HYDROLOGICAL PROCEDURE NO. 3

A GENERAL PURPOSE EVENT WATER-LEVEL RECORDER (CAPRICORDER MODEL 1598)

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(CAPRICORDER MODEL 1598)

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MALAYSIA

ACKNOWLEDGEMENT

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(CAPRICORDER MODEL 1598)

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MINISTRY OF AGRICULTURE AND FISHERIES

MALAYSIA

PRICE $5/-

CONTENTS

ABSTRACT

The principles and potential advantages of event recording have been described previously by Chandler and Patterson (1970).
A battery-operated event water-level recorder developed for general purpose uses is now described here.

1. INTRODUCTION

This recorder is a modified Fischer and Porter series 1542 analog-to-digital water-level recorder (figs. 1 and 2). The modification can take the form of a kitset; this approach to the conversion is described later.

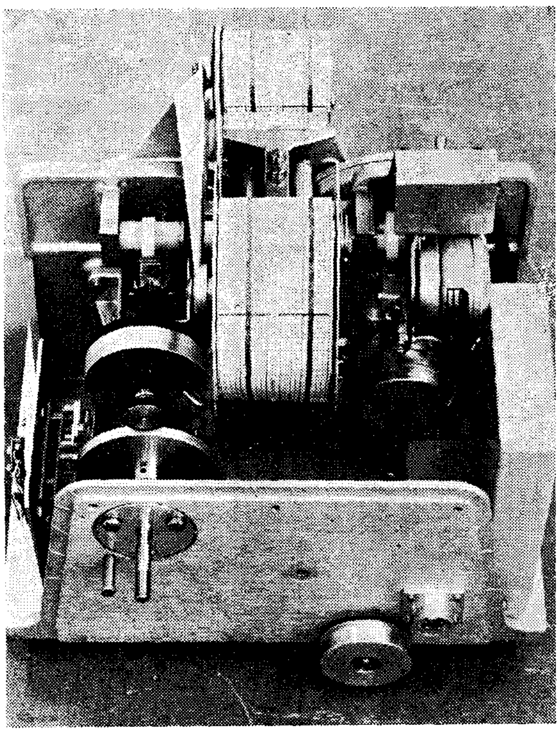


Fig. 1: Rear view of modified recorder

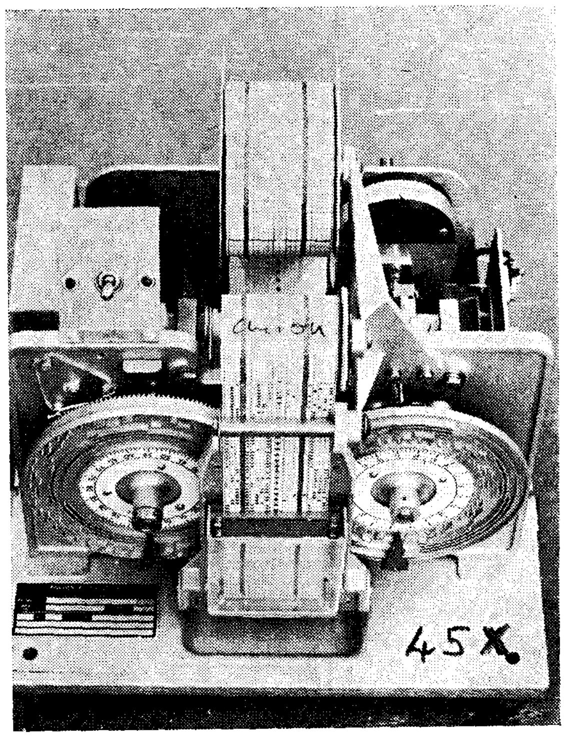


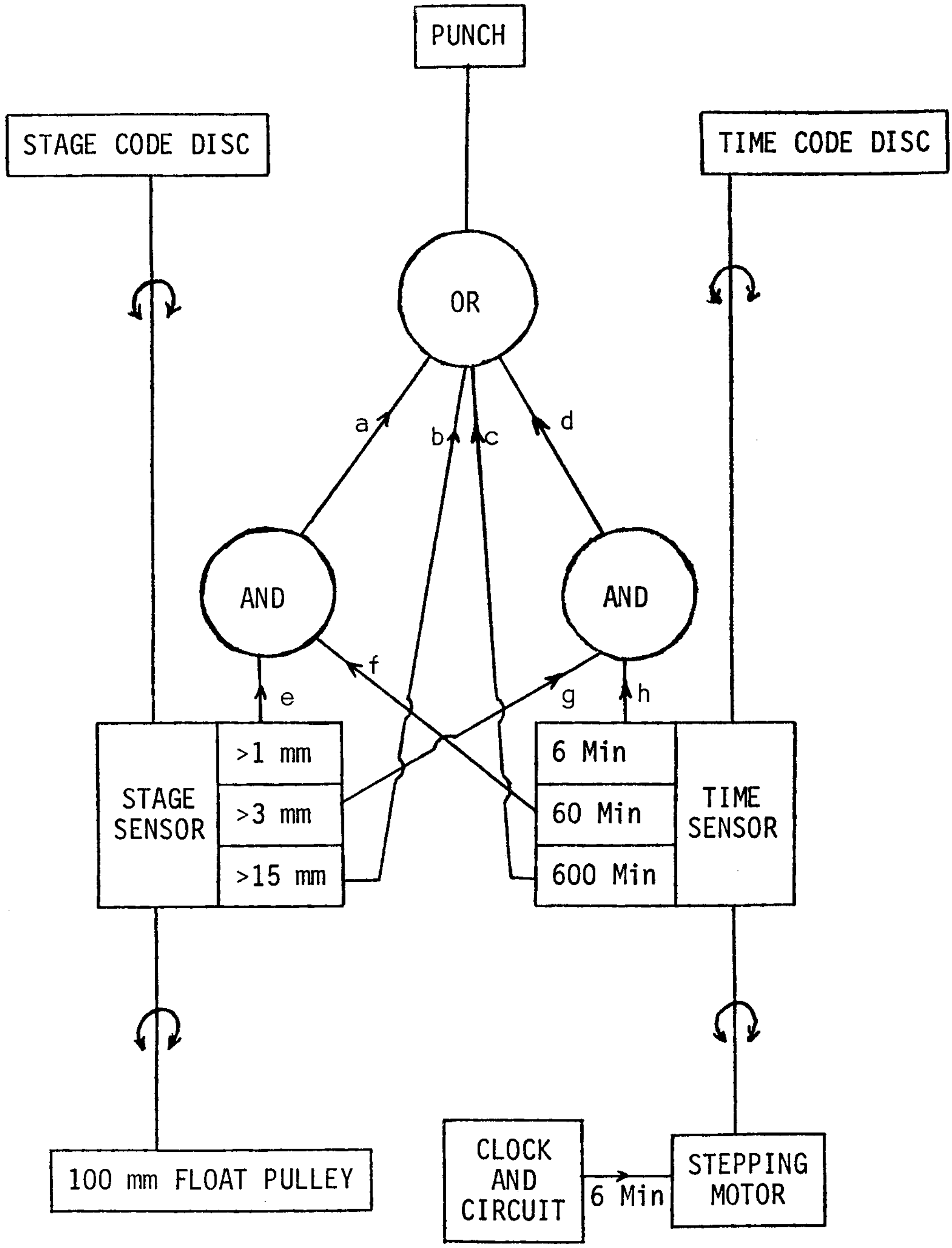
Fig. 2: Front view of modified recorder

The conversion is partly mechanical and partly electronic. The electronics consist mainly of a single printed circuit controlling several functions in the machine. As described previously, one code disc is devoted to water level and the other is devoted to time. Time and stage intervals are sensed according to the pattern shown in the logic diagram (fig. 3).

To drive the time code disc and to derive the timing functions without consuming too much power, initially a high-torque battery-wound clock was used. Experience proved that this approach is troublesome mainly because of the widely carrying loads being driven by the clock during the timing cycle. The margin of safety is not wide enough to guarantee operation in the field under all conditions.

A Philips stepping-motor drive had adequate torque, simplified the mechanical system, and retained the standard Ergas timer with the full flexibility of cam changing in the field for different time intervals.

The stage sensor was redesigned to allow shutter-blade intervals to be changed with single-shaft operation for simplicity. Light-emitting diodes are used rather than light bulbs because they are easier to mount physically, are more compatible with solid-state electronics and have a spectral output matching the light-dependent resistors used for sensing. A lensless optical system was devised for simplicity. The basic intervals chosen for the sensors are 1, 3 and 15 mm. The 15-mm deflection is



Inputs on lines a *or* b *or* c *or* d will trigger a punchout.
Inputs in lines e *and* f will give an output on line a thereby triggering a punchout.
Inputs on lines g *and* h will give an output on line d thereby triggering a punchout.

Fig. 3: Event water-level recorder logic

detected by a magnetically actuated reed switch. All machine-operated switches are either reed switches or microswitches for reliability.

Another feature of the design is that it is not very different, physically, from the standard recorder. For example, the clock remains in its original location.

The function of the circuit is described later. While the circuit seems rather complex (fig. 4), all functions can be performed simply, through the use of integrated circuits and other semiconductors. These low-cost components allow complex logical functions to be carried out with the minimum of physical complexity.

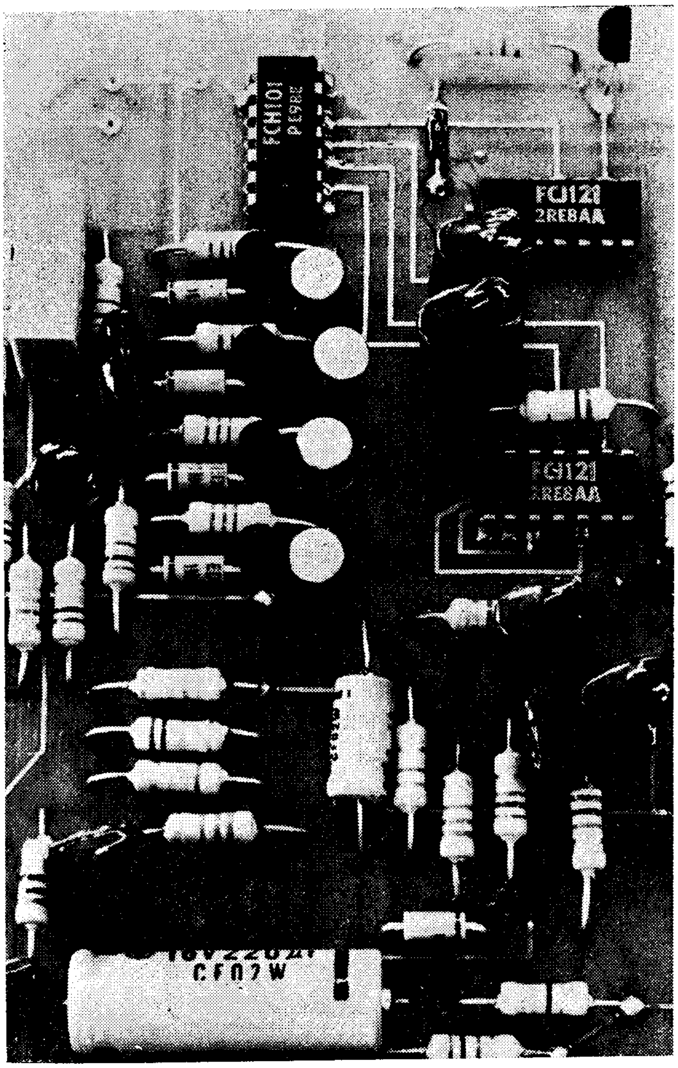


Fig. 4: Printed circuit

The wiring of the recorder is unique in concept. Instead of using a wiring harness, all wires are terminated on a sub-board below the main circuit connector (fig. 5). This gives a very tidy wiring layout and also allows maximum flexibility for future modifications. For instance, an external counter to accumulate time information, could be added. This might be useful for time checking.

The circuitry in the recorder has a very low duty cycle, i.e. most of its time, is spent in the "off" state. This means that battery life is at least as long as that for the standard recorder.

The design also incorporates a semi-automatic alignment of the high-order disc which prevents misadjustment during transit and installation. This adjustment is part of the installation procedure and is performed by operating a switch and pressing a button. The low-order disc uses the detent mechanism of the standard recorder for alignment during punchouts.

2. SOME RECORDING CHARACTERISTICS

A well known theorem in communication states that if a function of time, f(t), contains no frequencies higher than w hertz (cycles per second), the function is uniquely determined by giving it ordinates at a series of points spaced $\frac{1}{2w}$ seconds apart. Thus, if a digital recorder records f(t) over a time interval t, then $2tw$ samples are needed to define the record accurately (Raisbeck, 1963).

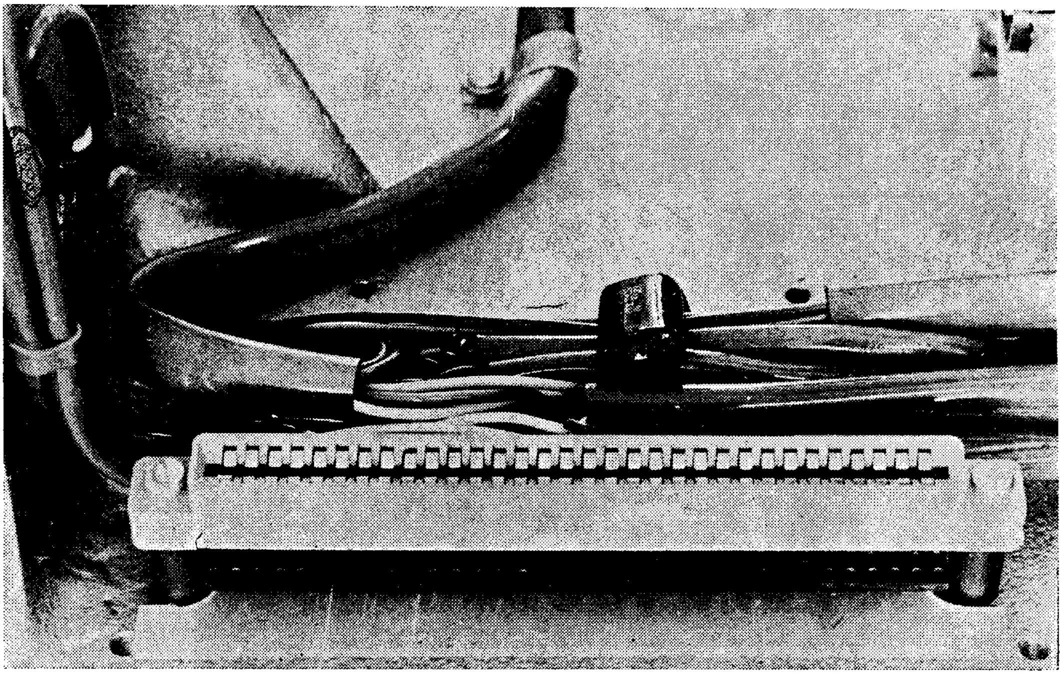


Fig. 5: Thirty-two way connector and wiring onto sub-board

The factor w may be called the bandwidth of the recorder, i.e. it is the maximum frequency the recorder can handle without ambiquity. The bandwidth of a standard 15-minute recorder may be calculated in cycles per hour:

$t = 0.25$ hour

$w = \frac{1}{2}t$

$= 2$ cycles per hour

For a 6-minute recorder

$w = 5$ cycles per hour

Frequencies above these values will not be recorded accurately.

The event water-level recorder can record frequencies above 120 cycles per hour when the rate of stage change is over 3600 mm/hour. The performance of the recorder with a 100 mm pulley is:

Bandwidth (cycles/hour)	Samples/ hour	Min. rate (mm/hour)	Max. rate (mm/hour)	Min. interval between readings (mm)	Max. interval between readings (mm)
0.05	0.1	0	0.1	0	1
5	1	1	3	1	3
5	10	30	150	3	15
120	240	3 600	11 760	15	49

These data are summarised in a response curve (fig. 6). Data for standard fixed-time recorders are also illustrated. At the bottom left of the graph, low rates of stage change give very low punch rates, thus economising on tape production and machine wear and tear. At the top right of the graph high rates of stage change give high punch rates, thus allowing better definition than standard recorders.

Fig. 7 shows how the event water-level recorder compares with standard recorders when trying to record rapidly changing inputs. Above 450 mm/hour the event water-level recorder gives better resolution than a standard 2-minute recorder. At stage change rates up to 3600 mm/hour the interval

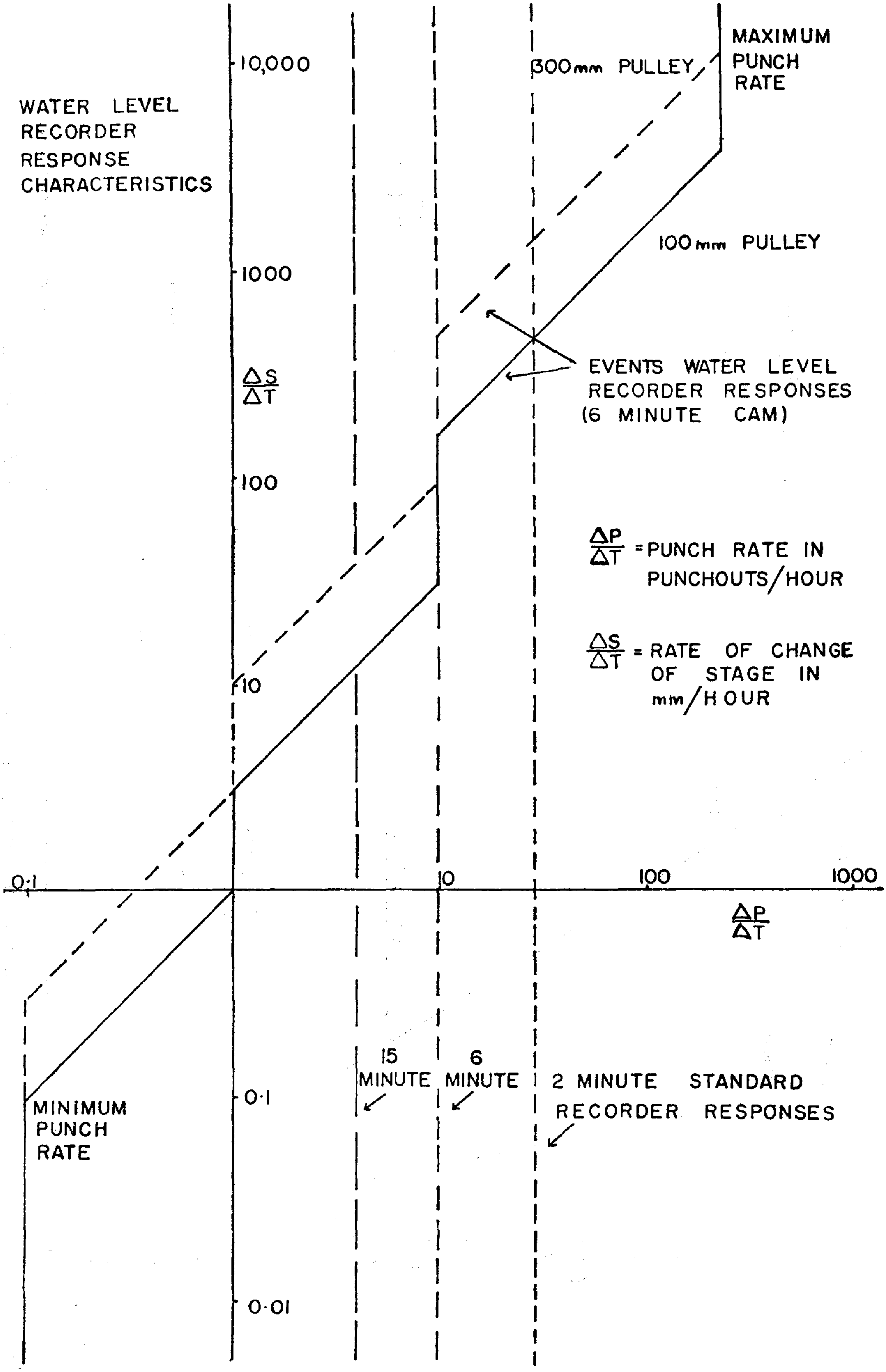


Fig. 6: Water-level recorder response characteristics

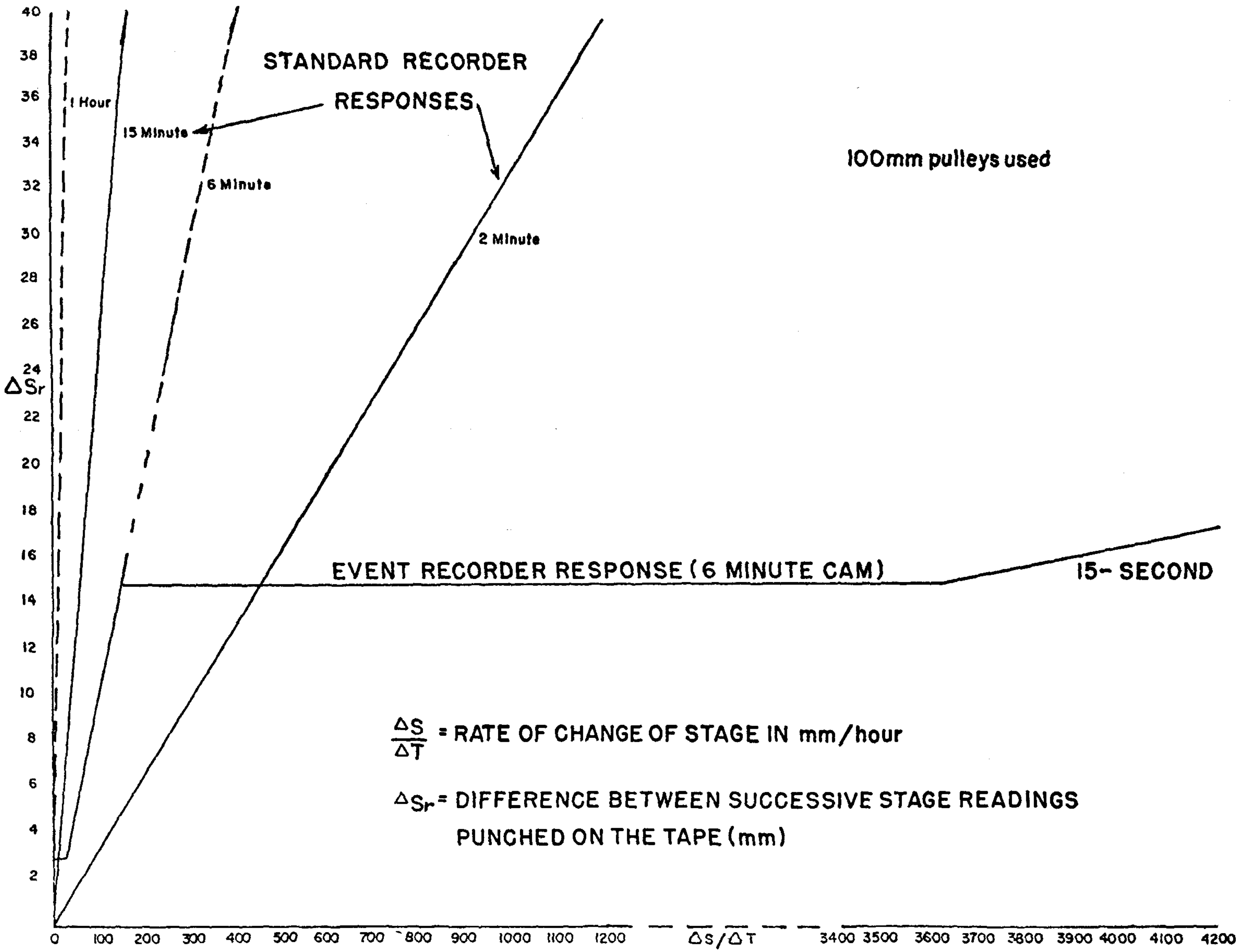


Fig. 7: Comparative resolution of digital water-level recorders vs rate of change of stage

between readings does not exceed 15 mm. This figure may vary in practice as the sensor may momentarily be free from the code-disc shaft during the latter part of the punch cycle. Because the recorder defines rapidly changing inputs more accurately than other recorders, more work may be needed to manually check the tape through a particular storm. The user must decide whether these extra data are needed. If not, a 300-mm pulley is recommended. The 300-mm pulley is spring loaded (fig. 8), so bent punches, due to surging, should not occur. Since the band-width or sampling rate of the recorder increases with rapid stage changes, the recorder can become very responsive to strong surging. There is no cure apart from damping and/or reducing resolution. A valve on the intake pipe of the stilling well is one method of damping.

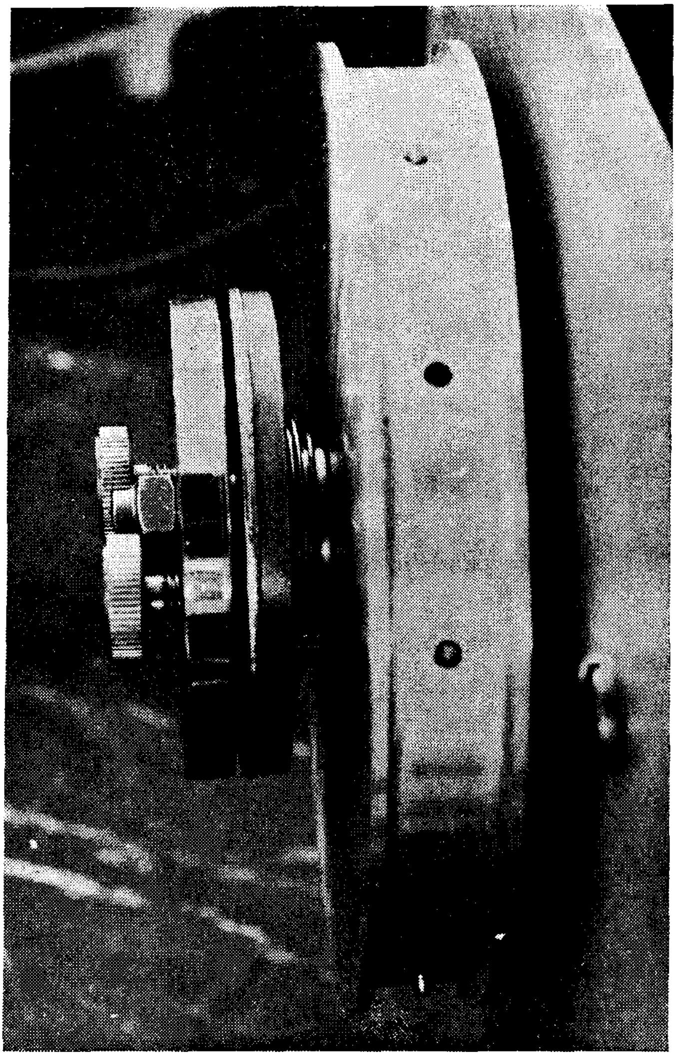


Fig. 8: Spring loaded 300-mm pulley

Fig. 7 also shows that the criteria for deciding the punch rate of standard recorders for a particular site cannot be used in choosing a basic timing interval for an event water-level recorder. If a linear interpolation over 6 minutes is acceptable, the 6-minute event water-level recorder can be used on sites normally reserved for standard 2-minute recorders.

The 6-minute basic time interval chosen for the initial release of 20 recorders simplified the problem of working out real time from the record. This should not inhibit the use of other time intervals, i.e. 15, 30 or 60 minutes if the site requires it. However, wide coverage should be possible with the 6-minute recorder.

Fig. 9 shows how the recorder responds to an increasing rate of stage change. Initially, the recorder is on a 10-hour rate. It gradually moves to a 1-hour rate as the slope approaches 1 mm/hour. From

1 mm/hour to 3 mm/hour the hourly rate is maintained. As the slope exceeds 3 mm/hour a gradual shift over to the 6-minute rate occurs. From 30 mm/hour to 150 mm/hour the 6-minute rate is maintained. At 150 mm/hour a shift towards the 15-second rate occurs. From 3600 mm/hour to 12 000 mm/hour the 15-second rate is maintained. The 15-second rate represents the maximum punch-cycle time of the recorder. Usually a time of about 10 seconds is obtained. The 12 000-mm/hour slope represents a theoretical maximum rate of stage change input to the recorder. Rates above this value will cause ambiguous records as the code-disc movement exceeds half a revolution between punch-outs. The solution in this case is again damping and/or lower resolution. A 300-mm pulley raises the upper limit to 36 000 mm/hour.

The question of different shutter blade ratios in the sensor has not been examined fully yet, and more field experience is required before tailor-made sensors can be offered. At present the shutter responds to 1, 3 and 15 mm.

Another way of expressing the response of the event water-level recorder to change in stage is as follows:

0 mm in 600 minutes to 1 mm in 600 minutes	1 punch in 600 minutes
1 mm in 600 minutes to 1 mm in 60 minutes	1 punch in 600 minutes to 1 punch in 60 minutes
1 mm in 60 minutes to 3 mm in 60 minutes	1 punch in 60 minutes
3 mm in 60 minutes to 3 mm in 6 minutes	1 punch in 60 minutes to 1 punch in 6 minutes
3 mm in 6 minutes to 15 mm in 6 minutes	1 punch in 6 minutes
15 mm in 6 minutes to 15 mm in 15 seconds	1 punch in 6 minutes to 1 punch in 15 seconds
15 mm in 15 seconds to 49 mm in 15 seconds	1 punch in 15 seconds

3. CONVERSION

The standard fixed-time Fischer and Porter analog-to-digital water-level recorder may be readily converted to an event water-level recorder by means of a conversion kit.

The conversion kit comprises

(1) A sensor to detect stage changes (figs. 10 and 11).

(2) A set of components mounted behind the high-order code disc for producing time pulses and allowing alignment of the code disc with respect to the punches.

(3) A stepping motor and gearbox driving on to the high-order code disc.

(4) An electronic circuit which controls the stepping motor and the punch motor in response to commands from the clock, the sensor and the time switches behind the high-order code disc.

Options include 100 or 300 mm pulleys, a surge compensating mechanism, a range of shutter blades for different sensor responses, and cams giving basic time intervals from 1 hour down to 2 minutes.

Six minutes is the standard time interval, while 1 mm, 3 mm and 15 mm ($\times 1$ or $\times 3$ depending on the pulley used) are the standard sensor intervals.

Note that installation on sites subject to surging greater than ± 3 mm will cause extra punchouts as the recorder attempts to follow. Larger float pulleys or sensor modifications may be needed.

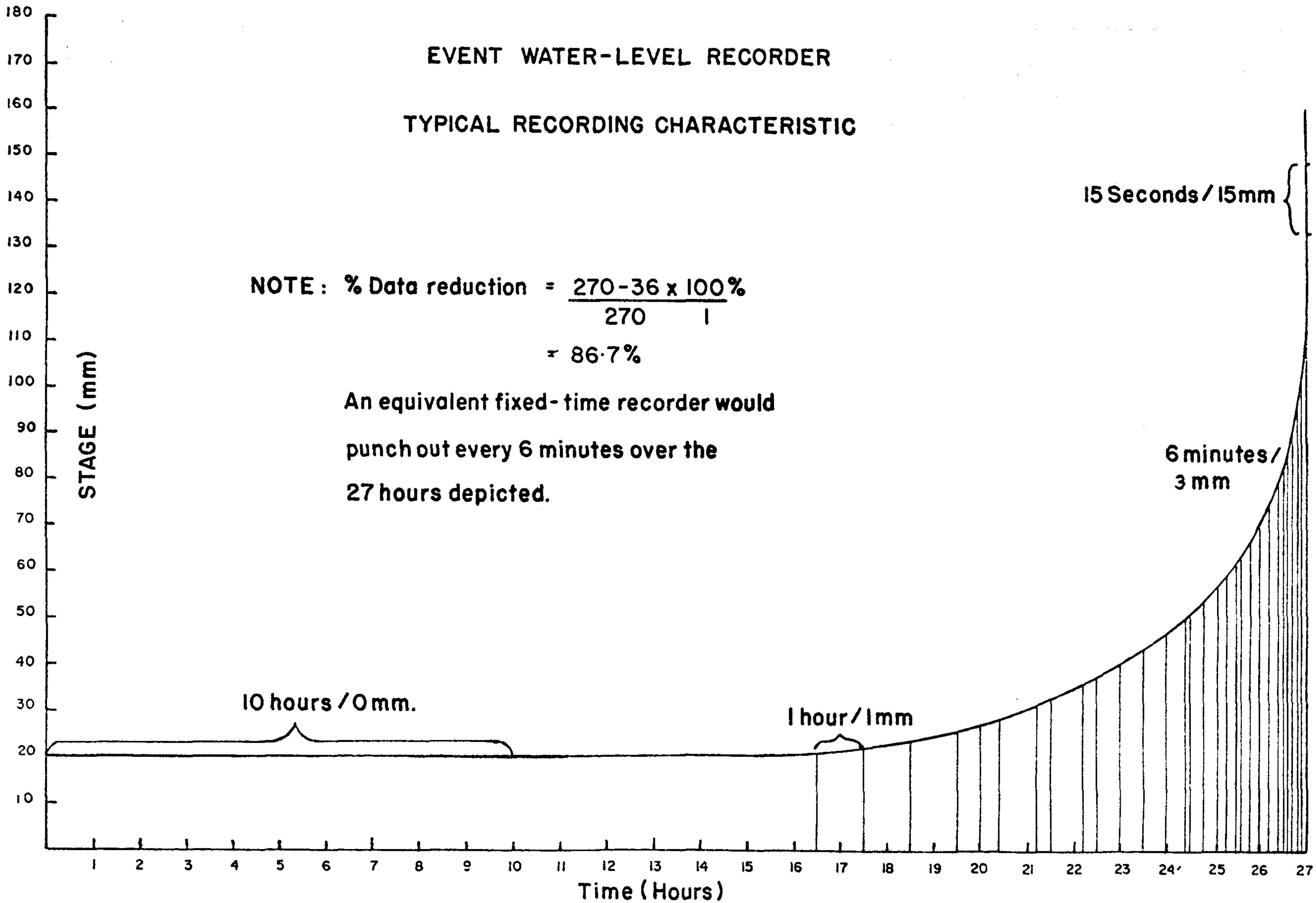


Fig. 9: Event water-level recorder—typical recording characteristic

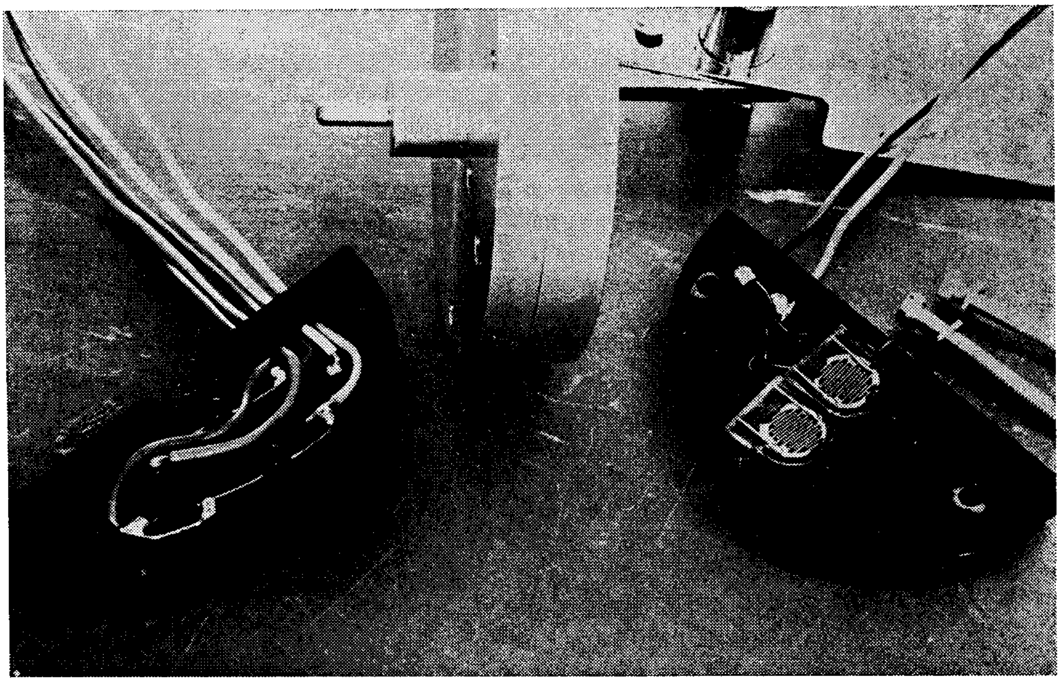


Fig. 10: Sensor parts: Left: Light-emitting diodes and reed switch
Centre: Sensor box
Right: Light-dependent resistors

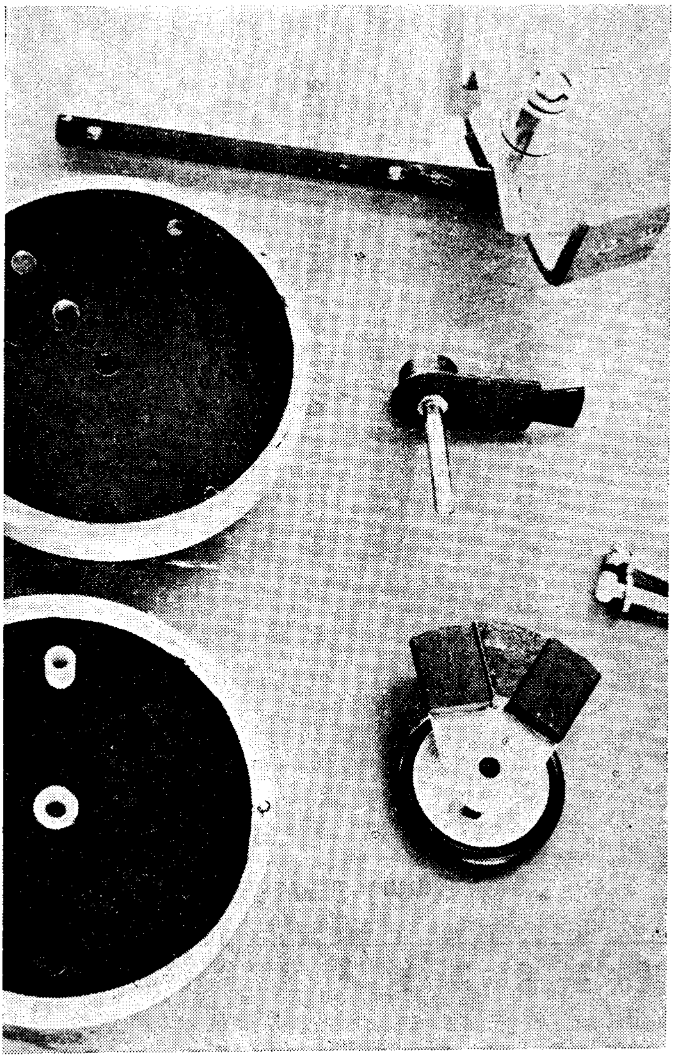


Fig. 11: Sensor parts
Left: Sensor box halves
Right from top: Sensor pivot arm, shutter and magnet plate assembly

The conversion-kit approaches means that little work needs to be done on the standard machine. A set of holes is drilled and tapped in the front plate for component mounting (fig. 12). The hub of the high-order code disc is machined down to accept a 120-tooth gear and a 10-step cam assembly. A reed-switch actuating magnet is glued on the back of the code disc. This allows electronic disc allignment in the field and ensures that a punchout occurs at least once per revolution.

A further set of holes is drilled and tapped in the base to accept the circuit connector and cover. Existing holes are used for the sensor mounting.

The gears connecting the two code discs are omitted during assembly, as the discs now have separate functions.

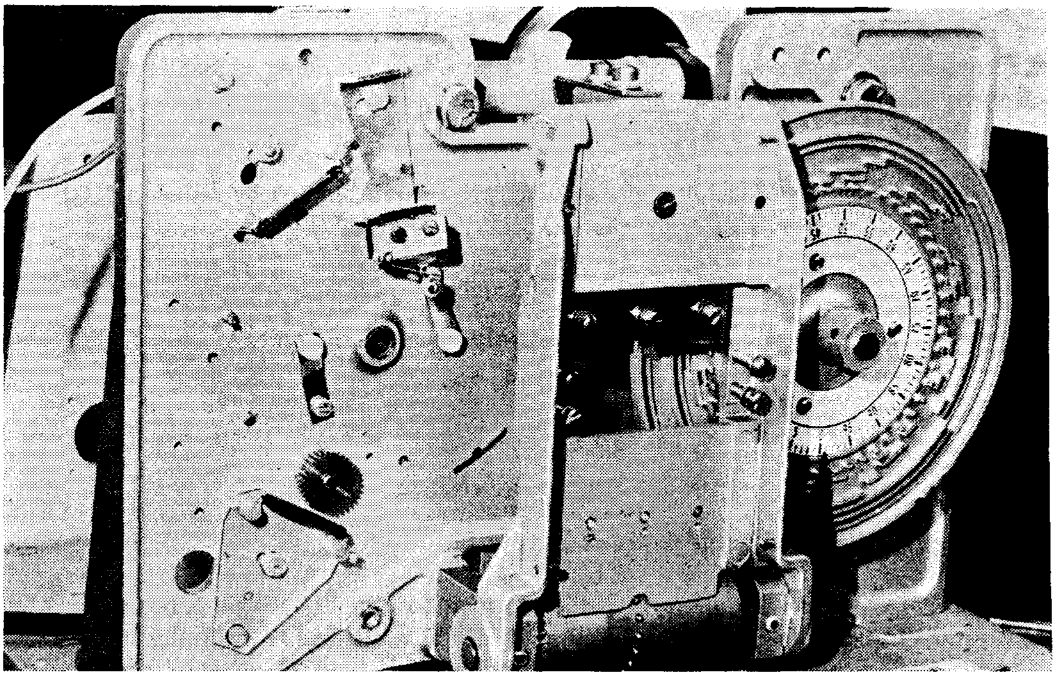


Fig. 12: Front plate before wiring. Switches and pressure pads are visible

After all components (sensor, switches, steeping motor, punch motor, etc.) have been mounted, the machine is hand wired. All wires from the various components lead to the sub-board below the circuit connector, which avoids the problem of soldering several wires on to one connector pin. The sub-board also allows future modifications.

The circuit is a plug-in printed circuit using a double-sided copper pattern.

The clock is a standard Ergas timer which can accept cams giving time intervals from 1 hour to 2 minutes.

4. ELECTRONIC CIRCUIT

The circuit varies the punchout rate in response to time and stage information supplied from the time and stage sensors. It also drives the stepping motor, coupled to the high-order code disc, in response to 6-minute time pulses from the clock.

Each pulse from the clock energises the stepping motor for 16 steps. This is converted by gearing to a one-division movement on the high-order code disc.

The stepping motor has a 24-pole rotor positioned between two stators, each energised by two coils switched in a logical sequence. By altering this sequence, forward or reverse operation can be obtained. There are 48 steps per revolution. The gearing gives 1,600 steps per revolution of the high-order code disc. This means that there is more than sufficient torque and, with teflon damping pads, operation is smooth.

The stepping motor has self-lubricating bearings, is tropic-proofed and will operate in ambient temperatures of −40°C to +70°C. The recorder has been tested from −22°C to +60°C with good results.

The stepping cycle starts when SW6 (fig. 13), operated by the clock cam at 6-minute intervals, causes the silicon controlled rectifier (SCR) Q5 to be energised via R7 and C2. Power is applied to the stepping motor and to the voltage regulator. The voltage regulator, Q11, R27 and D7, supplies 6 volts (approx.) to the logic and thus initiates the automatic reset function. In this state the coils L2 and L4 are energised.

The automatic reset function is provided by R14 and C4. When power is first applied by Q5, C4 is uncharged; thus all the reset inputs are pulled down to a low voltage until C4 charges up via R14. This occurs before the first pulse arrives from Q10.

The four coils L1, L2, L3 and L4 of the stepping motor are energised by transistors Q1, Q2, Q3 and Q4 according to the following table where Q on = 0 and Q off = 1.

Q1	Q2	Q3	Q4	Result
1	0	1	0	This state after automatic reset
1	0	0	1	Step 1
0	1	0	1	Step 2
0	1	1	0	Step 3
1	0	1	0	Step 4 = reset state

Thus there are four steps before the sequence is repeated.

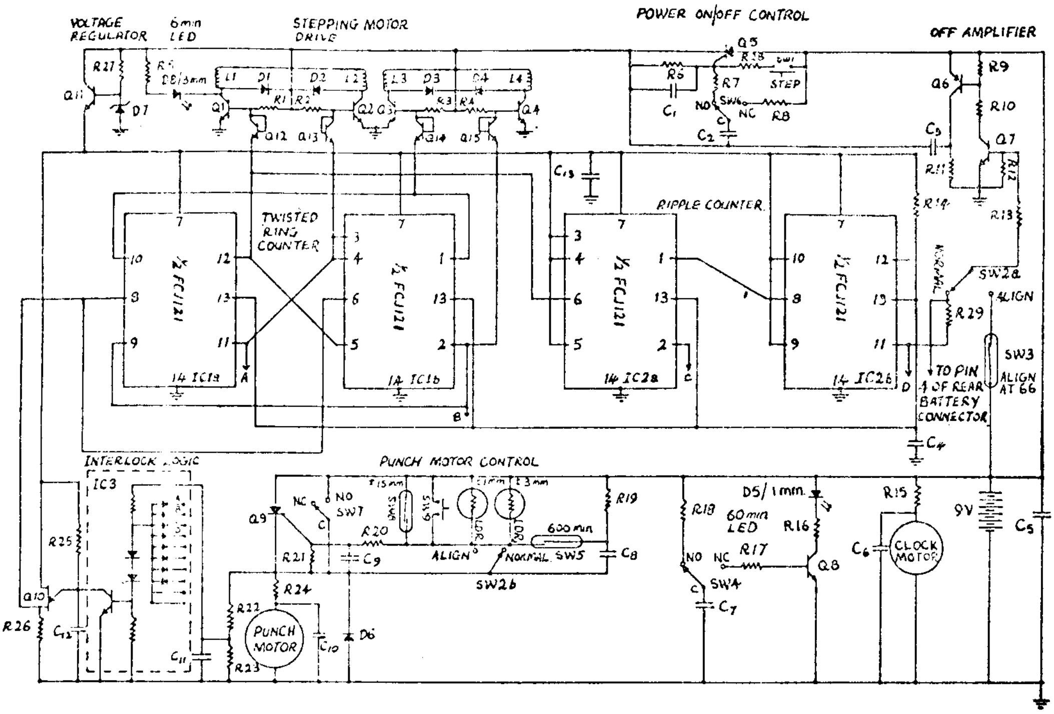
The transistors Q1 to Q4 are driven according to the above table by logic pulses derived from a twisted ring counter consisting of ICIa and ICIb, a Philips FCJ 121 dual JK DTL flip flop. The twisted ring counter is clocked by pulses from the unijunction transistor Q10. Power supply ringing and noise is removed by capacitors C13 and C5 and the voltage regulator.

The zenar diode D7 in the regulator is not bypassed with a capacitor as a rapid 6-V supply-line turn-on is necessary for the automatic reset function to take place.

The transistor Q10 supplies 16 pulses in about 0.5 seconds. Division of these pulses occurs in the twisted ring counter and then in the ripple counter IC2a and IC2b. IC2b drives Q7 which controls Q6. At power turn-on Q6 turns on in response to the output of IC2b, but the 'turn off' function provided by Q6 and the comutating capacitor C3 is overriden by the charge on C2 holding Q5 on. Thus, before Q6 can become effective it must turn off and then on again. This takes 16 pulses to achieve. Six minutes later the cycle is repeated.

The 6-minute/3-mm light-emitting diode D8 in the sensor is controlled by Q1 to give a slight delay, thus preventing two punchouts when the time disc is on 99. One would occur upon the disc reaching 99, and the other when it was about to move away if the shutter in the sensor happened to be deflected. With the delay provided, the second punchout would not occur until the disc moved to 00. The interlock logic guarantees this mode of operation. Thus, extra punchouts on 99 can only occur for large changes of stage. The computer interprets this as a rapid change of stage at time = 99 rather than an advance of 10 hours in time.

The interlock logic provided by IC3 ensures that the punch action and the stepping of the high-order code disc do not interfere. It senses the condition of IC1a, IC1b, IC2a, IC2b and of the punch motor. It decides whether it is safe to continue stepping or whether it is better to wait for the punch cycle to be completed. Steeping is allowed very early in the punch cycle when no harm can occur.



CIRCUIT: EVENT WATER LEVEL RECORDER.

RESISTORS.

All ¼ W, ± 5 %, cracked carbon.

R1	2·2 KΩ.
R2	2·2 KΩ.
R3	2·2 KΩ.
R4	2·2 KΩ.
R5	220 Ω.
R6	1 KΩ.
R7	1 KΩ.
R8	18 KΩ.
R9	10 KΩ.
R10	470 Ω.
R11	470 Ω.
R12	470 Ω.
R13	470 Ω.
R14	10 KΩ.
R15	39 Ω.
R16	220 Ω.
R17	4·7 KΩ.
R18	100 KΩ.
R19	470 KΩ.
R20	1 KΩ.
R21	1·5 KΩ.
R22	33 Ω.
R23	100 Ω.
R24	10 Ω
R25	100 KΩ.
R26	100 Ω.
R27	470 Ω.
R28	220 Ω.
R29	560 Ω.

CAPACITORS.

C1	0·1μF	50V. NCC Mylar.
C2	0·22μF	50V. NCC Mylar.
C3	1μF	50V. NCC Mylar.
C4	0·22μF	50V. NCC Mylar.
C5	220μF. 16V Elna Electrolytic.	
C6	0·22μF. 50V NCC Mylar.	
C7	10μF, 25V Elna Electrolytic	
C8	0·22μF	50V NCC Mylar.
C9	0·1μF	50V NCC Mylar.
C10	0·22μF	50V NCC Mylar.
C11	not used	50V NCC Mylar.
C12	0·22μF	50V NCC Mylar.
C13	0·22μF	50V NCC Mylar.

DIODES.

D1, D2, D3, D4	1N4001
D5	MLED600. Motorola Light emitting diode.
D6	1N4001
D7	BZY88 C6V8 Zener diode.
D8	MLED600. Motorola. Light emitting diode.

TRANSISTORS. etc.

Q1, Q2, Q3, Q4	2N5225 Motorola transistors
Q5	2N5060. Motorola SCR.
Q6	2N3638A Fairchild or 2N5226 Motorola transistor.
Q7	2N5225 transistor.
Q8	2N5225
Q9	2N5060 SCR.
Q10	2N4871 Unijunction.
Q11	2N5225
Q12, Q13, Q14, Q15	AC127 Philips transistors.

INTEGRATED CIRCUITS.

IC1, IC2	Philips FCJ121 Dual JK Master-slave flip-flops.
IC3	Philips FCH101 single 8 input NAND gate.

All standard temp. range DTL logic.

SWITCHES.

SW1	Crouzet ref: 83·547. (type 514·800)
SW2	Bulgin SW270 DPDT 250V, 2A.
SW3	G.E.C. Dry reed capsule type RCX.
SW4	Burgess V4T6YR1 microswitch.
SW5	G.E.C. Dry reed capsule type RCX.
SW6	Burgess V4T1 microswitch on clock
SW7	Honeywell type V3 style 38.
SW8	G.E.C. Dry reed capsule type RCX.
SW9	Crouzet ref: 83·547 (type 514·800)

MISC

LDR1, LDR2	Philips light dependant resistors version 2322 600 93001.

Printed Circuit Socket – Continental Connectors Ltd. No. 6PS4600AH32 7137 (for type 308 veroboard)

L1, L2, L3, L4	Philips stepping motor type AU 5055/81 with 10 tooth pinion to fit Philips type AU 5300/80CG gearbox, reduction 8·33 : 1.

COMPONENTS.

Fig. 13: Event water-level recorder circuit

When IC3 is actuated it discharges C12, thus preventing Q10 supplying stepping pulses. Only the reset phase can occur. If the stepping cycle is partly completed when the punch cycle starts then the interlock logic ensures that the stepping cycle is completed during the first stage of the punch cycle, before the punches make contact with the code discs.

The 60-minute/1-mm light-emitting diode D5 is controlled by Q8. A microswitch SW4, situated behind the high-order code disc and actuated by a 10-step cam, pulses D5 on at 60-minute intervals by discharging C7 into the base of Q8. D5 is thus pulsed on every 10 stepping cycles, preferably on 5, 15, 25, etc.

The punch-motor control is basically very similar to the SCR latching circuit employed in the rainfall event recorder (Chandler and Patterson, 1970). A punch cycle can be initiated by the ±15-mm reed switch SW8 or the ±3-mm/6-min LDR2 or the ±1-mm/60-min LDR1 or the 600-minute reed switch SW5 or SW9. It can be inhibited by SW2b. The resistor R24 and the capacitor C10 suppress electrical noise, while R15 and C6 provide similar suppression for the clock motor. The switch SW3 is used when SW2a and b is switched to the 'align' position for an alignment check of the high-order code disc during installation. The switch SW2b prevents punchouts during this operation.

5. ADJUSTMENTS, ALIGNMENT AND TESTING

5.1 Pressure pads (Fig. 12)

The pressure pads damp the high-order code disc rotation so that a smooth chatter-free drive is obtained. The pads are made of teflon, which allows controlled friction. They should be set by flexing, so that the friction is 130±20 grams when measured at the perimeter of the high-order disc, with the stepping motor removed from the gearbox.

5.2 Switch settings (Fig. 12)

Set the microswitch behind the high-order disc so that "overtravel" on the high sections of the 10-lobe cam is not excessive.

Set the upper reed switch so that it closes half way between 98 and 99. This ensures that a punch-out always occurs at 99 when the high-order code disc stops moving. The lower reed switch adjustment is given in section 5.3.

5.3 Alignment of code discs and punches

(1) Centralise the punch block with respect to the mounting screws to allow later adjustment, and level with respect to the code-disc centres.

(2) Set the stripper plate to 0.01-inch clearance from the punches.

(3) Remove the punch block.

(4) Set the toggle switch on the control panel (fig. 14) to the 'align' position and apply power.

(5) Press the step button and the high-order code disc will take up a position near 66.

(6) Repeat (5) but move the lower reed switch assembly until an alignment as near as possible to 66 is attained. On moving to 67 this alignment should leave the outer digit only one third covered by the stripper plate when checked with a square. If alignment is not satisfactory, disengage the 120-tooth gear from the 30-tooth gear and shift either way by one tooth. Check the 67 alignment. Repeat the gear disengagement twice only, if not satisfactory.

(7) If alignment is correct, check the reed switch movement for tolerance without effect on 67 alignment. Centralise.

(8) Final alignment may be made by a slight adjustment of the punch block and stripper plate.

(9) Note the low-order disc is aligned by adjustment of the detent plate.

5.4 Sensor adjustments

Adjust the magnet plate assembly of the sensor by releasing the Allen screw so that sensor operation is symmetrical when the recorder is level.

Adjust the nylon sensor box cam so that the sensor lifts just before the punch-motor switch changes over. With the sensor reset the recorder should only punch out when the high-order code disc reaches 99.

With the sensor shutter deviated by an amount equivalent to 1.5 divisions, the recorder should punch out 11 times per revolution of the high-order code disc. An ideal sequence would be 5, 15, 25, 35, 45, 55, 65, 75, 85, 95, 99. Move the 120-tooth gear/cam assembly behind the high-order code disc relative to the code disc if only 10 punchouts occur.

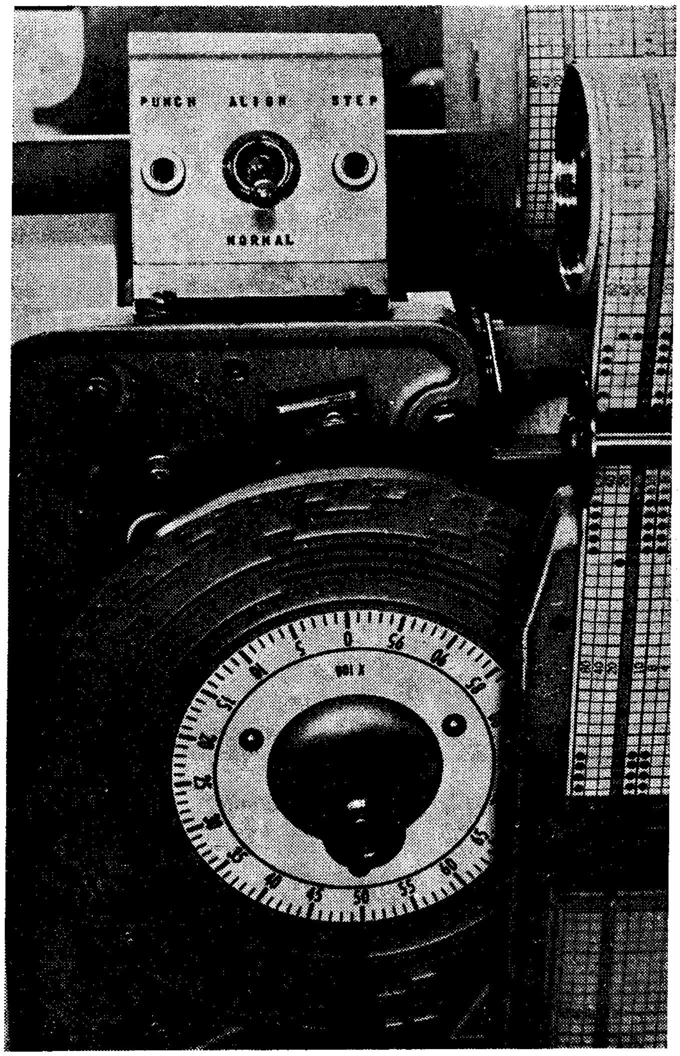


Fig. 14: High-order code disc and control panel

With the sensor shutter deviated by an amount equivalent to about 7 mm (greater than 2, 3, 4 or 5 mm, depending on the shutter used) punchouts should occur 100 times per revolution of the high order code disc, i.e. once for each stepping cycle. Long-term checking should be done with the shutter fixed in this position. A five-day run should produce a tape containing the sequence ...0, 1, 2, ...99, 0, 1, ...99 etc. on the left half of the tape. Sources of error may be incorrect adjustment, settings working loose with the punch shock, faulty motor SCR, or faulty contacts.

6. COUNTERS

Since only the last two digits of time and of stage are recorded, counters may be useful to keep track of the missing digits.

For stage, a small three-digit revolution counter (fig. 15) is driven via a 1:1 gearing from the input shaft. It is located behind the detent housing of the recorder and may be read when the clock cam

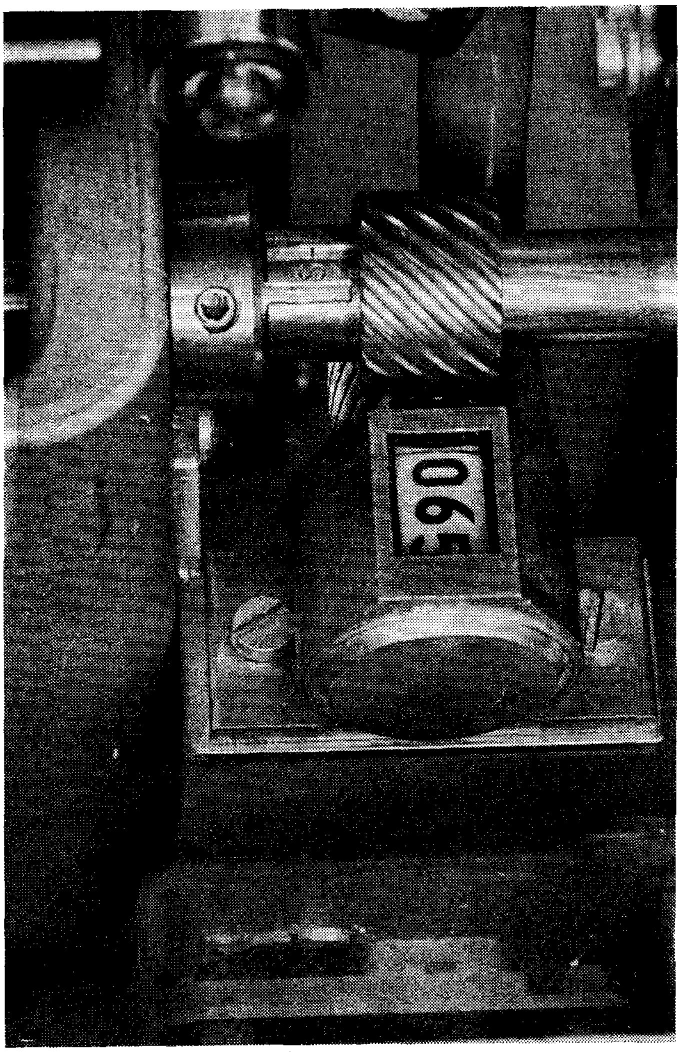


Fig. 15: Stage counter

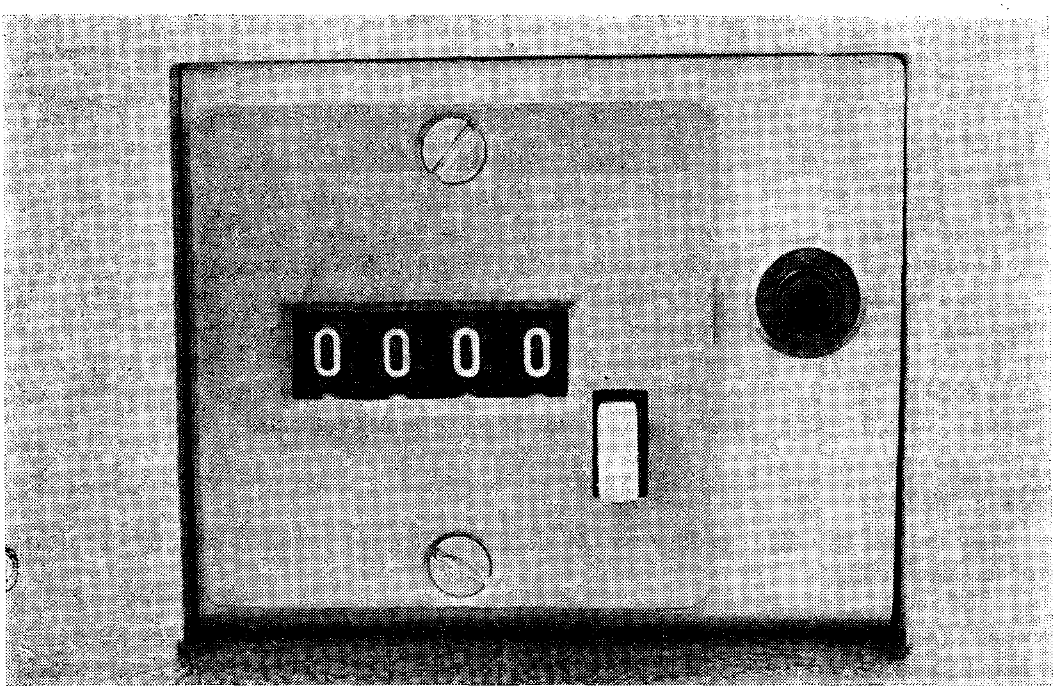


Fig. 16: Time counter

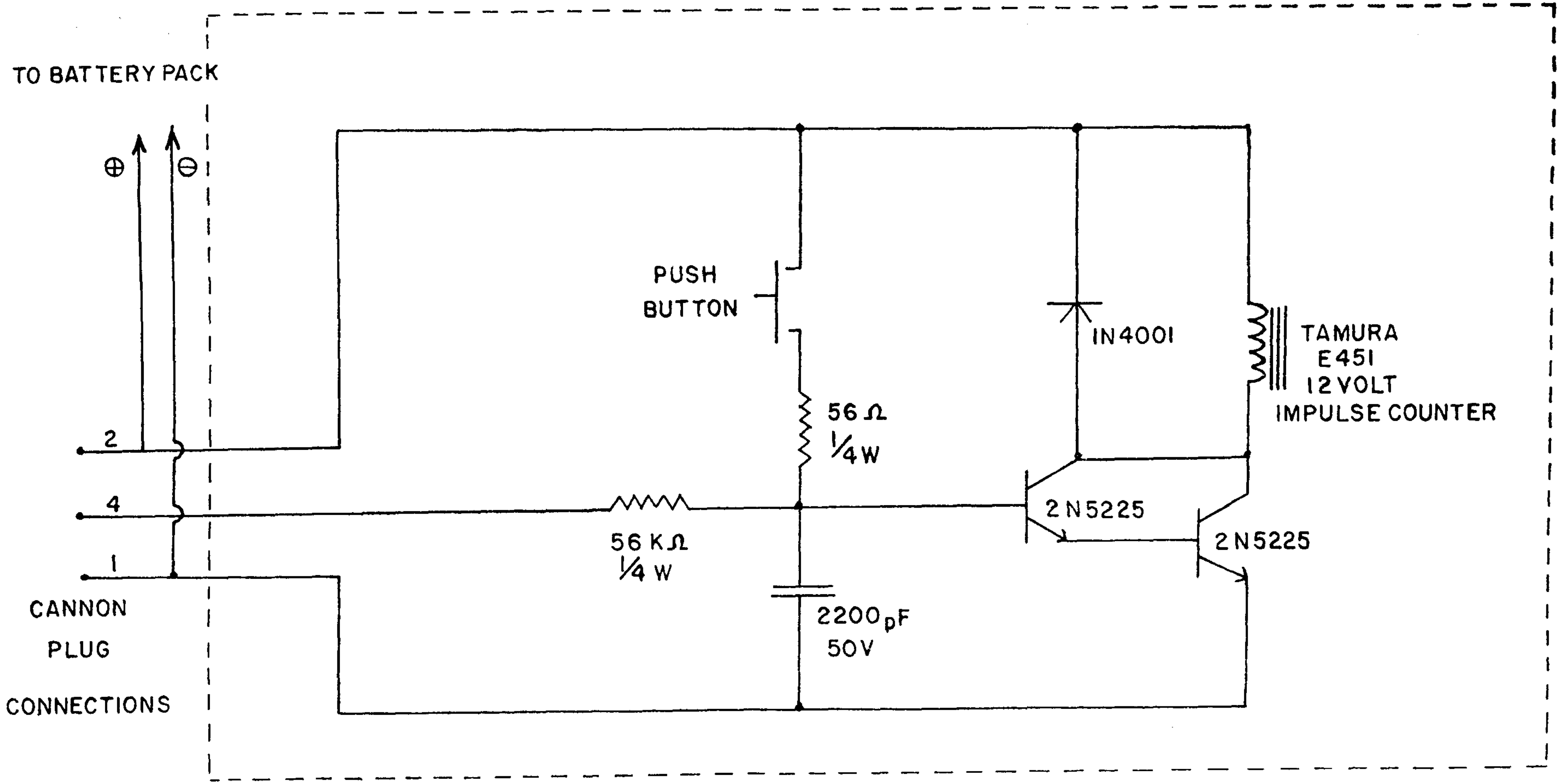


Fig. 17: Time counter circuit for event water-level recorder

is checked. Its main use is to help detect gross stage errors that would occur in unusual circumstances. The counter reads in hundreds of divisions, i.e. a change of 100 stage code disc divisions equivals a one-digit change in the counter.

For time, an impulse counter is used (fig. 16). It is driven by an electrical signal from the stepping motor circuitry (fig. 17). Because the counter is driven indirectly, it provides three useful checks.

(1) A check on correct stepping motor circuit operation.

(2) A check on elapsed time, during visits, without referring to the tape.

(3) A check against the tape during later analysis of the record.

The counter repeats the time code disc readings and gives two more significant digits. It is connected to the recorder via the rear battery socket. Presetting and resetting push-buttons are provided to establish initial agreement between the time counter and the time code disc.

The need for these counters depends on the operating circumstances of the recorder. In current research they provide a useful check on the reliability of the event water-level recorder and provide help if errors occur during data processing.

7. FIELD PROCEDURE

A detailed field procedure will be covered in a later publication.

The observer must make sure that all manuscrip notations made on this check list record *and the copy* are readable. A sharp pencil or ballpoint pen must be used. The observer must fill in, where indicated, his name and initials, the date of the observation, the river name, the site name and the site number.

8. REFERENCES

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9. ACKNOWLEDGEMENTS

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PROCEDURE PREVIOUSLY PUBLISHED

1. Estimation of the Design Rainstorm 1973
2. Water Quality Sampling for Surface Water 1973