AN OCEANOGRAPHIC INSTRUMENTATION SYSTEM

for in situ application*

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ABSTRACT

An oceanographic instrumentation system has been developed and applied to *in situ* chemical measurements. The system is composed of a submerged assembly and a surface data reduction unit built around a small, general-purpose digital computer (PDP-8/L). The information is recorded digitally by an *in situ* recorder unit, which uses a modified entertainment-type tape recorder to provide eight hours of continuous recording. The resulting data tapes are fed to the computerized data reduction unit that converts the raw data into tabulated physical units. The instrumentation system has been used to measure pH, Eh, temperature and *in situ* carbonate saturation to a depth of 3200 meters.

INTRODUCTION

In a previous paper (Ben-Yaakov and Kaplan, 1968a) we described an oceanographic probe designed for *in situ* measurement. This report describes extended applications of the probe and additional units that provide *in situ* recording and automatic data processing of the information obtained by this oceanographic instrumentation system.

A schematic representation of the original *in situ* probe is depicted in Figure 1a. The unit is supported by an electrical cable which is used as a single channel transmission line to and from the probe. The unit incorporates signal conditioners for the various sensors and a stepping relay that can interconnect any sensor to a voltage-to-frequency converter. The stepping relay is controlled via the electrical cable by a positive going pulse of approximately 30 msec. The output signal of each sensor is thus converted into a proportional frequency signal which is transmitted through the electrical cable to the surface. At

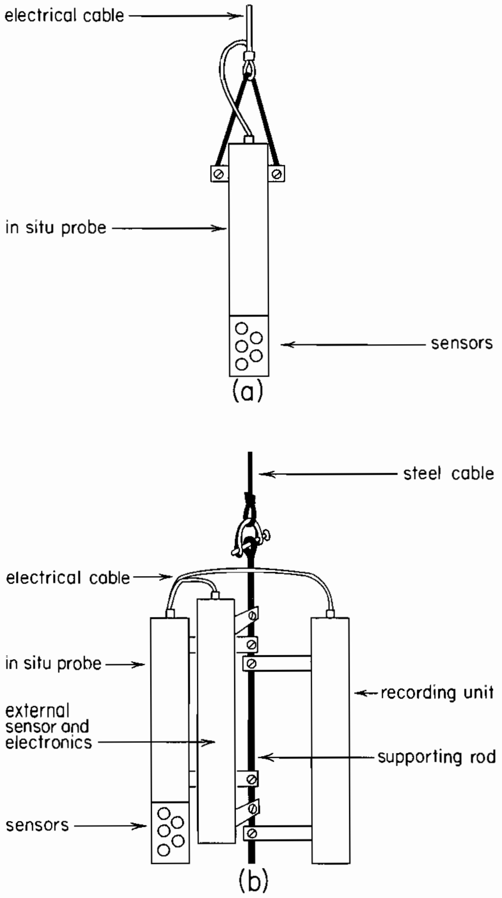

Figure 1. Schematic representation of the original in situ unit (a) and the extended in situ assembly with a recording unit and an external probe (b).

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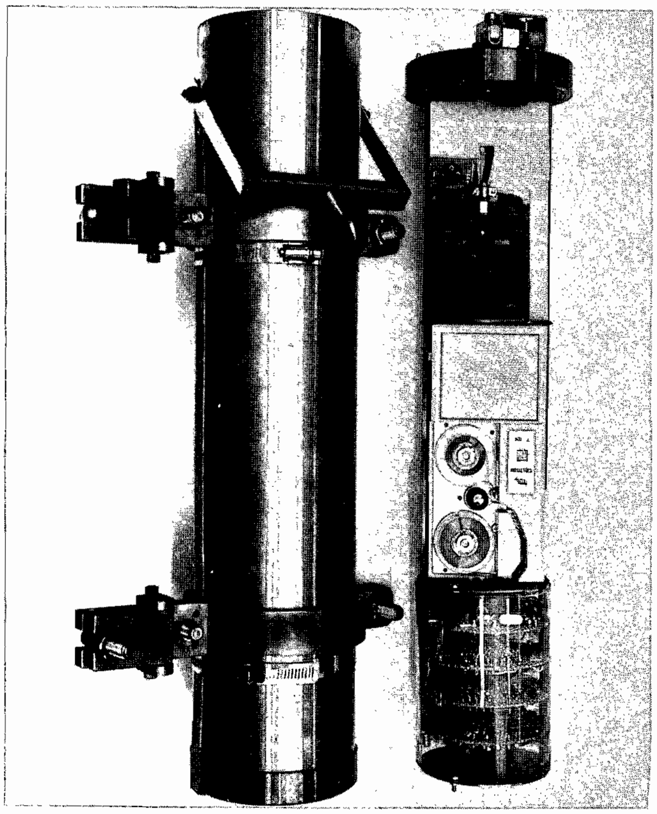

Figure 2. Photograph of the disassembled recording unit.

the surface, the frequency signal can either be measured by a frequency counter or recorded for later manipulation.

The *in situ* unit, as described above, has been used satisfactorily both in the ocean and in lakes to a maximum depth of 1000 meters (Ben-Yaakov and Kaplan, 1968b). In these studies, the frequency was measured by a frequency counter (1 sec. counting time) and recorded manually. The frequency information was converted to physical units by using a desk calculator (Programma 101). This mode of operation has two major drawbacks that limit the practicality of the instrumentation system. These are the needs for an electrical cable and the manual data handling.

An oceanographic electrical cable which is strong enough to support both itself and the in situ probe is a very expensive item. Such a cable is highly vulnerable in the marine environment and will have a short service life. In many applications—and in particular in marine chemistry studies, for which the present system is used—real time measurement is not of prime importance. A delay of a few hours until the data are available can be tolerated. There is therefore, no operational need for the electrical cable, and it should be avoided if possible. A logical solution to overcome the problem of the electrical cable is to use *in situ* recording, so that the probing assembly will be independent and can be supported by regular steel cables which are standard items on any oceanographic vessel. This is the approach adopted in the present study and a recording unit has been developed and constructed.

A schematic representation of the assembly with a cable recording unit is depicted in Figure 1b. In this case we have three units: the probe, a casing for an external sensor and the recording unit. Some of the sensors (such as the conductivity meter) are too large to be incorporated in the casing of the probe itself. It was found more practical to encase such a sensor in a separate housing and to interconnect it to the probe by an electrical cable. The probe, however, will service such a sensor in exactly the same way as any other sensor incorporated within the housing. The present units were designed to withstand a pressure of 10,000 psi which is equivalent to an ocean depth of approximately 6500 meters.

RECORDING UNIT

The recording unit is built around a miniature magnetic tape recorder (Telmar 100T, made in Japan and distributed by Martel, Los Angeles, California) that has external dimensions of 19.5 x 8.5 x 5 cm and a capstan-drive mechanism which is governed by a feedback speed control. The tape recorder was slightly modified in three respects: the amplification circuitry was bypassed feeding the signal directly to the head, a tape spool security lock was incorporated to hold the spools firmly, and the tape speed was decreased. The latter was achieved by adding an extra resistor to the speed control circuit so as to reduce the speed from 15/16 inch per second to approximately 0.125 inches per second. The tape recorder uses tape spools of 1-3/4-inch diameter which will run continuously for four hours, with a 0.5 mil tape and eight hours with 0.25 mil tape. At this low speed, the magnetic head is capable of recording directly (no bias) the frequency band 200-300 Hz. All data are, therefore, modulated with a 250 Hz signal before being fed to the magnetic head.

The recording unit is built into a 4-inch I.D. 21-inch long stainless steel high pressure housing (EG & G type 270) which is rated to 10,000 psi. The unit is built in three sections: the lower electronics compartment, the tape

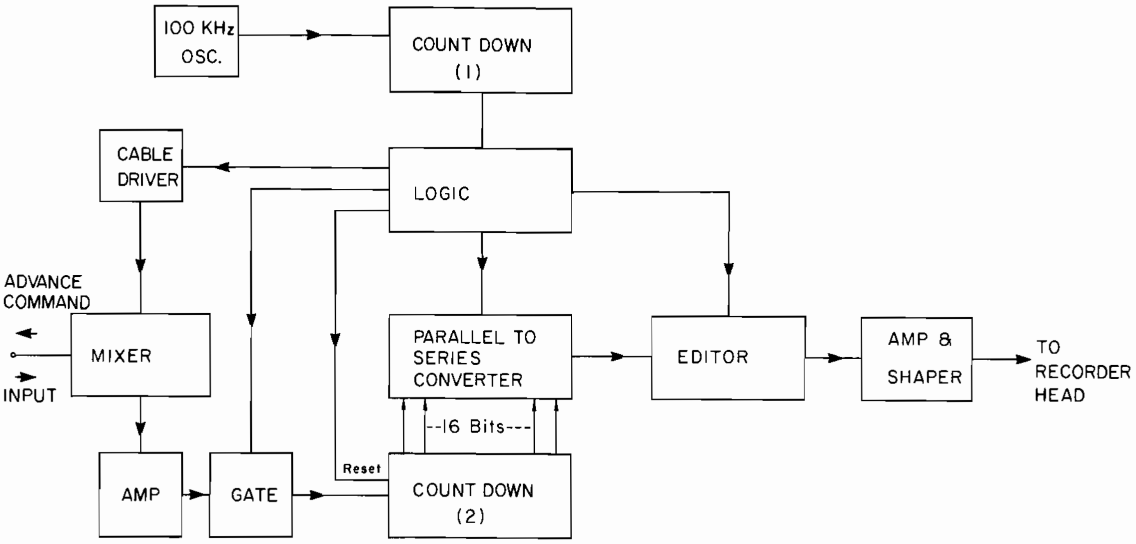

Figure 3. Functional block diagram of the recording unit.

recorder, and the battery pack. The electronics section is protected by a plastic shield to prevent damage when handling the unit. Two high-pressure electrical connectors, at the upper cap of the unit, provide the required electrical connection. Figure 2 is a photograph of the disassembled unit and the block diagram of Figure 3 demonstrates the basic design.

The circuit is basically a frequency counter which counts the incoming signal over a period of 1 second. Counting is done by an IC BCD counters and the result is represented as a four-digit BCD number, namely 16 bits. These parallel bits are converted to a serial string of pulses, edited and fed to the head of the magnetic tape. The unit also provides an "advance" pulse which is sent through the cable to the probe and used to advance the stepping relay. All the timing pulses are derived from a 100 KHz crystal controlled oscillator. Detailed descriptions of the electronic circuitry and logic design is given elsewhere (Ben-Yaakov, 1970).

DATA REDUCTION SYSTEM

The magnetic tapes are processed by a surface system built around a small, general purpose digital computer (PDP 8/L). The basic blocks of this system are depicted in Figure 4. It is composed of another entertainment-type magnetic tape recorder feeding the computer through a read-out unit and a computer interface. The read-out unit rearranges the serially recorded numbers in parallel and produces a pulse whenever a data point is ready to be read into the computer. The tape is played back at 1-7/8 ips, namely 15 times faster than the recording speed, which results in a data rate of approximately six four-digit numbers per second. The original 250 Hz modulating signal is converted to 3.75 KHz, well within the audio range so that any audio tape recorder can be used to play back the tapes. (We are using the CRAIG 212, which is a small entertainment-type tape recorder).

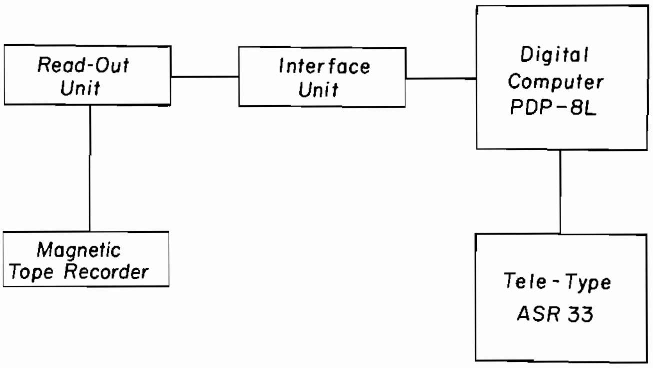

Figure 4. Block diagram of the data reduction system.

The use of entertainment-type tape recorders with relatively poor performance, dictated a careful design to ensure reliable readout. The main problems that had to be overcome were inconsistency of the tape speed, wow and flutter. These were overcome by basing the bits and sync identification on the number of cycles (the original 250 Hz modulating signal) which are contained in them. The "zero" bit contains 5 cycles, the "one" bit contains 20

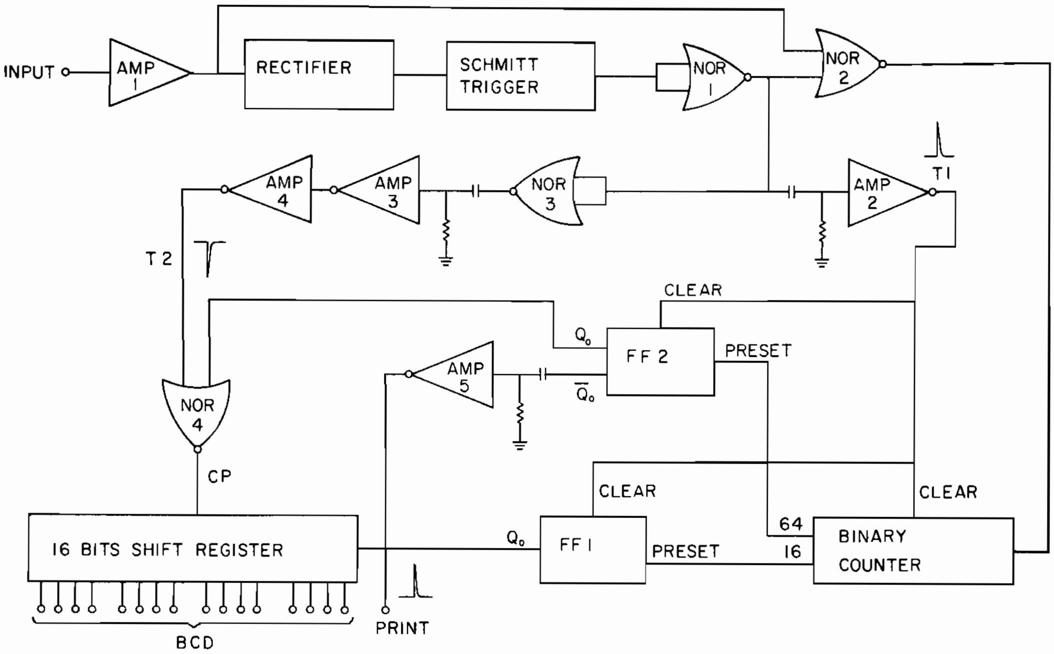

Figure 5. Functional block diagram of the read-out unit.

```
NUMBER OF DELETIONS:4
D(I):48.0
D(I):50.0
D(I):95.1
D(I):96.5
PH (MV) MAX:-360
PH (MV) MIN:-390
SCALE=    0.500  MV/DIVISION
START:45.0
END:110.5
```

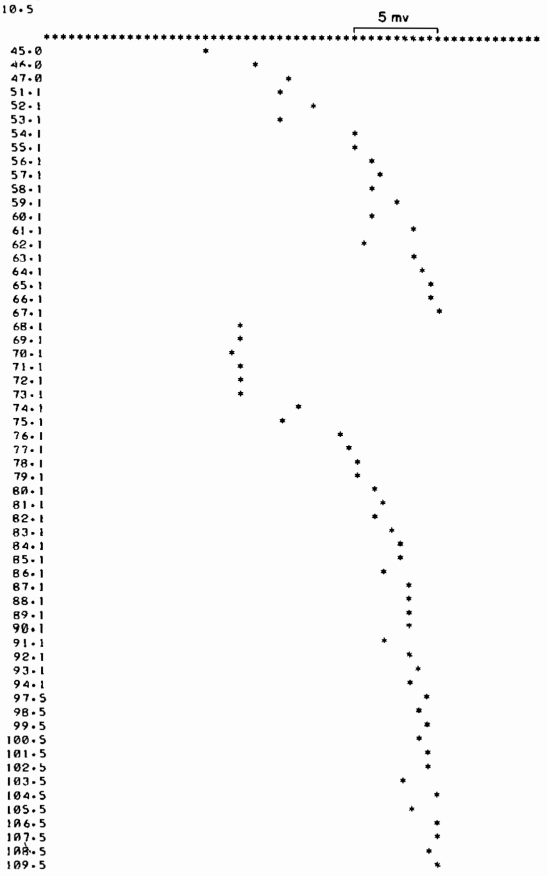

Figure 6. In situ carbonate saturometry. Santa Monica Basin. Station 3. Depth: 100 m.

cycles and the "sync" bit contains at least 75 cycles. Hence, one can identify the various pulses by counting the number of cycles within them. This method is completely independent of the recording or playback speeds as long as the read-out unit is capable of counting the (original) 250 Hz cycles. A block diagram of the read-out unit is depicted in Figure 5.

The interface unit is mainly a gating circuit which facilitates the strobing of the information into the computer accumulator. The output of the read-out unit is compatible with a number of commercially available digital printers (such as Hewlett-Packard 562A or Monsanto 501A), which can be conveniently used on board ship when it is desirable to scan the raw data.

The data are processed in two steps: the information is first translated from the magnetic tape to a perforated paper tape, which is later read by the computer for calculation. The computed results are simultaneously typed on the teletype while punching a paper tape for later manipulation, such as plotting. The two-step process greatly simplifies the programming procedure because a higher level language can be used.

Processing time is mainly controlled by the input-output facilities of the system. Our computer has only the teletype as an input-output device, apart from the magnetic tape recorder that is used initially to read in the raw data. The reading and printing speed of the teletype is 0.1 sec per character, whereas the reading speed of the magnetic tape recorder is approximately 0.05 sec per character. Each data

Table I – A Sample of a Print-Out of Raw Data

```
0585;4548;6908;2423;1347;0403;8560;2032;2030;4163;1271;8012
0597;4526;6908;2422;1347;0403;8559;2032;2030;4163;1370;7995
0595;4525;6909;2421;1347;0403;8558;2031;2029;4162;1457;7975
0595;4526;6909;2420;1347;0403;8557;2032;2029;4163;1563;7961
0595;4525;6908;2419;1347;0403;8558;2031;2029;4163;1589;7946
0596;4525;6909;2417;1347;0403;8558;2031;2028;4163;1616;7939
0597;4525;6909;2417;1347;0403;8558;2031;2029;4162;1642;7924
0598;4525;6909;2415;1347;0403;8559;2030;2029;4163;1660;7916
0599;4525;6909;2414;1347;0403;8560;2031;2029;4163;1675;7905
0600;4526;6910;2413;1347;0403;8561;2030;2029;4163;1686;7901
0601;4527;6910;2412;1346;0403;8561;2031;2029;4163;1694;7895
0602;4526;6910;2411;1346;0403;8562;2030;2029;4163;1702;7900
0603;4527;6910;2410;1347;0404;8563;2031;2028;4163;1724;7887
0603;4528;6910;2408;1346;0403;8563;2031;2029;4163;1732;7889
0604;4528;6910;2407;1346;0403;8563;2031;2029;4164;1738;7887
0605;4528;6910;0000;2406;1347;0403;8564;4058;4055;4163;1745
7927;0606;4529;6911;2406;1346;0404;8564;4058;4056;4163;1752
7941;0606;4530;6910;2405;1346;0404;8565;4059;4057;4164;1749
7944;0607;4529;6911;2404;1346;0403;8564;4059;4056;4164;1754
7945;0608;4530;6911;2403;1346;0404;8565;4059;4058;4164;1757
7945;0608;4530;6911;2402;1346;0403;8565;2032;2029;4165;1760
7912;0608;4530;6912;2400;1346;0403;8566;2031;2029;4165;1762
7896;0609;4530;6911;2400;1346;0403;8565;2032;2029;4164;1764
7885;0609;4531;6912;2398;1345;0403;8566;2031;2029;4165;1767
7897;0610;4531;6911;2398;1345;0403;8566;2031;2028;4165;1782
7879;0611;4531;6911;2397;1346;0403;8567;2031;2029;4165;1782
7876;0610;4531;6912;2396;1346;0403;8567;2031;2029;4165;1779
7876;0611;4531;6911;2399;1346;0404;8567;2031;2029;4165;1777
7867;0611;4531;6911;2394;1345;0404;8567;2031;2028;4165;1775
7875;0612;4531;6911;2393;1345;0404;8567;2031;2029;4165;1774
7862;0612;4531;6911;2392;1345;0404;8567;2031;2028;4165;1778
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Table II – A Sample of a Print-Out of Calculated Data

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 T(M)   D(M)   TEMP    PH(MV)    PH     EH      PUMP    B:

45.0   267.2  8.933  -373.70   8.037  474.62  2029.0  24.100
46.0   265.0  8.933  -372.46   8.015  472.46  2028.0  24.083
47.0   269.6  8.938  -372.60   8.018  471.62  2029.0  24.070
48.0   271.9  8.938  -372.30   8.012  471.12  2029.0  24.060
50.0   271.9  8.949  -377.80   8.110  469.61  4056.0  24.040
51.0   274.2  8.933  -378.06   8.115  470.06  4057.0  24.033
52.0   278.7  8.955  -378.04   8.114  469.47  4056.0  24.027
53.0   276.5  8.944  -378.10   8.116  469.21  4058.0  24.010
54.0   278.7  8.949  -374.64   8.054  468.97  2029.0  24.007
55.0   281.0  8.944  -372.99   8.024  468.74  2029.0  23.984
56.0   281.0  8.960  -372.04   8.007  468.46  2029.0  23.987
57.0   283.3  8.955  -373.09   8.026  468.23  2029.0  23.964
58.0   285.6  8.955  -371.34   7.995  466.77  2028.0  23.967
59.0   283.3  8.949  -371.04   7.989  466.77  2029.0  23.957
60.0   285.6  8.949  -370.99   7.988  467.04  2029.0  23.944
61.0   283.4  8.944  -370.20   7.975  467.31  2029.0  23.970
62.0   285.7  8.944  -371.00   7.989  467.51  2028.0  23.920
63.0   285.7  8.944  -369.70   7.966  467.61  2029.0  23.910
64.0   288.0  8.933  -369.30   7.959  467.22  2028.0  23.900
65.0   285.7  8.944  -369.60   7.964  467.41  2028.0  23.890
66.0   285.6  8.944  -369.04   7.954  467.28  2028.0  23.877
67.0   288.0  8.938  -369.64   7.965  467.28  2028.0  23.877
68.0   288.0  8.949  -368.64   7.947  466.87  2029.0  23.867
69.0   290.2  8.955  -368.59   7.945  465.83  2029.0  23.854
70.0   290.2  8.955  -374.39   8.049  466.23  2047.0  23.854
71.9   290.3  8.949  -377.94   8.113  465.87  4056.0  23.827
72.9   292.5  8.955  -378.08   8.115  464.33  4056.0  23.814
73.9   292.5  8.949  -378.48   8.122  462.04  4057.0  23.814
```
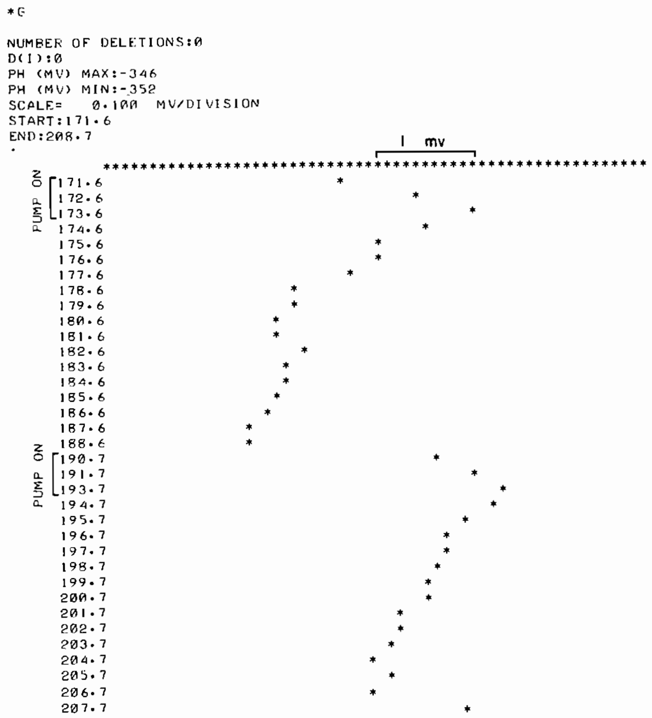

point is 5 digits (or characters) of information, and since it has to pass four times through the input-output (magnetic to paper tape and paper tape to typed results) it requires approximately 2 seconds read-write time. In practice, the total processing time per character is approximately 2.5 seconds, which is half real time. A complete processing of eight hours real time (one spool) which contains 11,000 numbers is approximately four hours. This processing time, although slow when compared to a large computer installation, is of course a tremendous improvement over manual computation.

The data processing system is small enough in its physical dimension to be brought on board the ship from which the study is being made. This mode of operation is highly desirable, since it provides tabulated results within a few hours, so that the study can be modified according to the data obtained.

The computer data processing system is the most expensive part of our instrumentation system, with a total cost of approximately $10,000. On the other hand, the *in situ* assembly is relatively inexpensive as a result of a basic philosophy of design which was aimed at reducing the cost of the vulnerable units. This was accomplished by: (1) using time multiplexing, namely measuring one parameter at a time rather than all the parameters simultaneously, (2) making all correction on the raw signal on the surface rather than by analog circuitry *in situ*, and (3) developing a novel, inexpensive recording unit which makes use of an



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NUMBER OF DELETIONS:0
D(I):0
PH (MV) MAX:-346
PH (MV) MIN:-352
SCALE=   0.100  MV/DIVISION
START:171.6
END:208.7
.
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Figure 7. In situ carbonate saturometry. Santa Monica Basin. Station 9. Depth: 400 m.

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entertainment-type tape recorder rather than a professional digital tape recorder. The time multiplexing technique also simplifies additon of new sensors to the probe, since the bulk of the electronic circuitry is shared by all the sensors.

RESULTS

This system presently incorporates five sensors for measuring the following parameters: depth, temperature, pH, Eh, and conductivity of seawater. Two of the sensors, the pressure transducer and the thermistor, have been obtained commercially, whereas the remaining sensors have been developed during the course of this study (Ben-Yaakov 1970). The pH electrode, together with an *in situ* centrifugal pump, has been used to perform an *in situ* carbonate saturometer experiment. In this case, the glass electrode is placed in a cell and surrounded by fine grains of calcite. The cell is connected to the pump by a hose, so that it can be flushed by seawater when the pump is turned on. The pump is powered by a nickel cadmium (NiCd) battery pack and controlled by a timer which fixes the duty cycle. By this arrangement, the pH of the seawater—before and after contact with a solid phase of $CaCO_3$—can be measured. This information can then be used to estimate the degree of saturation of the seawater with respect to $CaCO_3$.

A print-out sample of the raw data is given in Table I, and a sample of the computer output is shown in Table II. The calculation steps include the correction of the raw data for electronic drift and take into account the calibration data of the various sensors.

The output print-out (Table II) includes the running time (starting from the beginning of the experiment), depth, temperature, mV output of the pH electrode (corrected for electronic drifts), pH, Eh (corrected for temperature dependence of Ag/AgCl electrode potential), pump marker (4000 when pump is on), and battery voltage. The marker channel is used in the saturometer experiments to indicate when the cell is being flushed. This channel was used for recording salinity measurements in some earlier experiments.

The computer output data have been used to plot the change of the pH electrode output potential during the saturometer cycle. This was accomplished by another program that uses the teletypewriter as a plotter. Figures 6 and 7 are a sample of two plots obtained for two water depths in Santa Monica Basin. These are plots of mV output (horizontal) versus time (vertical). The scale sensitivity (mV/division) may be different for each plot and is indicated on each figure. The mV scale shows positive values to the right. The time scale is in minutes, and each point corresponds to a measurement that was taken during a cycle of the stepping relay. Figure 6, which corresponds to 100 m depth, indicates that the output of the glass electrode became more positive when the seawater was left to equilibrate with the $CaCO_3$. This implies that the calcium carbonate was precipitating (Ben-Yaakov and Kaplan, 1969) namely the water was supersaturated with respect to calcite. The data at 400m (figure 7) show a negative voltage shift, which indicates that the water was undersaturated, since $CaCO_3$ was dissolving. Results and interpretation of the *in situ* carbonate saturometer experiment are given elsewhere (Ben-Yaakov 1970).

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