR EXPERIMENT	5. FUNDING NUMBERS: ONR N00014-90-J-1719
6. AUTHOR(S): H. BERTEAUX, A. BOCCONCELLI, C. ECK, S. KERY AND PIERRE WANSEK	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES): WOODS HOLE OCEANOGRAPHIC INSTITUTION, WOODS HOLE, MA 02543	8. PERFORMING ORGANIZATION REPORT NUMBER: WHOI CONTR. 8129
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES): OFFICE OF NAVAL RESEARCH, ENVIRONMENTAL SCIENCES DIRECTORATE, ARLINGTON, VA 22217-5660	10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

In citing this report in a bibliography, the reference given should be:

GLOBAL OCEAN PARTNERSHIP, MTS '92 PROCEEDINGS. MARINE TECHNOLOGY SOCIETY, WASHINGTON DC 2:931-942, 1992

12a. DISTRIBUTION/AVAILABILITY STATEMENT: APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED	12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Under the sponsorship of the Office of Naval Research, the Ocean Systems and Moorings Laboratory (OS&M Lab) of the Woods Hole Oceanographic Institution developed (1990) and deployed (1991) a fully instrumented subsurface buoy in high current waters close to Woods Hole, MA.

The purpose of this engineering experiment, named DYNAMOOR, was to obtain long term, high frequency measurements of the buoy 3D position and of the tension in its mooring line, as a function of prevailing currents and variable, adjustable buoyancy.

This paper first describes the main components and the method of deployment of the DYNAMOOR complex experimental setup. It then reviews the mechanical and electrical designs of the entire system. Finally, a review of the data analysis and a summary of the results are presented.

14. SUBJECT TERMS: 1) MOORING DYNAMICS 2) SUBSURFACE BUOYS 3) BUOY MOTION REAL-TIME SENSING	15. NUMBER OF PAGES: 12
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18

THE DYNAMOOR EXPERIMENT

H. Berteaux, A. Bocconcelli, C. Eck, S. Kery
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543
and
Pierre Wansek
Institut National des Telecommunications
Paris, France

ABSTRACT

Under the sponsorship of the Office of Naval Research, the Ocean Systems and Moorings Laboratory (OS&M Lab) of the Woods Hole Oceanographic Institution developed (1990) and deployed (1991) a fully instrumented subsurface buoy in high current waters close to Woods Hole, MA.

The purpose of this engineering experiment, named DYNAMOOR, was to obtain long term, high frequency measurements of the buoy 3D position and of the tension in its mooring line, as a function of prevailing currents and variable, adjustable buoyancy.

This paper first describes the main components and the method of deployment of the DYNAMOOR complex experimental setup. It then reviews the mechanical and electrical designs of the entire system. Finally, a review of the data analysis and a summary of the results are presented.

INTRODUCTION

The objective of the DYNAMOOR experiment was to obtain a comprehensive set of empirical data to describe the dynamic response of a subsurface, spherical buoy moored in strong currents. Results from the experiment could be particularly valuable for the following applications: design of closely spaced buoy arrays; improved design of subsurface oceanographic buoy systems set in strong currents; current meter motion studies; cable strumming studies; validation of mathematical models of mooring mechanics (computer programs, empirical drag coefficients, buoy oscillations).

In its first configuration, the DYNAMOOR experiment was designed to measure the instantaneous 3D position of the buoy and the tension in the mooring line as a function of time, current, and buoyancy of the subsurface buoy. To accommodate the fast sampling rates and the resulting large volume of data, the measurements were transmitted to a shore station via a bottom mounted, electro-optical-mechanical (EOM) cable.

DYNAMOOR was deployed June 24, 1991, in waters close to Woods Hole in a flat, 27.5m (90 ft.) deep trench where strong (up to 3 knots) cyclic tidal currents prevail. The mooring was recovered July 1, 1991.

DYNAMOOR EXPERIMENTAL SET-UP

System Components: The experimental set-up, as deployed, is shown in Fig. 1. The principal components included:

- A Sonic High Accuracy Ranging and Positioning System (SHARPS), used to monitor the motion of the subsurface buoy. This system was designed for precise underwater track-

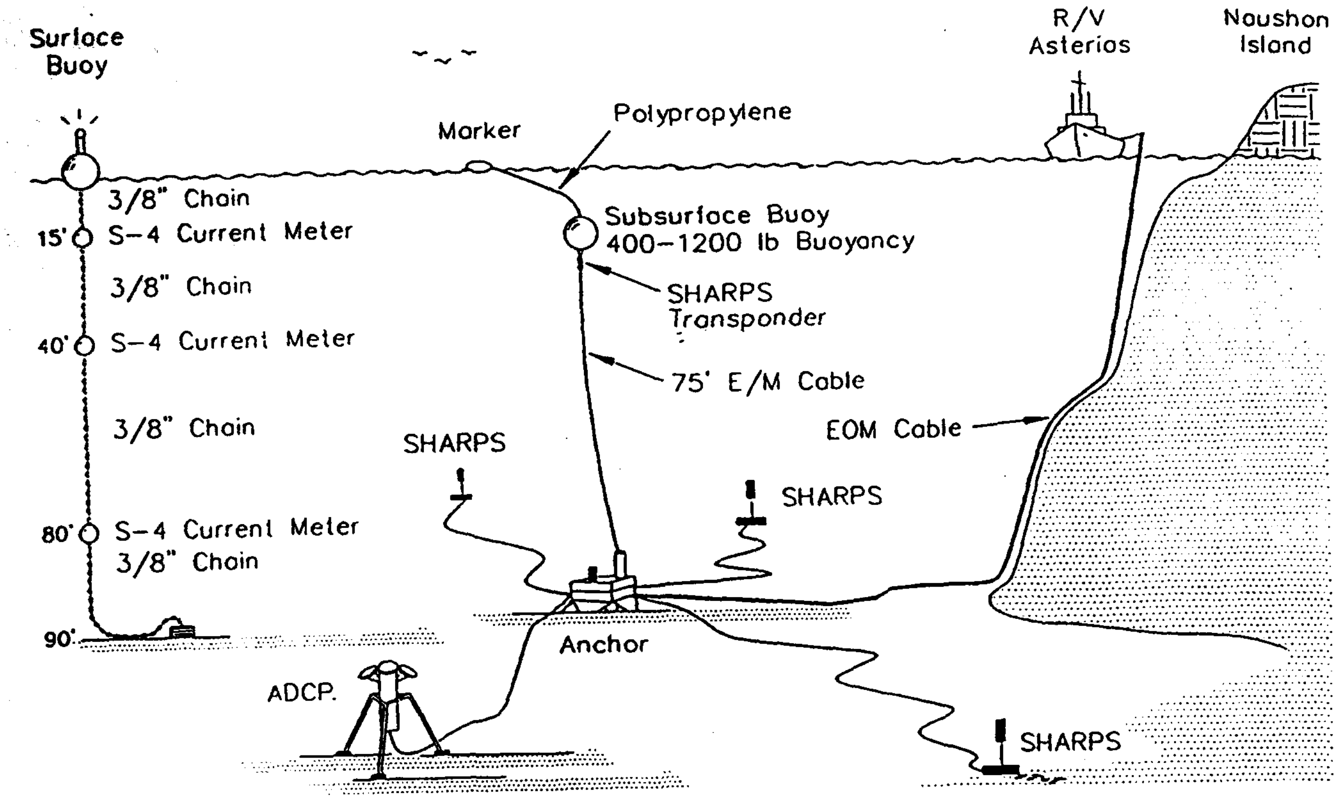


Fig. 1: DYNAMOOR Experimental Setup

ing at high update rates in high multipath environments. For a range of 100 m, positioning accuracy is within 2 cm, repeatability is better than 0.5 cm, and sampling rates up to 10 Hz can be achieved. The SHARPS network is based on a set of compact underwater acoustic transceivers, each independently capable of transmitting or receiving high-frequency acoustic pulses. The DYNAMOOR set-up included four such transceivers: one "master" located on the subsurface sphere and three "slaves" on the bottom [1].

• An Acoustic Doppler Current Profiler (AD CP) which uses the Doppler principle to remotely measure speed and direction of moving water masses. The 600 KHz ADCP was mounted on a steel frame and installed on the bottom by divers at 60 m from the anchor module [2].

• A variable buoyancy subsurface sphere, equipped with a flexible bladder, a ballasting pump, valves, a controller and a tension cell.

• A mooring line which consisted of an electromechanical (EM) cable with six conductors and a steel wire rope as the strength member. The tension in the mooring line was varied by pumping sea water in and out of a flexible bladder located inside the sphere by remote control from the field laboratory.

• An anchor module which maintained the mooring on station. Six cables were mechanically attached and electrically connected to the anchor module: the mooring line, the three bottom SHARPS transponder cables, the ADCP cable, and the EOM bottom cable. A large pressure case was mounted on the anchor frame and housed the power regulators and the data formatting and telemetry electronics.

• The 850 m long EOM cable, connecting the array to the field laboratory located on the moored R/V Asterias.

• An all chain surface mooring instrumented with three InterOcean current meters [3]. Its purpose was to serve as a site marker and provide redundant current measurements to back up the ADCP.

System Installation: A 30 m long barge equipped with a trawl winch, jack up system, lifting crane and capstans was used for the deployment. The DYNAMOOR main components, including the S-4 mooring were loaded on the barge, together with the EOM cable wound on its lowering winch. The barge was assisted by two tugboats (R/V Jaguar and R/V Cigana). The ADCP and its ground cable were loaded on the R/V Asterias. A small boat (R/V Mytilus) and a zodiac supported the diving operations.

The mooring was deployed during slack tide to ease station keeping, diving, and avoid anchor dragging and mooring entanglement. The subsurface buoy, with its tag line and surface marker, was deployed first. The mooring line was then eased overboard. The anchor end of the ADCP cable was then passed to the barge and connected to the anchor. Next the anchor module, with three SHARPS coiled on the frame and all electrical/optical connections made and checked, was slowly lowered by the crane with the help of a bull rope. At the same time the EOM cable was paid off from its winch, with no tension on it. The R/V Asterias nearby was simultaneously paying the ADCP ground cable overboard.

Once the anchor module reached the bottom, the lowering nylon rope was married to the EOM cable and casted off from the barge. At this point divers proceeded to deploy the SHARPS transponders on the bottom, check anchor position, install the ADCP, and check mooring status. The divers were back on the surface and recovered by the R/V Mytilus within 20 minutes.

With all sensors deployed and in good standing, the barge was pushed towards the shore site, paying off the EOM cable. The R/V Asterias proceeded to its lab station and anchored at the shore site. Eventually the EOM cable shore end was transferred to the R/V Asterias and connected to the monitors and controller. The DYNAMOOR system was promptly energized and it was found to be functioning properly. The barge was then moved back offshore in order to deploy the S4 mooring 100 m to the west of the DYNAMOOR anchor. This last operation concluded the installation.

After deployment, all components of the system performed flawlessly for six hours. Thereafter the SHARPS transmission became intermittent and finally ceased completely after 24 hours on station. The mooring remained active for two more days. ADCP and tension data were continuously recorded. The ballasting system was repeatedly and successfully exercised. Recovery of components was achieved by reversing the order of the deployment sequence.

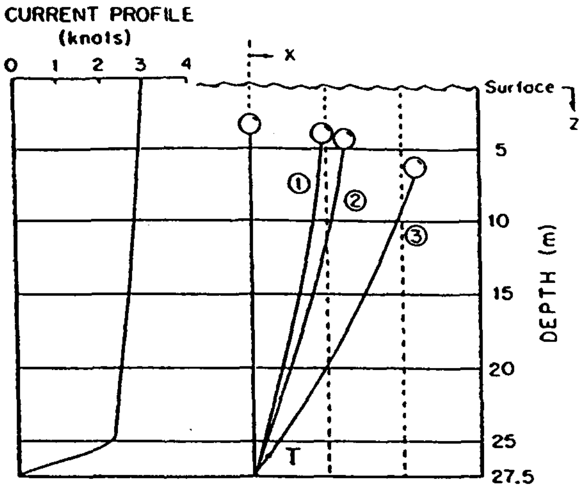
MECHANICAL DESIGN

Important features of the DYNAMOOR system mechanical design are hereafter briefly reviewed.

Mooring Design: Accurate predictions of the depth reached by the buoy and of the tension in the mooring line were needed to properly select the pump of the variable ballast system, the range of the tension cell, the size of the mooring line, and the weight of the anchor. The trajectory of and the tension in the mooring line of three subsurface moorings, each with sphere buoyancy of 400, 800, and 1050 lbs. (182, 363, 477 kg) respectively, were obtained with the help of the computer program SSMOOR [4]. Current data formerly obtained at the site were used to define the input current profile. Computer results and current profile are shown in Fig. 2.

Variable Ballast Sphere: The subsurface buoy, (Fig. 3), was fabricated from a 48" steel sphere modified to contain the variable buoyancy system. The sphere was cut in half at the equator, and reassembled with two internal flanges. The two halves were sealed with a face seal O-Ring, and held together by eight bolts through small tabs straddling the joint.

A 34" diameter polyform float, capable of holding up to 750 pounds of water ballast, was



	B (lbs)	x (m)	z (m)	T (lbs)
①	1050	4.7	5.2	1027
②	800	6.1	5.5	726
③	400	10.6	7.4	381

Fig. 2: DYNAMOOR mooring static analysis

mounted into the upper half of the sphere. A central pipe and four legs made of steel angle, supported the polyform bladder and minimize sloshing.

A small lifting lug was welded to the apex of the upper half of the sphere. A 4" long by 11" diameter section of pipe with an external flange was welded to the lower apex of the sphere. A plate with the tension cell in the center was bolted to the flange. Two Brantner connectors entered the sphere inside the pipe. One connected the tension cell and the other the mooring cable conductors to the electronics housing inside the sphere.

An annular ring was welded into the lower half of the sphere. It supported the electronics housing and the second housing containing the rechargeable batteries.

A DC motor driven roller pump, rated for 0.5 gallons per minute, and two solenoid valves were also attached to the ring. The back to back valves were used to prevent hydrostatic and internal ambient pressure from driving water past the pump, when off. Plastic tubing was used from the through hull fitting to the valves, from the valves to the pump and from the pump to the bladder.

An additional through hull fitting was provided for venting the inside of the sphere when on the surface.

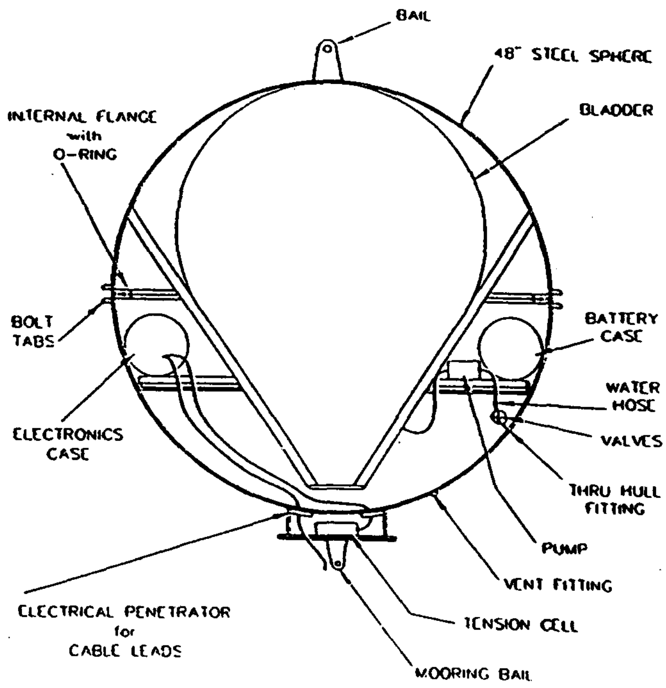


Fig. 3: Variable Ballast Sphere

Anchor Module: The Anchor module was designed to resist current induced forces and any overturning moment caused by the tension in the mooring cable. An anchor weight of 3500 pounds in air, 3040 pounds in seawater was selected. A 1/2" thick steel deck plate, two cast iron discs and a hexagonal, 1/2" thick, steel plate with six large, bottom grabbing flukes made up the base (Fig. 4). These were held together with a 1 1/4" central steel bolt.

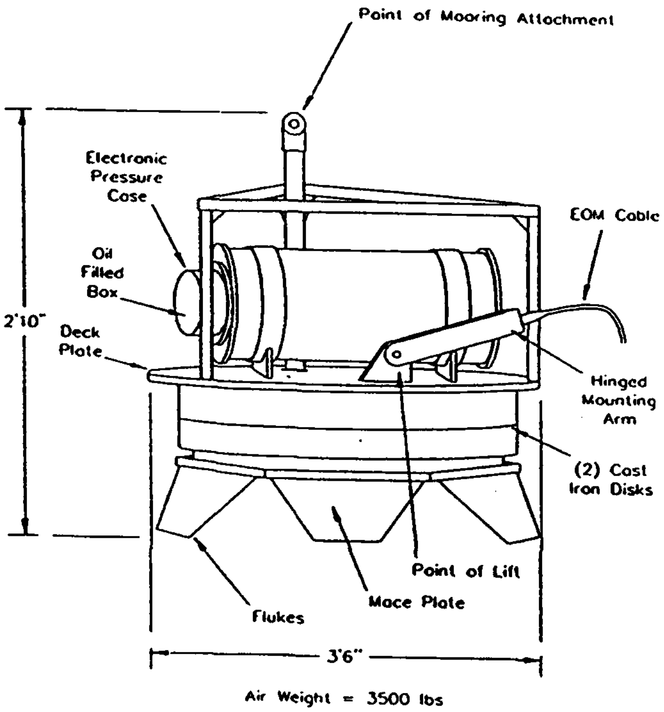


Fig. 4: Anchor module

The mooring attachment was located 34" above the bottom, at the end of a heavy wall steel pipe. This prevented the mooring from tangling with anything else on the anchor.

The EOM cable termination and a pear ring used for lifting the anchor were located on the deck plate, on the other side of the anchor module.

A 12" diameter pressure case, 30 inches long, was mounted on the deck, perpendicular to, and between the two cable attachment points. One end of the case has an oil filled box in which the EOM cable core terminates. The other end had bulkhead connectors for the SHARPS cables, the ADCP cable and the signal and power conductors for the sphere electronics.

Two other vertical pipes were welded to the anchor base to support a small wire mesh deck. Gussets did strengthen the mooring attachment pipe against bending.

Cables and Terminations: The cable connecting the subsurface buoy to the anchor module used a 5/16" diameter 3x19 wire rope, with 10400 pounds rated breaking strength as the tensile member. The wire rope was terminated at both ends in a WHOI standard swage socket and bending strain relief boot. The electrical conductors were soldered to Brantner and D. G. O'Brien pigtails. The solder joints were covered with heat shrink tubing and self vulcanizing tape to make a water tight splice.

The EOM cable (Fig. 5) was mechanically terminated at both ends in a welded steel clevis

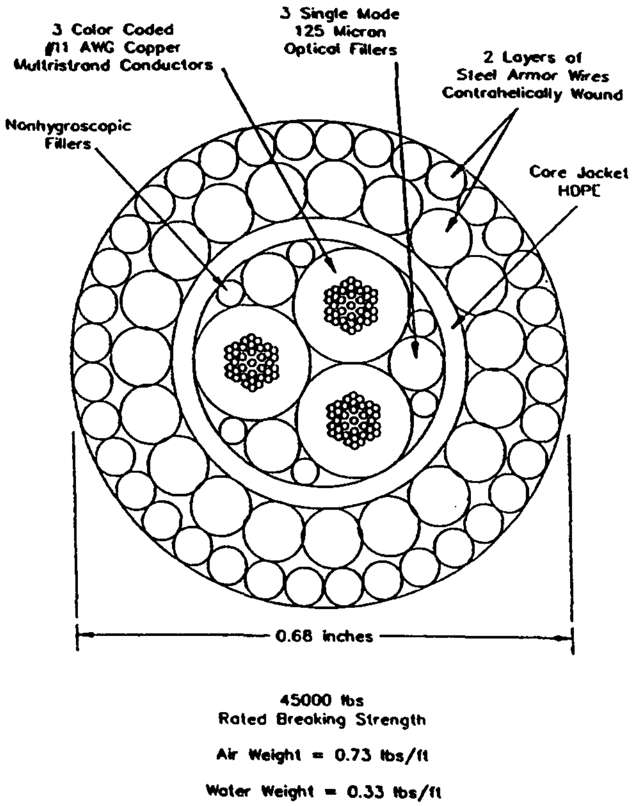


Fig. 5: Electro-Optical-Mechanical Cable

fitting. The clevis to anchor termination was designed to allow the clevis to follow the cable lead angle without bending the cable. The armor wires were cut back for fifteen feet from each end of the cable to expose the core. The armor wires were broomed out inside a steel cone machined into the clevis fitting and filled with epoxy. A bending strain relief boot was built around a pipe nipple and the cable with layers of vulcanizing tape. The core on the anchor end of the cable was lead through a stuffing tube into the oil filled box mentioned previously. The core on the shipboard end was connected directly to the electronics in the lab.

ELECTRICAL DESIGN

The electric design covered the following functions:

- remote control of the variable ballast system
- power for the sphere, the tension cell, the SHARPS, and the ADCP
- modulation and demodulation of the sensor data and controls onto the fiber optic cable
- recording and display of the time series of current velocity and direction, tether tension, and sphere position (XYZ).

The equipment designed to facilitate these functions will be described in brief detail below. The general electrical block diagram is shown in Fig. 6.

Sphere Electronics: The heart of the electronics in the subsurface sphere was an embedded controller which operated the valves and pump, measured the analog voltages from the tension cell and battery pack, and sent data to and received commands from the surface over a bidirectional RS232 communication link. This controller was a card set from STAR ENGINEERING consisting of CPU, A/D and memory, and power control and communication cards.

The firmware was written in BASIC for the 80C52 microprocessor and included the following command functions:

ov - open valves
hv - hold valves open on reduced power
cv - close valves
po - pump out
pi - pump in
st - stop pumping and close valves

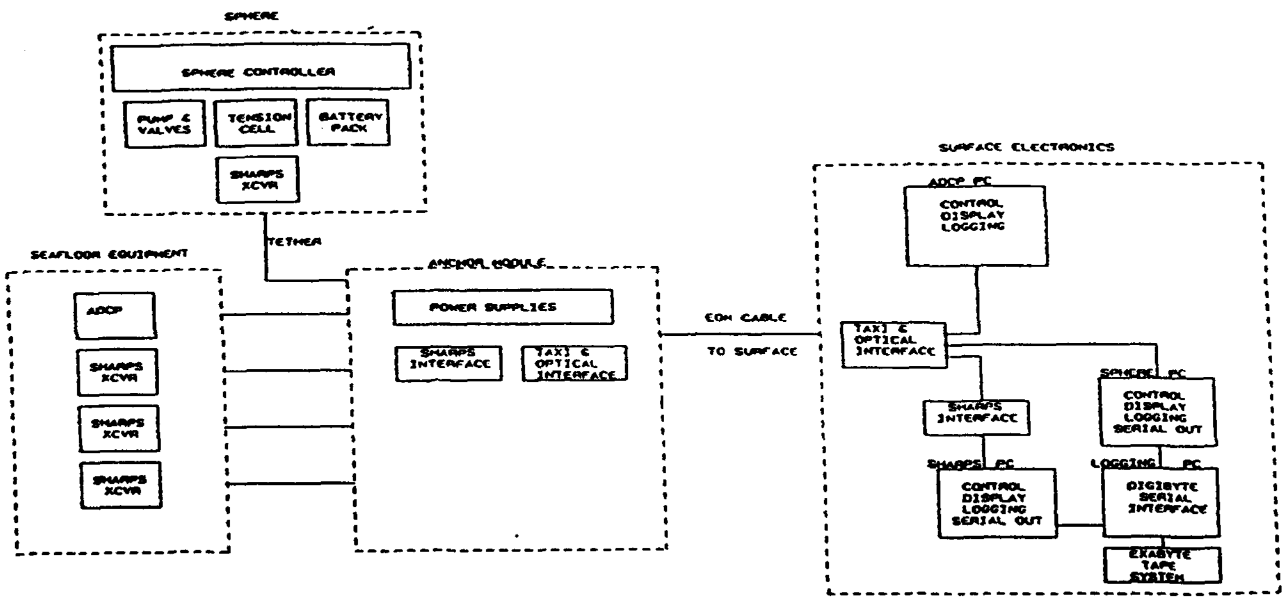


Fig. 6: Electrical Block Diagram

After receiving a command and initiating the action, a confirmation message was returned. When not initiating a control function the processor was measuring and sending data while waiting for the next command. For each 12 bit A/D measurement, two 8 bit bytes were trans mitted, coded with a parameter identifier and means to uniquely mark each of the two bytes to make them distinguishable.

The pump used was an Anko Products 0.5 gpm MITYFLEX positive displacement roller pump. A positive displacement was needed because the bladder and pump were subjected to a greatly varying amount of internal and external pressure as the confined bladder filled and the buoy descended. Back to back electric solenoid valves were used to overcome the problems associated with changing inlet/outlet conditions. These valves were energized at full power to seat them and then the power was reduced to a holding level (1/4) to conserve battery life.

The battery pack consisted of three parallel sets of 12 "D" size, sealed, rechargeable lead-acid cells providing a 24v supply of 7.5 ampere hours capacity, enough to fill and then empty the bladder of water without waiting for the battery to recharge.

Mooring Cable: The mooring cable consisted of three shielded twisted pairs, three RG-58 coaxial cables, and a wire rope for strength, married together in an outer jacket. One coax connected to the SHARPS transceiver mounted on the sphere. The multiconductor cable supplied 30 volt to recharge the battery and carried the bidirectional RS232 communication link.

Anchor Electronics Package: The underwater electronics package mounted on the anchor provided the interface between the electrical signals generated by the sensors and the fiber optic cable. A similar interface on the surface converted the optical signals back to electrical. Six power supplies also in the package provided power for the interface circuitry, the ADCP, the SHARPS transceivers, and the buoy electronics. The R/V Asterias supplied 115 vac, isolated and ground fault protected, for the power supplies through the copper conductors in the EOM cable.

The basic interface consisted of an optical receiver and transmitter at each end of the optic cable which transformed electrical signals to light with a 1300 nm laser. The laser was driven by the output of a ten channel digital multiplexer which sampled each channel at 10 MHz rate. The multiplexer used was the "TAXI" chipset with a bit rate of 100 mHz.

The normal SHARPS configuration consisted of transceivers connected by coaxial cables via a junction box directly to the transmitter/receiver card plugged into the PC backplane. The signals on the coax were a 30 volt transmit pulse and a 10 volt received signal superimposed on the 30 volt level. Since the fiber carried only logic level signals, the transmit and receive signals had to be transformed to logic levels, sent through the fiber, and then reconstructed at the other end. No timing degradation takes place in the SHARPS signals through use of the "TAXI", due to the high sampling rate.

Fiber Optic Cable: The fiber optic cable consisted of three #11 awg copper conductors and three single-mode fibers, jacketed and encased in a doubled armored sheath. Two fibers carried signals, one down from the surface (control commands), and the other up, (modulated data), the third being a spare. All three copper conductors were used to power the unit, two being connected in parallel to reduce the voltage drop in the 800 m of cable.

Topside Electronics: The topside equipment consists of three dedicated PC systems, an optical interface, a SHARPS interface, and a fourth PC used to mass store all the data on magnetic tape. This PC, a 25 MHz 386 with co-processor, processed up to eight channels of serial data using a eight serial channel controller/

buffer to sequence the acquisition and writing to tape of the multichannel output of the topside demultiplexer. The "TAXI" split the uplink signals from the fiber out to the appropriate PC for processing.

The SHARPS signals, having been converted back to normal levels, were processed by the transmitter/receiver card in the SHARPS control PC. It set the system parameters, initiated transmissions, displayed target and bottom net position data on the screen, and logged target position data to the hard disk. The same XYZ position data is also sent out the serial port to be logged on the tape drive.

The ADCP PC processed its data, displayed the current profiles, and logs these profiles (along with other operational and status information) to its hard disk to be decoded and analyzed later, off line.

The data stream coming from the sphere was processed by the logging computer. The data was decoded, the parameter identifiers stripped off, and the data stored on tape in blocks along with the SHARPS data in near real time. In addition to the data, each block on tape had a header including a block number and a time stamp reference, to allow later synchronization of all the data. The tape system used was an EXABYTE model EXB-8200 CTS storing up to 2000 megabytes on standard 8 mm tape cartridges using a SCSI interface.

DATA ANALYSIS

Long time series measurements of current mooring line tension and sphere position were obtained during the DYNAMOOR deployment. Horizontal and vertical components of the current were measured at thirty distinct depth levels by the ADCP with a sampling frequency of 0.125 Hz. Tension data were recorded at a frequency rate of 20 Hz with three different values of sphere buoyancy: 1050, 800 and 400 lbs. The three XYZ spatial components of the instantaneous sphere position, measured with the SHARPS network, were recorded at a sampling rate of 2.5 Hz.

The recorded time series commonly contained from one to five hundred thousand data points. Data reduction and presentation was performed using the classical methods of statistical and spectral analysis. The software MATLAB^r with additional programs specifically developed for this analysis [5], was extensively used. To reconstruct the appearance of the time variations of the parameters measured, the series were compacted, using a decimation by intervals procedure. Histograms were made. Power spectral densities (PSD) were derived to abstract the main frequencies and associated energy of the processes studied. Statistical averages (mean, STD, RMS) and series maxima and minima were also computed. Finally, an attempt was made at correlating certain output/input relationships such as tension versus current and position versus current. In these instances, the transfer and coherence functions were calculated to qualify the degree of correlation. Results from this analytical procedure are hereafter summarized.

SUMMARY OF RESULTS

Current: The analysis of the 30 ADCP current records shows that the tidal current is strongly coherent, both in direction and strength. The tidal axis follows a course of 67 degrees from the magnetic North, with very little deviation from surface to bottom. The current profile (Fig. 7) shows an astonishingly small decrease with depth. Under maximum current conditions, the surface current is three knots, and is still two knots a mere two meters above the bottom.

Spectral analysis of the records confirms that the tidal period is close to six hours. Records obtained from the InterOcean S-4 current meters compare well with those obtained from the ADCP.

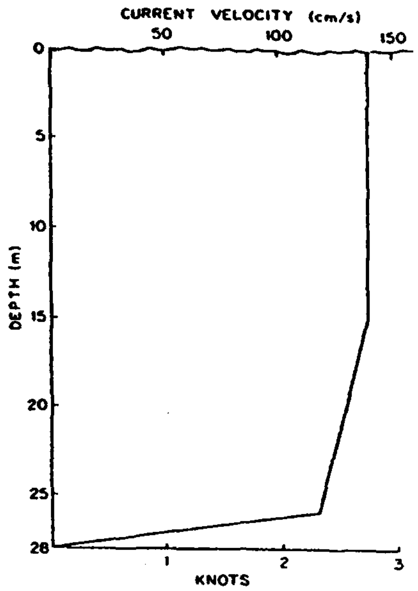


Fig. 7: Current profile (41° 29.3'N, 70° 42.3'W)

Tension: The analysis of the 3 days of tension records proved to be very informative. It is convenient to separate the tension signal into its low and high frequency components [6]. The first, with periods measured in hours, represents the mean or quasistatic tension experienced by the mooring line. Its variation spans from its minimum value equal to the net buoyancy of the buoy (zero current) to its maximum obtained when the hydrodynamic drag is highest (max. current). The second, with periods measured in seconds, represents the deviations from the mean imparted by the turbulence of the flow pass the buoy. Plots of the decimated data clearly indicated that the "static" tension followed a cyclic pattern, with the slack moor (400 lbs) being in phase with the tide, the two others (800 and 1050 lbs) having periods shorter than the tide.

The spectral analysis of the three tension records was done in two steps. The power spectrum of each series was first calculated using the entire series record. This yielded the power spectra shown in Fig. 8, with tabulated values of peak frequencies and associated energies as follows:

BUOYANCY	ENERGY at 0.5 Hz	ENERGY at 4.0 Hz	ENERGY at 6.7 Hz
1050	85	57	200
800	270	56	20
400	360	35	25

Table 1: Tension Peak Frequencies and Associated Energy

Obviously the sphere buoyancy appears to have a strong effect on the energy associated with the peaks contained in the record. At 0.5 Hz (Period = 2 secs), the smaller the buoyancy, the higher the energy. At 6.7 Hz (Period = 0.15 secs), the smaller the buoyancy, the smaller the energy.

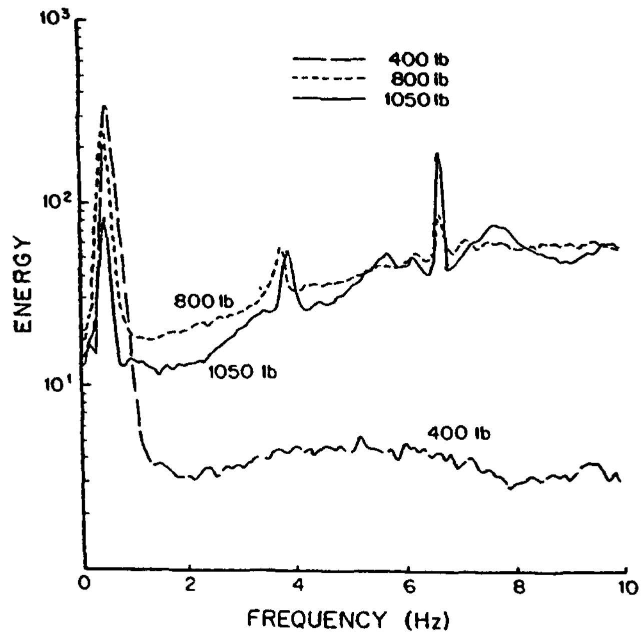


Fig. 8: Power spectra of tension records

Next the tension data of the three buoyancy records were analysed over a full, 360 minutes tidal cycle. Each series was divided in six equal time intervals and the hourly power spectra were calculated, as well as the associated mean tension records. Hopefully this set of 18 spectra would reveal which peak frequencies and what levels of energy were associated with the mean tension prevailing over the particular time interval. Results obtained are summarized in Fig. 9.

In the 1050 lbs. case, the 6.7 Hz frequency dominates, being present in each time interval. Its energy content roughly follows the mean tension, the larger the tension, the larger the peak. The 0.5 Hz, low frequency signal appears also in all intervals, but with a much smaller energy level, except at the end, when the mean tension is very small. The 4.0 Hz is also strongly present at that time. It is as if the dynamic tension was locked in and oscillating at one or both of these two frequencies.

In the 800 lbs. case the 0.5 Hz frequency prevails. Its energy content however becomes very small when the mean tension peaks. At intermediate values of tension the 4 Hz and 6.7 Hz appear with negligible energy.

In the 400 lbs. case only the 0.5 Hz frequency appears. Its energy peaks when the mean tension reaches its minimum.

Next, plots of maximum and minimum tension over two minutes interval were obtained for the three different buoyancy cases. These plots clearly indicated that 1) the dynamic tension range is increasing with decreasing buoyancy and 2) for any buoyancy, strong dynamic action is associated with low mean tension. Thus the sphere with minimum static pull not only endures the largest dynamic impulses, but their occurrence is also the most frequent. Maximum dynamic ranges obtained for the three buoyancy tension records are shown in Table 2.

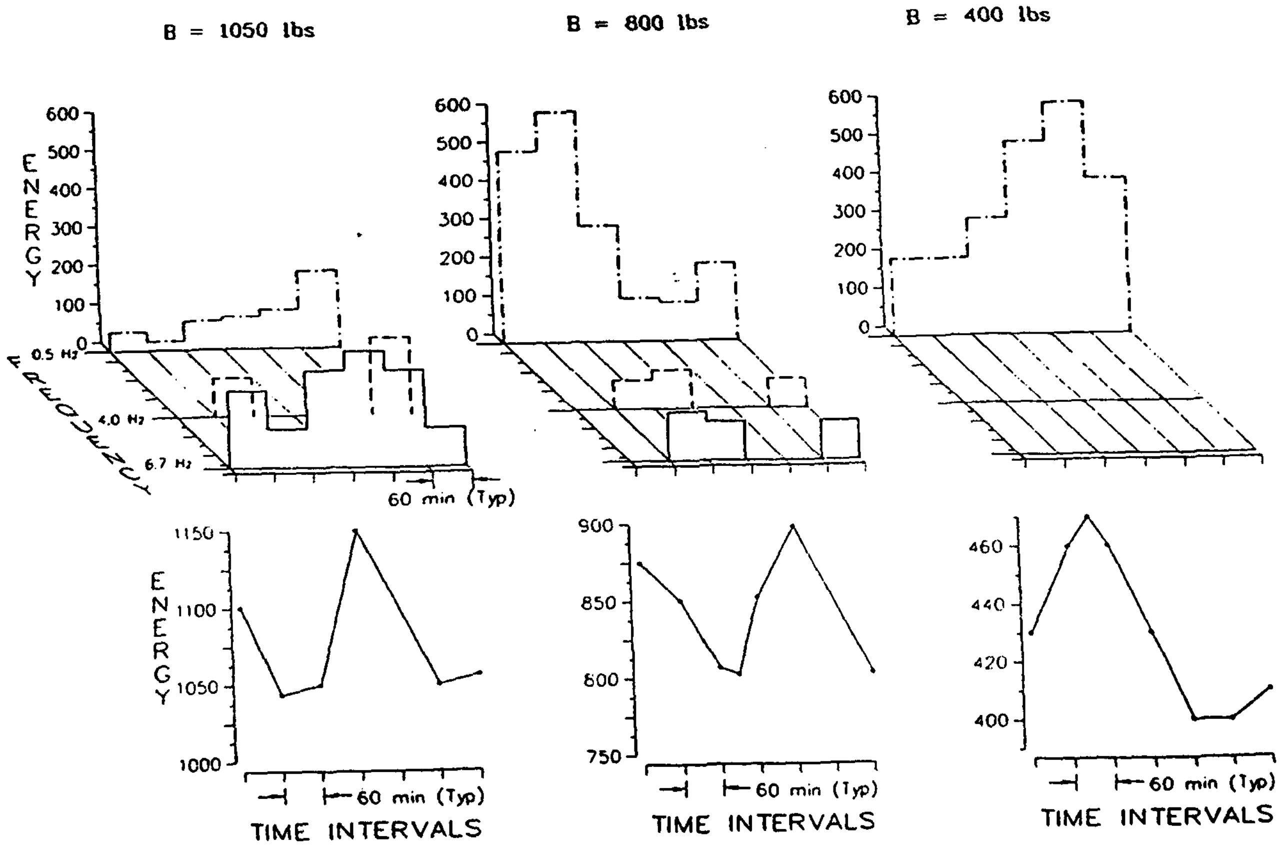


Fig. 9: Hourly Tension Power Spectra peaks and associated mean tension diagrams

NET BUOYANCY (lbs) ①	MEAN TENSION (lbs) ②	MAX. TENSION (lbs) ③	MIN. TENSION (lbs) ④	TENSION RANGE (lbs) ⑤=③-④	FRACTION of NET BUOYANCY ⑥=⑤/①
1050	1084	1367	814	573	0.546
800	856	1248	468	780	0.975
400	433	1024	238	786	1.965

Table 2: Dynamic Tension Ranges

This shows that the dynamic tension range is approximately half, equal, or twice the net buoyancy of the 1050, 800 and 400 spheres.

Buoy Position: Tumbling of two SHARPS transducers on the bottom and interface malfunction after six hours on site, interrupted the buoy position measurements early in the experiment. Two hours of good position records were nonetheless obtained and their analysis produced interesting facts. The current at the buoy depth prevailing at the time of these records ranged from 40 to 80 cm/sec. The buoy buoyancy was 1050 lbs.

The mean buoy position was found to follow a straight line, having the same course as the current (67°M). At the end of its East-North-East travel, the buoy downstream excursion had increased by 4.5 meters and its vertical dip by 3 meters.

The record also showed that the buoy fluctuated around its mean position, describing a figure eight with average amplitude of 20 cms and average periods ranging from five to eight seconds. The lobes of the figure eight were aligned with the current. Maxima of displacements, on two minute intervals, for the entire record were 50 cm eastward. and 30 cm vertically. Spectral analysis of the displacement records confirmed that the movement of the buoy was not energetic. No key frequency could be detected. Cross-spectral analysis of position versus current did not reveal any linear coupling between the two.

CONCLUSION

Despite the SHARPS setback, the DYNAMOOR experiment has been very productive. The development of the remotely controlled variable ballast, the integration of the tension cell, the ADCP, and the SHARPS in a single power/control telemetry unit, and the installation of the whole system in a high current location, all add up to a remarkable engineering and operational achievement.

The preliminary analysis of the data obtained has revealed some very interesting facts: the locking of the tension response at discrete frequencies, the unexpected extent of the dynamic tension range, the "eight" shaped displacement loops, the coherence of the current in direction and intensity. The causality of these observations remained to be addressed.

The DYNAMOOR experiment has pioneered a technique for taking, transmitting, and recording direct, in situ, synchronous measurements of the forcing environment and the dynamic response of moored buoy systems. This technique has already been expanded in 1992, by the OS&M Lab of the Woods Hole Oceanographic Institution, to include measurements of translation and rotation of submerged cylinders and the strumming (up to 200 Hz) of their mooring line. The same technique could be used to monitor the response to waves of buoys of different shapes and different mooring schemes. Such knowledge would be precious to accurately model the dynamic response of surface buoys in wave trains and eventually improve the performance of moored arrays.

ACKNOWLEDGMENTS

This difficult deployment was successfully completed thanks to the skilled assistance of

Dan Clark and his crew, the captains and crew of the tugboats R/V Jaguar and R/V Cigana, and the WHOI divers. D. Olmsted, captain of the R/V Asterias, and S. O'Malley, operator of the R/V Mytilus, were very helpful during diving and deployment operations. Sumitomo Electric Industry (Japan) kindly donated the EOM cable. P. O'Malley was instrumental in the preparation and testing of all the mooring components. W. Liberatore and B. Doherty provided precious assistance with the writing and the illustrations of this paper.

The personal interest and continued support of Dr. S. Ramberg of the Office of Naval Research are also greatly appreciated. The DYNAMOOR experiment was performed under Office of Naval Research Contract No. N00014-90-J-1719

This is WHOI contribution #8129

REFERENCES

[1] SHARPS: Sonic High Accuracy Ranging and Positioning System, Model 51-10, Marquest Group Inc., Operation and Software Manual, February 1992.

[2] Acoustic Doppler Current Profiler, RD Instruments, Operation and Maintenance Manual, April 1988.

[3] S4 Users' Manual, InterOcean Systems, Inc., Third Edition, June 1990.

[4] Berteaux, H. O., SSMOOR, A Subsurface Mooring Computer Program, 1989.

[5] Wansek, P., Observed Motion of a Subsurface Sphere in Strong Tidal Currents, Woods Hole Oceanographic Institution, February 1992.

[6] Berteaux, H. O., Coastal and Oceanic Buoy Engineering 1991. Published by CDMS, P.O. Box 182, Woods Hole, MA 02543