International Council for
the Exploration of the Sea

C.M. 1977/C:22
Hydrography Committee

The design and use of a profiling instrument for measuring and recording physical variables in the sea

By

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Summary

The paper describes a measuring system for profiling of the upper few hundred meters of the sea. The system consists of a recording instrument and a readout unit. The recording instrument has sensors for current, direction, temperature, pressure and sound velocity. Each sensor is scanned and recorded appr. 8 times per second. The readout unit has both analogue and computerinterfaced, digital outputs.

Introduction.

In many fields within physical oceanography a fast profiling of the water properties under the observation platform is needed. Such a profiling is best obtained by simultaneous measurements at a fast repetition rate of the variables wanted.

The most wanted variables are usually:

- The horizontal current components
- The current direction
- Temperature
- Density
- Salinity
- Pressure.

However, also a wide range of other parameters like oxygen, light intensity, distribution of plankton, dissolved metals etc. are of importance when one tries to obtain an understanding of the processes that take part in the sea.
Since the advent of CTD-instruments that hang from a cable through which data are also transferred, a substantial part of the profiling work can be done by cable moored CTD's. However, - an instrument that hangs from a cable may not always be practical. First of all it needs a rather large ship with a slip ring equipped winch which is connected to a special deck unit. Secondly not all variables can be measured correctly from an instrument that is tied up to a cable. In particular the ship's own movements will seriously reduce the precision of the current measurements. The use of a slowly, free falling self recording instrument may therefore in many aspects be of a great practical value. For the profiling of shear currents it may be the only practical available method.

Specifications for a profiling instrument.

A profiling oceanographic data collecting instrument must include:

1. A mechanical body with provisions for adjusting the falling rate and which will both carry and protect the components involved.

2. Fast responding sensors for the variables involved fitted to the instrument body.
3. Electronic circuits that amplify the sensor signals and multiplex them into a common A/D-converter.
4. A modulation system that transform the signals from the A/D converter into a suitable recording format.
5. A tape recorder which can record the information at a recording rate that corresponds to the wanted vertical resolution.
6. A power supply consisting of batteries, DC/DC converters and regulators that can be remotely switched on and off to economize with the energy.
7. A readout unit on which the tapes can be replayed and from which both analogue and digital information of the recorded variables can be obtained in the field.
8. A computer and a program software pack that can transform the resulting enormous amount of raw data into a comprehensive form.

A working prototype of such a system has now been built as the result of a cooperation between the Institute of Marine Research and the Christian Michelsen Institute in Bergen. This paper will give a brief description of the instrument and show some examples of results obtained with the new system.

Mechanical design.

Fig. 1 shows the mechanical design of the instrument. The body is made of a 6" Delrine tube which is strong enough to take 600 meters of water pressure. The choice of a plastic material rather than metal was made to save weight. The top and bottom of the instrument are sealed with covers made from aluminium. On the bottom is a protection cage for the sensors. On the upper part of the instrument tube is a flexible holder for uplift buoys. The top cover is fixed to the tube by standard C-clams. The top cover also contains a magnet which is used to start and stop the instrument via a magnetic sensitive "Reed" - switch on the inside.

When used the instrument weight can be adjusted to make the instrument to slide down a hydrographic wire or to sink slowly, only connected to a very thin rope to retrive it. It may also be equipped with a mechanism that drops a load at a preset depth, causing the instrument to float up by itself after the drop. The latter method will frequently cause the loss of the entire instrument and has therefore not yet been adopted.

Sensors.

The present system is equipped with sensors for,

1. Current U-direction
2. Current V-direction,
3. Compass North component
4. Compass East component
5. Pressure
6. Temperature (platinum sensor)
7. Sound velocity
8. Temperature (fast response, thermistor sensor)

For future expansion a total number of 16 sensor inputs are available.

Current measurements.

The current sensors are shown on Fig. 2. This is a two axis ultrasonic current meter based on the travel time difference principle. At a rate of about 60 per second short bursts of 4MHZ ultrasonic waves are transmitted from the two pairs of probes. If the water between the probes move, the ultrasonic travel times in two opposite directions between two probes will become unequal. It can be shown that the time difference between the up and downstream travel time equals.

$$\Delta t = \frac{2.1.v \cos \theta}{c^2}$$

l = distance between probes

v = water velocity

θ = angle between the ultrasonic path direction and current direction.

c = sound velocity.

In the current meter electronics Δ t is transferred to an analogue voltage signal in the range $\pm$ 5V, which corresponds to a current range from 0-$\pm$1,3m/sec. Thic is done for both of the two orthogonal axes simultaneously.

The current meter has a resolution of 1mm/sec and a bandwith of about 10Hz. The ultrasonic current meter which is the most advances sensor in the system is described in detail in ref. 1.

Direction.

Direction is measured continuously by a flux gate type compass. Fig. 3 shows the principle. An easy saturable toroidal, magnetic core is excited with an AC signal.

With no external magnetic field present, the core will saturate symmetrically at a fixed phase angle of the excitation current. When exposed to the horizontal component of the magnetic field, the magnetic flux distribution along the core will become unequal, as the magnetic fluxes add on one side and subtract on the other side.

Two orthogonally wound pick up coils on the core detect a second harmonic component of the excitation signal in proportion to the relative strength of the external magnetic field that enter their winding areas. After a phase sensitive demodulation the electronics present two DC currents that are proportional to the North and East component of the earth magnetic field. The two currents are finally fed back to their respective pick up windings to make the cores always operate at the same working point. The magnitude of the fedback current is fed to the data multiplexer via resistors to obtain analogue voltage signals.

The compass just described presents continuous signals with resolution of appr. 1/10 degree. However, to obtain that kind of precision, the toroid must hang perfectly horizontal which may be difficult to control. In the instrument the core hangs from an universal joint in a compass house filled with siliuone oil. Fig. 4 shows a calibration curve as recorded on an x-y recorder. The angle of rotation is computed by taking the arc tangent of the North/East amplitude ratio. Due to unsymmetrical windings the curve is not a perfect circle. Estimated practical compass resolution with the present version is $3\text{-}4^{o}$.

Temperature.

The temperature is measured by two sensors. The first sensor is a platinum resistor which is encapsulated in a slender prong. The platplatinum sensor has been selected for its excellent stability and good linearity. However, due to the encapsulation the time constant is about 0,6 second. When falling through a large temperature gradient this is too slow to reveal the true structure.

To compensate for the slow platinum response, an unprotected thermistor bead is mounted on the tip of another prong. The thermistor has a time constant of less than 1/10 second, but it has a nonlinear response, and will also be sensitive to the increasing pressure as the instrument sinks. To obtain the fastest possible temperature response, the temperature therefore may later be calculated from a combination of the platinum sensor signal and the time derivative of the thermistor signal. Both sensors are used in a Wheatstone's bridge configuration and cover a range from ÷ 2 - + 18°C with a resolution of 1/100°C.

Pressure.

For pressure measurements use is made of a standard strain gage type pressure sensor with a resolution of about 10 cm of water over the actual pressure range 0 - 500 meter. Any zero point ofset is later automatically adjusted by the computer as the moment when the instrument penetrates the surface - which corresponds to zero depth - is readily detected by other sensors.

Sound velocity.

The sound velocity is extracted from the current sensor by measuring the acoustic travel time across the probe gap and divide this time by the distance between the probes. As the actual range of c is usually between 1450 and 1550 m/sec. this particular range has been expanded to make possible a sound velocity resolution of about 2, 5 cm/sec with the selected 12 bits digital system resolution.

Multiplexing and A/D - conversion.

Fig. 5 shows the organisation of the data acquisitionsystem.

The channels 1 - 8 of analogue information are connected to a 16 channel multiplexer followed by a 12 bit A/D converter.

The channels are multiplexed in sequence. The A/D converter converts each channel into a 12 bit word which is clocked into a chain of shift registers during the appr. 350 micro-seconds of conversion time. The shift registers are then clocked out at a rate of 1000 bits per second.

As soon as 12 bits have been clocked out of the register, the multiplexer is addressed to the next variable and a new convert command is given. This takes place between two successive clock pulses.

Thus a continuous and uninterupted stream of information flows out of the shift register at a rate of 1000 bits per second. To identify the individual measurements, a 24 bit syncronisation code is added each time the multiplexer has completed a scan and is about to jump back to channel 1 again.

The number of scans that can be carried out per second become a function of the number of sensors connected. For an 8 channel system the repetition rate

$$f_r = \frac{1000}{8x12+24} \approx 8 \text{ Hz} \qquad (2)$$

With a typical falling rate of 20 cm/sec. the vertical resolution will thus be 3 - 4 cm.

Modulation.

The modulation is needed to transfer the digital information on the skift registers to a tape recorder. To keep costs down, a miniature, audio cassette recorder for C-60 format tapes has been selected. This tape recorder has a typical bandwith from 30 Hz - 8 kHz.

In the modulator a logical 0 is converted to one cycle of 1kHz and a logical 1 is converted to two cycles of 2 kHz. The change between 1 and 0 always occur when the signals cross the zero line- thus avoiding discontinuites. The signal on the tape now contains information on both data and clock on one track.

Demodulation.

Fig. 6 shows a block diagram of the demodulator. In the demodulator the data and clock information are first separated. The data and clock information are then put into a serial shift register. Each time the syncronisation code is detected, the demodulator logics know that the next 12 bits belong to channel 1. The information on these 12 bits are copied in a latch, fed to a D/A converter and sampled by a sample and hold circuit. The next 12 bits must belong to channel 2. As soon as these have been counted up, they are copied in the latch, converted into anolog form and sampled by a second sample and hold unit etc. In this way the information becomes available both as a digital 12 bit word suitable for loading into a computer and as separate analogue signals suitable for direct connection to an ink recorder, or simply a voltmeter. In hardware the demodulator consists of a standard audio cassette recorder connected to the described electronic unit. It can be used in the field to check the data as soon as the cassette has been taken out of the instrument. It is also readily interfaced to any standard TTL and C-Mos compatible computer.

Computer programming.

One C-60 cassette side will contain appr. 1,8 million bits of information. To present this information in a practical and understandable way a standard computer programme written in Fortran has been developed. The program in particular computes the current vector, its direction and also the North and East component of the current as a function of depth. The other variables are transformed into suitable engineering units and printed. For a comprehensive, compressed information the computer finally may plot the calculated information as curves. During developement a PDP- 11 prosessor has been used.

Results.

The complete instrument has been tested and refined during and after several minor cruises over a span of 1 year. The practical operation has proved to be very easy.

The instrument weighs less than 10 kg and can thus if necessary be operated by one man. Starting and stopping of the instrument is done by removing and inserting the magnet from the instrument top.

A battery pack made from a stack of lithium cells has enough power to run both the electronics and the tape recorder for more than 24 hours which corresponds to appr. 50 full datacassettes containing 3, 6 million bits each.

Fig. 7 shows ways of operating the instrument from a ship.

Fig. 8 shows result from a drop in a Norwegian fjord during June 1976. As can be seen, this fjord had a marked temperature and density gradient in the upper layer. Fig. 9 shows the significance of the time constants in temperature sensors.

Conclusion.

The profiling instrument described consists of a data administration system and a range of sensors. The development has til now consentrated on the data administration. Our tests show that the system works very well with no loss of information due to the process of modulation and demodulation beyond the 12 bit resolution limit. The selected system is also very economical as use can be made of commercially available entertainment recorders. The work will now continue by improving and increasing the number of sensors. Presently the addition of a sensor for conductivity and for oxygen is planned.

Also field comparisons between the falling instrument and stationary, moored instruments will be made.

The instrument will finally be used as a routine data collecting instrument by the Institute of Marine Research.

Ref. 1:

GYTRE T. The use of a high sensitivity ultrasonic current meter in an oceanographic data collecting system. The Radio and Electronic Engineer Dec. 1976.

Fig. 1. Design of the instrument anatomy.

Fig. 2. The ultrasonic current sensor. From encapsulated piezoelectric crystals in the probe tips short bursts of ultrasonic waves are simultaneously emitted. The current is computed by measuring the travel time differences between travel times in opposite directions.

Fig. 3. Principle for flux-gate compass.

Fig. 4. Calibration curve for flux-gate compass made by feeding the north and east components of the compass to the x and y-inputs of an x-y -recorder. 360° rotation of the compass has been done at 0, 5 and 10° tilting angles to estimate the ability of the universal joint to keep the compass core horizontal.

Fig. 5. Organisation of the data acquisition system. The analogue inputs are scanned in sequence and the information is converted to a continuous stream of digital data which are modulated to 1 and 2 kHz oscillations suitable for recording on a standard audio tape recorder.

Fig. 6. Block diagram of the demodulator.

1 and 2 kHz AC - signals are converted to digital data and clock signals and fed into a shift register. The individual channels are identified and converted to analogue and digital signals ready for analogue recording and for digital computer processing.

Fig. 7. Principal ways of operating the instrument from the ship.

A. Hanging from a hydrographic wire to be used like a CTD without cable.

B. Sliding along the hydrowire.

C. Sliding along a moored wire independent of the ship's movements .

D. Freely sinking instrument with automatic load release mechanism.

Fig. 8. Recordings of corresponding values of current, direction, depth, sound velocity and temperature in a Norwegian fjord in June 1977.

Fig. 9. The effect of time constant in temperature sensors. Curve A and B are simultaneously recorded temperature profiles with temperature and platinum sensors respectively.

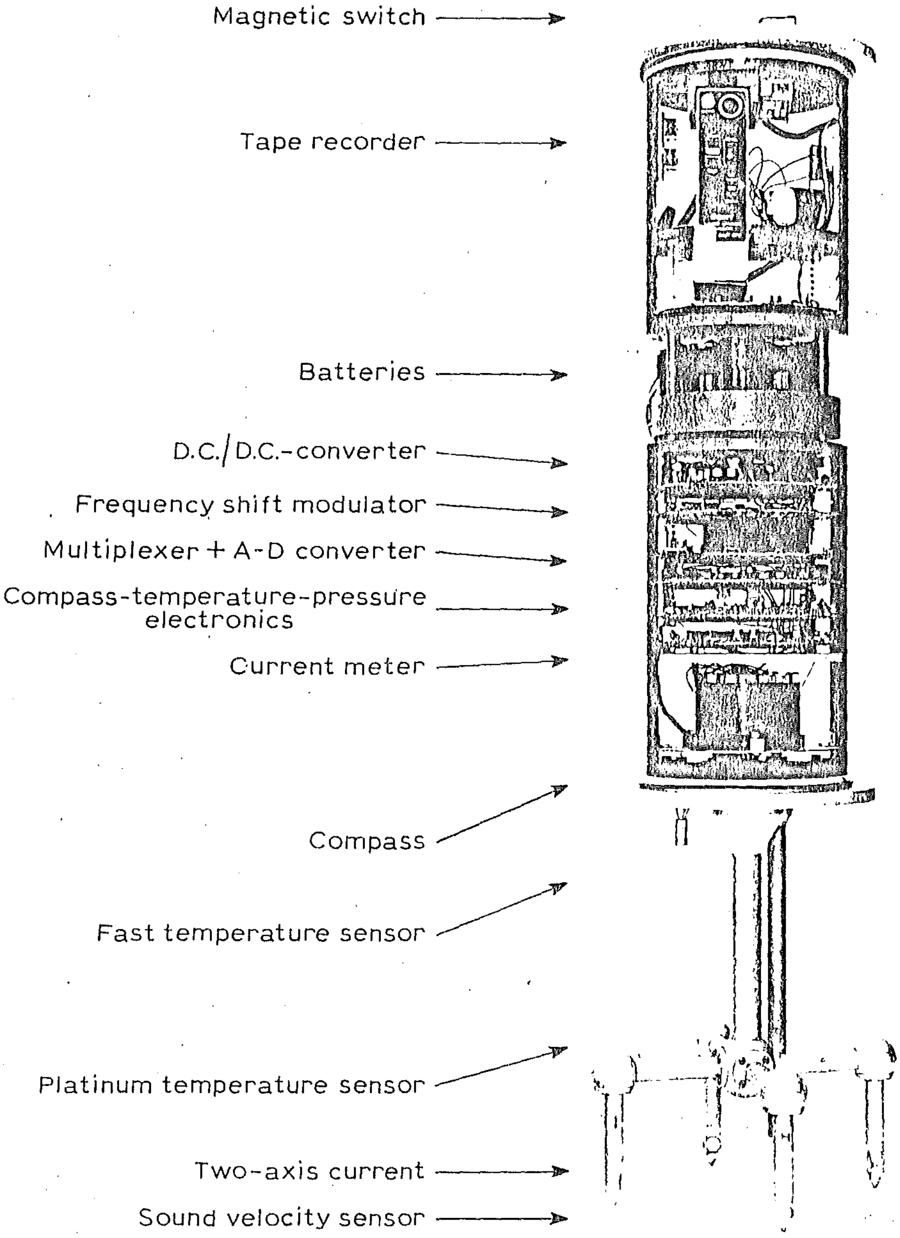

Magnetic switch
Tape recorder
Batteries
D.C./D.C.-converter
Frequency shift modulator
Multiplexer + A-D converter
Compass-temperature-pressure electronics
Current meter
Compass
Fast temperature sensor
Platinum temperature sensor
Two-axis current
Sound velocity sensor

Fig. 1.

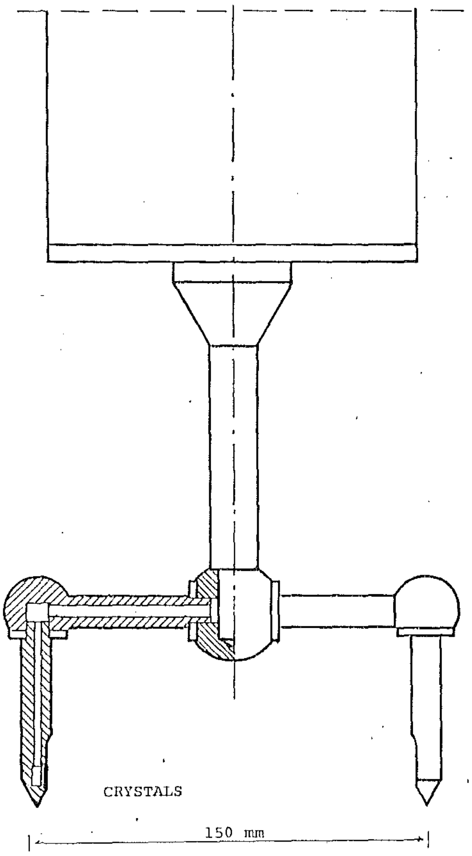


Fig. 2.

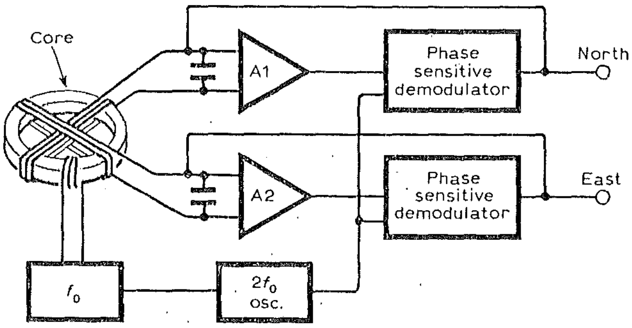


Fig. 3.

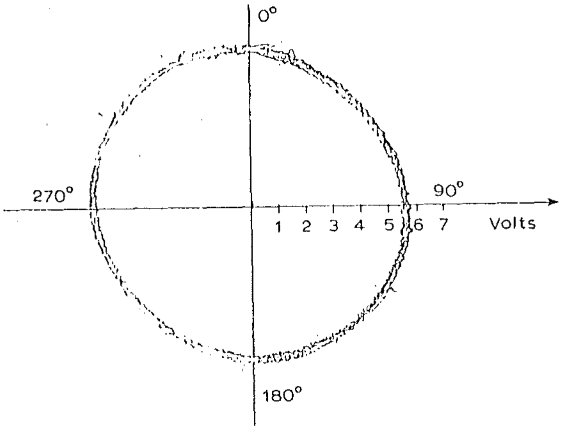
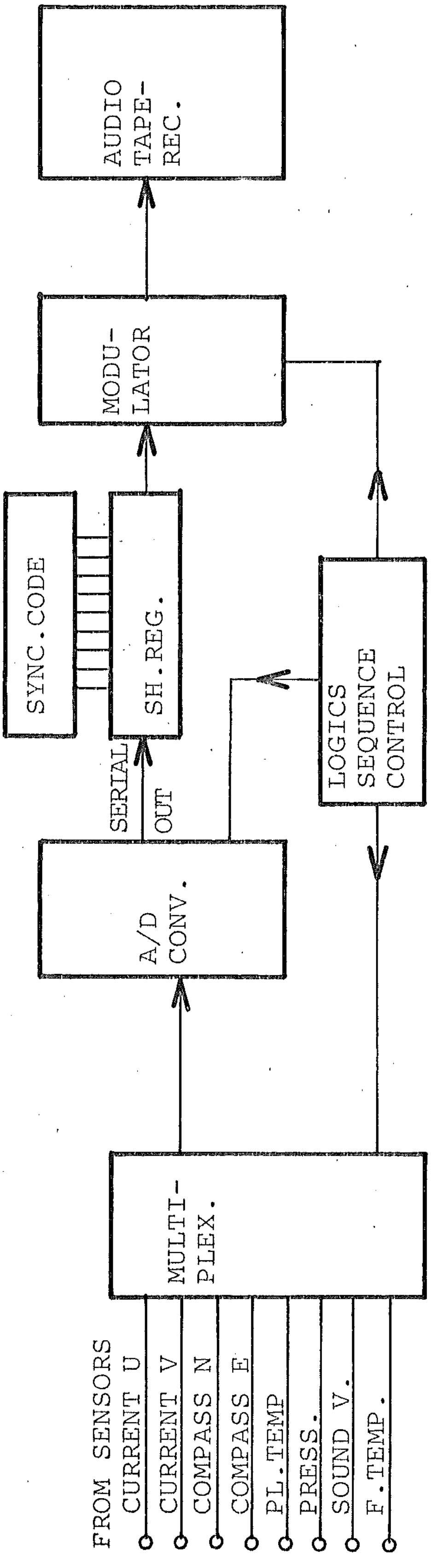


Fig. 4.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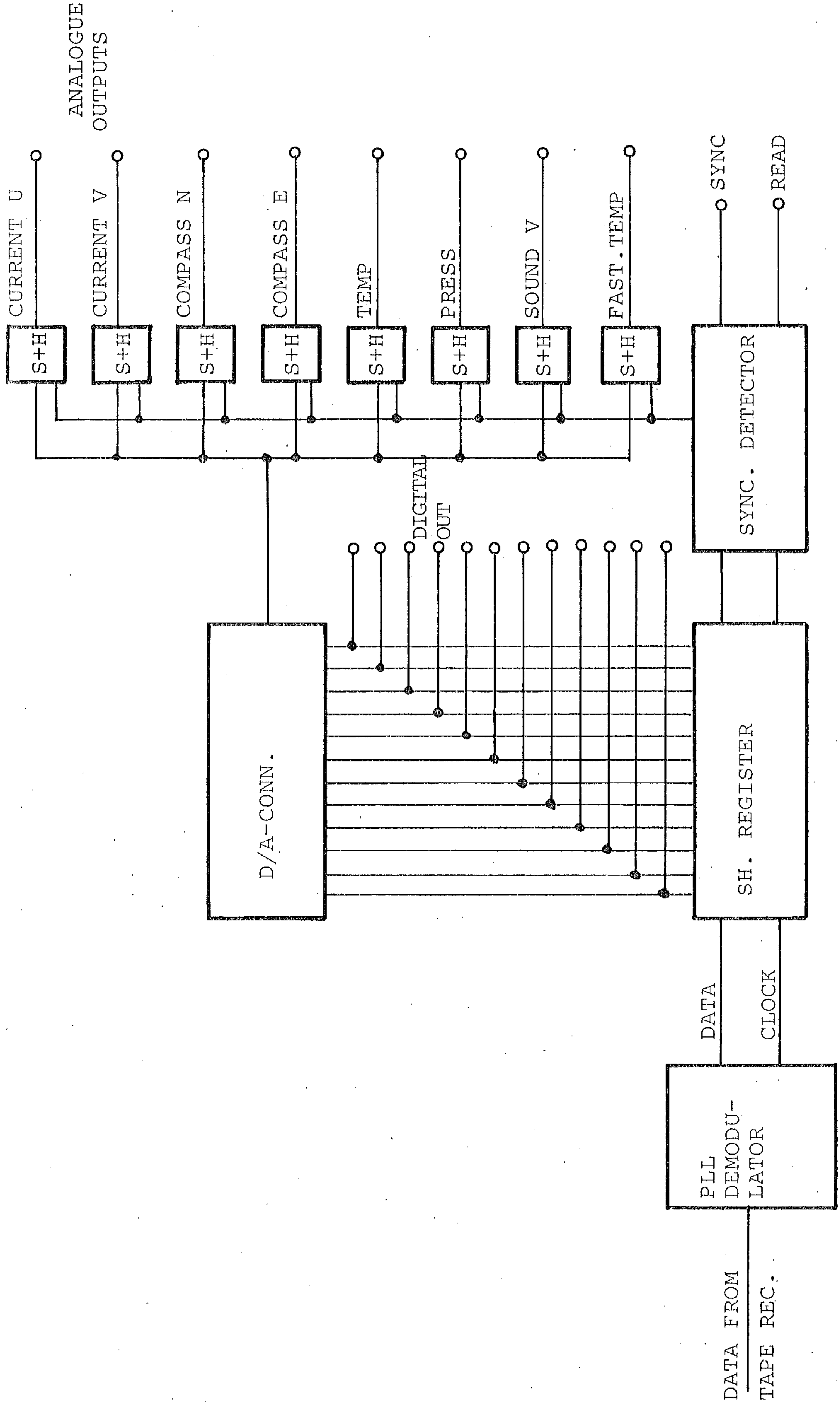
SYNC.CODE
LOGICS SEQUENCE CONTROL
MODU-LATOR
AUDIO TAPE-REC.

Fig. 5.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CLOCK
PLL DEMODU-LATOR
DATA FROM TAPE REC.

Fig. 6.

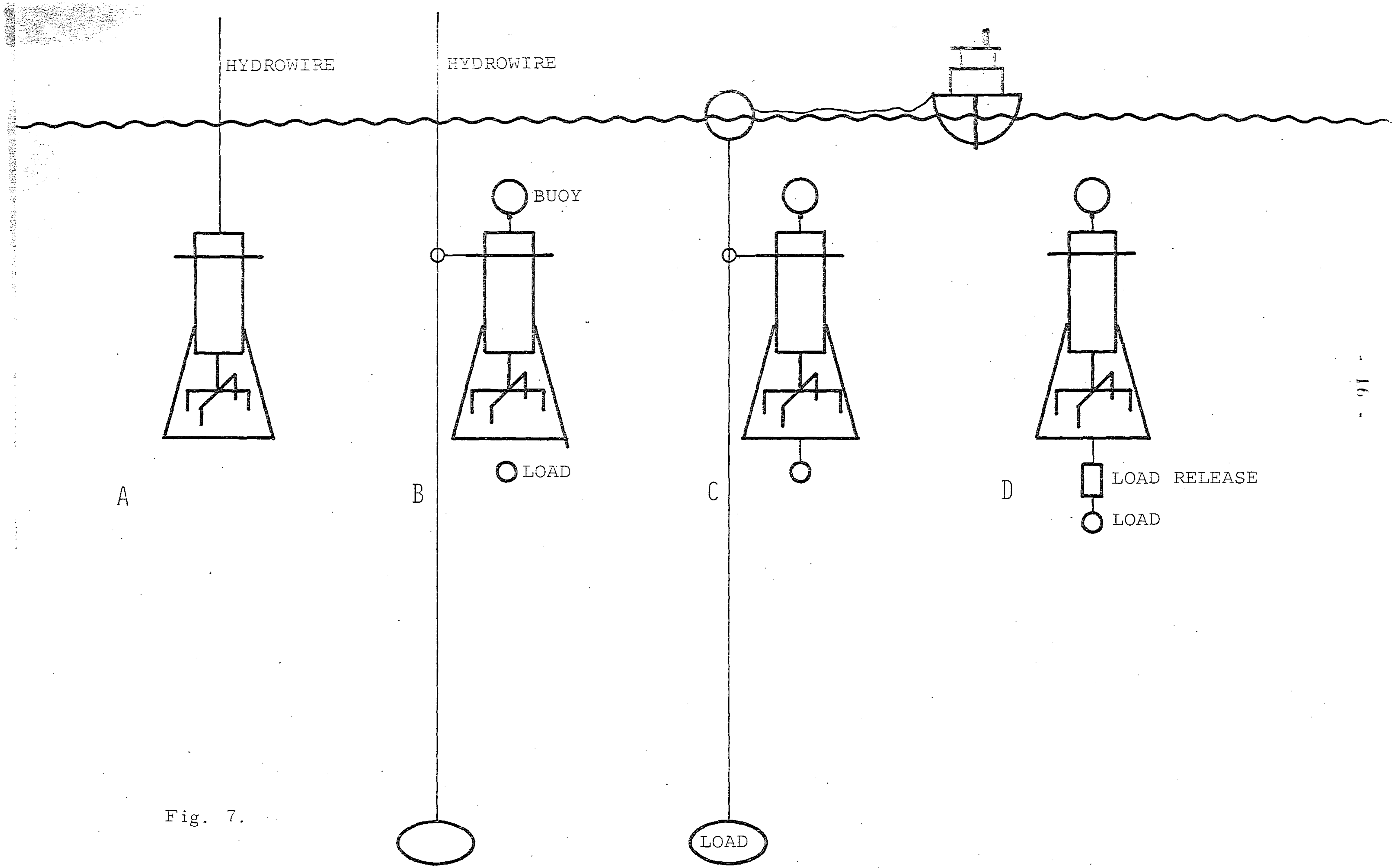

Fig. 7.

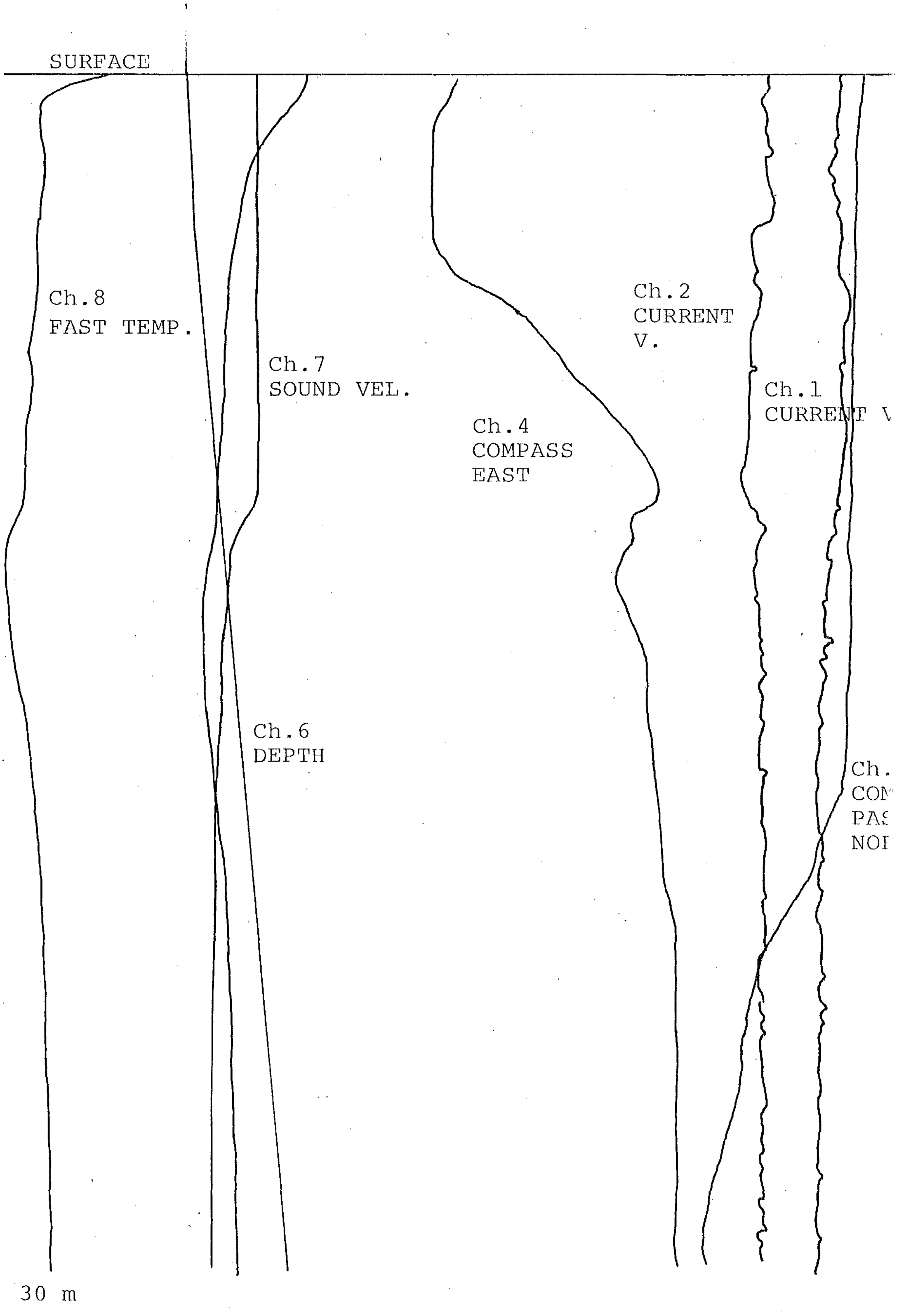
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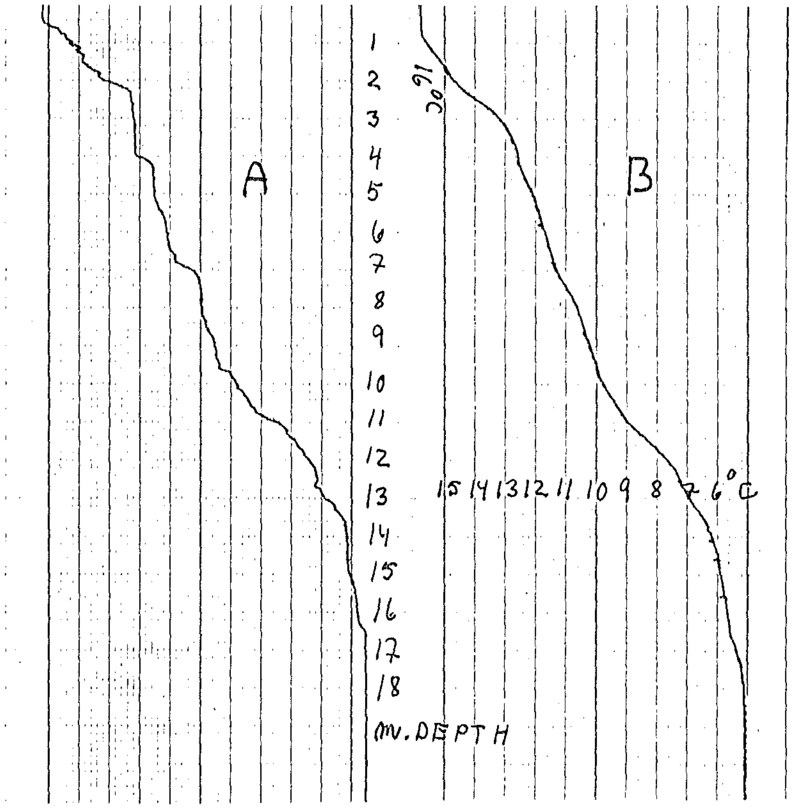
Fig. 8.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16°C

Fig. 9.