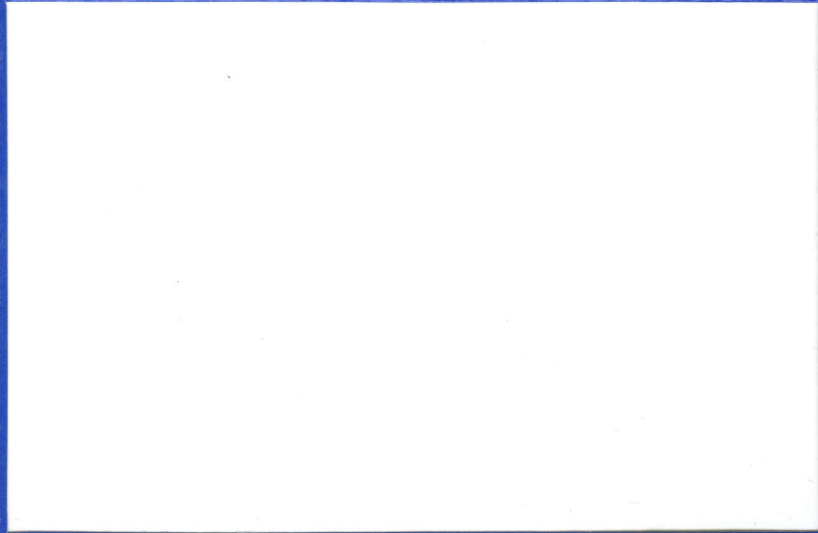
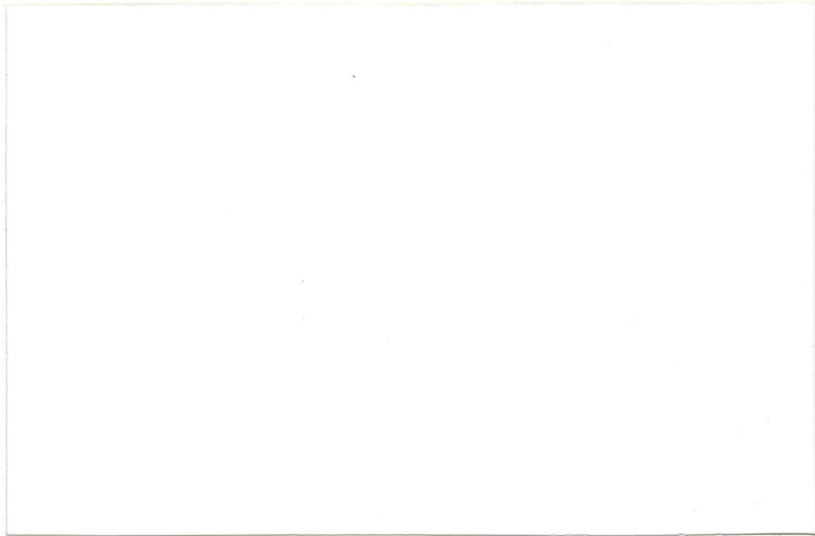


THE UNIVERSITY OF WISCONSIN—MILWAUKEE

CENTER  
FOR  
GREAT LAKES STUDIES



MILWAUKEE, WISCONSIN 53201 U.S.A.



**COMPLETION REPORT**

**for the Project**

**"DEVELOPMENT OF AN AUTOMATIC  
VESSEL-OPERATED TEMPERATURE  
DEPTH PROFILING SYSTEM"**

**Army Corps of Engineers Contract DACW-35-38-C-0071**

**Project Director  
Dr. C. H. Mortimer**

**Center for Great Lakes Studies  
University of Wisconsin--Milwaukee  
Milwaukee, Wisconsin 53201**

## ABSTRACT

During October and November, 1971, 15 temperature profiles of Lake Michigan were completed with the Undulating Temperature/Depth Profiling (UTDP) System that was designed and built at the Center for Great Lakes Studies, The University of Wisconsin--Milwaukee. These profiles were run from the railroad carferry S. S. Madison while on its normal service between Milwaukee, Wisconsin and Muskegon, Michigan. The isotherm diagrams which are the result of an initial computer analysis of the recorded data of each cruise clearly exhibit the internal wave patterns encountered by other investigators. The UTDP System consists of a simple towed sensor package in a depressor configuration that responds to ambient temperature and pressure, and an on-deck sub-system that controls the sensor depth, and monitors and records the information from the sensor. The electrical and mechanical link between the submerged sensor and the on-deck equipment is a thin steel cable with a single insulated center conductor.

This system has proven to be durable and seaworthy. Dives with the sensor have been made to 100 meters during data runs and static tests have been made to the equivalent of 140 meters in a pressure tank. The system has been operated continuously for nearly five hours at a time and at speeds of 14 mph and over. There have been no unusual signs of fatigue, uncontrolled vibration, or wild motions of the sensor. Data resolution is

estimated at better than 1/10 of a degree-Centigrade from the temperature module and about one meter of depth from the pressure module. The two sensors respond rapidly but not at equal speeds --the temperature module being the slower. The response of both transducer modules is linear with no evidence of hysteresis.

During the 1972 International Hydrological Decade, International Field Year on the Great Lakes (IFYGL) program on Lake Ontario, the UTDP System will be in continuous operation for three separate week-long cruises aboard the National Oceanic and Atmospheric Administration research vessel, R/V Researcher.

## ACKNOWLEDGEMENTS

The initial development and the design of the towed body was carried out by Mr. Brian Gallagher, at that time engaged on a course of graduate study combining oceanography and electrical engineering at the University of Wisconsin--Milwaukee. Mr. Gallagher is seen conducting some of the initial trials from the car ferry S. S. Madison in Figure 1. Unfortunately, the work was interrupted when Mr. Gallagher left to found Limnetics, Inc., --a business concern operating in the field of water pollution control and research--but some progress was made in the electrical design. For example, the electronics package in the towed body was designed by Mr. Richard Arrington, then also with Limnetics, Inc.

Recent progress with this device, and its preparation for use in the IFYGL, stems from the appointment of Mr. David Baumgartner as Electronics Technician in the Center for Great Lakes Studies and the devotion to the project of the efforts of Mr. Frederick Bates, a graduate student in the Center. Mr. Baumgartner has been responsible for many aspects of the design, including the modification of the time constant of the transducer and the development of the on-deck recording circuits. Both he and Mr. Bates have carried out the field trials described in this report, in addition to numerous test runs in which they were assisted by Mr. Donald Mraz, (Project Associate) and Mr. Robert Scott (Instrument Maker, responsible

for the construction and several features of the design, including the slip-ring swivel).

The work would have not been possible without the considerable assistance of the Grand Trunk Western Railroad Company and the kindness of the officers and crew of the carferry S. S. Madison. The Company negotiated an agreement with The University of Wisconsin, whereby space and facilities on the carferry were placed at the University's disposal for scientific research on a non-interference basis.

Funds for the project were provided by the U. S. Army Corps of Engineers under Contract No. DACW 35-68-C-0071.

## TABLE OF CONTENTS

Section No.	Title	Page No.
1.0	INTRODUCTION	1
2.0	THE SYSTEM	4
2.1	System Mechanism	6
2.11	Sensor Housing	6
2.12	Towing Cable and Terminator	13
2.13	Winch	14
2.2	System Electronics	16
2.21	Pressure (Depth) Sensor	16
2.22	Temperature Sensor	19
2.23	Time Constant Compensation	20
2.24	Multiplexer	28
2.25	Analog/Digital Converter	29
2.26	Sensor Power Supply	31
2.27	Towing Cable and Winch Commutator	32
2.28	On-Deck Electronics	34
2.29	Tape Recorder	39
3.0	DATA QUALITY AND ACCURACY	39
3.1	Stability	42
3.2	Analog/Digital Converter Response to an Input Voltage	43
3.3	Temperature Module Response to an Applied Temperature	46
3.4	Pressure Module Response to an Applied Pressure	49
3.5	Time Constant of Temperature Module	52
3.6	Temperature Rise Inside Sensor Housing	53
4.0	SYSTEM OPERATION	54
4.1	Theory of Motion	55
4.2	Actual Motion	56
4.3	S. S. <u>Madison</u> Cruises (1971)	60
5.0	DATA MANAGEMENT AND ANALYSIS	63
5.1	Initial Processing	66
5.2	Calibration	66
5.3	Time Calculation	68
5.4	Final Processing	69
5.5	Noise	87
5.6	Vessel Influence on the Recorded Data	88

## LIST OF FIGURES

<u>Figure</u>	<u>Title</u>	<u>Page</u>
1	Towed transducer system undergoing trials on the car ferry S. S. <u>Madison</u> . Top: Lowering an early design of towed "fish". Bottom left: Inserting the pressure transducer into a later design. Bottom right: Winch (with single-conductor armored towing cable) and controls, designed to cause the "fish" to undulate in depth while the ship is under way.	7
2	Undulating Temperature/Depth Profiling System electro-mechanical diagram.	8
3	Detail of the sensor housing. Figure is scaled to 27% of full size.	9
4	Exploded view of the UTDP System sensor housing. Figure is scaled to 37% of half size.	10
5	Block diagram of major electrical sections and data flow through the UTDP Sensor electronic package.	17
6	Block diagram of the major electrical sections and data flow in the on-deck electronics.	18
7	Thermistor time constant compensation circuit in simplified form.	22
8	Thermistor response to a temperature step function with high and low limits of $T_1$ and $T_2$ , respectively. $\lambda$ ( $\lambda$ ), is the natural time constant of the thermistor which is roughly the time the thermistor takes to reach 63% of the change in temperature impressed upon it.	22
9	UTDP System temperature module frequency response. The dashed line represents the sum of the thermistor and compensation frequency responses. The thermistor signal drops 3 db. at approximately 0.03 Hz. Both "Response" and "Frequency" scales are logarithmic.	26
10	Photograph of oscilloscope display of compensated and uncompensated response of temperature module. Lower curve is compensated output. Horizontal axis is 1.5 second per division. Vertical axis is 4 °C per division.	27

## List of Figures (continued)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
11	UTDP System data transmission format. Sequence of data sent up towing cable to on-deck electronics.	29
12	Laboratory results of data pulse attenuation by 1,000 meters of cable.	33
13	Timing of selected signal pulses of the UTDP System.	36
14	Timing of selected signal pulses of the UTDP System.	37
15	Schematic diagram of UTDP System sensor, power supply, and pulse transmitter circuitry.	40
16	Schematic diagram of the UTDP System on -deck circuitry. This does not include the winch or tape recorder.	41
17	Plot of the Reference signal from the "fish" during the first data cruise of 1971. Every eighth signal is plotted.	44
18	Plot of the Reference signal from the "fish" during the last data cruise of 1971. Every eighth signal is plotted.	44
19	Analog to Digital Converter Response test equipment inter-connection.	45
20	Analog to Digital Converter Response test results.	47
21	Temperature module temperature response test equipment interconnection.	48
22	Pressure module pressure response test equipment inter-connection.	50
23	Temperature response test results.	51
24	Pressure response test results.	51
25	Predicted path of UTDP System sensor.	56
26	Towed sensor ("fish") path in time and depth, derived from system data.	58
27	Towing cable configuration before and after a dive.	60
28	System Data before and after initial processing. These examples are not of the same data.	67

## List of Figures (continued)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
29	Internal temperature structure of Lake Michigan from cruise 1.	71
30	Internal temperature structure of Lake Michigan from cruise 2.	72
31	Internal temperature structure of Lake Michigan from cruise 3.	73
32	Internal temperature structure of Lake Michigan from cruise 4.	74
33	Internal temperature structure of Lake Michigan from cruise 5.	75
34	Internal temperature structure of Lake Michigan from cruise 6.	76
35	Internal temperature structure of Lake Michigan from cruise 7.	77
36	Internal temperature structure of Lake Michigan from cruise 8.	78
37	Internal temperature structure of Lake Michigan from cruise 9.	79
38	Internal temperature structure of Lake Michigan from cruise 10.	80
39	Internal temperature structure of Lake Michigan from cruise 11.	81
40	Internal temperature structure of Lake Michigan from cruise 13.	82
41	Internal temperature structure of Lake Michigan from cruise 14.	83
42	Internal temperature structure of Lake Michigan from cruise 15.	84
43	Temperature and depth data from one dive plotted together.	86

## LIST OF TABLES

<u>Table No.</u>	<u>Title</u>	<u>Page</u>
1	Sensor Housing Measurements.	11
2	Table of symbols.	25
3	1971 Data Cruise Information.	64 - 65

## 1.0 INTRODUCTION

It is perhaps surprising that the opportunities of measuring the depth distribution of physical variables or biological populations, on a continuous or frequently repeated basis from moving vessels, have not often been exploited. A successful example is the Hardy Plankton Recorder, which is regularly towed by commercial vessels, sailing on their normal business, over thousands of miles of the world's oceans. That instrument is towed at a constant depth.

The concept of a transducer package which undulates in depth, and which can be used from "vessels of opportunity" or from research vessels while travelling at full speed, is not new. Dr. J. Joseph, then of the German Hydrographic Institute, Hamburg, developed a towed undulator with various transducers and on-deck recording soon after World War II; the Plessey Company of Great Britain are now developing for the Scottish Marine Biological Association an undulating version of the Hardy Plankton Recorder, with additional sensors and recorders; and the "Batfish", developed at the Atlantic Oceanographic Laboratory, Bedford Institute, Nova Scotia, is now marketed by Hermes Electronics Ltd., Dartmouth, Nova Scotia, Canada. In all three of these instruments, undulation is achieved by control of the angle of the diving planes. In the earlier versions of these instruments the upper and lower depth limits were usually pre-set before each run; but in the latest version of the

Batfish the limits can be controlled from the deck of the ship continuously, by hand or automatically. With 300 meters of "faired" 7-core armoured electric cable, the depth range of the Batfish is from the surface to 200 m depth at towing speeds of 5-10 knots and from the surface to 170 m when towed at 14 knots.

The impetus which led to the development of the instrument system described in this report came from the need to obtain detailed pictures of the depth distribution of temperature in cross sections of Lake Michigan, for example those regularly traversed by railroad ferry vessels on the Milwaukee to Muskegon track of the Grand Trunk Western Railroad Company. Previous work along these lines (Mortimer, C. H. 1968) was carried out with bathythermographs and laborious manual data reduction. Eighty-seven cross sections in all were run (cf. the 87 appendix figures in the report), not all complete, involving over 5,000 bathythermograph slides. The need, therefore, was for an equivalent of the bathythermograph, capable of being operated from a vessel travelling at 12 knots and with the temperature and depth information recorded on computer-compatible magnetic tape.

That requirement became even more apparent during the planning stages for the IFYGL (International Hydrological Decade), during which variations in temperature distribution in two Lake Ontario cross sections will be studied during selected episodes in 1972, to contribute to the understanding of the structure and mode of generation of upwelling

and dominant internal wave patterns. These are described in report by Mortimer (1971) which also outlines the kind of information which an undulating transducer package may be expected to provide, in combination with measurements from moored instruments along the track of the towing vessel, when allowance is made for the timing and speed of the vessel crossing in relation to the phases of the internal wave.

In the instrument system described here, depth is controlled by the winch, manually in the present phase of development, by paying out or hauling in the towing cable, much as is done with the bathythermograph. This technique has certain advantages and disadvantages. The advantages are that the towed body can take the form of a simple, streamlined depressor, with no moveable diving planes, linkages, or servo motors. Ample depth coverage can be provided by paying out enough cable, and the depth range can be altered, from the deck, if shallow and deep areas are to be investigated during a single survey. A disadvantage, with the present design at least, is that the diving pattern is strongly asymmetrical; the descent is relatively rapid and the latter part of the ascent is relatively slow, with the present power limitations on the winch. Much better control of the diving pattern is possible with the Batfish, for example; but improvements in winch power and control design should make such control possible for our instrument also.

In order to achieve the depth capability at a towing speed of 12 knots without the expense of faired cable, we selected an Amergraph

armoured cable of 1/8 inch diameter, with a single electrical conductor which serves as a data link between the towed body and recording equipment on deck and also carries the power supplies to the transducers and the analog to digital conversion circuits in the towed body. To minimize the loss in the event of cable failure or collision with the bottom, the components in the towed body are kept to a minimum, while the more expensive recording equipment remains on deck.

It is the purpose of this report to describe in detail the hardware and method of operation, and present a preliminary discussion of the data derived from trial runs of the Undulating Temperature/Depth Profiling (UTDP) System developed at the Center for Great Lakes Studies, The University of Wisconsin--Milwaukee.

## 2.0 THE SYSTEM

The UTDP System is an instrument for the rapid, large scale measurement of the temperature fields in the Great Lakes. The system is composed of a towed sensor package or "fish" and an on-deck electro-mechanical sub-system. The "fish" as it moves through the water samples the temperature and hydrostatic pressure around it and relays this information, via the towing cable, to the on-deck equipment for recording and real-time monitoring. Together the submerged and on-deck packages make up a semi-portable system that can be operated from any vessel providing there is enough deck space for the winch and sufficient electrical power for the electronics and winch.

The sensor package offers a different approach to the design of vessel towed sensors. It has no moving parts, moveable control surfaces or servomotors. It is, in essence, a continuously operating electronic bathythermograph with all depth control coming from the winch on the towing vessel. It is believed that towing may be done at speeds above the speeds that are used for similar instruments but this has not been proven yet.

There are two sensors (transducers) mounted in the fish, one for depth (pressure) and the other for temperature. Each depth and temperature sample makes up one data point or data sequence, with approximately four data points taken each second.

The on-deck portion of the system provides for immediate monitoring and permanent storage of the data from the sensors, and path control of the towed "fish". This control derives entirely from the vessel-mounted, electric winch which is manually controlled. Normal operation requires a two-man crew. One person is required at the winch, and the other must monitor the sensor depth, and oversee the system operation.

The undulating depth track is achieved by alternately paying out and hauling in the towing cable. Theoretically, by letting the cable pay out rapidly the towed "fish" will dive, and hauling the cable in forces the "fish" to rise to the surface. Alternately paying out and hauling in will cause the "fish" to cycle up and down behind the towing vessel. During

actual data runs in 1971 this was exactly the method used to effect an undulatory motion to the sensor. In detail the exact path taken by the "fish" is a complex motion that depends on many variables such as towing speed, cable length, hydrodynamic characteristics of the "fish", but the desired undulation is clearly the dominant motion.

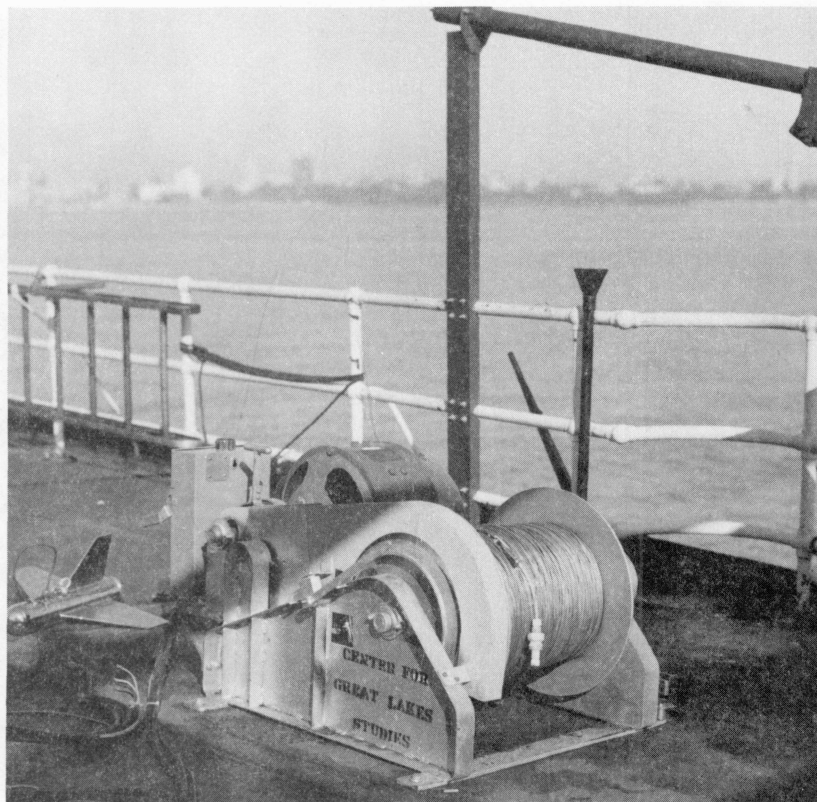
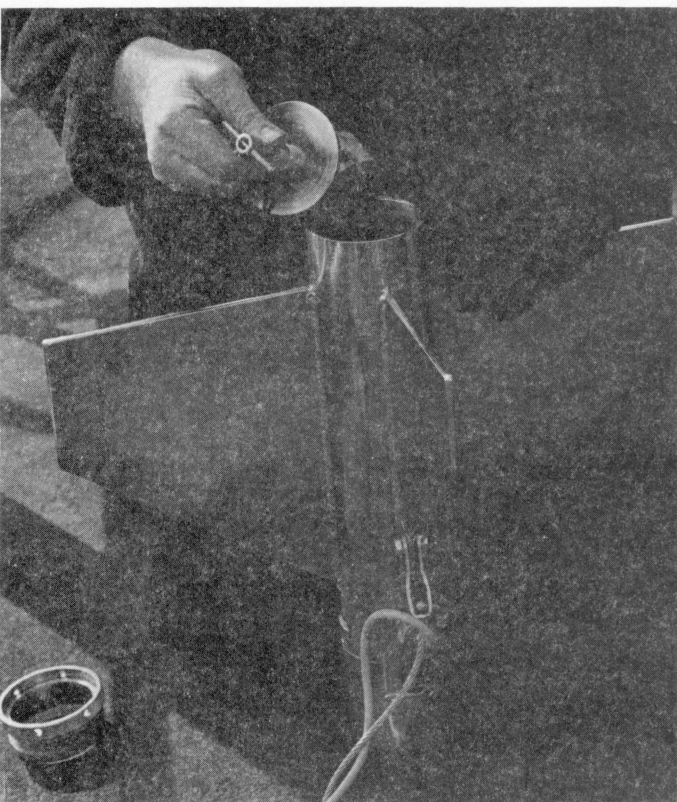
Figure 1 shows the system boom arrangement, and winch aboard the S. S. Madison during early trials. This is virtually the same mechanical system used during the 1971 data cruises. The metal "fish" to the left of the winch in the lower right picture is the one used as a sensor housing on the 1971 runs. The total UTDP System is shown schematically in Figure 2.

## 2.1 System Mechanism

The best way to examine the system in detail is to separate it mechanically and electrically. Mechanically this system consists of a towed metal fish, a thin steel cable with an insulated single conductor, and a winch. The "fish", houses the sensors and is continually submerged when the system is operating. The winch is mounted on the after deck of the towing vessel. The cable connects winch and "fish" and through its length governs the depth of the sensor.

### 2.11 Sensor Housing

The sensor housing or "fish" is shown in Figures 3 and 4. This housing serves as a vehicle for the temperature and pressure sensors,



**Figure 1** . Towed transducer system undergoing trials on the car ferry S.S. "Madison." Top: Lowering an early design of towed "fish". Bottom left: Inserting the pressure transducer into a later design. Bottom right: Winch (with single-conductor armored towing cable) and controls, designed to cause the "fish" to undulate in depth while the ship is under way.

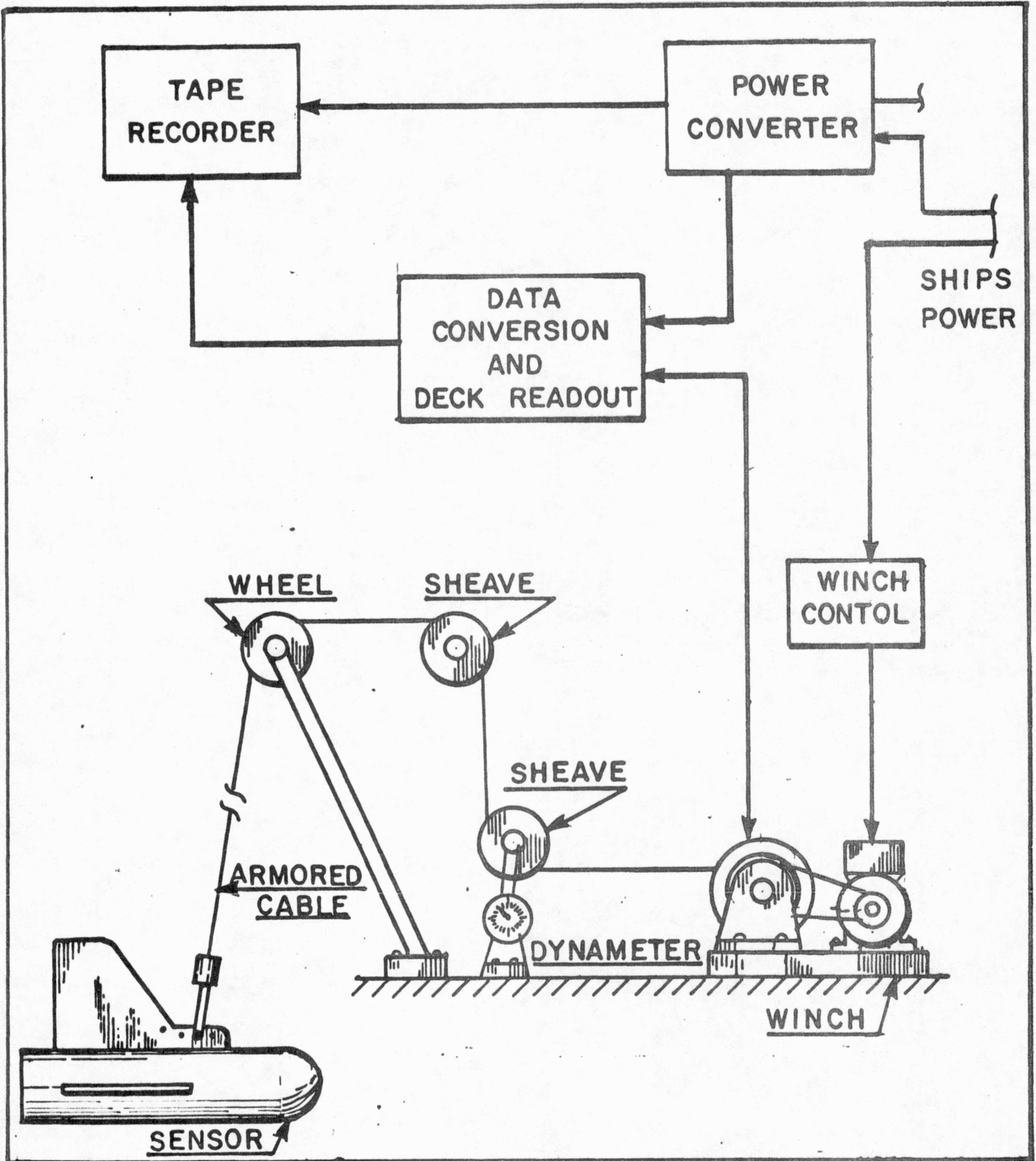


Figure 2. Undulating Temperature/Depth Profiling System electro-mechanical diagram.

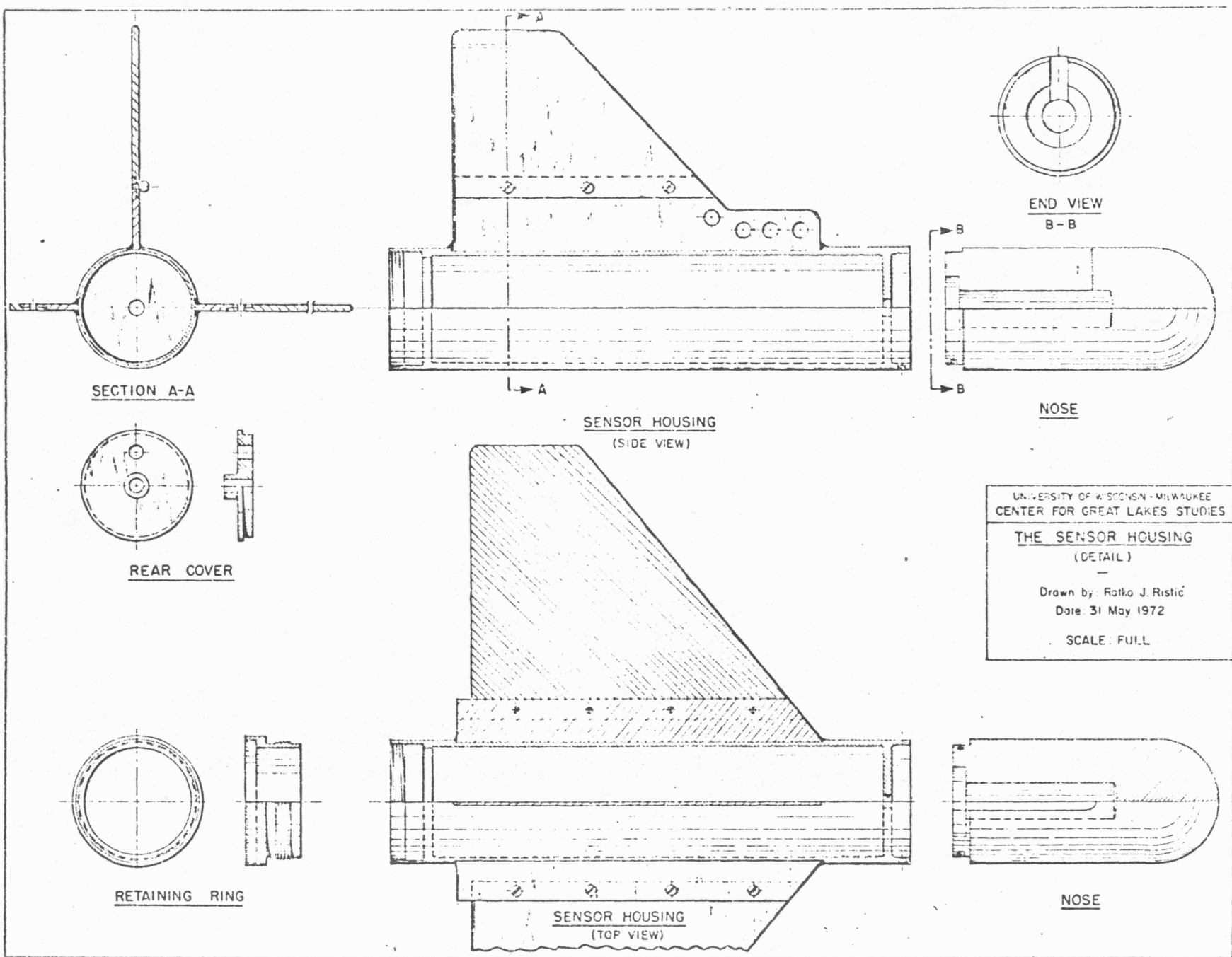


Figure 3. Detail of the sensor housing. Figure is scaled to 27% of full size.

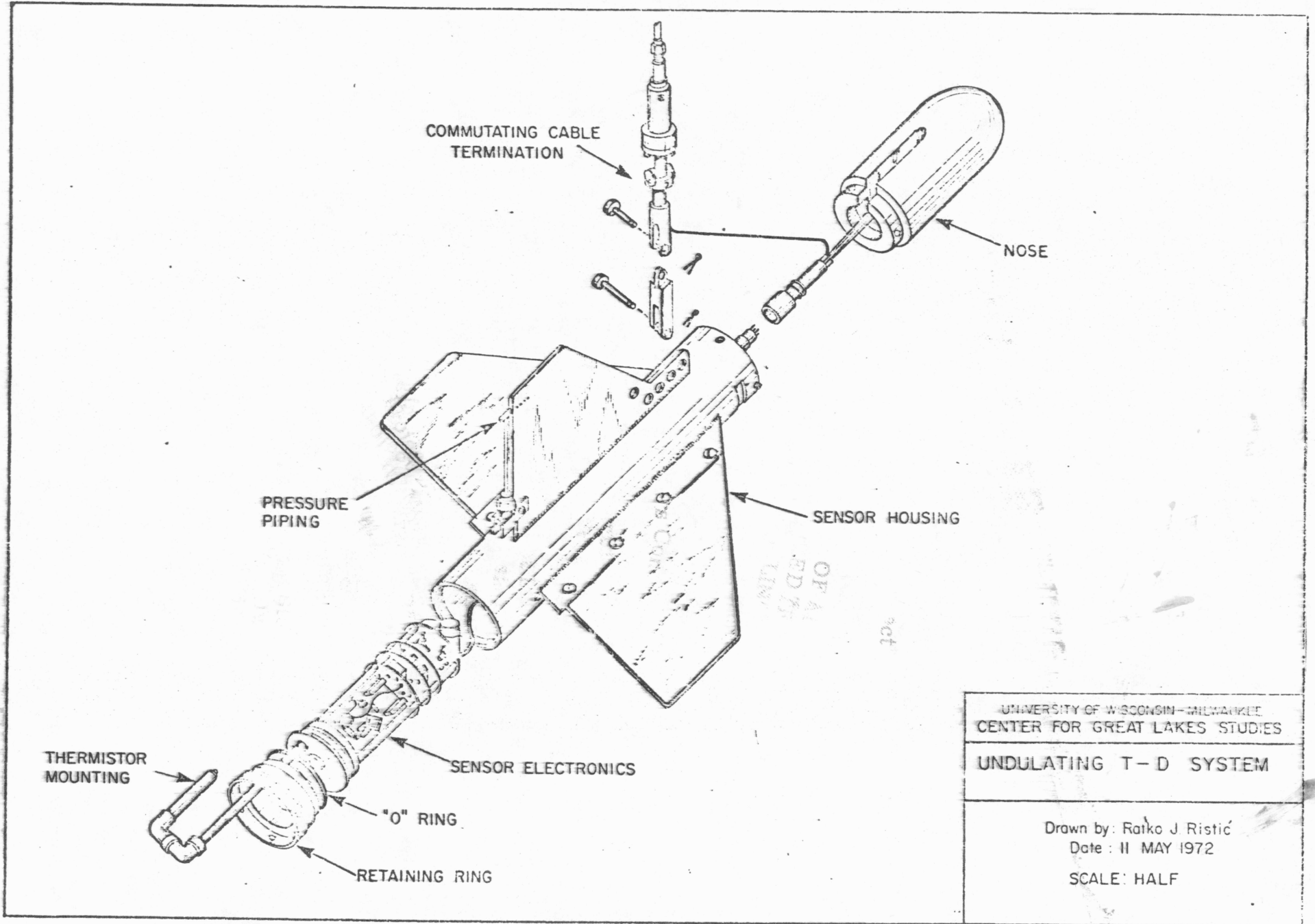


Figure 4. Exploded view of the UTDP System sensor housing. Figure is scaled to 37% of half size.

and their associated electronics. Detailed measurements and information about the housing materials appear in Table 1.

Table 1. Sensor Housing Measurements.

Body	steel tubing, 1/4 inch wall, 3-1/2 inch OD. 22 inches long, nickel plated, wt. 25 Lbs.
Nose Piece	machined steel, 3-1/2 inch diameter, 6-3/4 inches long, nickel plated, wt. 16-1/4 Lbs.
Fins	steel plate, 1/4 inch thick, nickel plated welded to body, all three fins demountable on new housing.

The "fish" design is the result of a desire for a rugged and simple package--the minimum requirements being a stable, water tight, and robust instrument housing. The body was machined from 1/4 inch walled steel tubing. The housing is relatively small with a length of 22 inches and a diameter of 3-1/2 inches. The electronic payload is completely removable through the rear of the "fish".

The "fish" has three fins; two horizontal and one vertical, that are of nearly equal surface area. These two wings and vertical stabilizer are welded to the body. The wings have been made demountable so that the sealed body could be pressure tested in a one foot diameter pressure testing tank available at the Center for Great Lakes Studies. Each wing is fastened to the body by four small screws. The vertical fin is not demountable on the original housing but has been made so on a new one.

The towing cable is attached to the housing just forward of the vertical fin. There are several holes provided for this attachment-- the best one for towing being chosen by trial and error.

At the front of the housing there is a solid bulkhead with a hole drilled and threaded to receive a Marsh-Marine RM-4-FS-P, watertight connector. This is the only electrical connection to the circuitry inside the housing. Over this connector is fitted a heavy nose piece that is attached to the front of the housing by four set screws. This nose piece weighs about 16.25 Lbs., and is solid iron except for a slot that allows the electrical wires to exit and connect with the towing cable.

The thermistor piping (1/4 inch galvanized iron) exits the rear cover and bends beneath the housing. The thermistor bead is embedded in epoxy but is partially exposed at the end of the pipe. It is felt that the location for the thermistor, about an inch below the body, is free of cavitation and that good thermal contact is made between the thermistor and the passing water. Also coming through the rear cover is the piping for the pressure sensor. This pipe is 1/8 inch diameter copper tubing. It runs from the housing rear up along the trailing edge of the vertical fin to a hole drilled in its edge. It is fastened to the fin at two locations which necessitates disconnection of the tubing at a coupling located at the base of the fin when the electronic package is removed from the housing. Near the top of the vertical stabilizer the pressure tube enters a 1/8 inch hole drilled into the trailing edge of the stabilizer. This hole goes into the

stabilizer about 3/4 inch and connects with several 1/32 inch holes that are open to the water pressure. In this configuration the small holes open perpendicularly to the flow of water past the stabilizer. The pressure sensed in this manner is, as much as possible, independent of the "fish's" velocity through the water.

The rear cover through which the temperature and pressure pipes pass is sealed in place by a large steel ring that is screwed into the housing thereby forcing the rear cover against a rubber "O" ring between the rear cover and the housing wall.

#### 2.12 Towing Cable and Terminator

The cable used to pull the "fish" through the water is a 1/8 inch diameter, counter spiral wound, armoured steel cable with a single, insulated center conductor. It is manufactured by United States Steel Company. The cable is multi-functional, that is, it tows the "fish", it conveys information (data) from the sensors to the on-deck electronics, and it supplies electrical power converter.

In the early towing tests conducted in 1968 on Lake Michigan off of Milwaukee, Wisconsin, it was noted that changes in cable tension caused twisting of the cable. The result of this twisting was a broken center conductor at the sensor housing. To allow the cable to twist and preserve the electrical connection to the sensors, a swivel connector with a watertight rotating contact was built. This swivel connector was installed as a termination to the towing cable at the "fish".

During the runs of 1971 we had available 1,000 meters of cable wound on the winch drum. Of this 1,000 meters, typically the length of cable over the side reached a maximum of 400 meters during a dive of 100 meters or less. This 400 meter length was found to be about the maximum amount of cable that the winch could pull without stalling.

In the installation on the S. S. Madison the cable was fairled over the side during towing through two sheaves and a meter wheel (see Figs. 1 and 2). Each bend in the cable was approximately  $90^{\circ}$ . During a typical run, 200 to 300 meters of cable were alternately payed out and pulled in about 200 times. At the end of 15 such runs an examination of the cable and sheaves showed no significant signs of wear. The meter wheel, however, because of its brass construction did show serious wear.

### 2.13 Winch

The winch used in the system during the runs of 1971 was a modified Hydro-Products, Model HR-60, gasoline powered winch. The gasoline engine was replaced with a five horsepower, direct current (DC), compound wound, Century electric motor.

It had been planned in the original design of the system to provide for speed control of the winch. A motor speed control using silicon controlled rectifiers was built and tested but it was discovered during the early data cruises that speed control was not necessary

because the winch needed only to be fully on or totally off. As a result this motor control was rarely used on subsequent data runs.

For the cruises on Lake Ontario during the IFYGL, the DC motor will be replaced by a three-phase, alternating current (AC), five horsepower electric motor. This change is necessary because there is not sufficient DC electricity available on the towing vessel.

To control the speed of the AC motor, if necessary, a HI-LO fixed center, variable diameter pulley drive will be used. One advantage of this method of speed control is that if motors are changed again no additional modifications will be needed providing that the new and old motors are of similar dimensions.

A simple hand operated level wind device was fabricated and placed above the winch drum in easy reach of the winch operator to facilitate cable handling. With it, although it is not possible to lay the cable on the drum in perfect rows, the cable may be distributed over the drum to prevent piling up and pulling beneath earlier layers.

The arrangement of sheaves, boom and winch is custom-built for each vessel and each installation. The winch requires about 25 square feet of deck area. Four, one-half inch diameter bolts are sufficient to hold it to the deck. All installations should make provisions for mounting a dynamometer to measure cable tension and a meter wheel to measure working cable length. Because of the wear evident on the brass meter wheel a rotation counter mounted on the winch drum would be superior.

## 2.2 System Electronics

Electrically, the major divisions of the system are the sensors and sensor electronics, the cable and its center conductor, and the on-deck monitoring and recording equipment. The sensor and sensor electronics located inside the "fish" are electrically connected to the on-deck electronics through the cable.

The submerged package, as shown diagrammatically in Figure 5, multiplexes and transmits the temperature and pressure data along with a reference signal to the on-deck electronics. The type of data transmission used by the system is known as time division multiplexing. This means that the time duration for each data-reference transmission sequence varies according to the value of the temperature and pressure. On the average the system was operated with four data-reference sequences a second, but this is adjustable.

The on-deck electronics monitors the information from the "fish" and then formats, blocks and records it on computer compatible magnetic tape (Fig. 6). Complete schematic diagrams of the sensor and on-deck electronics are presented in Figures 15 and 16 at the end of this section.

### 2.21 Pressure (Depth) Sensor

The pressure sensor is a Statham Instruments, Model PA505-200 transducer. The following specifications that accompanied

## UNDULATING SENSOR ELECTRONICS

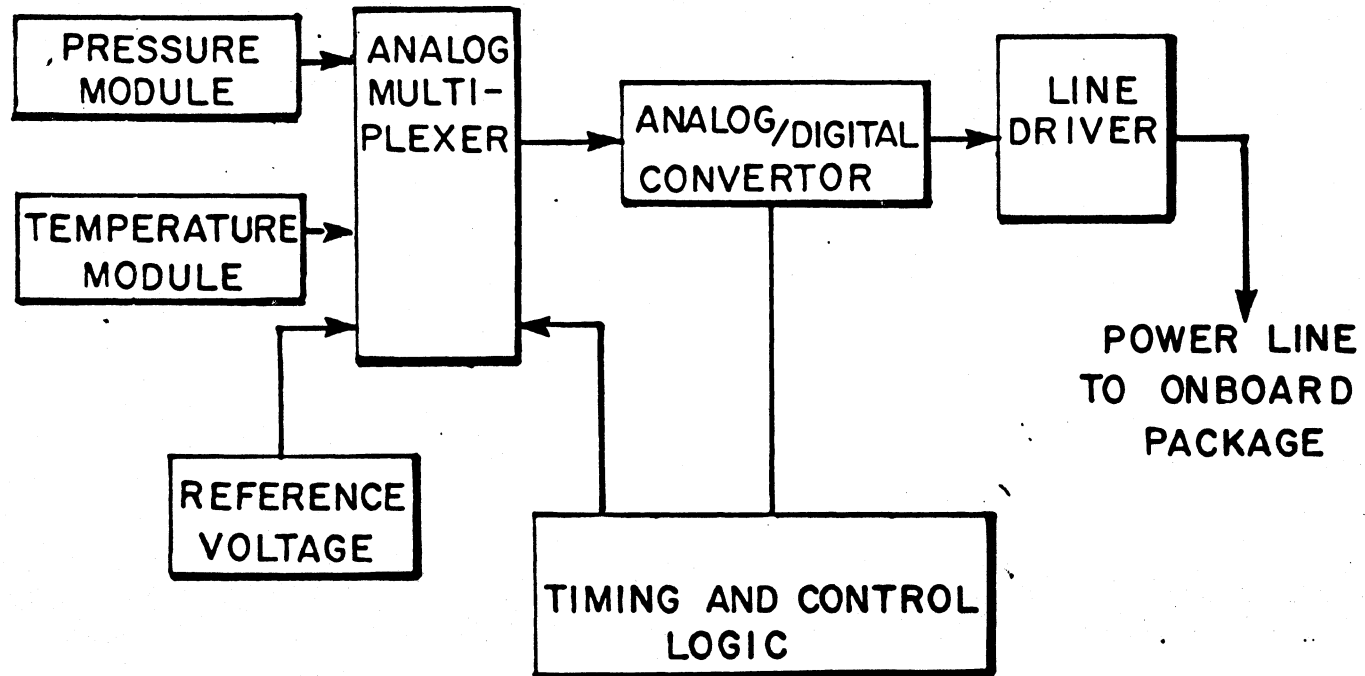


Figure 5. Block diagram of major electrical sections and data flow through the UTDP Sensor electronic package.

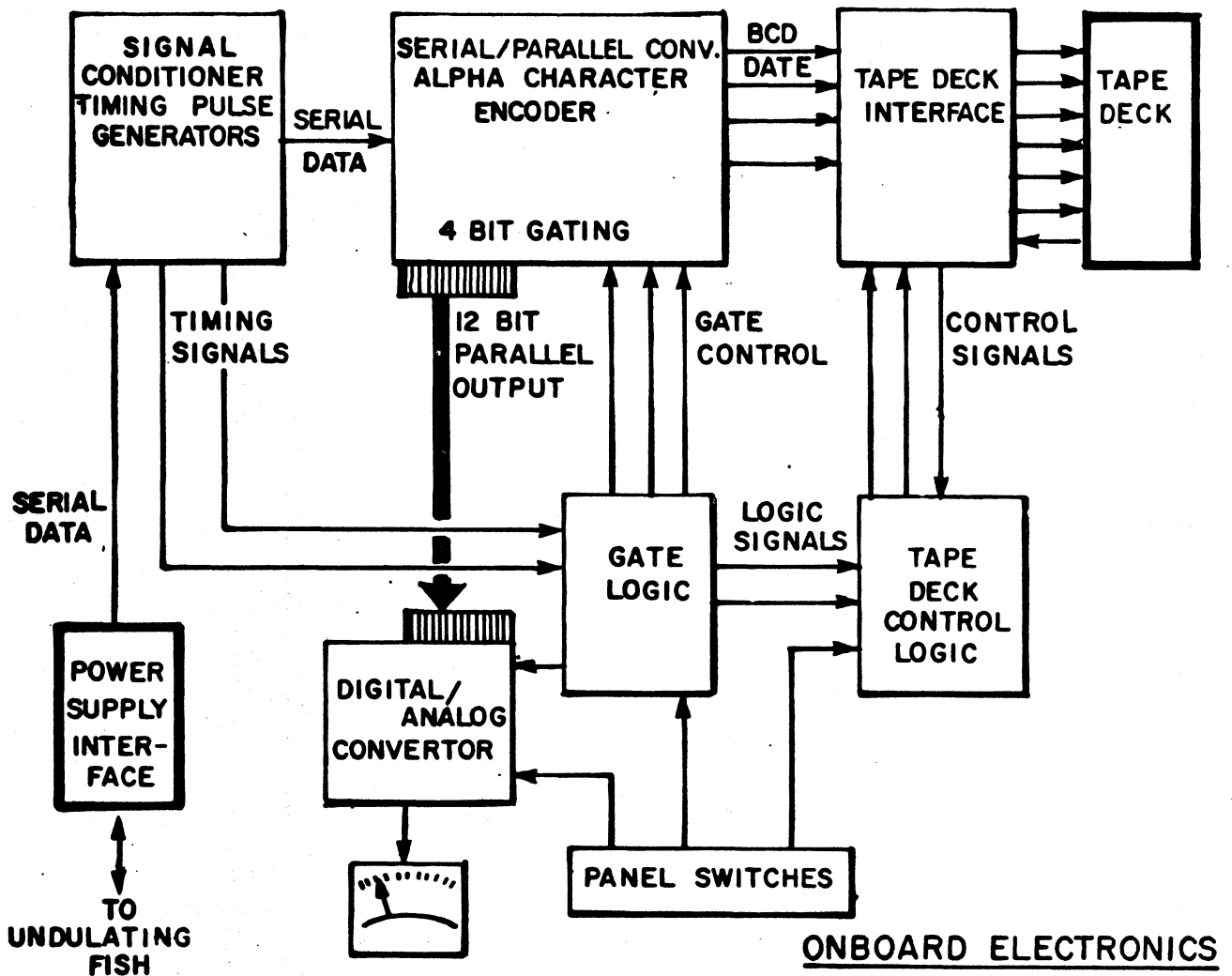


Figure 6. Block diagram of the major electrical sections and data flow in the on-deck electronics.

the device have, on the most part, been verified in our laboratory:

1. Range: 0-200 psi.
2. Maximum overload: 400 psi.
3. Transduction: resistive, balanced, fully active strain gage bridge.
4. Power requirements:  $28 \pm 4$  volts DC, (25 ma @ 28 VDC).
5. Output voltage: 0.1 to 5 VDC nominal.
6. Output noise: less than 5 mV rms.
7. Non-linearity and hysteresis: less than  $\pm 0.75\%$  full scale.
8. Compensated temperature range:  $0-65^{\circ}\text{C}$ .
9. Shape: cylindrical, 1.0 in. dia., 3.0 in. long.

## 2.22 Temperature Sensor

The temperature sensing element is a YSI Termilinear Thermistor Network. The two most important characteristics of this transducer are its thermal time constant which is established by the manufacturer as 1 second in a well stirred oil bath, and its temperature range which is  $-1^{\circ}\text{C}$  to  $38^{\circ}\text{C}$ . The temperature range of the thermistor is certainly more than adequate for lake temperatures but the time constant is considered slow for two reasons. First, to maximize the accuracy of any system that uses two or more sensors in conjunction, the time

constants of the sensors must be equalized, otherwise with one sensor slower than the other data values from each sensor at the same point in time would not be correct (Dauphinee, T. M. 1967). Second, the sensor being towed at 14 mph as it was in 1971, must be fast enough to respond to expected rapid changes in temperature and pressure. It is important to note here that the pressure and temperature data points are not taken simultaneously but one follows the other by 32 milliseconds (Fig. 11).

### 2.23 Time Constant Compensation

In a system such as the UTDP System the accuracy with which the sensors follow a parameter gradient is crucial. The relatively high rate at which this particular towed body moves through the water makes the time constants associated with the sensors an important limiting factor. Consequently, if the temperature or pressure sensor cannot react fast enough to changes in temperature or pressure to give a true profile then the speed of towing must be slowed. The pressure sensor used here is a very fast instrument and no lag problems are anticipated with its use. The thermistor which has a one second time constant cannot be considered fast with respect to the towing speeds encountered and expected. Behind a vessel such as the S. S. Madison the average speed of the sensor was approximately six meters a second. At this speed, after one second (the time constant), the sensor has moved six meters. In the thermocline, where characteristically the temperature gradient is one degree centigrade for

every meter of depth, the thermistor would be behind the actual temperature by about two degrees. It is evident then, that the temperature sensor must be sped up, both to approach the response of the pressure sensor and to make rapid towing speeds feasible.

A circuit that does increase the response time of the temperature sensing module was designed and built. The circuit shown in Figure 7 is a simplified version of this time constant compensation circuit. A mathematical analysis is carried out here to show that the response of a temperature sensor using a thermistor can be made independent of the natural time constant of that thermistor.

The response of a thermistor to a fast temperature change is exponentially varying as depicted in Figure 8. The thermistor/ $R_1/R_2$  network in the compensator circuit, Figure 7, is linear and not active; therefore, the voltage  $e_1$  varies linearly with the temperature of the thermistor. Writing

$$e_1 = B + D[1 - \exp(-t/\lambda)], \quad (1)$$

expresses  $e_1$  of the network as a function of B, D,  $\lambda$ , and t. Where B and D are time-independent functions of the environmental temperature, sensor speed, and network constants. Lambda is the temperature time constant of the thermistor. We are assuming that the temperature changes

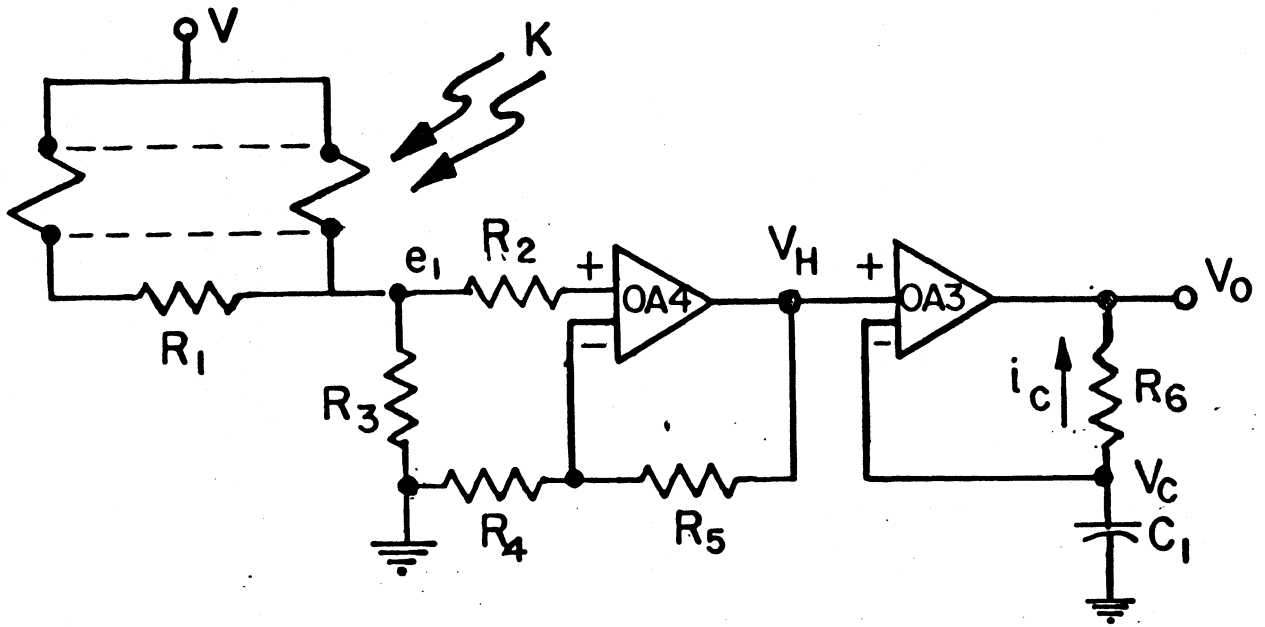


Figure 7. Thermistor time constant compensation circuit in simplified form.

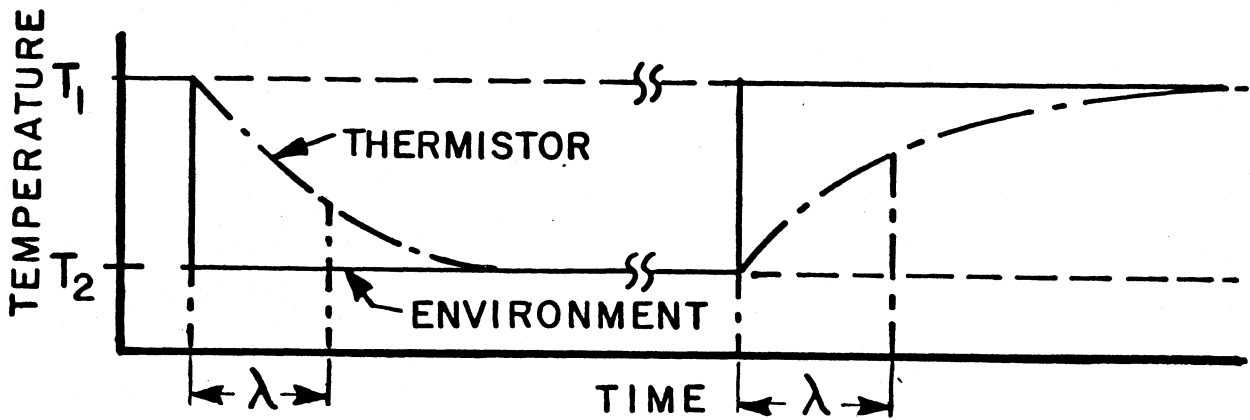


Figure 8. Thermistor response to a temperature step function with high and low limits of  $T_1$  and  $T_2$ , respectively. Lambda ( $\lambda$ ), is the natural time constant of the thermistor which is roughly the time the thermistor takes to reach 63% of the change in temperature impressed upon it.

in the thermistor environment occur in discrete steps, that is the changes in temperature take place in zero time. The quantities B and D can be determined empirically using the steady state form of (1).

$$e_1 = B + D. \quad (1)'$$

Letting  $A'_4$  represent the closed-loop gain of operational amplifier OA4, which is determined by R5 and R4, (Seidman, A. H. 1963) we can write

$$V_H = A'_4 e_1 \quad (2)$$

for the output voltage  $V_H$ , of OA4. The output voltage  $V_O$ , of the entire compensation circuit is given by

$$V_O = A_3 V_H - A_3 V_c. \quad (3)$$

$A_3$  is the open-loop gain of the second operational amplifier, OA3. The voltage  $V_O$ , can also be expressed as the sum of  $V_c$ , the voltage across the capacitor, and the voltage across R6.

$$V_O = V_c + R_6 i_c. \quad (4)$$

The current through R6 is very nearly equal to the current through the capacitor  $i_c$ , which is

$$i_c = C_1 \frac{dV_c}{dt}. \quad (5)$$

The difference between the current through resistor R6, and the current through the capacitor C<sub>1</sub>, is that current which returns to the input of OA3. This is a very small current that can be ignored which makes (4) a reasonably valid expression for V<sub>O</sub>.

Combining (4) and (5), and manipulating the equation gives

$$V_c = V_o - R_6 C_1 \frac{dV_c}{dt}. \quad (6)$$

Then combining this with (2) and (3) we get

$$V_o = A_3 A'_4 e_1 - A_3 V_o + A_3 R_6 C_1 \frac{dV_c}{dt},$$

and

$$V_o = \left[ A_3 A'_4 e_1 + A_3 R_6 C_1 \frac{dV_c}{dt} \right] / (1 + A_3).$$

If A<sub>3</sub> is much greater than one (A<sub>3</sub> >> 1), then

$$V_o = A'_4 e_1 + R_6 C_1 \frac{dV_c}{dt}. \quad (7)$$

Substitution of (7) into (6) gives

$$V_c = A'_4 e_1 + R_6 C_1 \frac{dV_c}{dt} - R_6 C_1 \frac{dV_c}{dt},$$

and

$$V_c = A'_4 e_1,$$

and taking the time derivative of this, results in

$$\frac{dV_c}{dt} = A'_4 \frac{de_1}{dt},$$

and

$$\frac{dV_c}{dt} = \frac{A'_4 D \exp(-t/\lambda)}{\lambda}. \quad (8)$$

Using (8) in equation (7), with the full expression for  $e_1$  gives

$$V_O = A'_4 (B + D) + A'_4 D \left[ \frac{R_e C_1}{\lambda} - 1 \right] \exp(-t/\lambda). \quad (9)$$

Equation (9) shows that if

$$R_e C_1 = \lambda,$$

then the circuit output becomes independent of the thermistor time constant and under this condition (9) becomes

$$V_O = A'_4 (B + D).$$

(10)

Table 2. Table of symbols.

K	Heating or cooling from environment acting on thermistor.
$V_H, V_O, V_C,$ $e_1$	Voltages at points indicated in Figure 1.
B, D	Time-independent parameters of the voltage output of the thermistor network.
$T_1, T_O$	Environmental temperatures.
$A_4, A_3$	Operational amplifier gains.
$i_c$	Current through capacitor $C_1$ .
t	Time
$\lambda$	Time constant of temperature sensing system.

Another way to look at what is happening in the compensator circuit is to consider the frequency response of the thermistor and the OA3 amplifier circuit (Giles, J. N. 1966). Figure 9 shows that the thermistor has a response that falls off above 0.03 Hz at nearly a constant rate on a logarithmic scale of signal amplitude. This rate is estimated to be about 20 decibels for every frequency decade above 0.03 Hz.

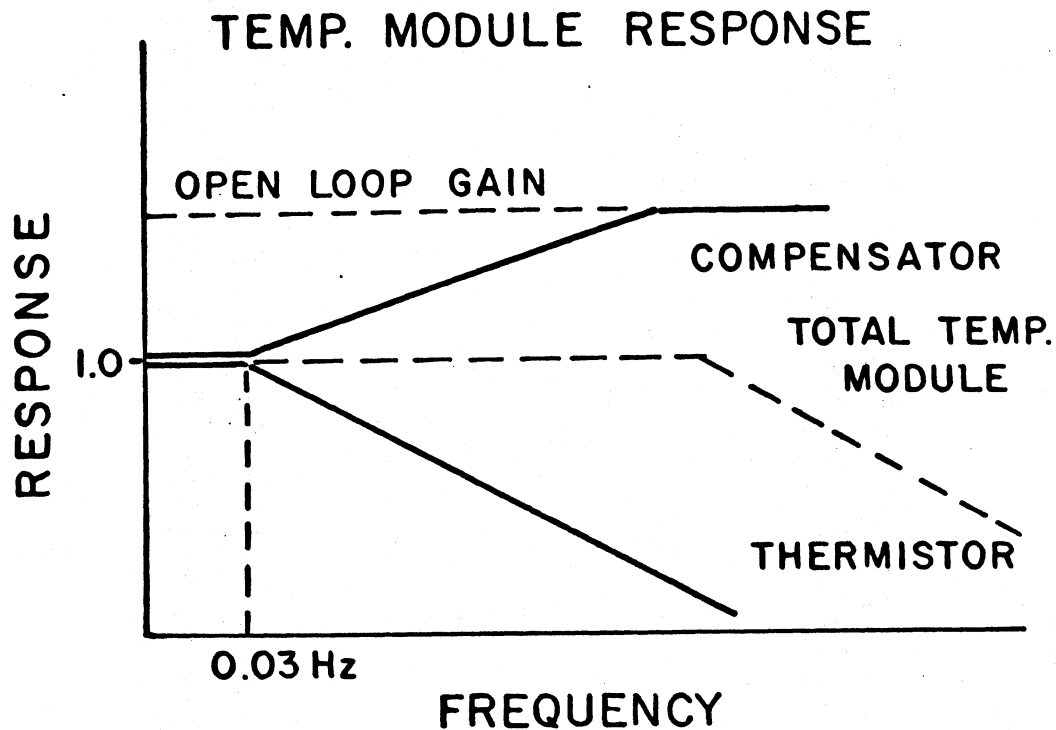


Figure 9. UTDP System temperature module frequency response. The dashed line represents the sum of the thermistor and compensation frequency responses. The thermistor signal drops 3 db. at approximately 0.03 Hz. Both "Response" and "Frequency" scales are logarithmic.

To counter this decrease in signal amplitude as frequency increases, it is possible to use an amplifier that produces the opposite effect. That is, its gain is a function of frequency which has the same

slope as the response of the thermistor but with an opposite sign. The result at the output of the compensation circuit is the dashed line which falls off eventually as the thermistor response, but at a higher frequency.

Through the use of such a circuit the temperature response of the sensor was made "faster" than the natural response of the thermistor alone. As shown in the circuit schematics, (Fig. 15), additional components were needed to achieve stability and reduce high frequency noise in the actual circuit.

Figure 10 shows an oscilloscope picture of the response that the sensor exhibits with and without the compensation circuit, to a temperature change imposed on the instrument in the laboratory.

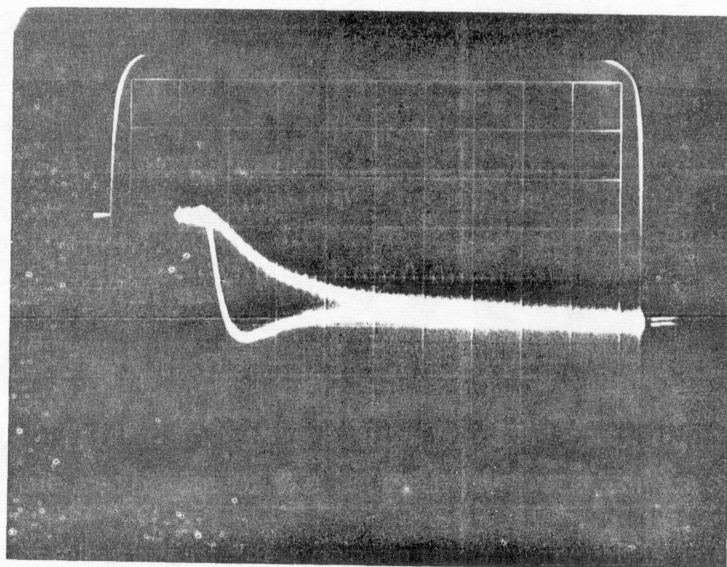


Figure 10. Photograph of oscilloscope display of compensated and uncompensated response of temperature module. Lower curve is compensated output. Horizontal axis is 1.5 second per division. Vertical axis is  $4^{\circ}\text{C}$  per division.

It is evident from the picture that equation 10 is not completely correct since the response with the compensation circuit remains an exponential function but with a new time constant. This time constant however, is much shorter than the natural time constant. An important feature here is that the resulting time constant is adjustable so that the overshoot evident in Figure 10 can be minimized, but there will be a corresponding increase in the new response time.

#### 2.24 Multiplexer

The multiplexing circuitry accepts and multiplexes the temperature and pressure data and a reference voltage. This reference is generated in the multiplexer and serves to indicate the quality of the data received on-deck. Simply, the multiplexer sequentially sends the reference, temperature, and pressure analog signals (voltages), to the Analog/Digital Converter.

In detail, using the circuit schematic, Figure 15, as a guide, the FET switch Q3, with drivers Q4 and Q5, accepts a +5 volt logic signal from L8 which will turn on switch Q3. This allows the pressure transducer output to be the input signal to the Analog/Digital (A/D) Converter. Switches and drivers Q6-Q11, and Q3-Q5 are identical. They are turned on and off by a clock signal from the A/D Converter. The counters F1 and F2, and the decoding logic L8-L10 (RCA 1970), provide sequential signals that turn

on one of the three FET switches. A fourth logic element L7, signals the monostable L1, L2, and Q12, which generates a time delay, shown as T3 in Figure 11. This time delay signal from L2 is used to set counters F1 and F2, and also to prevent the A/D circuitry from cycling.

### DATA TRANSMISSION FORMAT

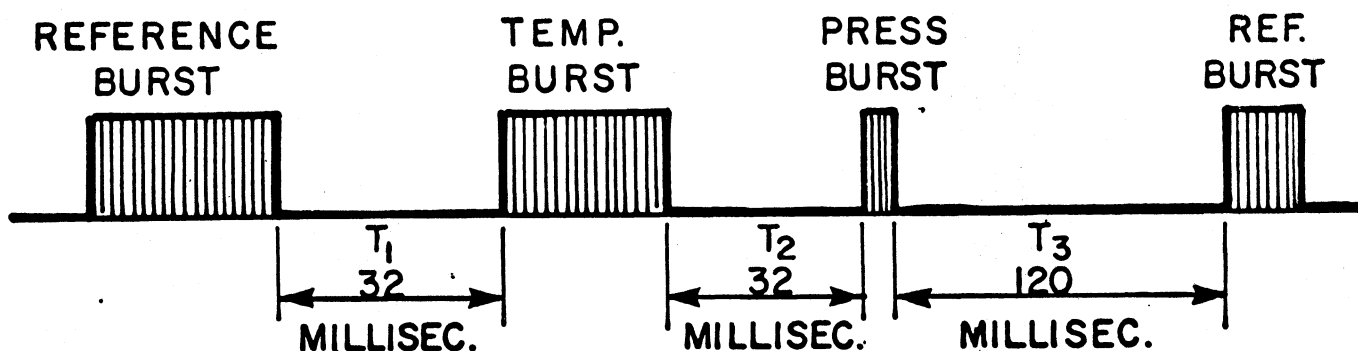


Figure 11. UTDP System data transmission format. Sequence of data sent up towing cable to on-deck electronics.

#### 2.25 Analog/Digital Converter

The sequential analog signal from the Multiplexer is fed to the Analog/Digital (A/D) Converter and transformed into sequential digital signals. The process is essentially one of comparing the analog data signal to an increasing voltage. Equally spaced pulses are generated so long as the two voltages are unequal; but when they are equal, the pulses are stopped, the increasing voltage is reset to zero, and a new analog signal is fed to the A/D Converter. The number of pulses generated for any one analog signal (reference, temperature, or pressure), is proportional to the magnitude of that signal. From the A/D Converter the pulses

are amplified and then sent to the on-deck electronics via the center conductor of the towing cable.

An examination of the schematic, Figure 15, shows that operational amplifier OA1, generates the voltage ramp that is used by amplifier OA2, in the comparison with the multiplexed input. At the start of the sequence the output of L6 is low, this allows pulses from Q14 to be passed by L12 and transmitted up the cable. When the ramp voltage becomes equal or greater to the analog signal the output of OA2 becomes positive. The output of L3 is forced low and the L6 input goes high. This action stops the pulses from being transmitted. The low output of L3, through Q13 and Q2, then causes Q1 to discharge capacitor C1. When this happens the output of OA1 goes low and the output of OA2 goes low. This information is fed back to the multiplexer and advances it to the next signal in the cycle. The high output of L6 then allows capacitor C8, to charge and after a delay of 32 milliseconds the unijunction transistor Q15 fires and resets L6 and L3 to their original conditions. Again OA1 generates a ramp voltage and the cycle repeats.

This cycle is allowed to run three times, once for each analog signal, until F1 and F2 reach their fourth state. At this point a pulse from L7 starts a timer made up of L1, L2, and Q12, which inhibits operation for 120 milliseconds. After this time period the above sequence is begun again. The resulting data format from the A/D Converter is three bursts

of a digitized parameter separated from each other by a 32 millisecond space and each group of three is separated from the succeeding group by a 120 millisecond interval. The data transmission format is shown in Figure 11.

### 2.26 Sensor Power Supply

The circuits in the "fish" receive their power from the on-deck power converter through the cable and its center conductor. The total electrical path between the on-deck electronics and the sensor electronics is composed of the cable's center conductor and its steel outer wrap. Inside the "fish" the power is reduced in voltage as needed and routed to the various circuits. The cable is electrically connected to the power supply-transmitting section of the fish electronics at the junction of resistors R55 and R54, shown on the schematics. Resistor R55, limits the turn-on current surge through diode D7. This diode is a fast reverse recovery type with a recovery time of 0.2 microseconds. It prevents capacitor C10, from discharging through R55 and R54 when data is being transmitted. An unregulated +28 Volts is supplied from C10 for use by the pressure transducer.

Zener diode D8, provides a regulated +10 Volts for use by the operational amplifiers and the multiplexer. Similarly, zener diode D9, and forward biased diode D25, provide a regulated +5 Volts for use by the logic circuitry.

Finally, there is one more voltage necessary for the operational amplifiers and the multiplexing circuitry. All the other voltages have been positive and it is a simple matter to reduce the positive voltage available from the cable using zener diode circuits but this last voltage must be negative. The negative voltage is created by using multi-vibrator Q18 and Q19, to drive the current switches Q21 and Q22, creating an alternating current that is rectified by diodes D22 and D23. This rectification results in a direct current that is regulated to -10 Volts by zener diode D24, and then conducted to the necessary locations.

Physically the multiplexer, A/D Converter, and "fish" power supply use integrated circuits and miniature components to make them compact and rugged.

### 2.27 Towing Cable and Winch Commutator

The 1/8 inch diameter, steel cable with a single center conductor is not only the mechanical link with the control system on the towing vessel but it is also the electrical link. The inner conductor and the spiral wound outer jacket are used as a power line from the on-deck power supply to the sensor electronics and as the transmission medium for sending data from the "fish" to the on-deck monitoring and recording equipment. The cable impedance causes a drop in power and a change in data pulse shape. Figure 12 is the result of a laboratory test of the cable's response to a typical data pulse. The power drop due to the cable is a constant function

of the cable impedance and the current passing through it to the sensor electronics. With a current flowing of 0.4 amperes it is estimated that the drop across the cable is 30.0 Volts which means that the input voltage to the cable must be 60.0 Volts for the necessary 30.0 Volts at the "fish".

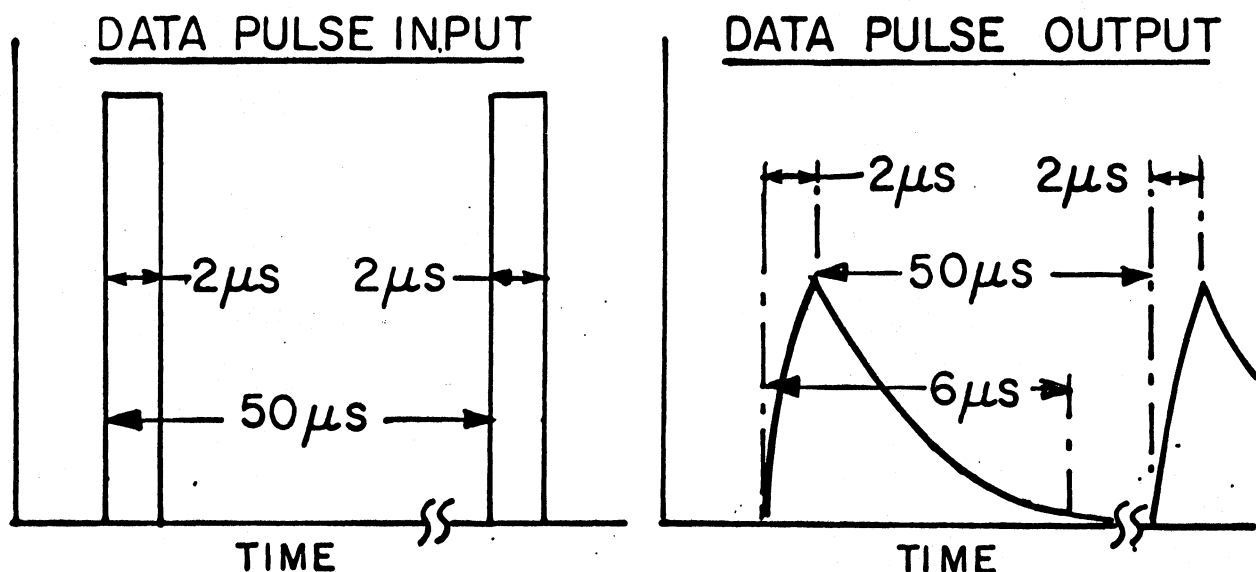


Figure 12. Laboratory results of data pulse attenuation by 1,000 meters of cable.

Figure 12 shows that the one volt data pulses reaching the on-deck electronics from the "fish" should be easily distinguishable.

To pass the data, power, and ground between the cable on the rotating winch drum and the on-deck electronics, a slip-ring commutator is used. There are seven rings each with a bronze brush. In an attempt to minimize slip-ring noise, four ring-brush sets were connected in parallel for the ground and three sets were connected in parallel for the data and power. Both the slip-ring commutator at the winch and the rotating cable termination at the "fish" present possible sources of electrical noise

that could obscure the data. To prevent this, these parts are carefully maintained and lubricated.

### 2.28 On-Deck Electronics

Once the data pulses reach the on-deck circuits they must be picked out of any noise that might be on the cable and reshaped. The sensing and shaping is done by transistors Q1 and Q3 shown in schematic 16. Binary elements F1-F3 (RCA 1970), and their time dependent feedback elements Q4-Q9, produce the new shaped data pulses and timing signals CS and REF.

Data is recorded on the magnetic tape in blocks of binary coded decimal (BCD) numbers during a write cycle. This parallel BCD data is also used by the on-deck Digital/Analog Converter F4-F15, to provide an analog output to the meter read-out. This is the meter that gives the operators real-time information about the depth and temperature of the "fish". The reference signal from the "fish" may also be monitored at this meter so that information about the quality of the temperature and pressure data is available.

Logic and external controls are provided to manually stop the system in two modes. The first mode (Run/Hold Switch) stops the system at the end of a sampling sequence and the second mode stops the system when the block length counter initiates an inter-record gap sequence. The second mode is used prior to the end-of-file sequence generated by the manual controls on the tape deck. A third manual input (Sample Frequency Select Switch) selects recording rates of four data points a

second, and one data point a second. For each of these recording rates the "fish" continues to sample at a fixed rate of four samples a second. The pulses in a burst are counted and stored in a three-decade binary coded decimal counter. Three sets of nand gates (L23-L26, L27-L30, L31-L34), gate each decade in turn to the coder/voltage level shifting circuitry and to the magnetic tape data input. Refer to Figures 13 and 14 for clarification of signal and data timing.

A block length counter accumulates the number of write cycles and at a predetermined number, it stops the write cycle and commands the tape deck to generate an inter-record gap. Upon completion of the gap generation a signal from the tape deck allows the system to go into the write sequence again. Logic is provided so that the system always completes a sampling sequence before the write cycle is stopped and the system always waits for the start of a sampling sequence before the write cycle is commenced.

The two monostable elements M1 and M2, form a gateable oscillator. The gating signals for this oscillator are derived from F19, and F20, which are advanced by the PREWRITE output. The oscillator is started by CS going to "O" and stopped by UNITS going to "1". The purpose of the gateable oscillator is to generate write commands for the tape deck. CS also serves to reset F19 and F20, and advance counter F16-F18, from which reference, temperature, and pressure A/D clocks are derived. These counters are reset by PRESSD and BCD RESET. The BCD RESET resets

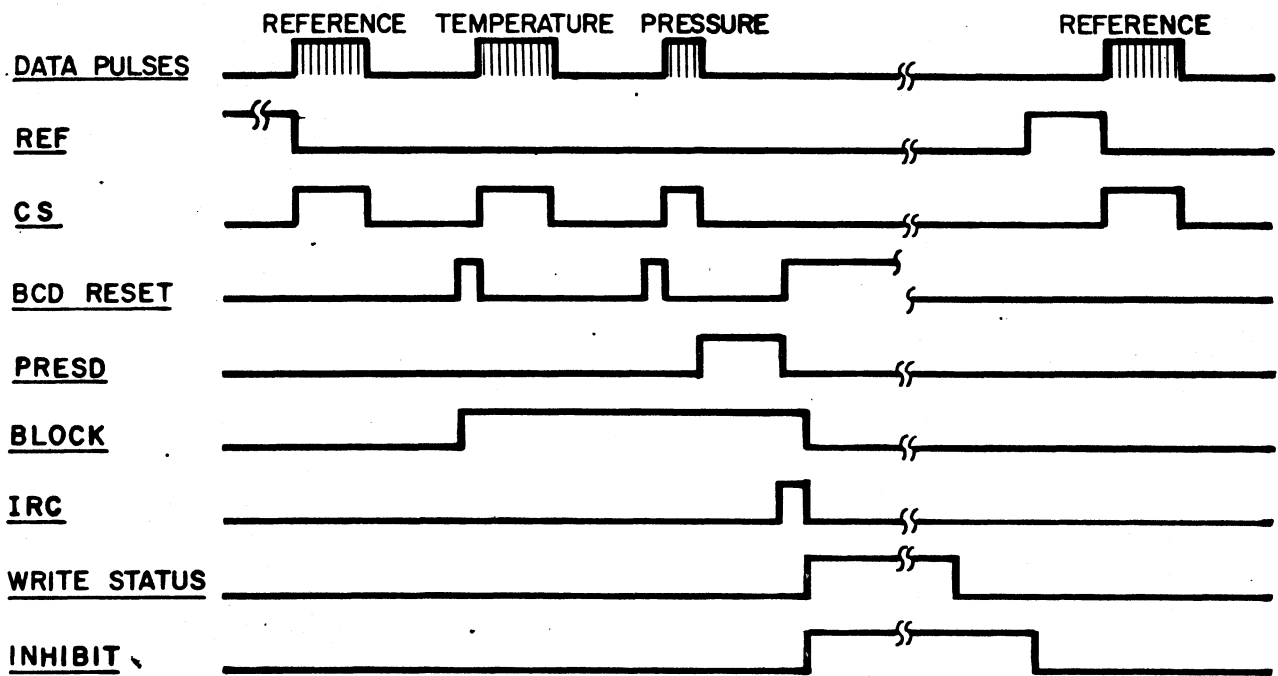


Figure 13. Timing of selected signal pulses of the UTDP System.

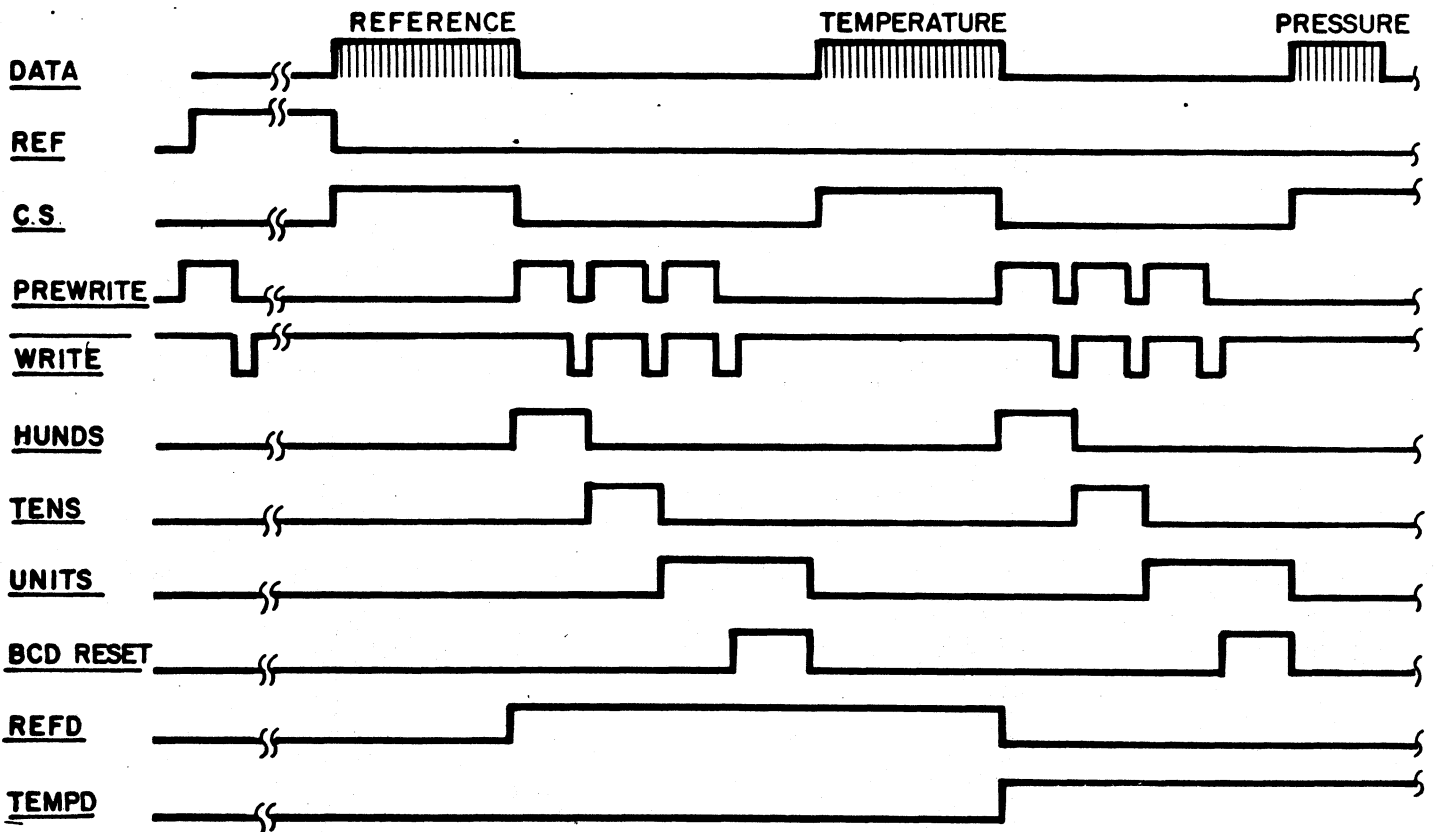


Figure 14. The timing of selected signal pulses of the UTDP System.

the decade counters at the end of the write cycle. The function of switch S1, is to select one of the three data signals for display of the meter. Moving the Write-Inhibit switch S2, to the "Hold" position allows F22 to be clocked at the end of a sampling sequence. This means that F22 is toggled to the opposite state by an input to the CLOCK input to the flip-flop. INHIBIT then goes to "1" and stops the block length counters SN 7493, from being clocked and also inhibits the WRITE signal to the tape deck, when S2 is returned to "Run" the system waits for the start of the next sampling sequence before INHIBIT is returned to "0".

If at the end of a sampling sequence the BLOCK signal which is from the block length counters CN1, and CN2, is "1" then the inhibit sequence is initiated and an interrecord gap, IRG, command is sent to the tape deck. The tape deck then forces WRITE STATUS to "1" which resets the block length counters to zero and holds the system in the inhibit mode.

The WRITE STATUS signal goes to "0" when the tape deck has completed the record gap and the system waits for the start of the next sampling sequence before being reset to the run condition. When the "End Data Block and Stop" switch S3, is in the "stop" position, REF is prevented from returning the system to the run condition. This mode is used to insure that the last block to be recorded is the correct length. The "Sample Frequency Select" switch S4, allows the operator to choose between recording every data point or every second data point, or every fourth data point.

## 2.29 Tape Recorder

Storage of all data generated by the system is recorded on magnetic tape by a Precision Instrument Tape Recorder, Model PI-1177. The recorder internally generates the required IBM compatible loadpoint gaps, interrecord gaps, longitudinal redundancy check characters and end-of-file tape marks.

The tape is divided into 7 tracks that run the length of the tape. All data inputs are either a logical "zero" (0 + 1 volt), or a logical "one", (-12 + 2 volts). Each logical "one" is recorded on the tape as a reversal of magnetic saturation while a logical "zero" is recorded as no change in magnetic saturation. Parallel data is applied to the inputs for tracks 1, 2, 4, and 8, and tracks A and B, with track C being generated internally as parity. An input command is a change from 0 volts to -12 volts which is applied to one of the command inputs. The Step command is generated by the on-deck electronics as the gated WRITE signal. The Inter-Record gap command is also generated by the on-deck electronics as the IRG signal. The End-of-File command is generated by a manual push button on the tape deck. Finally, the output signal STATUS signal is used by the on-deck electronics to return the system to the run condition.

## 3.0 DATA QUALITY AND ACCURACY

A major concern in the development of such a system or in any scientific instrument is how good the data will be. Will the data be worth the costs incurred in building and using the instrument? Obviously everything in the designing and the building is tied to the final measurement,

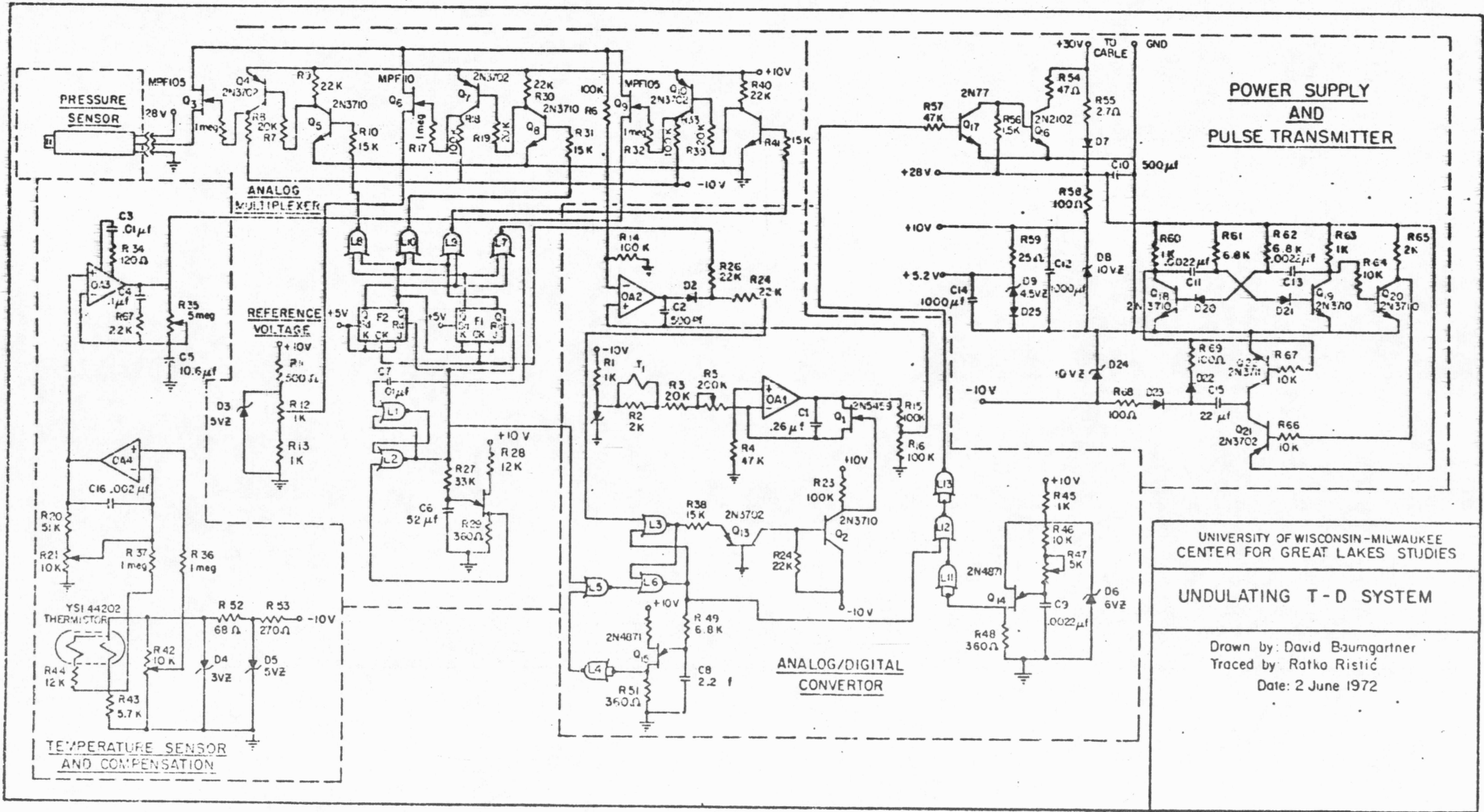


Figure 15. Schematic diagram of UTDP System sensor, power supply, and pulse transmitter circuitry.



but, even with all considerations given to the quality and accuracy of the information derived from the instrument there can exist some doubt. To remove as much of this doubt as possible certain tests and calibrations must be completed. So in an attempt to calibrate and estimate the quality and accuracy of the information from the UTDP System, the following tests were conducted.

### 3.1 Stability

It is of the utmost importance that any scientific instrument be stable and maintain calibration during periods of measurements. Since the UTDP System is intended to be operated for many hours at a time, long-term stability is an important consideration. To test this the temperature module was calibrated in the laboratory against a good quality mercury thermometer by placing both thermistor and thermometer in a controlled temperature water bath. The pressure module was calibrated against a 0-600 psi mechanical gauge in a hydrostatic pressure chamber. Once calibrated, stability was determined in the laboratory by simply turning the system on and holding the temperature and pressure sensors at some fixed temperature and pressure for an extended period of time.

Tests of this type were conducted numerous times during the construction of the instrument and again after the last data run of 1971. In each case the maximum change in the data was one part in a thousand or less, over the test period which usually lasted three hours or more. This

is just at the limits of the accuracy of the system since it cannot resolve the temperature or pressure ranges into more than one-thousand parts.

The above results indicate that the system is stable and maintains its calibration in the laboratory. To confirm this for field conditions a good estimate of the system stability can be obtained by examination of the data signal over the first and last data runs of 1971.

Figure 17 is a plot of every eighth reference signal from the "fish" during the first data cruise. The average signal is about 612 with an average deviation of approximately  $\pm 0.5\%$ . It follows that the other signals, pressure and temperature also can be assigned a similar deviation of  $\pm 0.5\%$  or in terms of centigrade degrees:  $\pm 0.1^{\circ}\text{C}$ , and meters of water:  $\pm 1.0\text{m}$ . The second Reference Signal plot, Figure 18, shows that on the last cruise of 1971 the system continued to be stable and even showed some improvement in stability over the first cruise. In both figures the relatively large changes in the Reference Signal at the beginning of the cruise are the response of the towed electronics seeking an equilibrium between the cold water outside the "fish" and the electrical heating inside.

### 3.2 Analog/Digital Converter Response to an Input Voltage

The Analog/Digital (A/D) Converter has a major role in determining the linearity of the system. To measure its response to an input voltage that under normal circumstances would be from the sensor, the following test was conducted in the laboratory. Figure 19 is a diagram

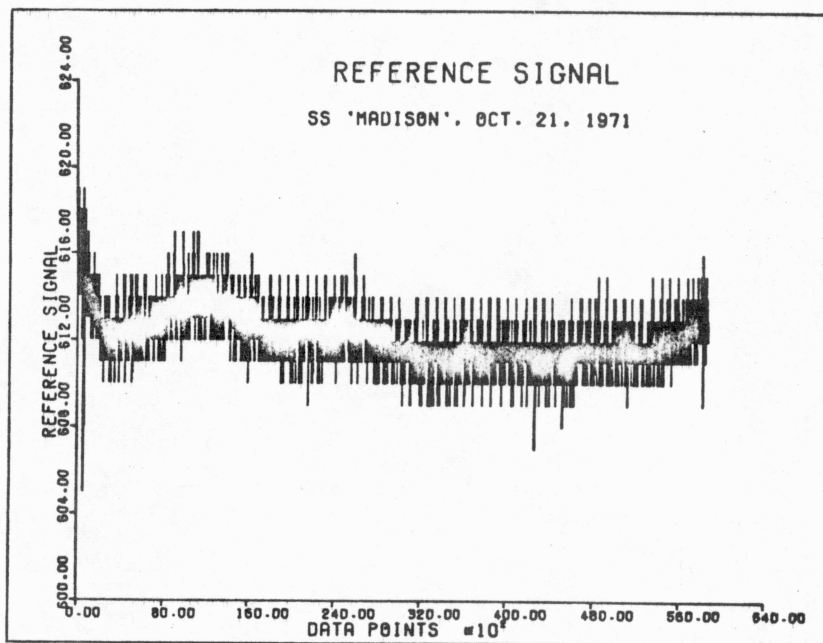


Figure 17. Plot of the Reference signal from the "fish" during the first data cruise of 1971. Every eighth signal is plotted.

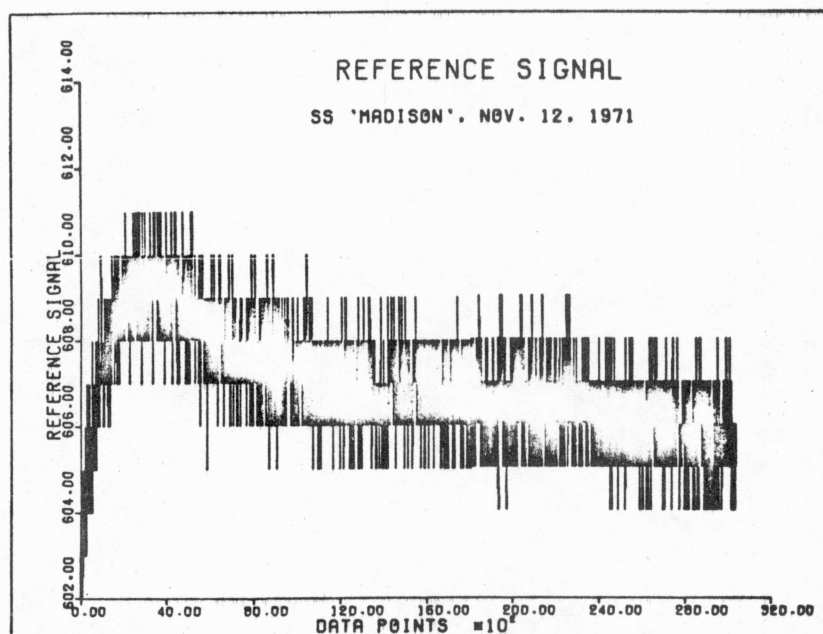


Figure 18. Plot of the Reference signal from the "fish" during the last data cruise of 1971. Every eighth signal is plotted.

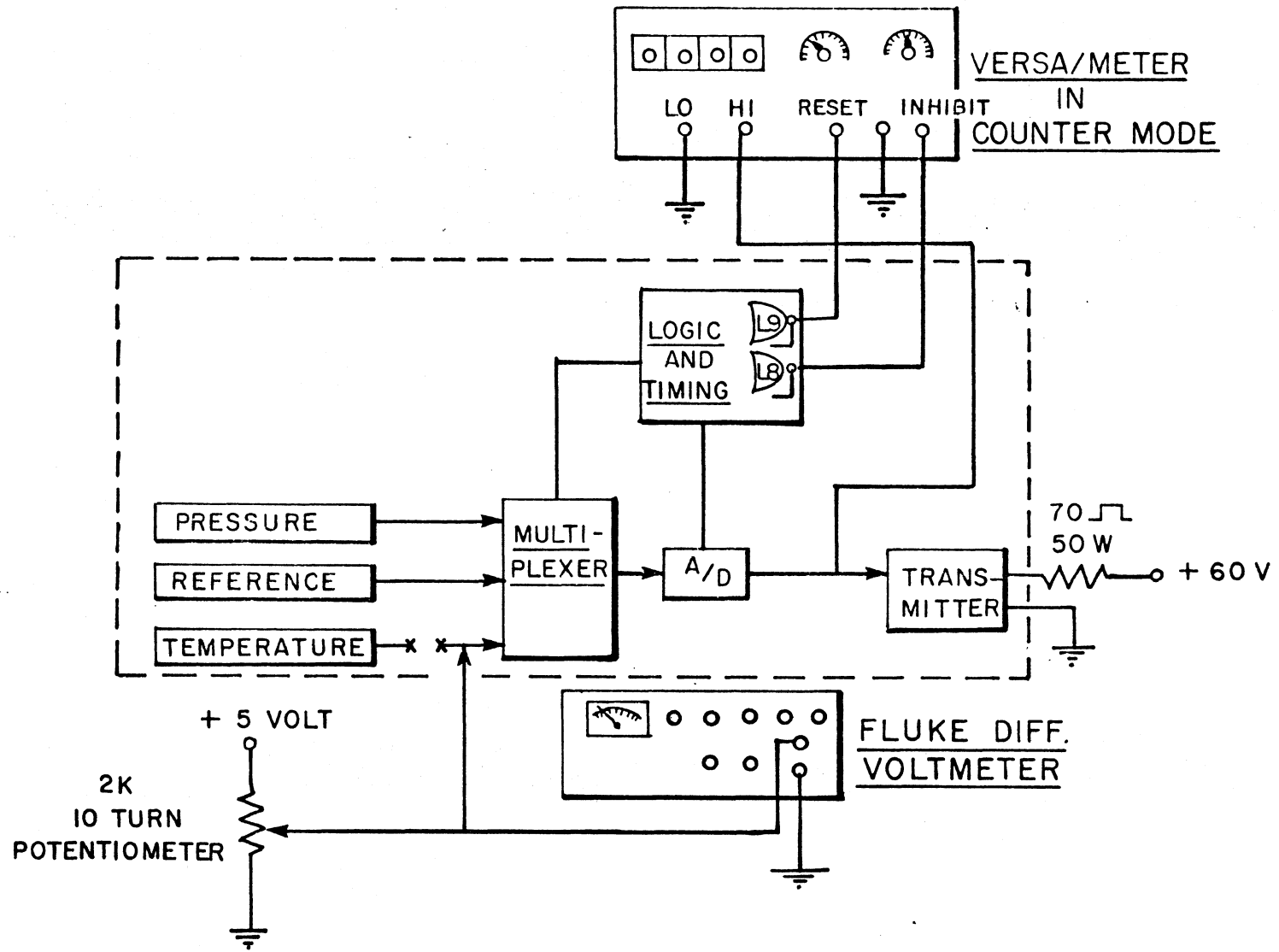


Figure 19. Analog to Digital Converter Response test equipment interconnection.

of the interconnection of the equipment listed below.

- a. Versatronics Versa/meter, Model DM5000
- b. Fluke Differential Voltmeter, Model 803 BR/AF
- c. Variable voltage source, 0-5 VDC
- d. Resistor, 70 ohm, 50 watt
- e. Power supply, 60 VDC, 500 ma

The output taken from L9 and L8 enabled the Versa/meter, in the count mode, to count the number of pulses in a temperature channel data burst. The temperature sensor module was replaced in the system by a variable voltage source. The Fluke Voltmeter was used to accurately measure this voltage as it was changed during the test. The pulse count from the A/D Converter was noted for different input voltages and plotted in Figure 20. It is evident that the linearity of this circuit is very good.

In addition to the response of the A/D Converter the response of the temperature and pressure sensors must also be known. Ideally their responses should be linear for easy analysis which avoids correction factors that would be needed to take into account nonlinearities over the temperature and depth ranges. To measure the response of these sensors, two tests were run in the laboratory.

### 3.3 Temperature Module Response to an Applied Temperature

To measure the response of the temperature channel the towed sensor was connected to the test setup as shown in Figure 21. The equipment used for the test was:

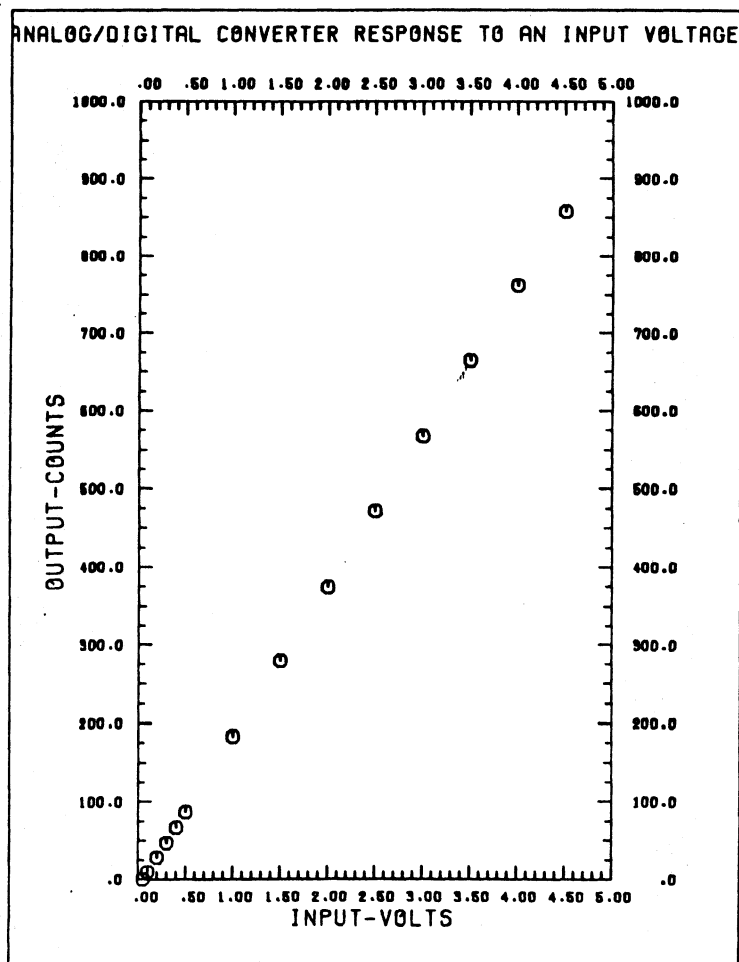


Figure 20. Analog to Digital Converter Response test results.

- a. Fluke Differential Voltmeter, Model 803 BR/AF
- b. Resistor, 70 ohm, 50 watt
- c. Power supply, 60 volt D.C., 500 ma
- d. Woodco M0019 Thermometer, -10 to + 110 deg. Cent.
- e. Ice water container.

The thermistor bead of the "fish" was immersed in a water bath that was cooled to  $0^{\circ}\text{C}$ . The water was kept well stirred as it was allowed to warm up to room temperature. As the temperature of the bath changed, paired thermometer and voltmeter readings were recorded.

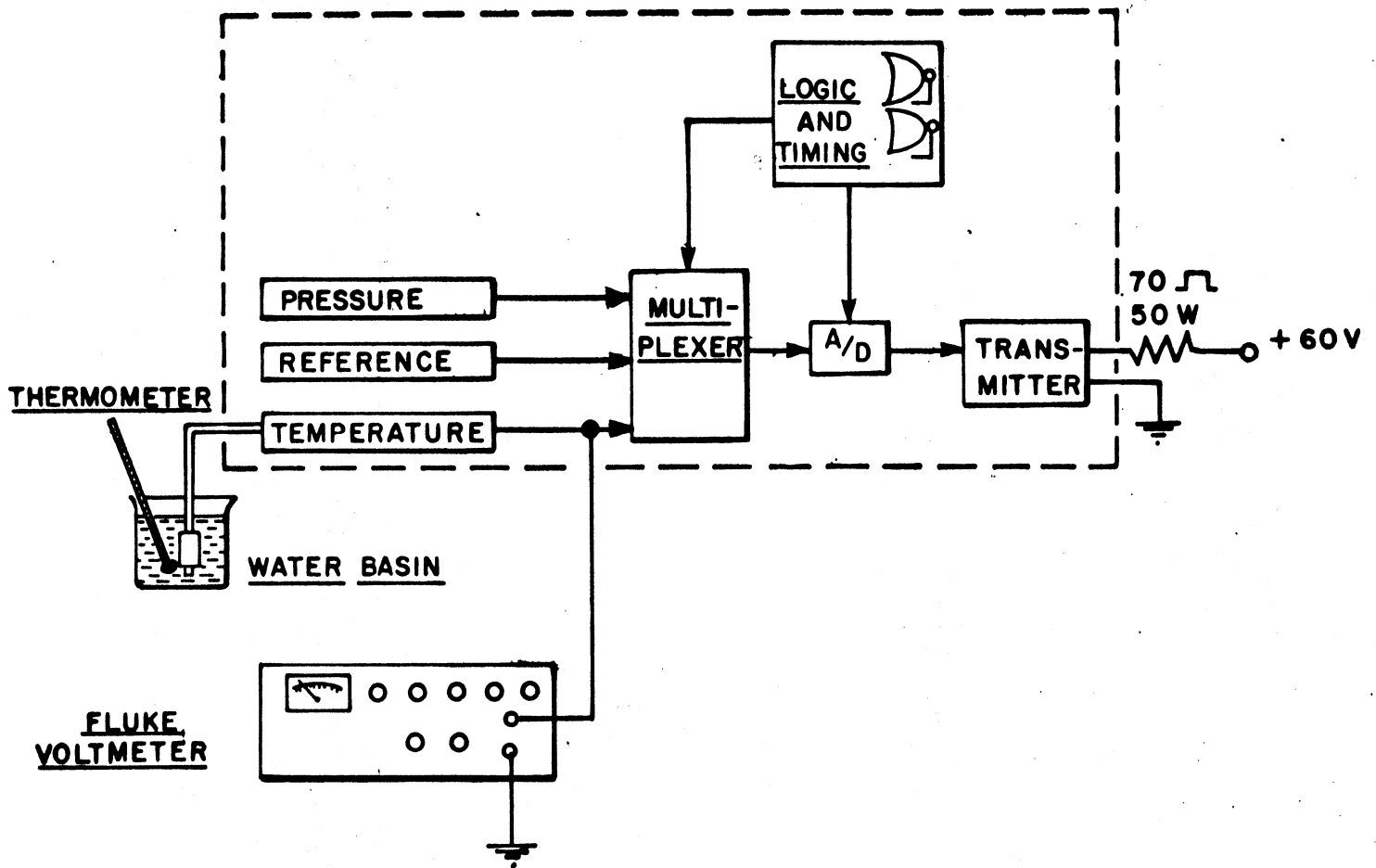


Figure 21. Temperature module temperature response test equipment interconnection.

The results, plotted in Figure 23 show that the linearity of the temperature module is very good.

### 3.4 Pressure Module Response to an Applied Pressure

The data sheet supplied with the pressure transducer indicated a linearity of response of  $\pm 0.75\%$  of full scale. To verify this with the transducer in the system, the "fish" was connected to the test setup shown in Figure 22. Equipment used in this test was:

- a. Fluke Differential Voltmeter, Model 803 BR/AF
- b. Resistor, 70 ohm, 50 watt
- c. Power supply, 60 volt, D.C., 500 ma
- d. Pressure gauge, Ashcroft, 0-600 psi
- e. Republic Pressure Pump, hand operated.

In the test the system pressure was pumped to 200 psi then it was reduced in 10 psi steps. The gauge and voltmeter readings were recorded at each step and plotted in Figure 24. Again, the linearity was very good.

Linearity in all three circuits; A/D converter, Temperature module, Pressure module, makes it possible to construct simple algebraic equations for conversion between temperature or pressure readings that are recorded in system data units to common units such as Centigrade degrees and meters of water (see page 68).

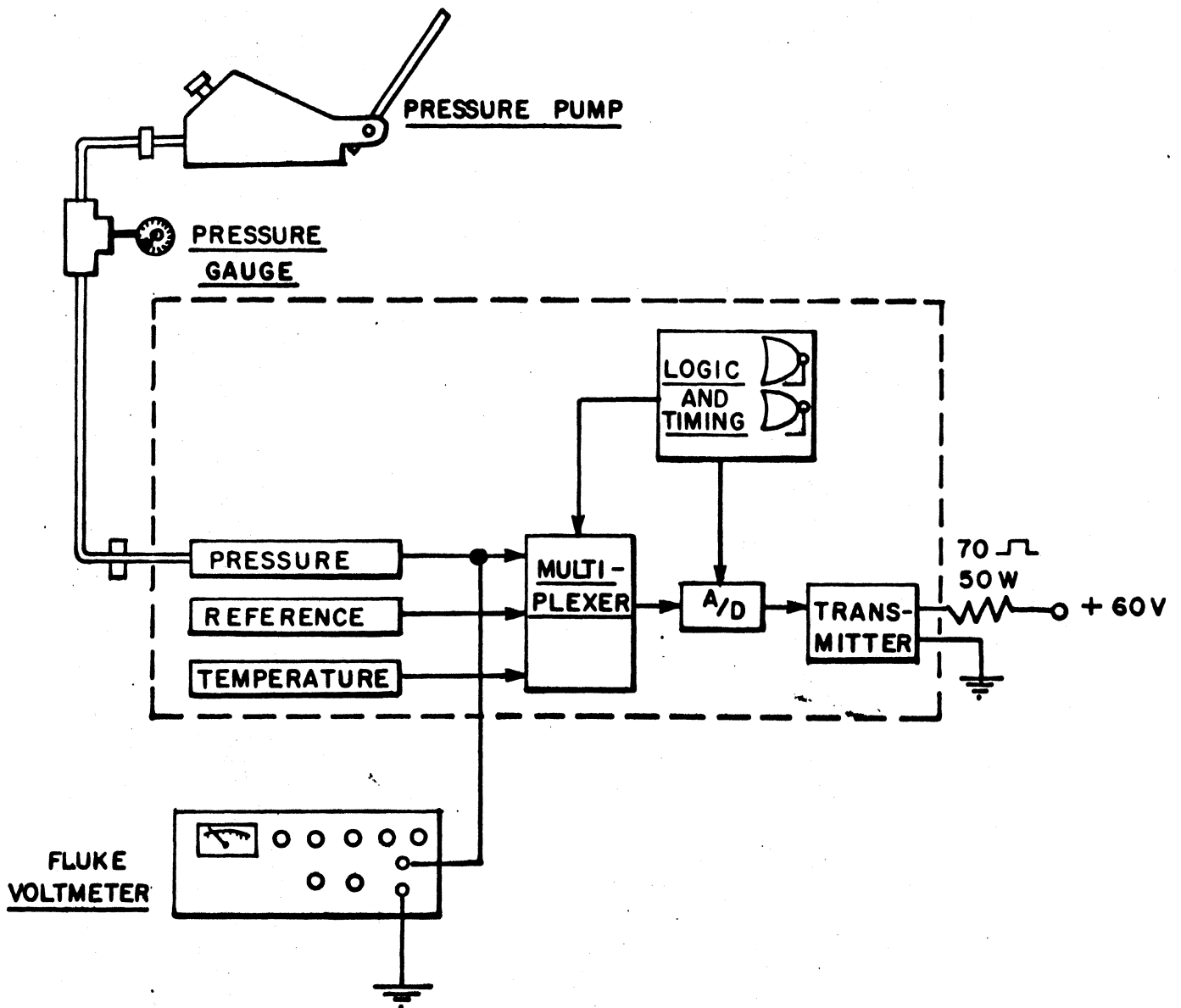


Figure 22. Pressure module pressure response test equipment interconnection.

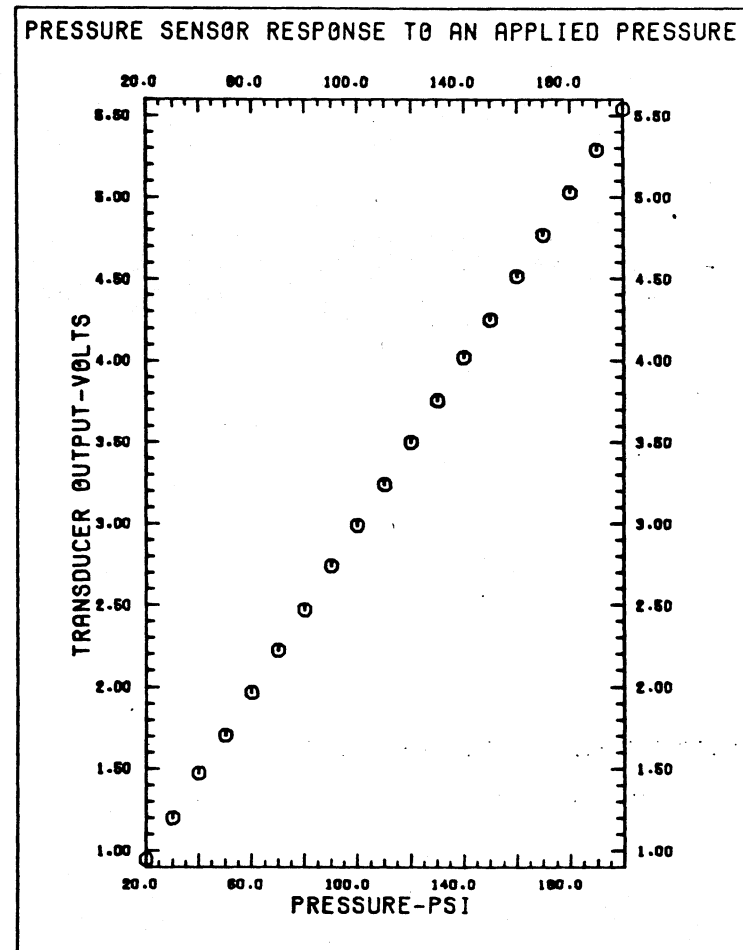
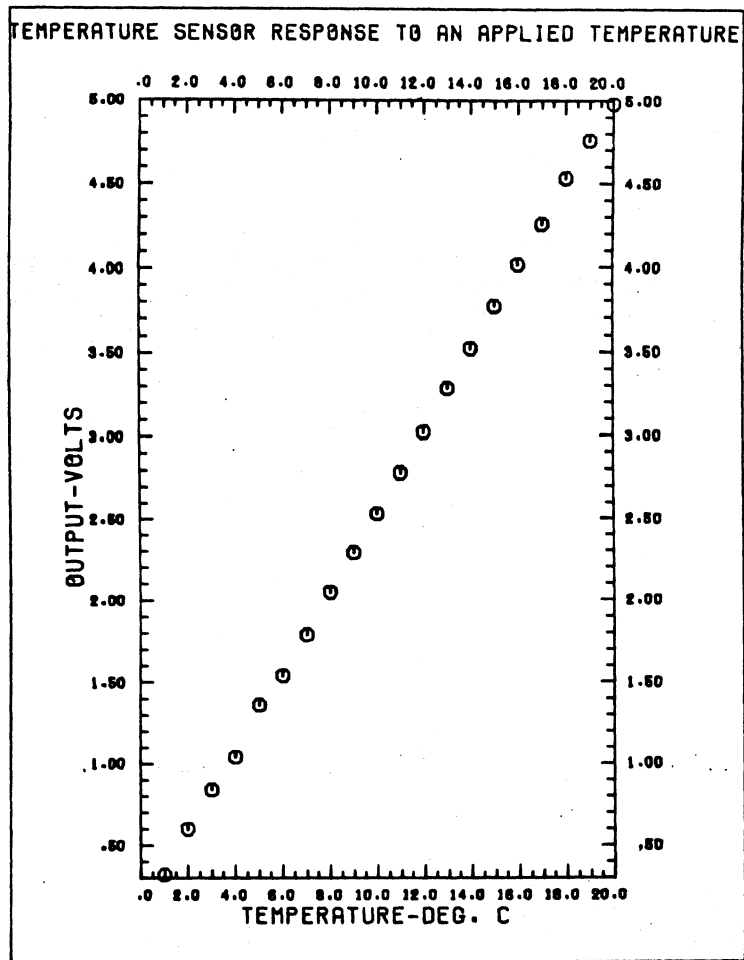


Figure 23. Temperature response test results.

Figure 24. Pressure response test results.

### 3.5 Time Constant of Temperature Module

As we have shown in section 2.23, the effective time constant of the temperature module can be changed electrically. It can also be modified mechanically. For example, the physical mounting of the thermistor has an effect on the Lambda. In this system the thermistor has only a portion of its surface area exposed to the water environment. This has the effect of lengthening the time constant because the rate of heating or cooling of the thermistor is directly proportional to the amount of surface area exposed. In this case the exposed surface area of the thermistor bead is approximately 30% to 40% of its total surface area. Also, around the thermistor bead, to hold it in place, is an epoxy filler of low thermal conductivity. This also tends to lengthen the time constant.

To measure the resulting time constant of the temperature sensing arrangement a very rapid temperature change was impressed on the thermistor and the system's response recorded. To create a rapid temperature change, a stream of water at 10°C was played on the thermistor after it was allowed to stabilize at room temperature. An attempt was made during the test to use sufficient amounts of water so that conditions similar to those experienced during an actual data run were encountered. Five measurements were made using this method. The time constant for each trial was estimated from the resulting response curve and these five values were averaged. This test indicated a 4.6 second time constant for the temperature channel without any compensation.

A 4.6 second time constant is much too long for the speeds with which the sensor moves through the water so the resistor - capacitor combination R35 and C5 (Fig. 15) of the OA3 response compensation network, was adjusted in value to 3.0 seconds (resistance/capacitance = time). Although this value is not exactly equal to the time constant of the temperature channel, it should improve the effective thermistor time constant yet keep the circuit from overcompensating. The effective time constant of the circuit with the indicated values of R35 and C5 is estimated to be 0.67 sec.

### 3.6 Temperature Rise Inside Sensor Housing

A potential problem is the increase in temperature of the sensor electronics due to the dissipation of heat by the electrical components inside the sensor housing. When heated, electrical devices, tend to change their characteristics. Such changes if not corrected or compensated for can cause a change in the system calibration and even system instability.

To determine how the internal heating was distributed in the circuitry, thermocouple elements that were connected to a Honeywell multi-point recorder were placed at various locations inside the sensor housing. The electronic package was sealed in the "fish" and the electronics allowed to run continuously for 5 hours in the laboratory. The highest temperature reached was 86°C and this was in the power supply section, as expected. The circuit components, in this area are rated to 175°C so even without the benefit of the cool lake water there is little danger of exceeding the maximum operating temperatures of the components.

The A/D circuitry showed a total drift of  $\pm 0.002\%$  over the temperature range of  $25^{\circ}\text{C}$  to  $62^{\circ}\text{C}$ . The drift of the temperature and pressure circuits was not measurable and assumed negligible.

Operating the "fish" in the laboratory exerts temperature extremes more severe on the electronics than would be encountered during an actual data run and as previously mentioned the water around the "fish" under normal operating conditions should effectively cool the circuitry.

#### 4.0 SYSTEM OPERATION

Once the "fish" is in the water and the "fish" and on-deck electronics are functioning, the operation of the UTDP System involves simply turning on and off the winch. For a dive the winch operator allows the towing cable to pay out as rapidly as possible. The winch brake is applied to stop the dive and the winch turned on to retrieve the cable and pull the "fish" back to the surface.

The most important real-time information from the system is the sensor depth because this is usually the information used to begin a new dive and to bring it to an end. Temperature information can be used to guide the start and end of a dive but the depth of the sensor must be known to prevent the "fish" from colliding with the lake bottom. Cable length as indicated by the meter wheel is an important check on the depth reading and has been used as such but most importantly there is a maximum cable length that if exceeded it is unlikely that the winch would be able to pull in the "fish" without help.

#### 4.1 Theory of Motion

The desired motion of the "fish" is a cyclic undulation across the thermocline in a vertical plane and any perturbations on this motion makes the analysis of the data more difficult. Ideally, the best path from the point of view of the data analysis is a square "wave" shape. This path implies that the dives and rises take place without any forward or backward motion and that they take place in a very short time. This type of motion makes it easy to locate the point on a cruise where a dive or a rise takes place if the time of the dive and the speed and course of the towing vessel are known. Unfortunately the sensor moves through the thermocline at a very fast speed and without a fast responding sensor that can keep up with rapid changes in temperature and pressure the data will be worthless. In this situation the experimenter is forced to short time constant sensors.

If one could approximate a square "wave" path with the sensor the dives and rises could be moved closer and closer together until some limit imposed by the system is reached. The point being that the horizontal resolution could be increased most easily with this type of path. A common bathythermograph has a path like a square wave but its high frequency limit is governed by the time it requires to take the instrument from the water, remove the spent slide and replace it with a new one. Usual procedure also calls for a temperature equalization period in the water before a dive.

To get a sharp, fast dive in the UTDP System, we built the "fish" with a very heavy nose piece. All that must be done then to create such a dive is to pay out the towing cable as rapidly as possible. To create a sharp rise is not so easy and most likely is impossible to do with a body that has no moveable control surfaces. The only thing that can be done is to haul in the towing cable as rapidly as possible thereby forcing the body to the surface. The result is a compromise, that has a sharp dive and a gradual rise that should look something like Figure 25.

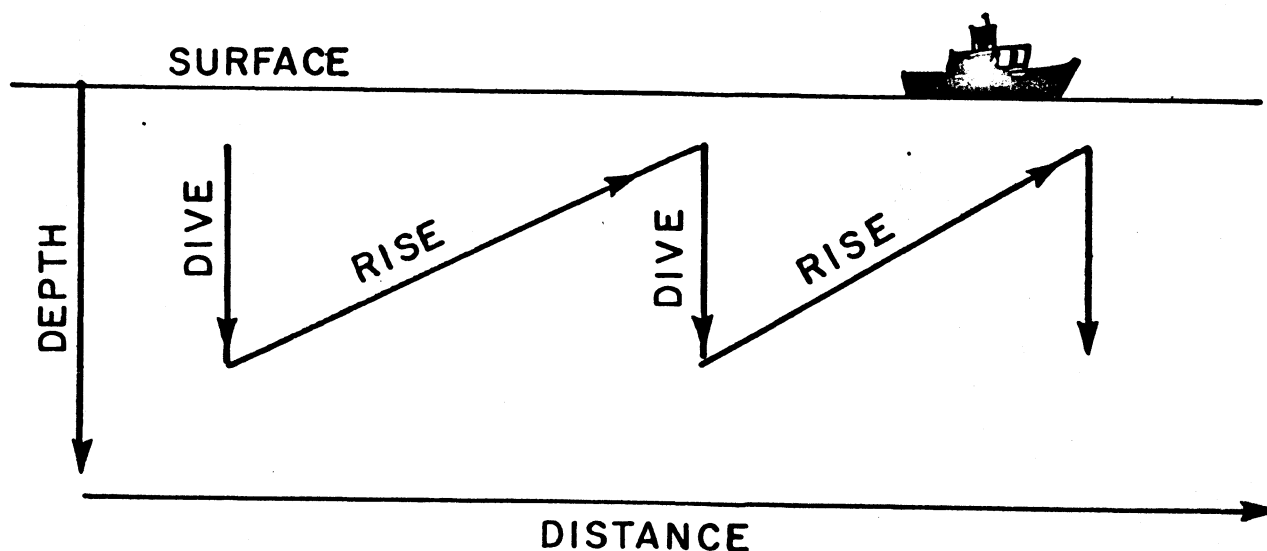


Figure 25. Predicted path of UTDP System sensor.

#### 4.2 Actual Motion

It should be stated at this point that the fish does behave as predicted. It dives and rises as expected but its path is not exactly that

of Figure 25. There does remain at this time a question about its exact motion during one undulation or cycle. Although the fish does follow the expected sharp dive-gradual rise path in a vertical plane, the possibility of small up and down motions cannot be eliminated. It is a simple matter to show that the path in time is that of Figure 26. This is taken directly from the recorded depth data and time calculation. It is important to note that the abscissa in Figure 26 is time and not distance.

We are reasonably certain that the "fish" in tow makes no wild gyrations or extreme swings. From visual observation of the "fish" close to the surface it appears that it tracks straight and true behind the vessel without veering to port or starboard. Even small perturbations of the motion are not evident.

Ignorance of the details of the path has led us to make certain assumptions about the undulation so that analysis of the data can be kept as simple as possible. On the scale of Lake Michigan, these assumptions about the small scale motions of the sensors should not introduce measurable error. The most important assumption about the path is that the dives are vertical and the distance that the 'fish' moves forward during a dive is negligible. This seems reasonable because during a dive there is little tension in the towing cable and since the "fish" is extremely nose heavy it will naturally tend to dive vertically. These facts do not eliminate the possibility of other types of motion such as a gliding arc on a dive.

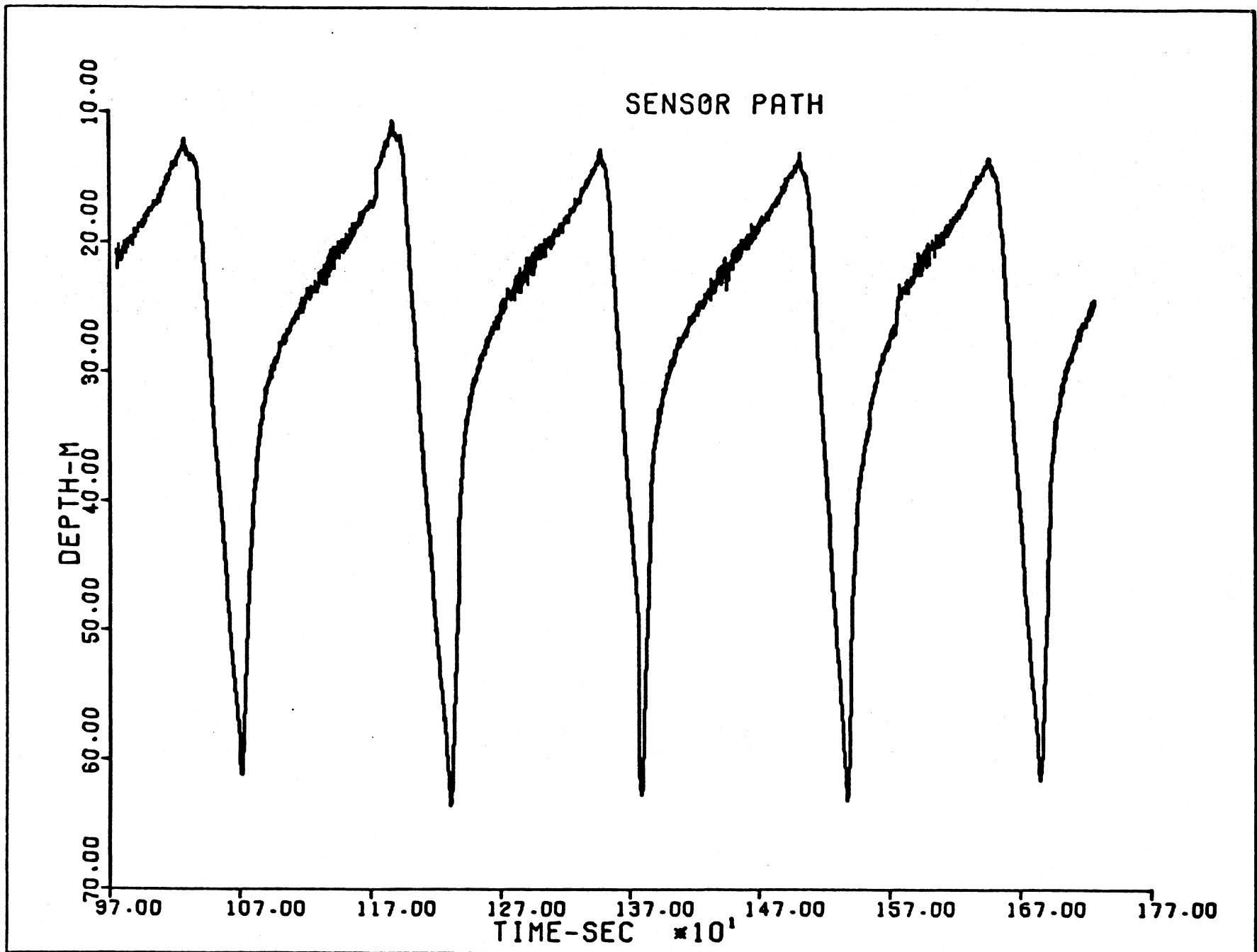


Figure 26. Towed sensor ("fish") path in time and depth, derived from system data.

When a dive is stopped by the application of the winch brake the "fish" performs a sharp rise to a level that is determined by the vessel speed, the length of cable out, and the hydrodynamic characteristics of the cable and "fish". From this point on, the winch is used to bring the "fish" to a near surface location for a new dive. This portion of the cycle is the slowest. It takes over four times as long to bring the "fish" up as it does to allow it to dive. Tension in the cable during a rise reaches values around 300 pounds, and although this is well below the breaking strength of the cable and its fittings, this seemed to be the upper limit for the winch. During the rise portion of the path cycle the "fish" runs as a depressor, stubbornly giving up depth as the winch strains, to bring it to the surface. The winch usually prevails and when the "fish" reaches some predetermined depth or temperature another dive is begun.

From experience with the system the average elapsed time for a dive of approximately 50 meters is 40 seconds. This gives the "fish" a vertical velocity in the neighborhood of 1 meter a second. In the same 40 seconds the towing vessel moving at a speed of 6.3 meters a second (14 mph), travels a distance of roughly 250 meters. The distance that the "fish" moves and the distance the boat moves adds to 300 meters. This 300 meters is a good approximation to the amount of cable payed out on a typical dive, which shows that there are not large excesses of cable being payed out during a dive and that the cable configuration is probably of that in Figure 27.

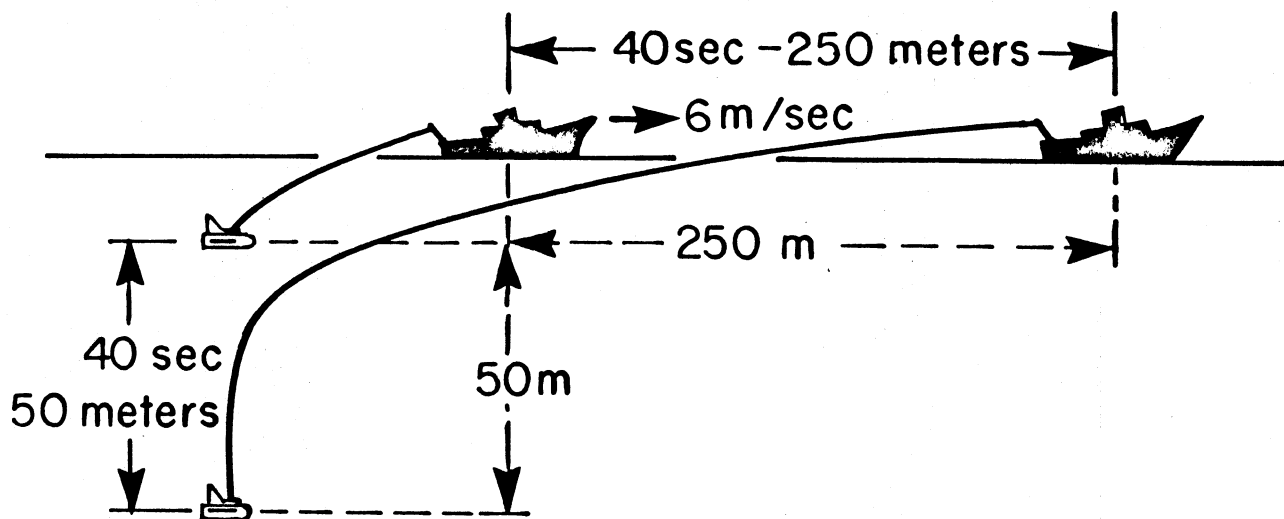


Figure 27. Towing cable configuration before and after a dive.

The fact that the "fish" rises sharply at the end of a dive also adds to the evidence that large excesses of cable are not payed out during a dive. Any excess of cable at the end of a dive over the shape shown in Figure 27 would be taken out before the "fish" would rise, which would mean a time lag between application of the winch brake and the beginning of the rise. There is no time lag. The fish rises immediately when the cable is stopped.

#### 4.3 S. S. Madison Cruises (1971)

On 21 October 1971 the first fully operational data run across Lake Michigan from Milwaukee, Wisconsin to Muskegon, Michigan was completed. On this cruise and on the 14 subsequent cruises during October and November of 1971 the system continuously monitored and

recorded the vertical temperature distribution behind the towing vessel to an average depth of about 65 meters. The towing vessel for each of these trips was the S. S. Madison of the Grand Trunk Western Railroad Company. Each towing of the sensor lasted approximately three to five hours with a minimum of down time due to equipment failure.

The winch was bolted to the deck and the cable was fairled over the after starboard railing through two sheaves attached to the ship's superstructure and a final meter wheel at the end of a boom. The boom and its associated supports were constructed from 3 inch steel pipe. Designed so that it folded when not in use to lie along the side of the vessel, it required two people to rotate it into a towing position and to bring it back when a data run was finished. When in the towing position the boom was nearly horizontal and perpendicular to the ship's keel. It projected approximately ten feet over the side of the vessel.

A Dillon Dynamometer, 0-2000 pounds, was fastened to the axle of the first sheave and to an eye on the deck as shown in Figure 2. With the dynamometer facing the winch operator he was able to monitor cable tension while controlling cable speed.

For crossings at night two flood lights were positioned to shine on the meter wheel and on the winch.

The usual data run began with the interconnection of the system units and the rigging of the towing cable. The boom arrangement

was rotated to its towing position and the "fish" lowered to just below the water surface. Next the system was turned on and the data examined for erroneous values. At this time a length of approximately 25 meters of cable was payed out and a visual check was made of the "fish's" track behind the vessel. If all was well the undulations were started. The recorder was switched on and the time recorded in the Cruise Log Book. The undulations were continued for a predetermined time or until other circumstances warranted ending the run or temporarily stopping for repairs. Upon termination of a run the time was again recorded as were all times of interruptions in the continuous data record.

In operation, after the "fish" was in the water and near the surface behind the vessel, the brake on the winch was released and the cable allowed to pay out as fast as it would go.

The dial on the meter wheel at the end of the boom proved valuable to the winch operator in judging the depth of the "fish" since the length of cable overboard is related to "fish" depth. Although not completely reliable, this method of judging the depth of the "fish" served as a good safety check against the depth meter during a dive.

On a dive it was the responsibility of the second crew member to monitor the depth meter and to signal the winch operator to end a dive. Immediately after a dive the winch was turned to pulling in the cable until the "fish" was near the surface so another dive could be started.

This cycle was repeated continuously during a cruise as long as sea and bottom conditions allowed. From the runs of 1971 the average cycle time was between four and five minutes which meant that at 6.3 meters a second (14 mph) the distance between dives was about 1.5 to 2.0 kilometers.

Table 3 is a condensation of the log kept during the 1971 cruise.

## 5.0 DATA MANAGEMENT AND ANALYSIS

If the Undulating Temperature/Depth Profiling System is operated continuously for four hours at an average rate of four data points or sequences a second, the total number of temperature/depth samples approaches 60,000. This is a formidable amount of data to sort through for analysis and makes processing by modern electronic computer almost a necessity. Various programs have been written in UNIVAC 1108 Assembler, ALGOL 60, and FORTRAN IV languages for handling the data from the UTDP System on a UNIVAC 1108 Multiprocessor System. The first operation on the raw data which is stored on magnetic computer tape is to check the data for errors due to faulty recording and to re-record the data on another tape in a format that is compatible with computer languages such as FORTRAN IV and ALGOL 60. This procedure does two things: it saves the original tape and makes it easier for programming in these higher level languages.

Table 3. 1971 Data Cruise Information.

Cruise No.	Date 1971	Departure Time	Time at Breakwall	Begin Data Recording	Stopped Data Recording	Comments
1	21 Oct.	Milw., 0000 Hrs	0030 Hrs	0052 Hrs	0525 Hrs	
2	21 Oct.	Musk., 1200	1230	1300	1730	
3	22 Oct.	Milw., 0000	0030	0045	0520	Possible error due to broken pressure tube.
4	22 Oct.	Musk., 1000	1030	1115	1550	
5	28 Oct.	Milw., 2020	2045	2150	0215	Pressure tube repaired; run started late.
6	29 Oct.	Musk., 0450	0520	0550 0820	0815	Course changed due to heavy weather.
7	31 Oct.	Milw., 2302	2321	2353 0022 0230	2359 0158 0437	Stopped recording due to circuit failure. Repaired. Stopped, bad data due to malfunction in terminator --repacked with grease.
8	31 Oct.	Musk., 1000	1030	1100	1525	
9	4 Nov.	Milw., 0030	0050	0137 0204	0150 0330	Commutator on winch dirty --data noisy --cleaned commutator. Heavy seas.

Table 3 (continued).

Cruise No.	Date 1971	Departure Time	Time at Breakwall	Begin Data Recording	Stopped Data Recording	Comments
10	4 Nov.	Musk., 1100	1120			Heavy Seas. Course 275° at 1235. Course 280° at 1250 Course 285° at 1300 Course 290° at 1312 Course 255° at 1340 Course 290° at 1558 Course 255° at 1607
				1255		
					1640	
11	8 Nov.	Milw., 2100	2115	2145	0300	High winds and heavy seas. Water surface temp. 7°C at Milw.
12	11 Nov.	Milw., 0015	0030	0100	0558	
13	11 Nov.	Musk., 0900	0915	0945	1305	Water from east edge of Milw. reef to Milw. Harbor is isothermal (homogenous).
14	11 Nov.	Milw., 1905	1925	2137	0050	
15	12 Nov.	Musk., 0330	0345	0450	0700	Heavy weather and isothermal conditions caused early stop.

All runs from S. S. Madison, time est: 12:00 AM = 2400 Hrs/0000 Hrs.

## 5.1 Initial Processing

The data formatted by the on-deck electronics is stored on the magnetic tape in IBM seven-channel BCD code. It is blocked in blocks of 430 characters each. An example of this blocking is shown in Figure 28a. Although the UNIVAC 1108 can read tape written in BCD code and non-standard blocks, as mentioned FORTRAN IV and ALGOL 60 cannot. For these languages to use the data it must be put into a card image format. On the UNIVAC 1108 this is called System Data Format (1108 Computing Handbook). This initial processor is written in UNIVAC 1108 Assembler Language.

An example of the data after initial processing is shown in Figure 28b. Each data point requires ten characters. The first character indicates good or bad data. The coding is "o" for good data and "l" for bad. The next three digits are the reference value. These are followed by three digits indicating the temperature value and the last three indicating the pressure. Eight of these data sequences appear in a line which looks to the computer like one card image. After the initial process of checking for bad data and conversion of the data to a new format the final processing can be started.

## 5.2 Calibration

Every instrument presents special problems in the handling of its data or readings. Such things as multiplicative factors, additive constants,



and error corrections, each peculiar to the system in use are common.

The UTDP System is no exception. The raw data from this system is not in a common unit. Depth and temperature appear as numbers from one to one-thousand. To change these readings to degrees -Centigrade and depth in meters, certain system-dependent conversion factors must be used.

From Figures 20, 22, and 24, equations 11 and 12 were derived to change temperature and depth readings from system units to degrees -Centigrade and meters, respectively.

$$T = \frac{SDT + 6.43}{47.3} \quad (11)$$

$$D = 0.14 (SDP - 74.4) \quad (12)$$

where: T = Temperature in Centigrade degrees

SDT = System Data Temperature units

D = Depth in meters of water

SDP = System Data Pressure units.

### 5.3 Time Calculation

A very important part of the data is information about when a data pulse occurred. If there were no way to tell when a data point was taken then there would be no way to tell where it was taken and the data in this case would be worthless. Though not separately recorded, time can be determined from the data because the individual pulse lengths and time intervals between the pulses are standardized. The calculation for the time

of a particular data point is simply a summation of all individual pulse and interval times that have preceded the point of interest. Figure 11 shows the timing for a typical data sequence. For example, if the reference burst contained 612 pulses and the temperature and pressure bursts each contained 310 and 205 pulses respectively, then the total time for this data sequence, including the interval times would be close to 0.24 seconds. The calculation is,

$$(612 + 310 + 205) \times 0.00005 + 2 \times 0.032 + 0.120 = 0.24 \text{ seconds.}$$

Knowing the time at which a data point was taken and also knowing the speed of the ship, makes it possible to calculate the location of the data point by multiplying these two values together. This simple calculation assumes that the ship's speed does not vary but is constant during the data run. For the data cruises on the S. S. Madison the operating personnel indicated that 14 mph was maintained during a crossing in good weather because this speed had proven to be the most economic and efficient for the company.

#### 5.4 Final Processing

Once the data has been arranged for efficient analysis by the initial processor program, the temperature distributions can be constructed. Probably the most fundamental analysis is the drawing of isotherms from the data. We have written a program in the FORTRAN IV language to search

through the data and plot out as many as ten isotherms of the investigator's choosing. More than ten can be plotted with a slight change in the program. Figures 29 through 43 are isotherm plots from each of the data runs of 1971 done on a computer plotter. The isotherm plot from cruise 12 is not presented because of computer system problems.

These diagrams are constructed from data taken during the breakdown of summer stratification. This is clearly evident in a comparison of the first and last cruises. In the later cruises the large volumes of nearly isothermal water are evident by the large amplitude, high frequency oscillations present on the warmest isotherms.

The spikes and straight lines along the individual isotherms are probably sensor and data processing caused rather than the actual isotherm. Such things that may contribute to the structure of the isotherm diagram in addition to the isotherm's true shape could be:

1. The undulation frequency of 1.5 to 2.0 kilometers for every cycle.
2. Any time lag of the sensors.
3. The possibility of cavitation around the pressure sensor ports at high speeds.
4. Any system noise present in the data.
5. The algorithm used to extract the isotherms from the data.
6. The straight line drawing of the plotter.

UNDULATING TEMPERATURE/DEPTH PROFILING SYSTEM  
 LAKE MICHIGAN TEMPERATURE PROFILE  
 SS 'MADISON', OCT. 21, 1971

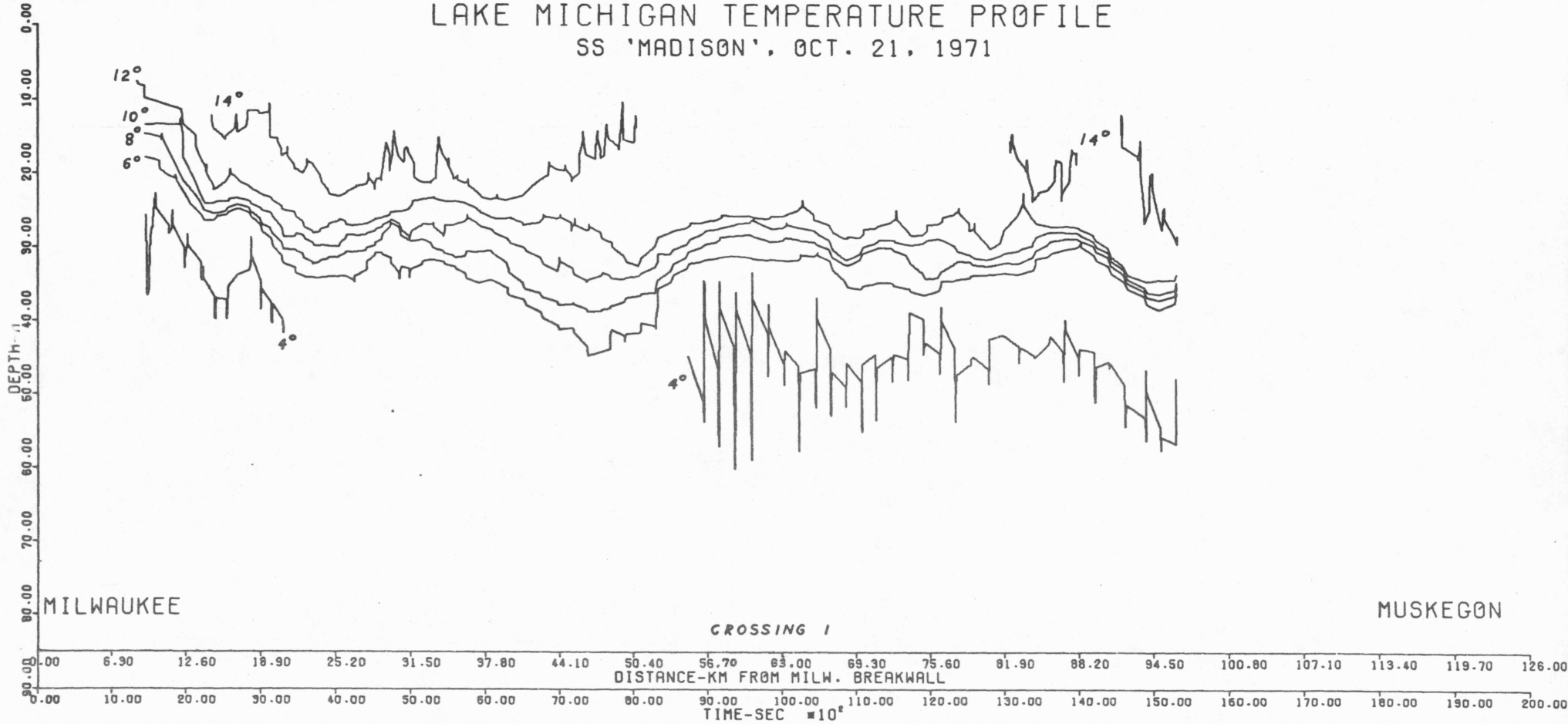


Figure 29. Internal temperature structure of Lake Michigan from cruise 1.

UNDULATING TEMPERATURE/DEPTH PROFILING SYSTEM  
 LAKE MICHIGAN TEMPERATURE PROFILE  
 SS 'MADISON', OCT. 21, 1971

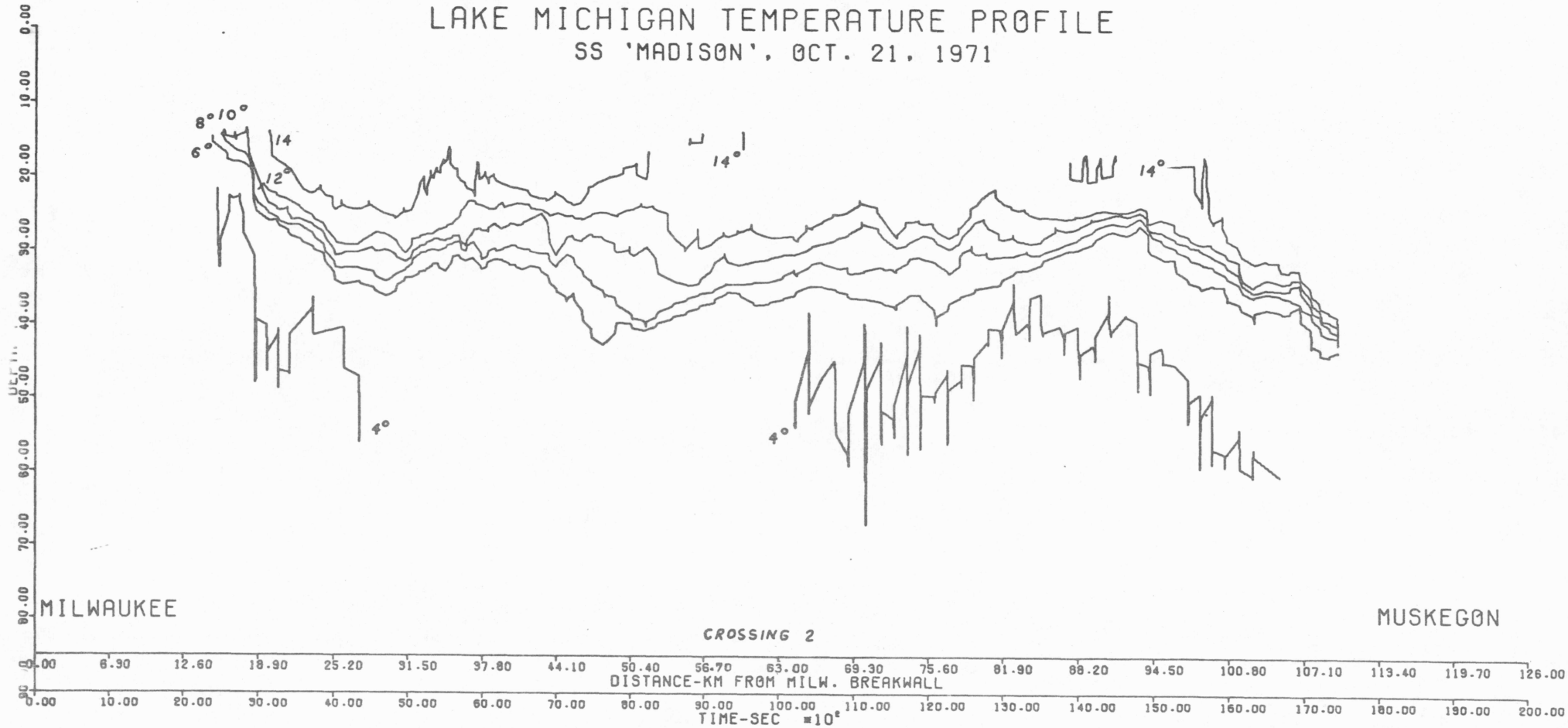


Figure 30. Internal temperature structure of Lake Michigan from cruise 2.

UNDULATING TEMPERATURE/DEPTH PROFILING SYSTEM  
 LAKE MICHIGAN TEMPERATURE PROFILE  
 SS 'MADISON', OCT. 22, 1971

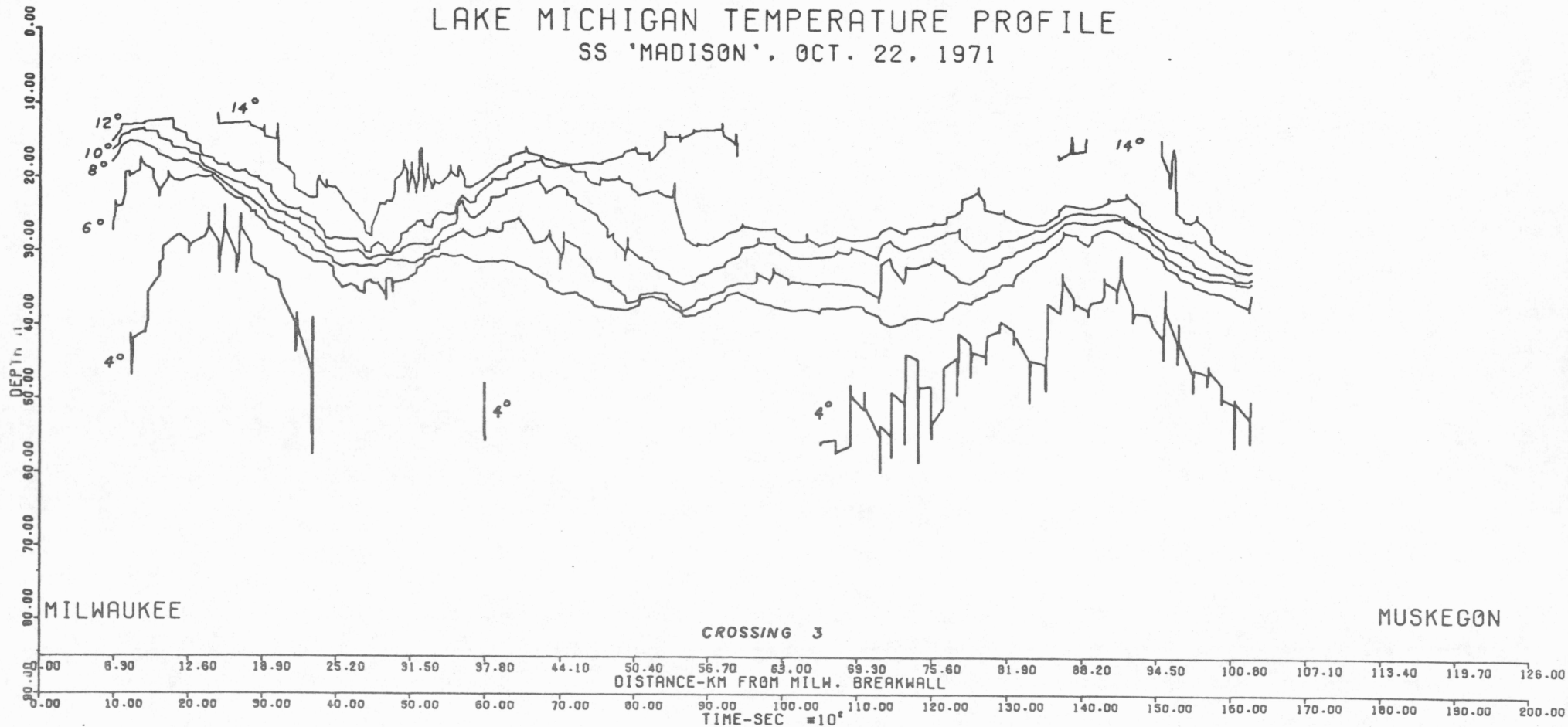


Figure 31. Internal temperature structure of Lake Michigan from cruise 3.

UNDULATING TEMPERATURE/DEPTH PROFILING SYSTEM  
 LAKE MICHIGAN TEMPERATURE PROFILE  
 SS 'MADISON', OCT. 22, 1971

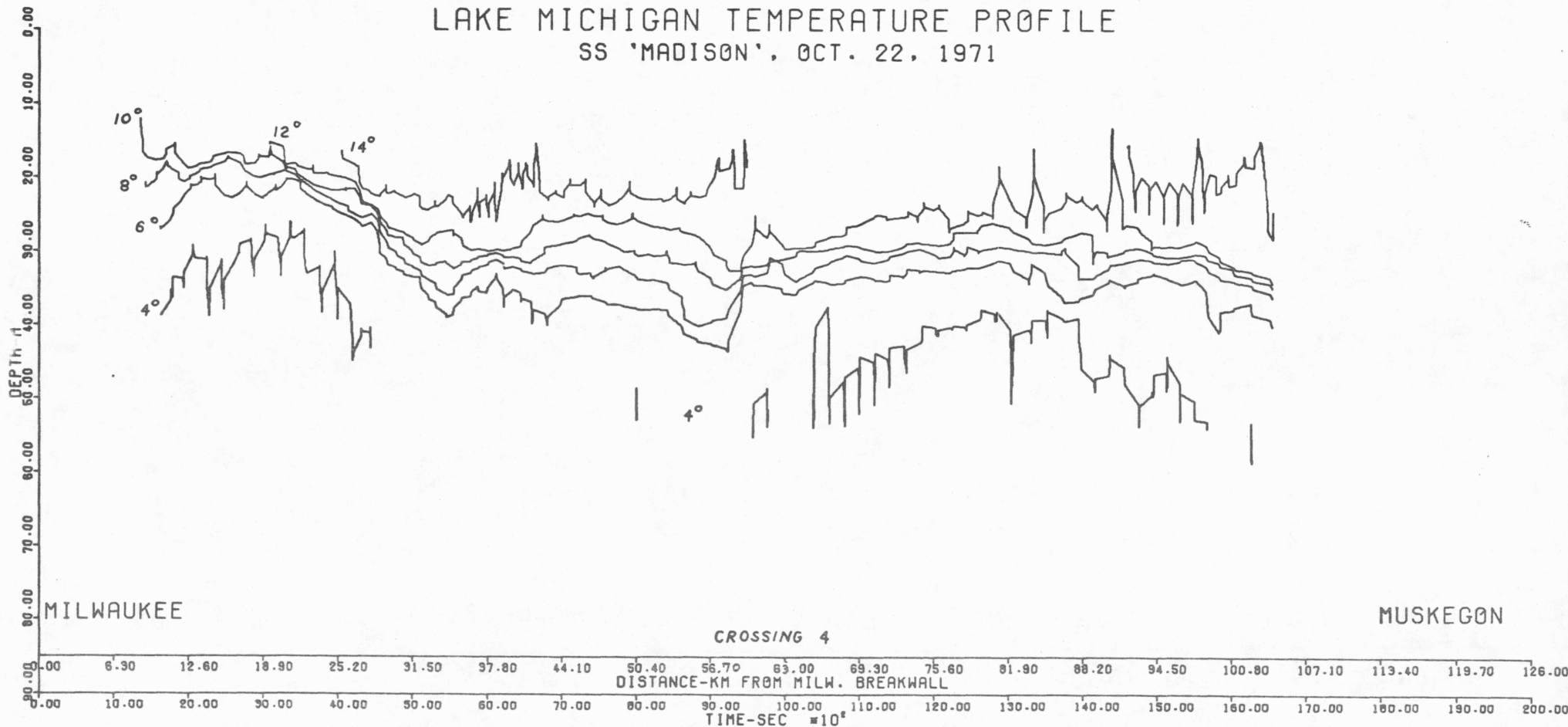


Figure 32. Internal temperature structure of Lake Michigan from cruise 4.

UNDULATING TEMPERATURE/DEPTH PROFILING SYSTEM  
 LAKE MICHIGAN TEMPERATURE PROFILE  
 SS 'MADISON', OCT. 28, 1971

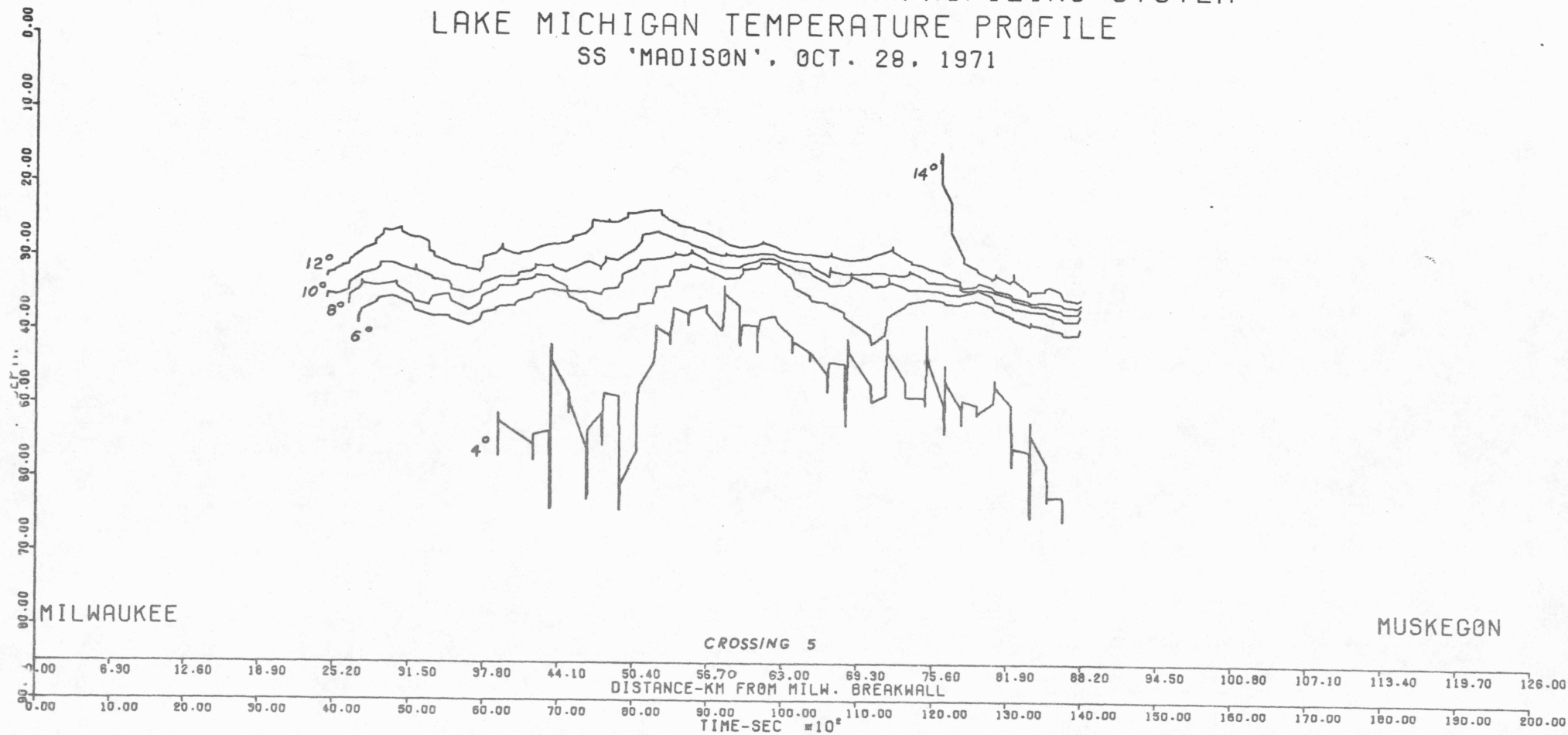


Figure 33. Internal temperature structure of Lake Michigan from cruise 5.

UNDULATING TEMPERATURE/DEPTH PROFILING SYSTEM  
 LAKE MICHIGAN TEMPERATURE PROFILE  
 SS 'MADISON', OCT. 29, 1971

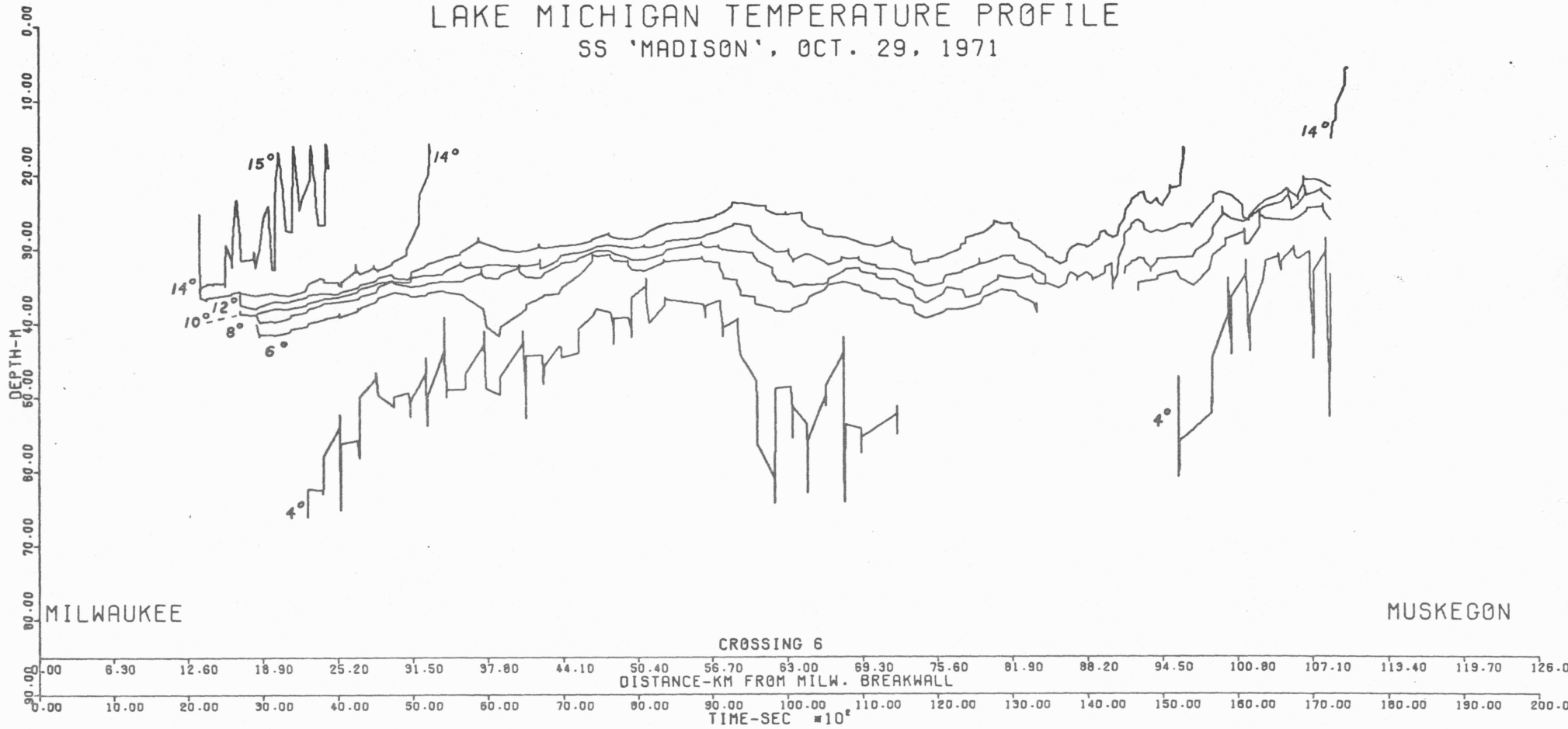


Figure 34. Internal temperature structure of Lake Michigan from cruise 6.

UNDULATING TEMPERATURE/DEPTH PROFILING SYSTEM  
 LAKE MICHIGAN TEMPERATURE PROFILE  
 SS 'MADISON', OCT. 31, 1971

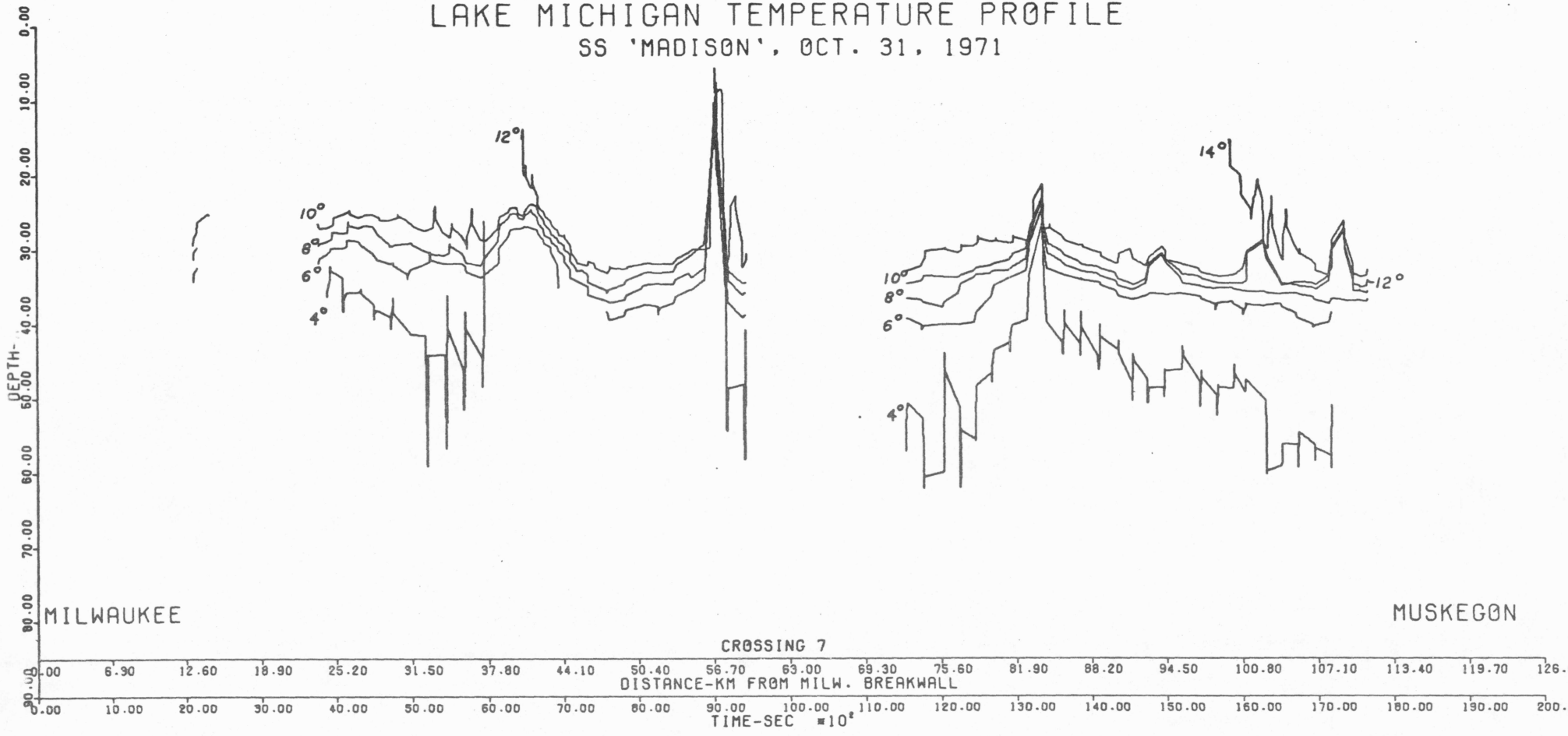


Figure 35. Internal temperature structure of Lake Michigan from cruise 7.

UNDULATING TEMPERATURE/DEPTH PROFILING SYSTEM  
 LAKE MICHIGAN TEMPERATURE PROFILE  
 SS 'MADISON', OCT, 31, 1971

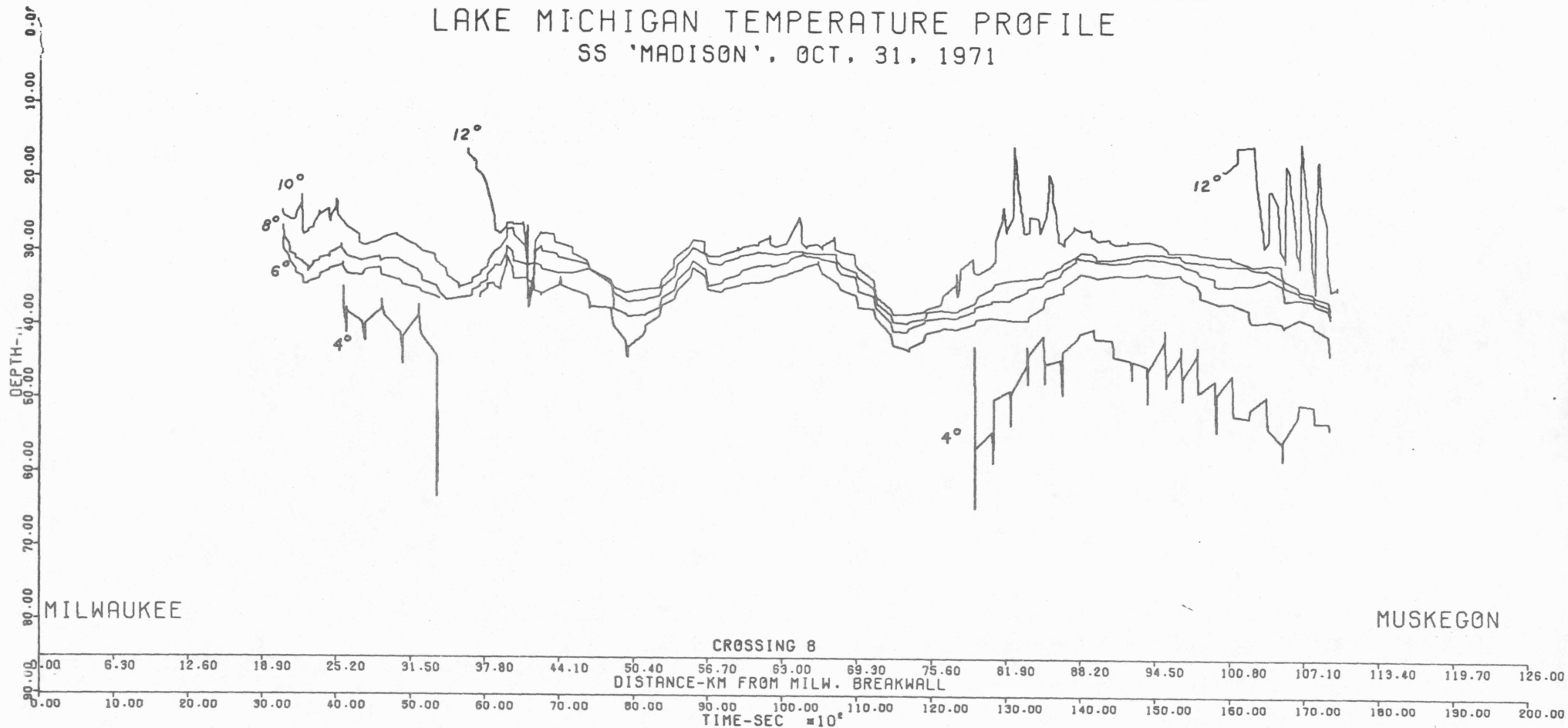


Figure 36. Internal temperature structure of Lake Michigan from cruise 8.

UNDULATING TEMPERATURE/DEPTH PROFILING SYSTEM  
 LAKE MICHIGAN TEMPERATURE PROFILE  
 SS 'MADISON', NOV. 4, 1971

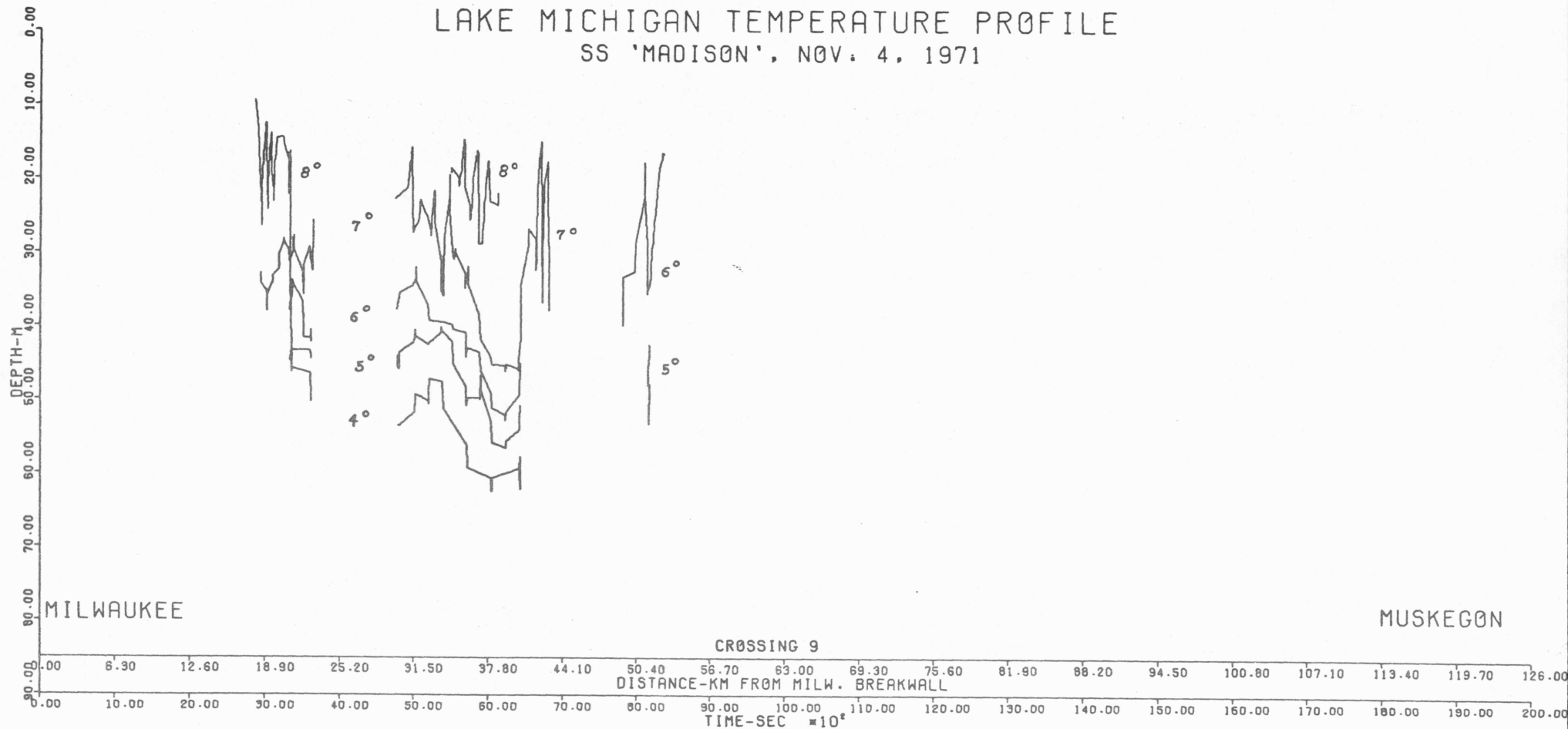


Figure 37. Internal temperature structure of Lake Michigan from cruise 9.

UNDULATING TEMPERATURE/DEPTH PROFILING SYSTEM  
 LAKE MICHIGAN TEMPERATURE PROFILE  
 SS 'MADISON', NOV. 4, 1971

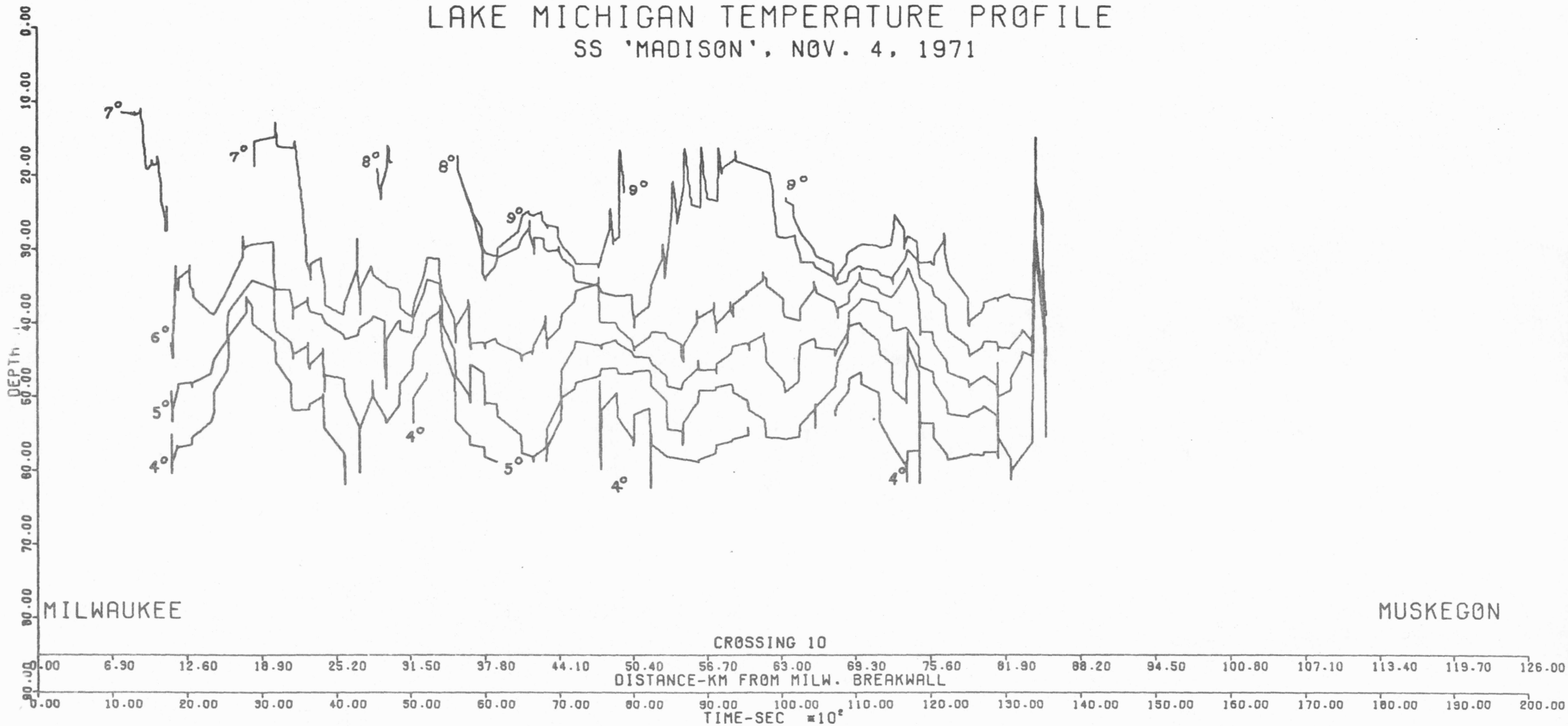


Figure 38. Internal temperature structure of Lake Michigan from cruise 10.

UNDULATING TEMPERATURE/DEPTH PROFILING SYSTEM  
 LAKE MICHIGAN TEMPERATURE PROFILE  
 SS 'MADISON', NOV. 8, 1971

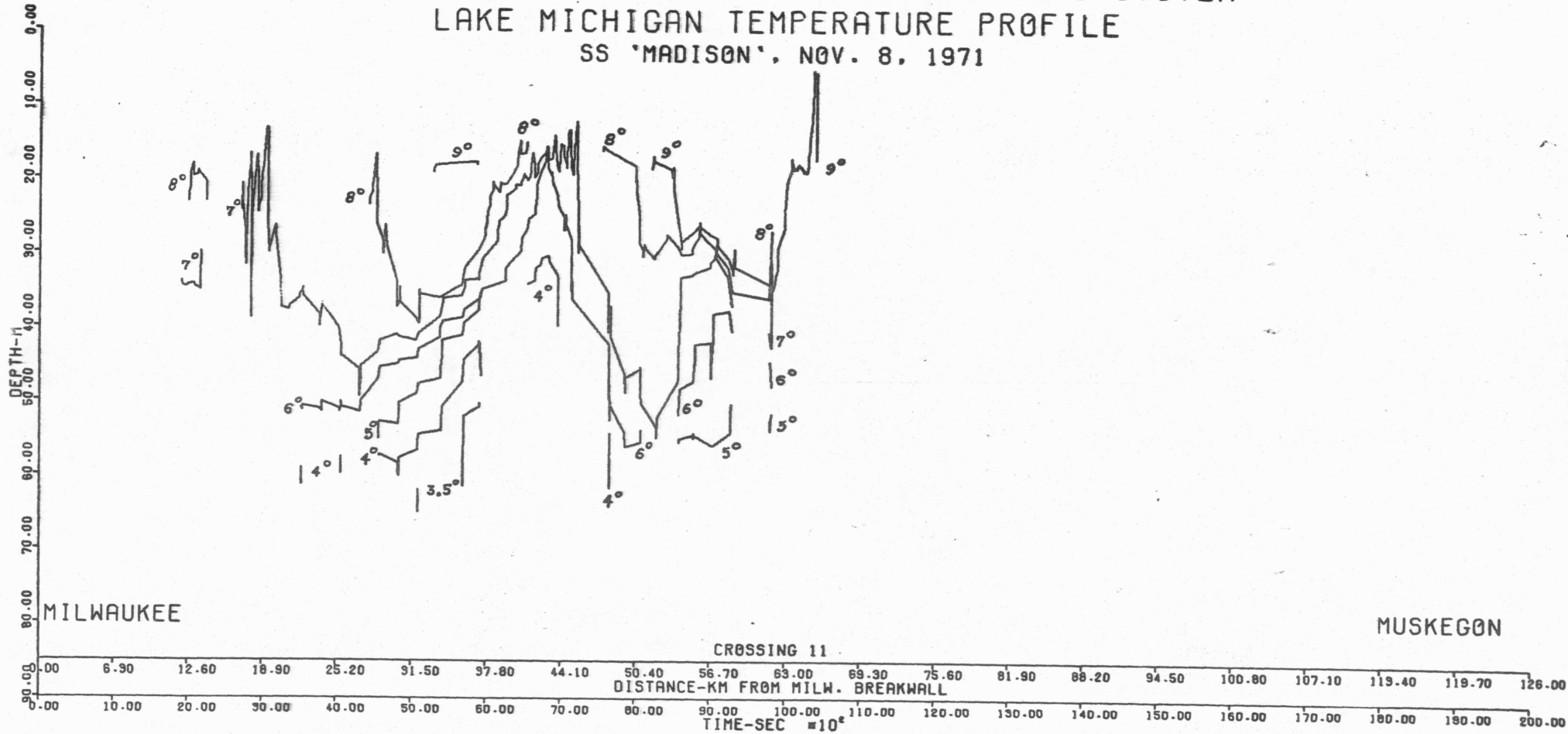


Figure 39. Internal temperature structure of Lake Michigan from cruise 11.

UNDULATING TEMPERATURE/DEPTH PROFILING SYSTEM  
 LAKE MICHIGAN TEMPERATURE PROFILE  
 SS 'MADISON', NOV. 11, 1971

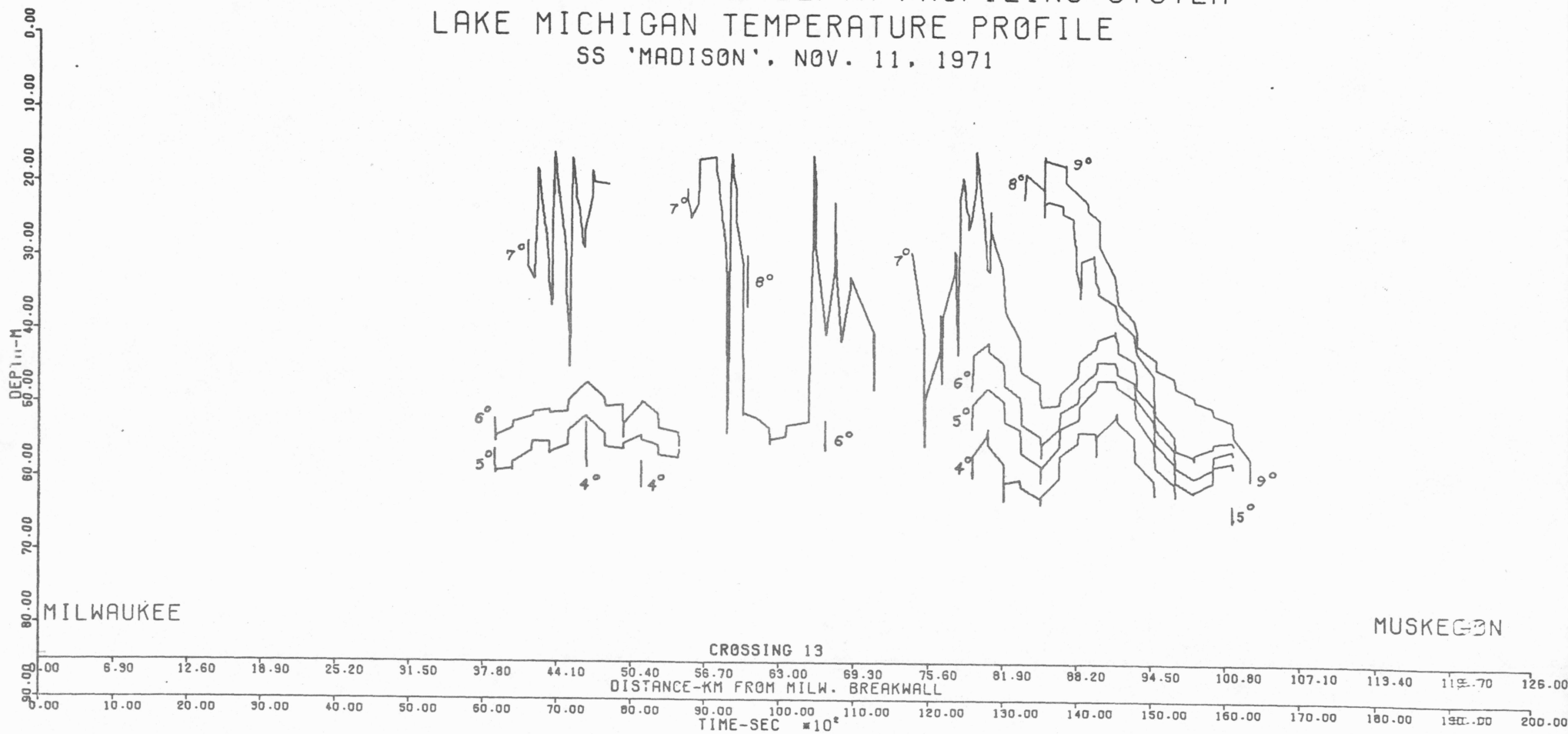


Figure 40. Internal temperature structure of Lake Michigan from cruise 13.

UNDULATING TEMPERATURE/DEPTH PROFILING SYSTEM  
 LAKE MICHIGAN TEMPERATURE PROFILE  
 SS 'MADISON', NOV. 11 - 12, 1971

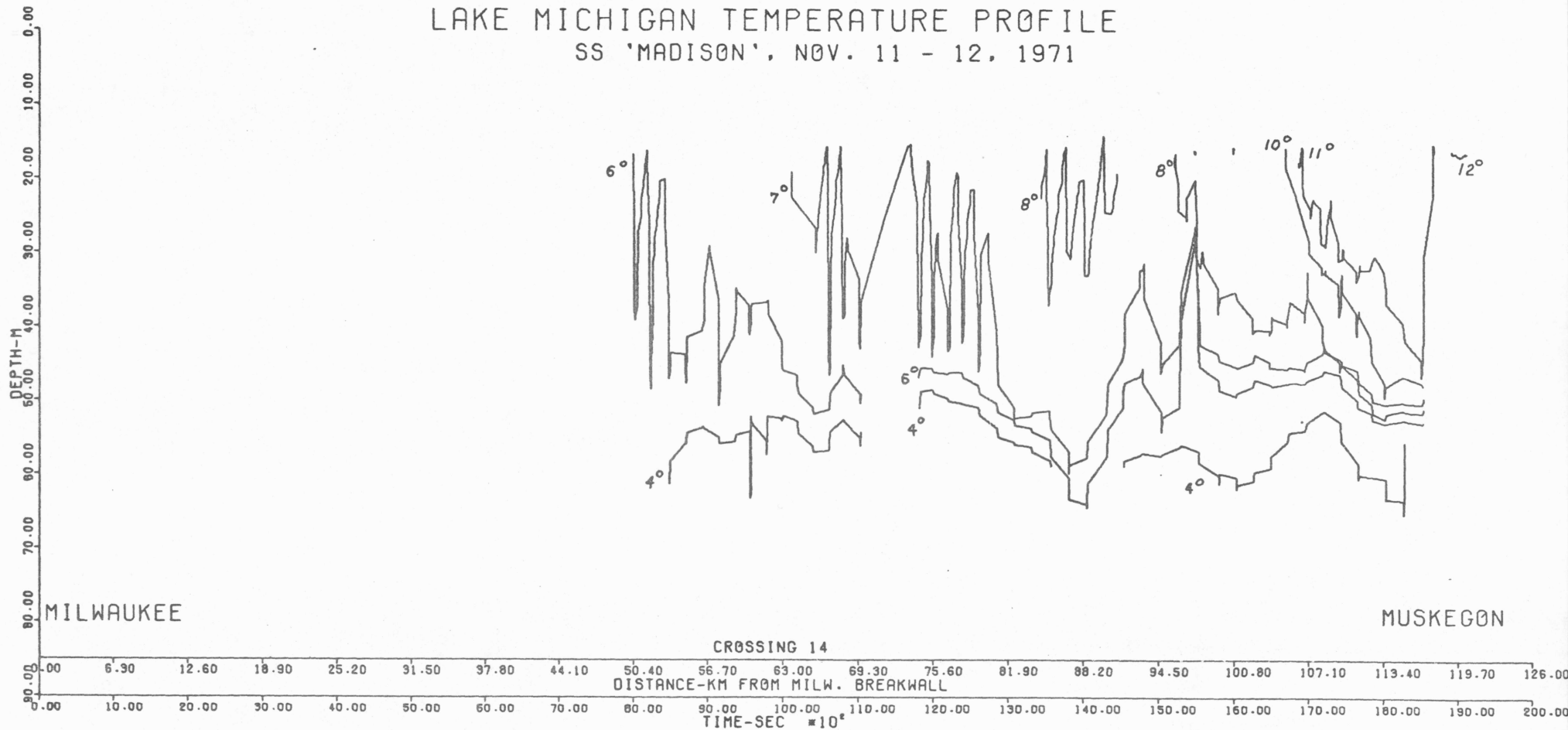


Figure 41. Internal temperature structure of Lake Michigan from cruise 14.

UNDULATING TEMPERATURE/DEPTH PROFILING SYSTEM  
 LAKE MICHIGAN TEMPERATURE PROFILE  
 SS 'MADISON', NOV. 11 - 12, 1971

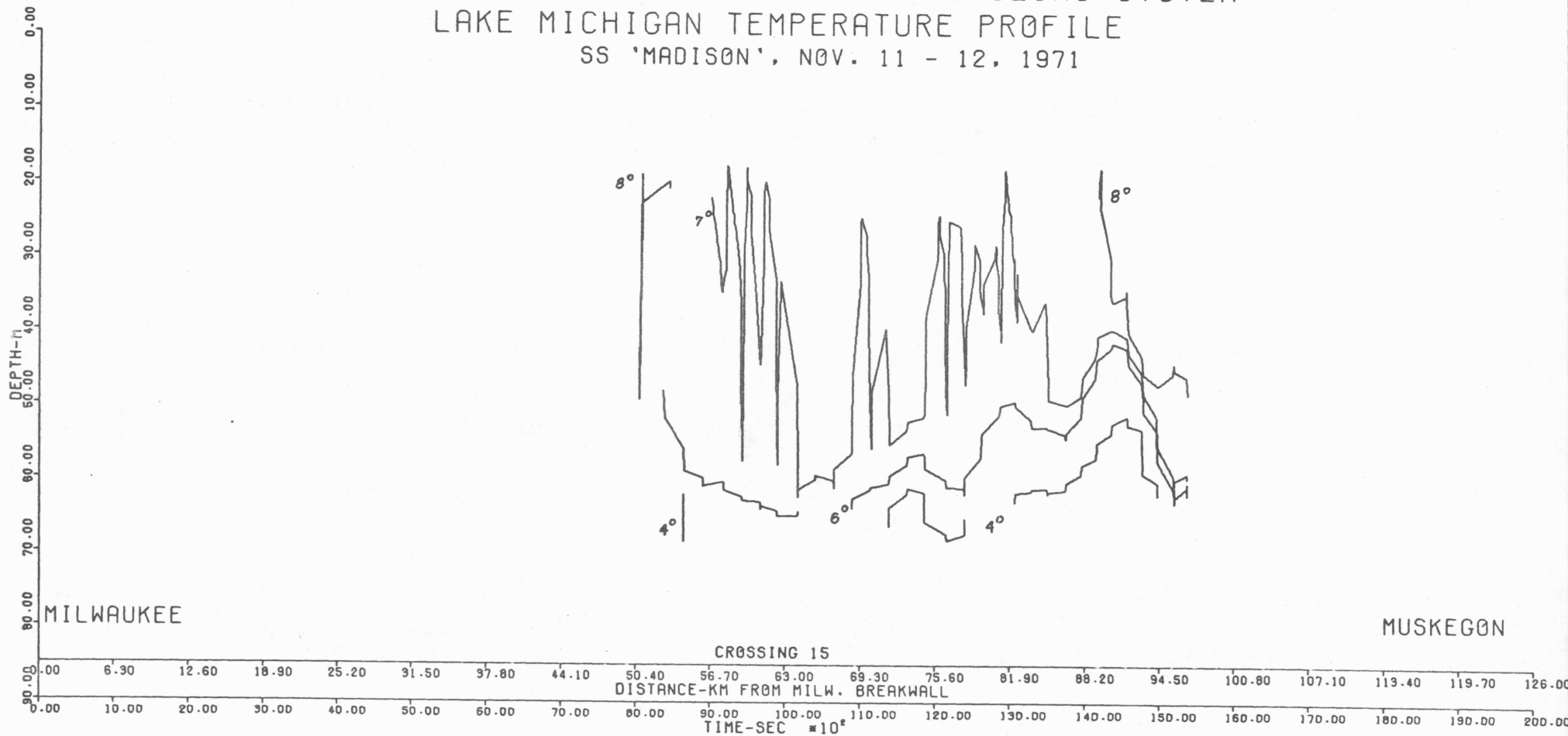


Figure 42. Internal temperature structure of Lake Michigan from cruise 15.

To get an idea of the quality of the data and to see it from a new perspective, other diagrams have been constructed from the data. Figure 26 is a plot of pressure versus time. This is assumed to be a close approximation to the actual path the "fish" follows during undulations. It is an approximation because there is no data kept on the forward motion of the "fish" during an undulation.

An important feature this figure shows is the noise present in the data. This noise seems to reach its largest values when the "fish" is about 20 meters below the surface. The cause of this noise is not known at this time.

A combination of pressure plotted over temperature is valuable because it shows for one thing how the path can be modified with respect to the thermocline. It is evident from Figure 43 that a large portion of this path is below the thermocline. To show this, one has only to draw a straight horizontal line from the temperature axis at  $4^{\circ}\text{C}$  to the temperature plot. Then to find the depth at which this temperature occurred, extend this line vertically from its intersection on the temperature curve until it intersects the depth curve. The depth at this intersection as indicated by the depth scale is about 35 meters. As a result of this analysis Figure 43 shows that a large portion of the particular dive shown took place below four degree water.

The temperature versus time plot is especially informative because on the rise portion of the "fish" path there seems to occur bands of constant

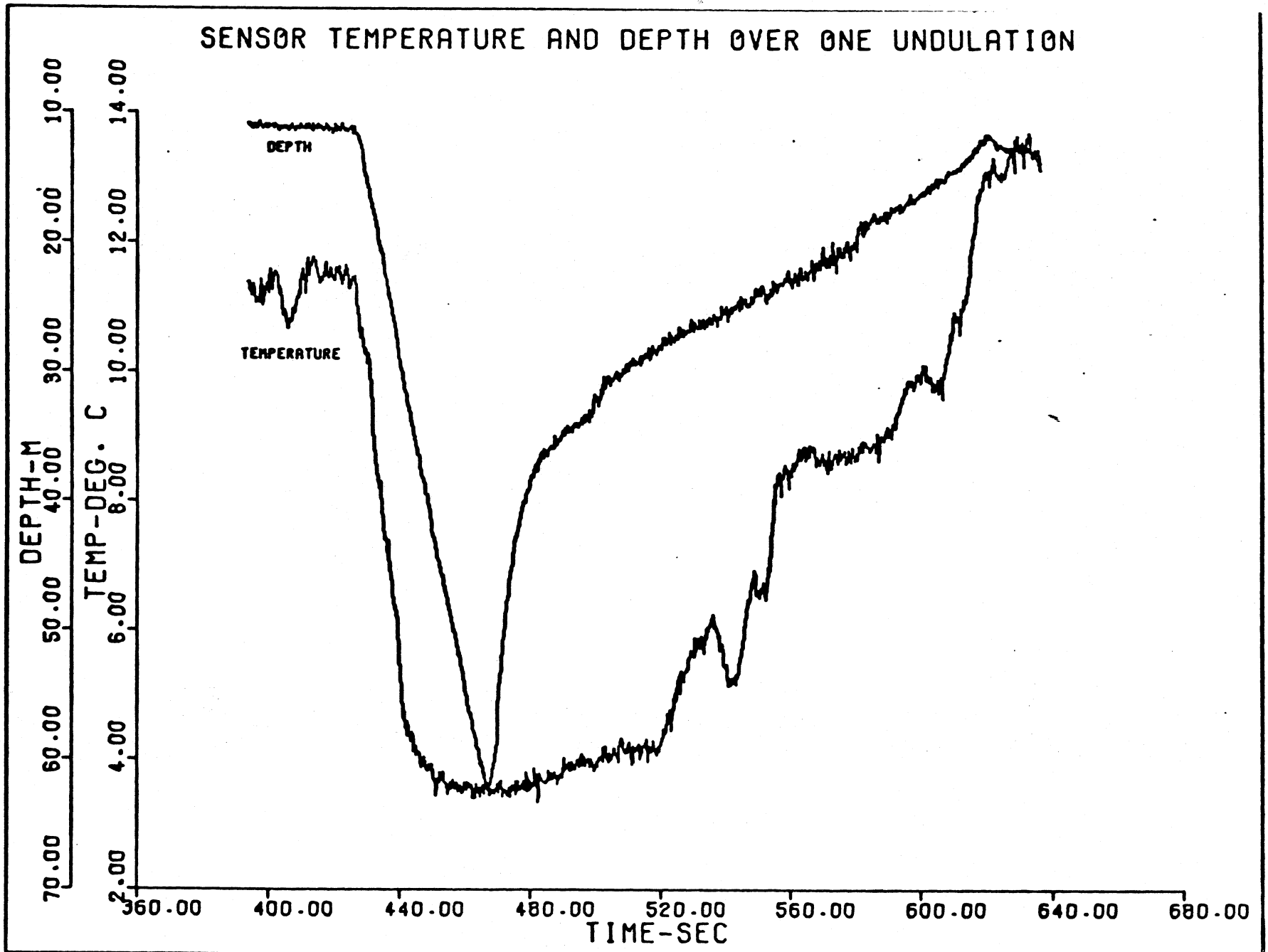


Figure 43. Temperature and depth data from one dive plotted together.

temperature water and temperature inversions. It is difficult to say if these apparent bands exist since little is known about the exact motion of the fish.

An explanation of these apparent temperature bands follows from the fact that the path of the "fish" on a rise is only slightly angled upward. This trajectory gives the sensors an opportunity to cut an oscillating isotherm several times before passing completely above the isotherm. A diagram like Figure 43 drawn from data taken in such a manner would appear to have constant temperature bands and inversions.

### 5.5 Noise

In all of these plots there is some high frequency noise present. The source of this noise is not known at this time but it is not found in the laboratory. This fact would seem to point to sources like mechanical vibration, or rapid up and down motion of the "fish". If perturbations of the path do exist they do not present themselves when the "fish" is near the surface and visible from the towing vessel.

As for vibration, the cable does exhibit some vibration but it is not of large amplitude. This is certainly not the case indicated by other towing systems which have reported that excessive cable vibration limited the maximum towing speed.

## 5.6 Vessel Influence on the Recorded Data

It is important to be aware of the effects that the towing vessel can and does have on the observed data. One possible effect on the data although not easily seen in the data is the rocking motion of the vessel. This motion very certainly has some effect on the rise portion of the "fish" path, but probably no effect during a dive.

Another effect that is difficult to assess is the disturbance of the temperature structure by the ship's wake. Since it is impossible to tell how far the mixing effect of the wake extends below the surface, data taken near the surface and directly behind the towing vessel will be open to question.

A vessel derived effect which may be nullified through additional processing is the distortion in the total isotherm picture caused by the time lag between the beginning of the cruise and the end. Mortimer (1971), has discussed this problem and has detailed a procedure for matching a specific observed internal wave picture to a combination of selected frequency components known to be present in the internal wave structure. This procedure may provide a method for reconstructing the total internal wave as it appeared at some specific time during the cruise.

## REFERENCES

- 1108 Computing Handbook. 1969. Academic Computing Center,  
Univ. Wisconsin--Madison. Thru change M.
- Dauphiner, T. M. 1967. Technical problems of in situ ocean temperature  
and salinity measurements. National Res. Council, Div. Applied  
Phys., pp 19, 8 figs.
- Giles, J. N. 1966. Frequency compensation techniques for an integrated  
operational amplifier. Fairchild Applications Bull., A pp-117/2.
- Mortimer, C. H. 1968. "Internal Waves and Associated Currents Observed  
in Lake Michigan During the Summer of 1963", Spec. Rept. No. 1,  
Center for Great Lakes Studies, Univ. Wisconsin--Milwaukee,  
24pp., 33 figs., 87 app. figs.
- \_\_\_\_\_. 1971. Large-scale oscillatory motions and seasonal temper-  
ature changes in Lake Michigan and Lake Ontario. Univ. Wisconsin--  
Milwaukee, Center for Great Lakes Studies Spec. Rept. No. 12,  
Pt. I, text 111 pp; Pt. II, illustrations, 106 pp. Produced under U.S.  
Army Engineers Contract No. DACW-35-68-C-0072 as a preparatory  
analysis for the International Field Year on the Great Lakes (Inter-  
national Hydrological Decade).
- RCA Linear Integrated Circuits. 1970. Technical Series IC-42, pp 128-144.
- Seidman, A. H. and S. L. Marshall. 1963. Semiconductor Fundamentals.  
New York: John Wiley & Sons, Inc., 169-176.



