THE ENGINEERING FOR PRODUCTION OF A RECORDING CURRENT METER

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SUMMARY

This paper describes a recording current meter which makes full use of a novel electro-mechanical analogue to digital converter to achieve the transfer of information onto standard domestic magnetic tape.

To measure the current flow the original meter was designed with a Savonius type rotor but the subsequent user requirement was for a propeller type rotor. This paper describes the further development and engineering carried out to adapt the meter to use a sensitive propeller rotor.

The author deals in greater detail with the subsequent engineering work on the instrument as he has been more directly connected with this aspect of the work.

Reference is also made to the tape translation unit designed to convert the recorded information from the magnetic to punched paper tape for final computer infeed.

1. — INTRODUCTION

The Recording Current Meter which is referred to in this paper was originally designed and developed at the Christian Michelsen Institute in Bergen, Norway. The work was carried out under the auspices of the N.A.T.O. Sub-Committee for Oceanographic Research and the author wishes to acknowledge the cooperation and help he has received from the Institute in Bergen. In particular to Dr. Odd DALH and Mr. I. AANDERAA who have provided the author with all the information on the prototype models.

The meter in the form designed at Bergen is explained showing the method by which the information is accepted and recorded onto the magnetic tape. The main feature of the instrument is the novel electro-mechanical analogue to digital converter which also drives the magnetic tape transport system and actuates the parameter selecting switch.

Subsequent to the completion of the design and development in Bergen the basic instrument was then further engineered by the Marine Systems Division of the Plessey Company Limited to make use of a propeller type rotor to measure current flow in place of the Savonius type rotor fitted to all previous prototypes.

Work was also carried out to make the instrument more suitable for quantity production and continued evaluation trials have resulted in the provision of a completely different type of mooring and suspension system.

The paper also considers the method used for processing the recorded information to provide a final form suitable for computer infeed which can at the same time be read by eye with the aid of a simple slide.

2. — BASIC DESIGN FEATURES

The Recording Current Meter is primarily designed to measure and record data on the speed and direction of water flow. To suit practical use of the meter all the instrumentation and power supplies are contained in a cylindrical pressure sealed tube which is 5 inches in diameter and 15 inches long. This is suspended in the water and has attached to it small directional fins and a rotor which drives through a magnetic coupling to the internal instrumentation so that the basic cylinder is completely sealed and self contained. Standard domestic magnetic tape is used for recording and storing the information from the speed and direction sensors. The information is related to variations in resistance ratios and is converted to ten bit binary numbers and recorded onto magnetic tape in the form of long and short D.C. pulses. The binary number code is obtained from an electro-mechanical analogue to digital converter which is generally referred to as the encoder.

The current speed is obtained from a change in a resistance ratio over a period of time of a potentiometer, driven by a rotor via a magnetic coupling and a reduction gear, the rotor being turned by the water current.

Current direction is obtained from a magnetic compass which is made to include a potentiometer resistance element and at the start of a direction measurement a floating contact clamps to the potentiometer to provide the required resistance ratio which is proportional to angle.

Simultaneously with the recording of the data on tape, the data is fed to a transducer and propagated through the water as an acoustic signal which can be picked up on a suitable hydrophone receiver at ranges up to 500 metres.

A further feature of the design is the inclusion of a fixed resistance ratio within the instrument the repeated measurement of which is used to identify the individual instrument. This is referred to as the Reference.

The whole system is powered by batteries and controlled by a separate battery driven clock mechanism which initiates the measuring cycle at preset time intervals.

3. — PRINCIPLE OF OPERATION

The actual measurement of each quantity is carried out by comparing the resistance ratio representing the quantity with another resistance ratio set up by the binary encoder. The two resistance ratios are connected to form a Wheatstone bridge with the output of an oscillating amplifier providing the bridge supply voltage, while the input of the amplifier is the null detector.

If the resistance ratio formed by the binary encoder is larger than that representing the variable under measurement, then positive feedback is applied to the amplifier and it will oscillate. If the converse is true then the feedback applied to the amplifier is negative and the amplifier will not oscillate.

The binary encoder is a motor driven device which consists of a series of sequentially operated switches combined with coding contacts. The coding contacts can be used to show whether the corresponding switches are closed or open. The mechanical construction is shown in figure 1 which illustrates the gear box and solenoid section, the main switching and coding contact ring, and the cap assembly which rotates and carries out the various functions.

Referring to this figure 1, the identification numbers of the switches and coding contacts are the same as those used in the circuit schematic of figure 2 so that the mechanical operation can be associated with the circuit function.

In operation the motor drives via the gear box two shafts A and B. Shaft A to the rear is used as the capstan drive for the magnetic tape transport system. Shaft B is concentric to the main switching ring C, passes through the solenoid D in the centre of this ring, and attaches to and drives the cap E, which goes over the ring and down the sides. A small angled block F is fixed on the inside of this cap.

The pins SWA/1 to SWA/10 are the switches in the ring and as the cap rotates these pins are sequentially pushed in by the angled block F. Diametrically opposite the block F and fixed to the cap lid a wiping contact G shorts the coding contacts SWA/11 and SWA/12 each time a switch pin is pushed in.

Joining block F and contact G across the cap is the solenoid arm H with its angled end by the block F and the rear of the Arm 1 also with an angled end by contact G. The cap rotates, and when block F pushes a pin in, the circuit makes a decision and according to the decision the solenoid arm is either pulled down or left up. If pulled down the pin is reset, and according to whether this switch pin position is in or out, the coding contacts SWA/11 or 12 produce the appropriate code which is a short or long pulse. The pulse length depends on whether the pulse is produced by SWA/11 or SWA/12 which are short or long contacts.

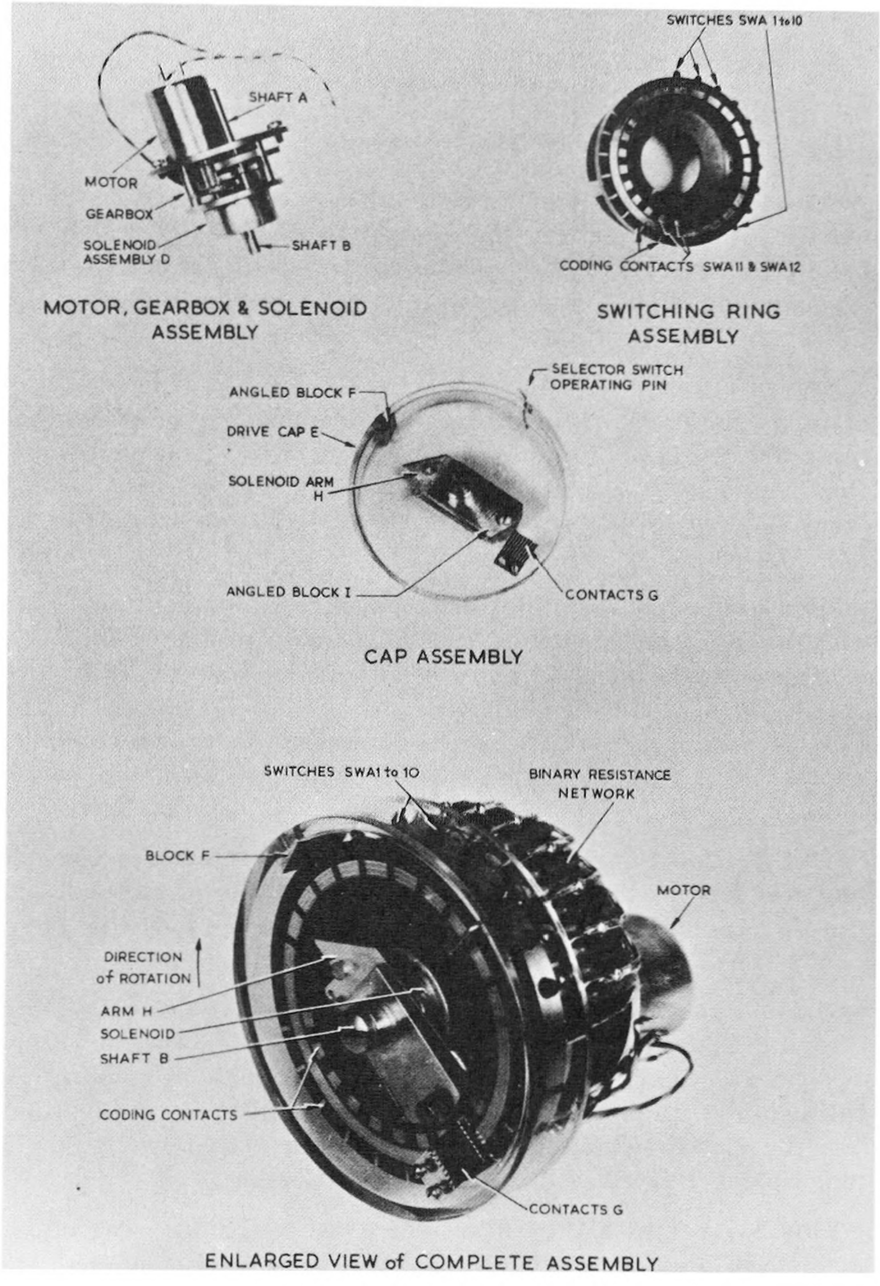

FIG. 1. — Encoder unit.

One half revolution of the cap completes ten such operations and decision functions. During the remaining half the angled Arm 1 by contact G makes sure all pins are reset irrespective of their position, and then finally a peg in the cap hits an external selector switch which puts incircuit the next quantity to be measured, and the operating sequence is repeated.

Thus one revolution of this encoder completes a trial and decision balance on a Wheatstone bridge, makes suitable contacts to provide a code on the decisions made, resets the whole system, drives the magnetic tape transport and finally selects the next quantity to be measured.

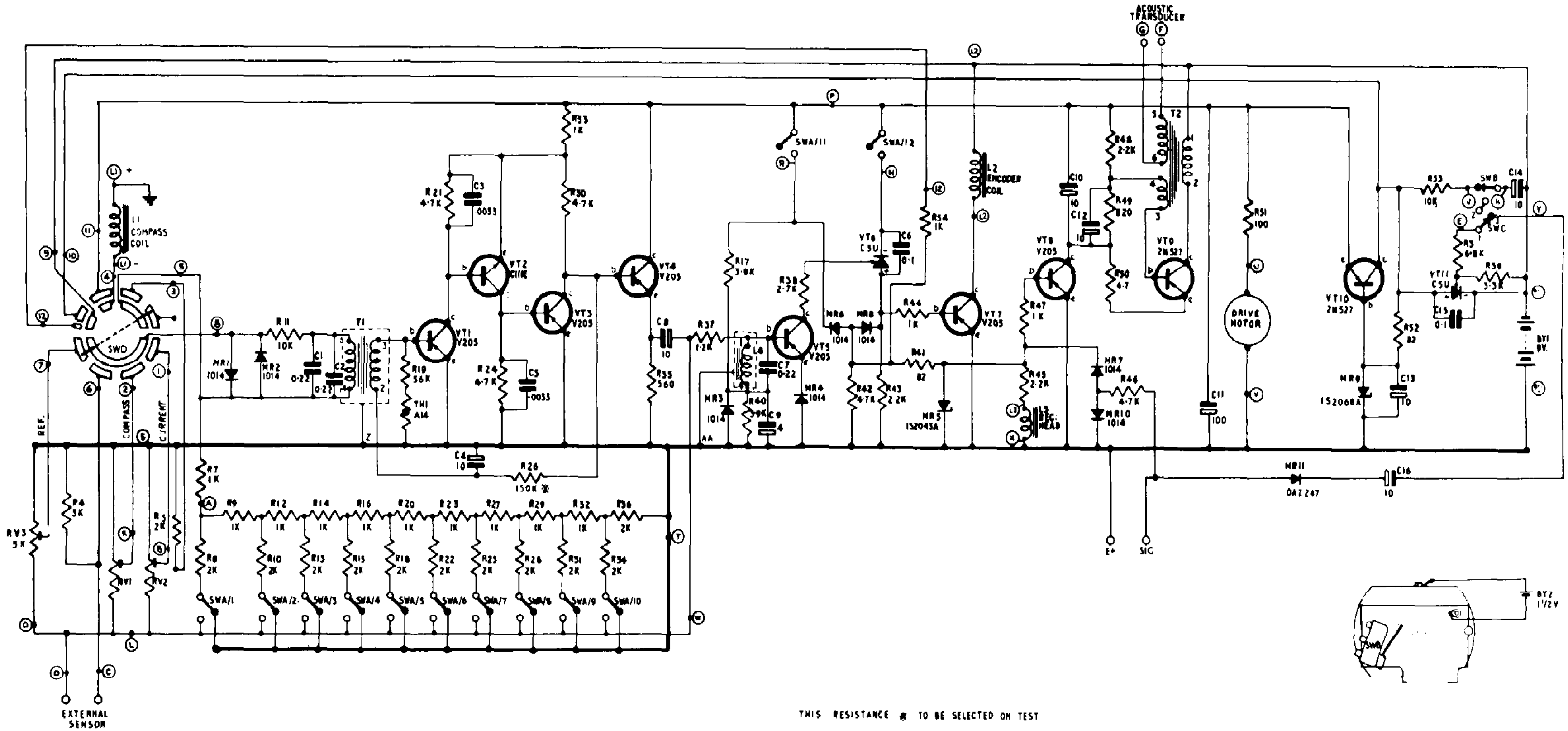

Fig. 2. — Recording current meter circuit diagram.

3.1. **Measuring Sequence** (see figure 2)

Switches SWA/1 and SWA/10 are used to set up a comparative resistance ratio and SWA/11 and SWA/12 operate each time one of the switches SWA/1 to SWA/10 operates and they supply battery power to their respective circuits, for a period of approximately 50 ms and 150 ms respectively.

By a suitable combination of switches SWA/1 to SWA/10 it is possible to connect a measuring ratio to the bridge having any value between zero and 1023/1024 in steps of 1/1024.

Initially all the switches are in the positions shown in the circuit diagram (figure 2). Since maximum negative feedback is applied to the amplifier it does not oscillate when the drive motor is energised, the encoder head rotates and switches SWA/1, SWA/11, SWA/12 are made simultaneously. If the resistance ratio put into the bridge circuit by SWA/1 is too large, positive feedback is applied to the amplifier and it oscillates and SWA/1 is returned to its original position. If the amplifier does not oscillate the resistance ratio is left in circuit. Operation of all the remaining switches is similar and sampling continues until all the resistance ratios have been either accepted or rejected and the bridge is completely balanced.

As described the above sequence of events takes approximately half a revolution of the encoder head and the other half revolution is used to reset the switches SWA/1 to SWA/10 to their original position.

When one of the binary encoder resistance ratios is sampled, switches SWA/11 and SWA/12 are made. If the amplifier does not oscillate, a 50 ms pulse of current is supplied to the recording head via SWA/11, MR6, R41, MR5 and R45. If the amplifier does oscillate, the A.C. signal is fed into VT5 which conducts and fires the SCR, VT6. A 150 ms pulse of current is therefore applied to the recording head via SWA/12, VT6, MR8, R41, MR5 and R45. Hence if the resistance ratio supplied by the binary encoder is accepted a short pulse is recorded and if the ratio is rejected a long pulse is recorded.

When the SCR, VT6 is fired VT7 conducts and energises the encoder coil L2, which rejects the resistance ratio in the encoder. To stop noise and spurious signals firing the SCR, VT6 incorrectly the Plessey production models are fitted with a narrow pass filter to permit only the one specific oscillator frequency to reach the base of VT5.

When a 50 ms or 150 ms pulse is applied to the recording head VT8 conducts for the same time period and causes the telemetering oscillator VT9 and T2 to be switched on, and the transducer emits the sound pulse.

3.2. **Measurement Programme**

A small battery driven clock mechanism is fitted to the instrument which has a cam fitted to the output shaft where the minute hand would normally be attached. This cam operates the microswitch SWB at intervals which depend upon the construction of the cam. Time selection intervals in steps of 5 minutes are made available by the use of various cams.

Before the commencement of the measurement cycle capacitor C14 is charged to the battery voltage. When SWB operates C14 will discharge via R3 and R39 causing the SCR, VT11 to run on. Power from the battery will be applied to the circuit, and a stabilized line of 6.3 V will be supplied to all circuits.

With the encoder motor energised the encoder will perform its measurement cycles with the reference as the initial value under measurement.

At the end of the cycle the pin fitted to the encoder head operates the selector switch SWD.

The measurement cycle is then repeated for the compass and finally the current. During the current measurement a pair of contacts on SWD closes and these contacts cause the SCR, VT11 to be short circuited. When the short circuit is removed the SCR is switched off and the power is removed from the circuit and the system stops until activated again by the operation of microswitch SWB by the clock cam.

4. — DIRECT READING, INTERROGATION, AND EXTERNAL SWITCHING FACILITY

For telemetry and direct reading the pulses fed to the recording head are propagated through the water via a spherical transducer mounted on the top plate of the instrument. These pulses can be monitored at a distance of approximately 500 metres by using a suitable receiving hydrophone.

The receiving hydrophone is used on board a surface vessel and can accept the pulses and convert these into an audible note which can be listened to and recorded or fed into a pen recorder or special printout unit which will show the pulses as short and long dashes. The long pulses represent binary 0 and the short pulses binary 1 and knowing this the binary number can be converted to its equivalent decimal number. Thus a direct reading facility is made available by this means.

In addition to this acoustic link a wire link is also available by connection to an external signal socket which is mounted on the top plate for this purpose. This external socket connects to the direct D.C. pulses. For interrogation a magnetic reed switch mounted under the top plate disconnects the instrument start line from the internal clock control when a magnet is placed on the outside of the top plate. With the magnet in position the reed switch connects this start line to the output signal socket. Thus, with a magnet placed in position on the top plate the instrument will not start unless a pulse is fed into the signal terminal and to SCR, VT11 in the same way as the microswitch SW8 does when activated from the clock.

An interrogation system is made available by this means and when used this way the D.C. pulse information can be received back by the same line or, alternatively, via the acoustic link.

This magnet placed on the top plate also acts as the on/off switch as the instrument clock cannot start the system until the magnet is removed.

On removal the next operation of the microswitch by the internal instrument clock starts the system.

If the wire link is left connected but the magnet removed then the information will be available from the wire link every time the internal clock switches on the system.

5. — MECHANICAL FEATURES

The illustration (figure 3) shows the construction and suspension arrangement of the original Bergen instrument fitted with a Savonius rotor. Figure 4 shows the construction and suspension arrangement of the Plessey Company model fitted with a propeller rotor. Figure 5 shows the

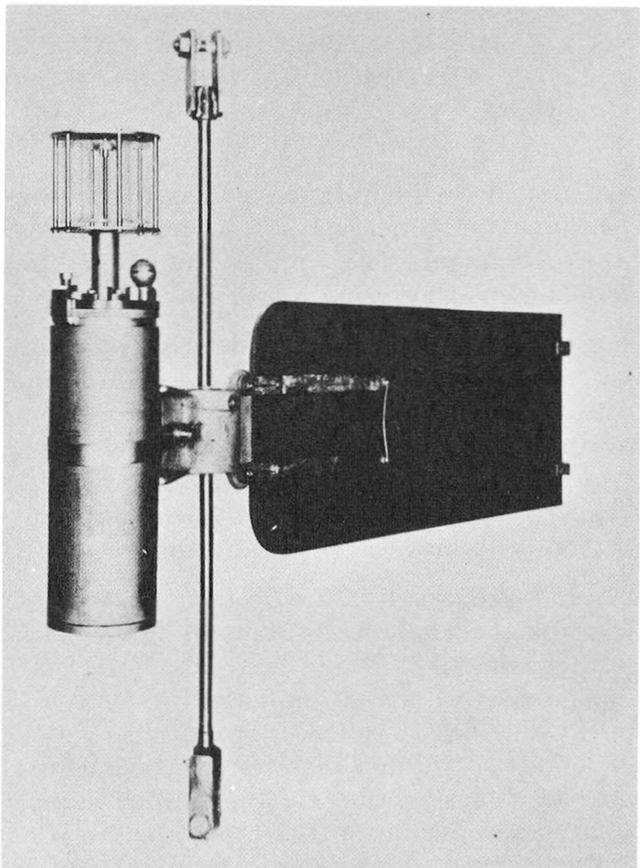

FIG. 3. — Bergen meter.

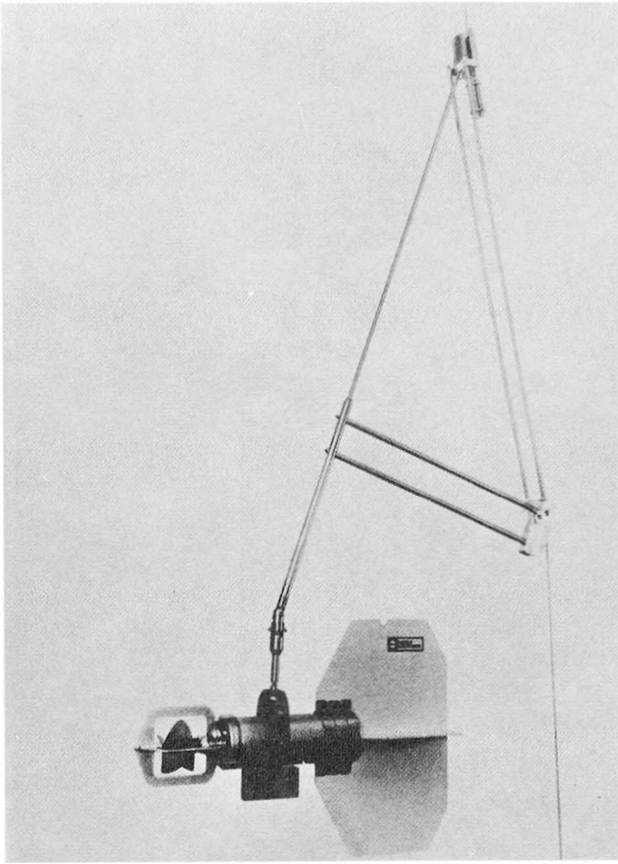

FIG. 4. — Plessey recording current meter model MO21.

internal construction of the instrumentation package which is suspended from the top plate holding the rotor.

The main assembly is built up on one central printed circuit board which acts as the mechanical support for all major items as well as providing the necessary circuit component support.

The illustrations show the two sides of this main support panel : figure 6, the side which contains the recording tape transport system, the compass and the battery for the clock; figure 5, the side which contains the digital encoder unit, the clock and the main battery case.

The compass which is at the base of the instrument is shown in the position suitable for the propeller type model. Use is also made of interlocking pegs and slots to ensure that the compass is horizontal and in the correct plane when the equipment is fully assembled.

A 3-inch diameter spool of $\frac{1}{4}$-inch wide triple play tape is fitted which contains 600 feet of tape and permits up to 55 000 readings to be taken.

5.1. **The Tape Transport System**

A necessary feature in the tape transport is to ensure immediate start up and movement of the tape with no slip. The running speed of the tape during recording is low — equivalent to only 0.01 inch per second and

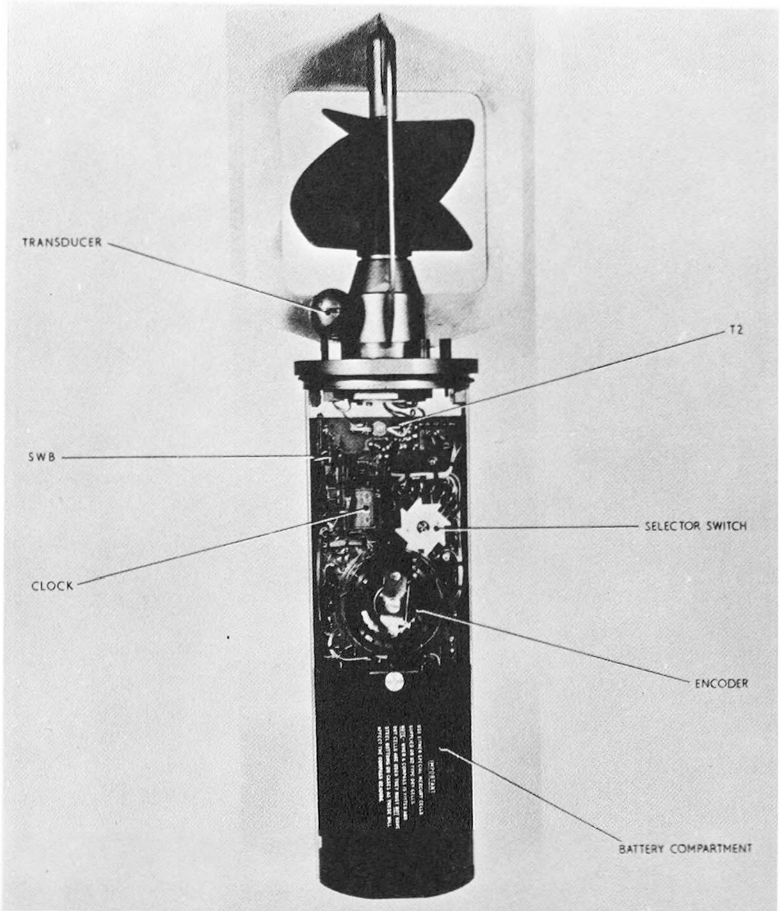

FIG. 5. — Interior of instrument. — Encoder side.

it is vital that there is no loss of drive at any time. Every recording starts from rest and start up slip cannot be allowed. It was found that the use of the original plain steel driving spindle and rubber pressure roller did not give consistent results and occasional slip was evident. Greater pressure on the pinch roller improved the condition but this introduced excessive side thrust and wear on the spindle bearings. The problem is overcome in the present models by the use of a thin neoprene surfaced driving spindle and rubber pinch roller. The neoprene surface gives immediate grip with no slip. To maintain the concentricity and size of this drive spindle it is first surfaced with the neoprene and ground down to size afterwards. In addition, the tape guide pillars are also coated with P.T.F.E. to reduce friction losses. Due to the fact that D.C. pulses are passed through the recording head, this is made with the normal recording gap and an additional air gap in the magnetic circuit to prevent the head becoming permanently magnetised by these continued D.C. pulses.

The present models also include a pressure pad to ensure intimate contact of the magnetic tape onto the recording head and a suitable linkage arrangement to hold off the pinch roller and pressure pad. Operation of this linkage assists when threading the magnetic tape as well as performing the more important function of keeping the pinch roller free when the instrument is not in use. This prevents the possibility of any flats forming

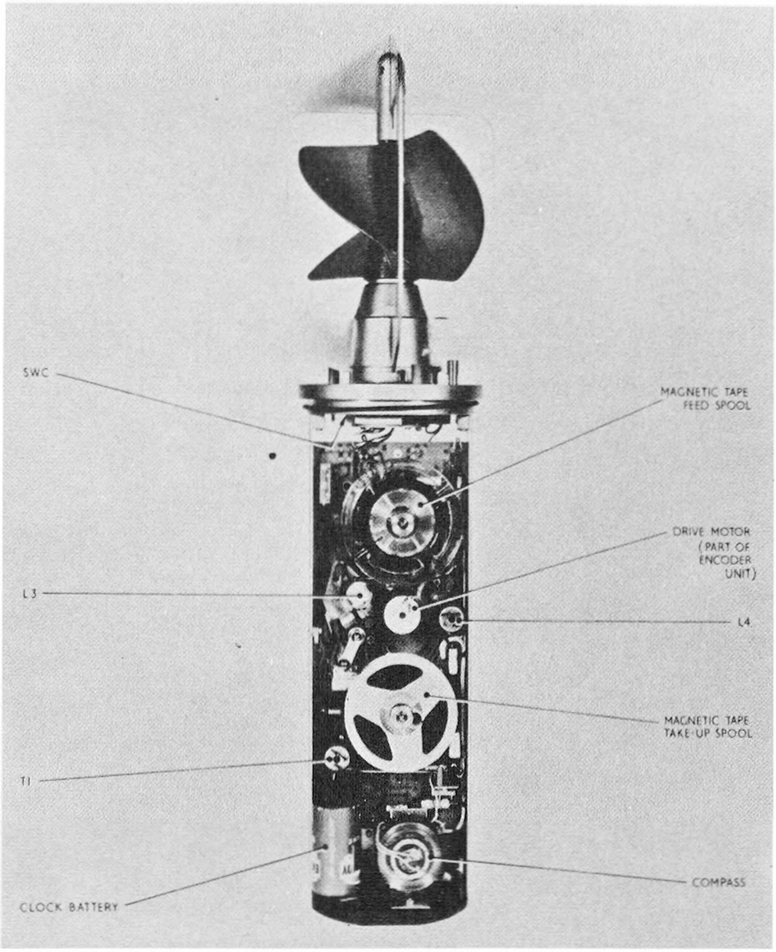

Fig. 6. — Interior of instrument. — Recorder side.

on the capstan and pinch roller surface due to their being left compressed in the one position for long periods.

6. — THE ADAPTATION TO A PROPELLER ROTOR

One of the major changes introduced in the Plessey meter is the propeller rotor in place of the Savonius type rotor. A propeller rotor of suitable design was therefore evolved which would fit into the general overall size of the existing instrument package.

The method by which the instrument measures the flow is by obtaining the total rotor revolutions over a known period of time. The total revolutions are divided by the time to give an average speed in revolutions per second which can be directly related to the flow in feet per second from a calibration curve. It will be appreciated that there is no means of knowing whether the total revolutions measured occurred at the average rate or at some other varying rate. To avoid error due to the assumption of an average rate the rotor calibration needs to be linear.

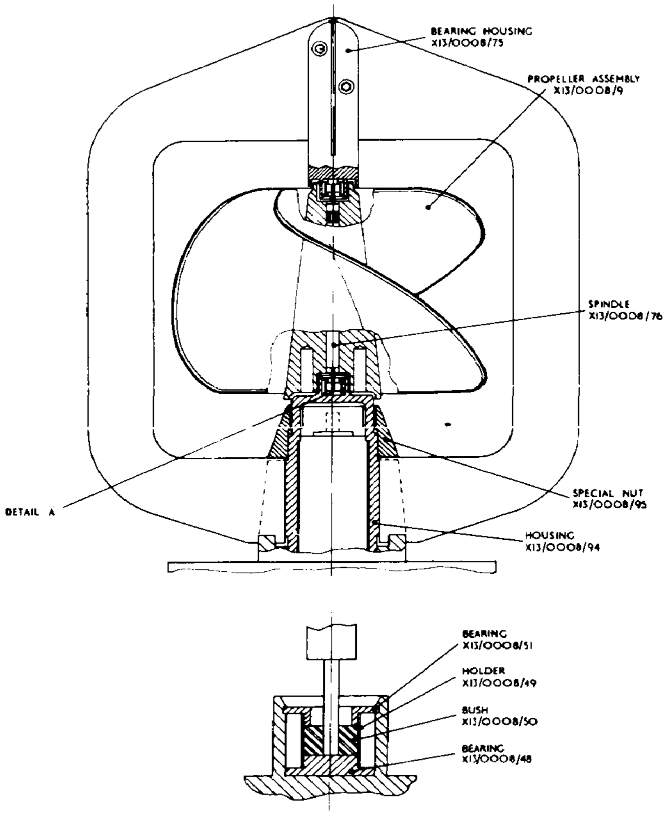

FIG. 7. — Propeller mounting details.

The main factors considered in the propeller design were to achieve this linearity, low speed response, good mechanical strength, with reliability and ease of servicing.

Linearity is obtained by designing the propeller to give a minimum of interference between blades and by ensuring that the blades never operate in a semi-stalled condition.

Consideration of a suitable size propeller makes this a 3-bladed design of a length to permit the trailing edge of a blade to be in line with the leading edge of the following blade. By the selection of a suitable length this results in a convenient nominal pitch of 1 foot.

For low speed response with consistent performance over a long immersed period the bearing design is based on a watch type escapement pivot. The assembly is also sprung loaded to give adequate mechanical protection. The pivot material is stainless steel and the bearing bush is loaded nylon. To reduce weight on the bearing the material chosen for the propeller itself is plastic.

Mechanical strength and reliability are achieved by the sprung design of the bearing bush which permits the whole assembly to move sideways until the hub is supported by the main frame (see figure 7). Very heavy side shock loads are supported in this manner and do not damage the

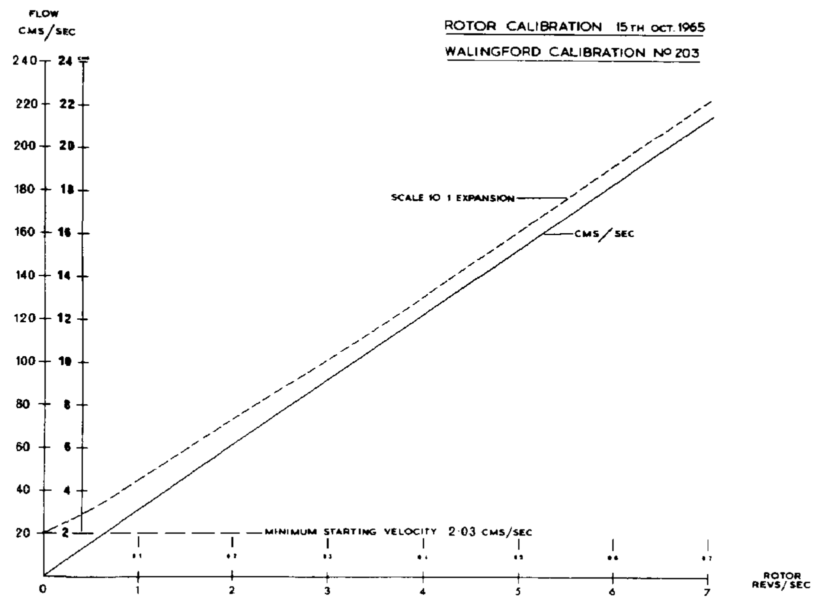

Fig. 8. — Rotor calibration, 15th October 1965.

pivot. This feature also provides a self aligning action which means that performance is maintained even if the outer frame is partially distorted. The hub is also shrouded both at the front and rear by suitable skirt extensions which are designed to prevent fouling from weed and growth. The whole propeller is painted with anti-foulant.

For ease of servicing the front bearing assembly can slide forward. This releases the propeller which can be extracted through the side supports and gives immediate access to the bearing assembly.

Figure 8 shows the performance data on such a typical propeller. These results are from figures taken at the Wallingford Hydraulics Research Station. The measured minimum starting speed is 2.03 cm/s. The stopping speed is 1.98 cm/s, and good linearity is maintained from 4 to 250 cm/s.

To further improve the low speed response no shaft extensions are used and the coupling to the instrument proper is made by magnets inserted within the propeller hub immediately on each side of the bearing housing. This magnet drive operates a concentric gearbox housed within the support pillar which also carries the propeller bearings and bearing frame. The final driven potentiometer is built as an integral part of the gearbox and the overall loading on the propeller has been kept to a minimum by this method.

7. — THE SUSPENSION SYSTEM

A second major change introduced in the Plessey meter is the method of suspension from the mooring cable. It can be appreciated that to make full use of the propeller type rotor for measuring flow it is essential that the rotor faces correctly into the direction of the water flow. It is little gain to have a propeller sensitive to low velocities if it is not also able to swing into the flow direction under the same low velocity conditions.

Initial towing trials to check the performance in this respect soon showed that the use of the in-line gimbal arrangement, as fitted to the original models, resulted in too much weight and drag to permit alignment at speeds lower than 7 cm/s. Variations in vane size and gimbal bearings within reasonable practical limits showed little improvement, and it was soon realised that a different method of suspension was needed if the desired performance was to be achieved.

The two main factors considered in order to give a low velocity alignment response are (1) the amount of instrument area forward of the pivot compared to the area of alignment fin to the rear of the pivot and (2) the overall size and weight and subsequent body loading on the pivot itself.

These factors are improved by the use of an off-line suspension system. In the off-line system the instrument only is suspended below the pivot and it can be positioned so that any proportion of the instrument can be placed on each side of the pivot. Repositioning the meter in this way results in less frontal area which means that less fin area is needed.

This reduces the overall hung weight and the load on the pivot is reduced. It is possible to use a much smaller pivot shaft and bearing as it does not have to carry the anchor and cable weight but just that of the instrument itself.

Other important features of the off-line system are that the mooring line does not need to be cut into predetermined lengths; also by the addition of sufficient self aligning or knuckle joints the transmission of vibration and oscillation of the mooring line to the instrument is prevented. A greater angle of mooring line slope can be tolerated.

This system used with the Plessey meter is illustrated in figure 4.

At high current flow horizontal stabilizers function to maintain the horizontal attitude of the meter. A special top stabilizer is fitted to counteract the drag of the pendulum weight in fast flow conditions. This complete off-line arrangement has very good performance results in respect of alignment velocities which are less than 3 cm per second and equal to the sensitivity of the propeller itself. Stability at high speeds is also excellent.

8. — PROCESSING OF THE MAGNETIC TAPE

As already described the series of each set of recorded values begins with a reference number which is thus repeated regularly throughout the length of tape. Indentification of the meter on which a particular tape has been recorded is therefore known by its own unique reference number.

However the range of discrete numbers that can be set up for this reference must of necessity also be within the same range as that used for the variable sensor information. It is therefore always possible that a sensor measurement may be identical to the reference number. Due to this fact it is not possible to consider using the reference number as a positive indication of the beginning of a set of measurements.

Some additional means is therefore needed to make this identification positive and in the Plessey production model this is done by introducing an additional pulse via a special contact on the channel selector switch.

When the tape is processed into punched paper tape for computer infeed this additional pulse is used to punch an extra hole to identify the start of a series of measurements and this extra hole is repeated throughout the entire length of the tape to show the start of each set of readings.

The reference number which identifies the instrument also serves a further purpose which is as a system checkout during the translation into punched paper tape. This is done by the process function checking this reference number against a similar comparison figure set up by the operator, and if this checkout does not agree then the translation of the magnetic tape is automatically stopped.

A small drift in the figure is allowed by the translation machine ignoring changes in the two least significant numbers.

In decimal equivalents this means that a drift of 3 parts is accepted in the 1024 parts which is the decimal total of the 10 bit number. In the circuit of the instrument the actual reference number is obtained from a variable resistance which is set during manufacture so that the encoder reads the appropriate figure.

The tape translator checks the first 8 bits of the binary reference which if the drift is within tolerance will always remain the same. All the ten bits of the binary reference number are however read and punched out in the final paper tape so that if desired the subsequent computer programme can be arranged to read the true figure and adjust all other sensor information to allow for the same percentage drift. This overall system means that the small errors can be permitted and corrected but large errors will stop the process and thus prevent wastage of time examining information which is unreliable.

The available translation machine reads the magnetic tape using a flux sensitive readout system which distinguishes the long and short pulses and uses these to operate via suitable logic an 8-hole paper tape punch machine to produce a binary coded paper tape suitable for computer infeed. Five holes of two adjacent rows are used to specify the 10 bit number. Odd or even parity check can be introduced in any preselected hole position so that various computer types can be catered for, and a positive indication of the start of each set of measurements is given by one specific hole position being allocated for this sole purpose.

This results in a format which can be read and converted by eye to the equivalent decimal numbers. A typical tape is shown in figure 9, one which is suitable for use with the Elliott 803 computer and can also be read by eye as the legend illustrates.

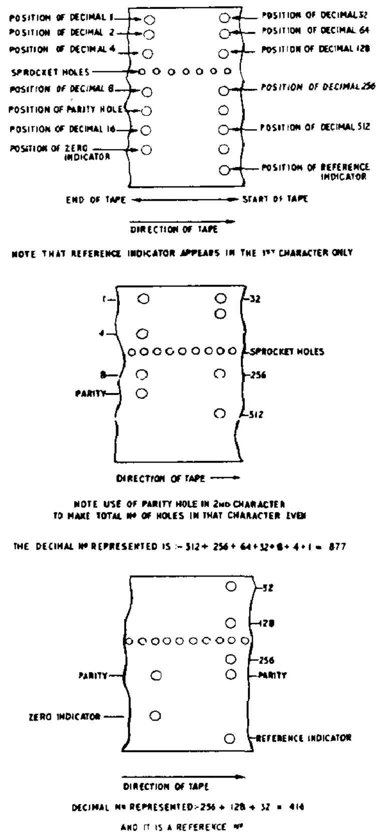

FIG. 9. — Punched tape code for Elliott 803.

9. — TYPICAL RESULTS

The chart shown in figure 10 has been prepared from actual results obtained from a production instrument moored in the North Sea. The tidal flow and direction is clearly indicated.

10. — ACKNOWLEDGEMENTS

The author wishes to thank the Plessey Company Limited for permission to publish this paper.

Also, the National Institute of Oceanography and the Ministry of Agriculture and Fisheries Laboratory at Lowestoft for their help and facilities in testing out the equipment.

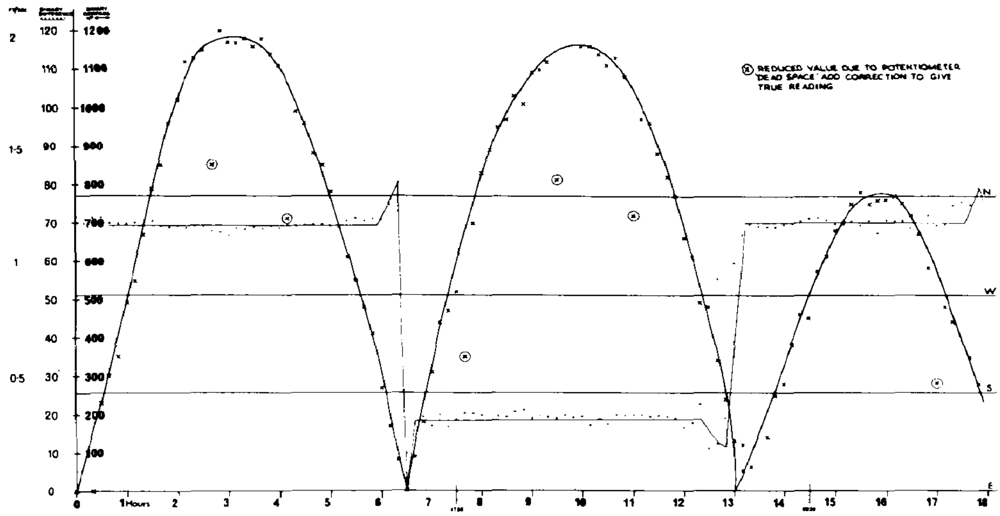

FIG. 10. — Typical on station flow and direction chart.

11. — REFERENCES

NATO : Sub-Committee on Oceanographic Research : Technical Report No. 16. *A Recording and Telemetering Instrument,* by I. AANDERAA.