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Contents

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Abstract. A hybrid analogue/digital device has been designed for semi-automatic processing of records from magnetic observatories. The machine produces hourly and daily mean values in final form (i.e. multiplied by scale factor and with baseline correction added), in a single operation. Output is either on printed sheets suitable for direct photo-offset reproduction, or on punched cards, or on both simultaneously. The machine features high reliability (no errors caused by equipment malfunction or operator mistakes), and moderate accuracy (±1 per cent ±1 gamma). A significant saving in manpower is achieved by its use; three component data for an observatory for one year can be completely processed in about six weeks. One unit has been in operational use at Victoria since 1962, and seven years of data have so far been successfully processed by this method.

Résumé. Un ordinateur hybride à représentation analogique et numérique a été mis au point pour assurer le traitement semi-automatique des données enregistrées par les observatoires magnétiques. L'appareil produit en une seule opération des valeurs moyennes horaires et quotidiennes dans leur forme définitive, c'est-à-dire en tenant compte du facteur d'échelle et des corrections en fonction de la ligne de base. Les sorties sont portées soit sur feuilles imprimées prêtes à la reproduction par procédé photo-offset, soit sur cartes perforées, ou simultanément sous les deux formes. L'appareil est extrêmement sûr en ce qu'il n'est pas faussé par le mauvais fonctionnement de son mécanisme ou les erreurs des préposés, et il est relativement précis (±1 p. 100 ± 1 gamma). L'emploi de cet ordinateur permet de réaliser d'importantes économies de personnel; les données à trois composantes fournies par un observatoire pendant une année entière peuvent être traitées en six semaines environ. Un de ces appareils est en usage à Victoria depuis 1962 et a déjà traité avec succès des données enregistrées au cours d'une période de sept ans.

Introduction

The machine described in this paper is used to process "standard" magnetograms, to provide the hourly mean values in a single operation. Although "on-line" digital magnetographs are in use at a few locations (for example Alldredge and Saldukas, 1964; Hultquist *et al.*, 1962; Andersen, 1969), the majority of magnetic observatories still record their data in analogue form. A major part of the work at each observatory therefore consists in the manual reduction of these data; at its worst, this consists of four steps: a) scaling in mm by making a visual estimate of the hourly mean value; b) multiplication by scale factor; c) addition of baseline correction; d) typing. The typed sheets are subsequently reproduced for publication in a standardized form. Step (b) can usually be eliminated by the use of gamma-graduated scales, provided the scale factors are sufficiently stable to warrant the manufacture of permanent gauges; even step (c) can sometimes be eliminated by the use of more complicated add and multiply scales, but this increases the probability of errors. Altogether, the entire process uses about 4-6 man-months for three orthogonal components of magnetic data recorded in one year.

It is clear that "on-line" digital systems, i.e. recording systems with direct digital output, are the ideal answer to this problem. However, their technical complexity inevitably results in lower reliability than can be obtained for photographic variographs; typically, a standard magnetograph may have one failure (bulb replacement) every 2 - 3 years. The use of digital recording systems will therefore be limited to locations where technical facilities for servicing are readily available. Even if all their technical disadvantages are overcome to the point where they would be used for all new installations, it is unlikely that funds for retroactive modification of all existing installations would be available. At present, and in the foreseeable future, standard magnetographs will therefore continue to be used by most observatories; some "off-line" processing machine is therefore needed for two reasons: a) to cut down the processing time for the production of hourly mean values and thereby free personnel for more productive interpretation work; b) to provide the data in computer-compatible form in order to facilitate the increased use of automatic processing.

Since the "off-line" processing machine need not be located at the observing site, its technical complexity is not an obstacle, nor does its reliability have to be very high. The recording equipment can be kept technically simple and reliable, and processing for one or several stations can be carried out at some convenient central location. It should be pointed out that use of a processing machine is not necessarily the best solution in all cases. It is certainly justifiable in countries where relatively high-priced technical or scientific personnel are used for the manual processing. However, the machine has no inherent scientific advantage (other than better manpower utilization) over manual processing. If low-cost reliable labour is available, it may well be more efficient to do duplicate manual processing with cross-checking, followed by manual keypunching (again in duplicate) if computer-compatible data is required. The purchase or construction of a complex processing machine (and this applies to "on-line" systems as well) must be carefully weighed in terms of the particular economic situation–such as for example the availability of a low-cost clerical labour pool, or the use of prison labour at no cost for punching of data (Malin, 1969).

The most common approach to "off-line" processing involves digitizing of the traces, with subsequent computer processing to obtain the hourly mean values. Machines used for this purpose range from standard commercial X-Y digitizers to a highly complex computer-guided automatic machine using optical scanning (Lenners, 1966). A practical compromise between these two extremes is a specially designed Y-digitizer with manual guiding (Nelson, 1967) which is being used by the Coast and Geodetic Survey in the U.S.A. This machine is available commercially at a cost of about $22,000.

The alternative approach, used in the design described in this paper, is a machine which provides the hourly mean values directly, without the use of a digital computer. By aiming for realistic accuracies (1 - 1.5 per cent) such a machine, using internal analogue computation with digital output, can be built more economically–about $10,000 - $12,000 for a commercial version. The choice between digitizers and such a machine depends on the specific application and facilities of the user. The main advantage of the "magnetogram reader" is that final results are obtained without the need for a computer. Although this is becoming progressively less important as computers become more easily accessible, it is still a significant consideration for installations which are not located near a computer facility. Other than this, the distinction between the two types of system is mainly the obvious distinction between any "special-purpose" and "general-purpose" system. To state the obvious, the special-purpose system is usually more efficient (initial cost, operating time, convenience) for the particular purpose for which it was designed, but it lacks the flexibility of the "general-purpose" system. Specifically, we feel that our magnetogram reader is preferable if print-out of hourly mean values is the primary objective, with or without computer-compatible output as well. However, if higher time-resolution output of all or most of the data is required as well, or if a digitizer can actively be used for other purposes within the organization, then a digitizer/computer system may be preferable.

Design of the magnetogram reader and construction of a prototype unit were carried out at Victoria and completed in 1962; preliminary results have been reported by Caner and Whitham (1962). The prototype unit was "home-made", using surplus and other cheaply available components. The 1962 and 1963 data from the Victoria magnetic observatory were successfully processed on this machine and a commercial version

Figure 1. Overall view of magnetogram reader with keypunch and printer, shown set up for left-handed operator.

was ordered from a local manufacturer. The new version was built to higher engineering standards, and also incorporated modifications which were suggested by operational use of the prototype. Since then a further five years of data have been processed: 1964-1965 with printer output only (see for example Auld and Andersen, 1966, for the 1964 data), and 1966-1967-1968 with punched card output as well (for example Auld and Andersen, 1968). Accuracy and reliability have been maintained at the specified level; the present publication describes technical details of the final design, which has been thoroughly evaluated in operational use as indicated above.

Basic design considerations

The magnetogram reader is designed specifically to provide hourly mean values from standard magnetograms (15 or 20 mm/hr). Output is directly on printed sheets in final form, and of a quality adequate to permit direct photo-offset reproduction in observatory publications. A secondary output is available for digital data in computer-compatible form (punched cards or tape); this output can be used in addition to (or instead of) the printed output.

The main emphasis in the design has been on reliability, ease of operation, and service-free long lifetime. Little emphasis has been placed on the more usual criteria of electronic design, such as compactness, low weight, and power consumption. It was designed for simplicity of operation, to permit use by unskilled personnel with a minimum of supervision and checking. It is liberally equipped with interlock circuits of the "fail-safe" type which would stop operation (rather than give a false read-out) in case of incorrect operation or equipment failure.

The nominal accuracy of the process has been specified as ±1 per cent of ordinate ±1γ in the mean hourly value. Although this compares unfavourably with the accuracy which can be obtained in theory from digitizer systems, particularly the complex optical scanning type of Lenners (1966), it is quite acceptable for this particular application, both from the point of view of data usage and the point of view of the accuracy of the original data (i.e. variograph calibration accuracy, baseline stability, and dimensional stability of the photographic paper). This accuracy applies to magnetogram time-scales of 15 or 20 mm/hr; since the machine operates on a cumulative principle, the accuracy becomes progressively worse when used over shorter intervals, and better for longer intervals; for example an accuracy of 0.1 per cent ±0.1γ can be obtained in the daily mean.

The range of output values is ±9999 (four-digit counter); the ordinate range is 175 mm on either side of the baseline. The scale-factor range is 0 - 15γ/mm for a time scale of 20 mm/hr, with a setting resolution of 0.005 γ/mm. The scale-factor range and setting resolution can be modified at each others expense, for example 0 - 30 γ/mm with 0.01 resolution. Declination is being handled in the same ranges, defining 0.1′ as the basic unit, i.e. scale factor range 0 - 1.5′/mm at 20 mm/hr. The decimal point is subsequently inserted in the output format.

The machine is bi-directional; traces above or below the baseline are respectively added or subtracted. A toggle switch reverses the above pattern, to select upward or downward directions of increase for the particular component. The baseline (i.e. zero reference line) can be positioned anywhere on the magnetogram. Baseline corrections to be added to the scanned value can also be either positive or negative; they are entered by digital thumb-switches to the nearest integer unit (1γ or 0.1′). The final output, printed and/or punched, is the correct algebraic value: (mean hourly ordinate) × (scale factor) + (baseline correction).

Principles of operation

The magnetogram reader is a hybrid analogue/digital device; its operating principle is outlined schematically in Figure 2; optional components are shown in dashed lines. Mechanical analogue methods (ball and disc integrators with suitable gearing) are used to integrate the motion of the hand-guided pointer which follows the trace, and to multiply this integrated value by the scale factor. Analogue-to-digital conversion is performed by a rotating slotted disc and photo-cell. The digital output is accumulated on an electronic counter, where the baseline correction is added as well (by starting the count from a preset value rather than from zero). The counter is bi-directional, i.e. counts are added or subtracted according to the position of the pointer with respect to the baseline.

The accumulated counter reading (i.e. final hourly mean value) is transferred to a decimal storage relay matrix at the end of each hourly interval, and the counter automatically resets to the "baseline correction" value. The output devices can then operate off the storage relays while scanning of the next hourly interval is in progress. Two independent outputs are provided, which can be used separately or simultaneously: an IBM Type 82 Output Writer (electric typewriter with solenoid-actuation of numeric and function keys), and an IBM Type 526 Summary Punch (keypunch with facilities for remote input-output). Both output devices retain their non-specialized functions, as typewriter and manual keypunch, when not in use as the output stage of the magnetogram reader.

The magnetogram is taped to a plate which is driven laterally by a lead-screw at a variable rate controlled by foot-pedal. The operator tracks the trace by means of a pointer which is free to move in the vertical direction; the guiding can be done by directly holding the pointer (useful for following large-amplitude deflections), or more usually by a rotary handle. Since the lead-screw is geared to the integrator "time" input, the integrated output ("ordinate" with respect to "time") is correct whatever the rate of scan, allowing a wide range of scanning speeds as well as mid-scan pauses. The system is completely reversible; algebraically correct values are obtained when retracing backwards after overshoot.

In addition to the basic *hourly mean* system, an optional parallel system accumulates the *daily mean* value to the nearest 1/10 unit (0.1γ or 0.01′), which is then printed (and/or punched) at the end of the 24th hour. Apart from saving some

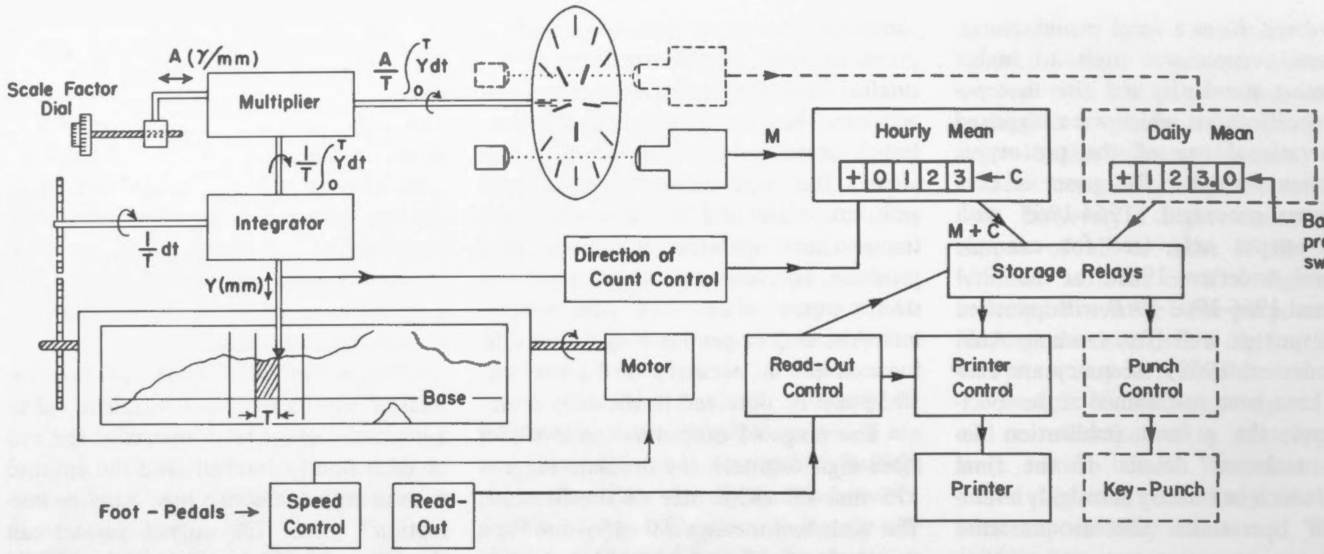


Figure 2. Block diagram of basic principle.

computations, this provides a double-check on the entire electronic and read-out system, since the two channels are processed independently. Since the mechanical system is inherently error-proof (short of actual physical damage), the overall output reliability is therefore very high. In fact no "random" errors which could be attributed to equipment were observed over the entire five-year period.

No line voltage stabilization is necessary, and there are no critical adjustments or alignments which can drift with time. Once zero reference, scale-factor, baseline correction, and direction of increase of the component have been entered, the operator needs to use only the "drive" and "read-out" foot-pedals.

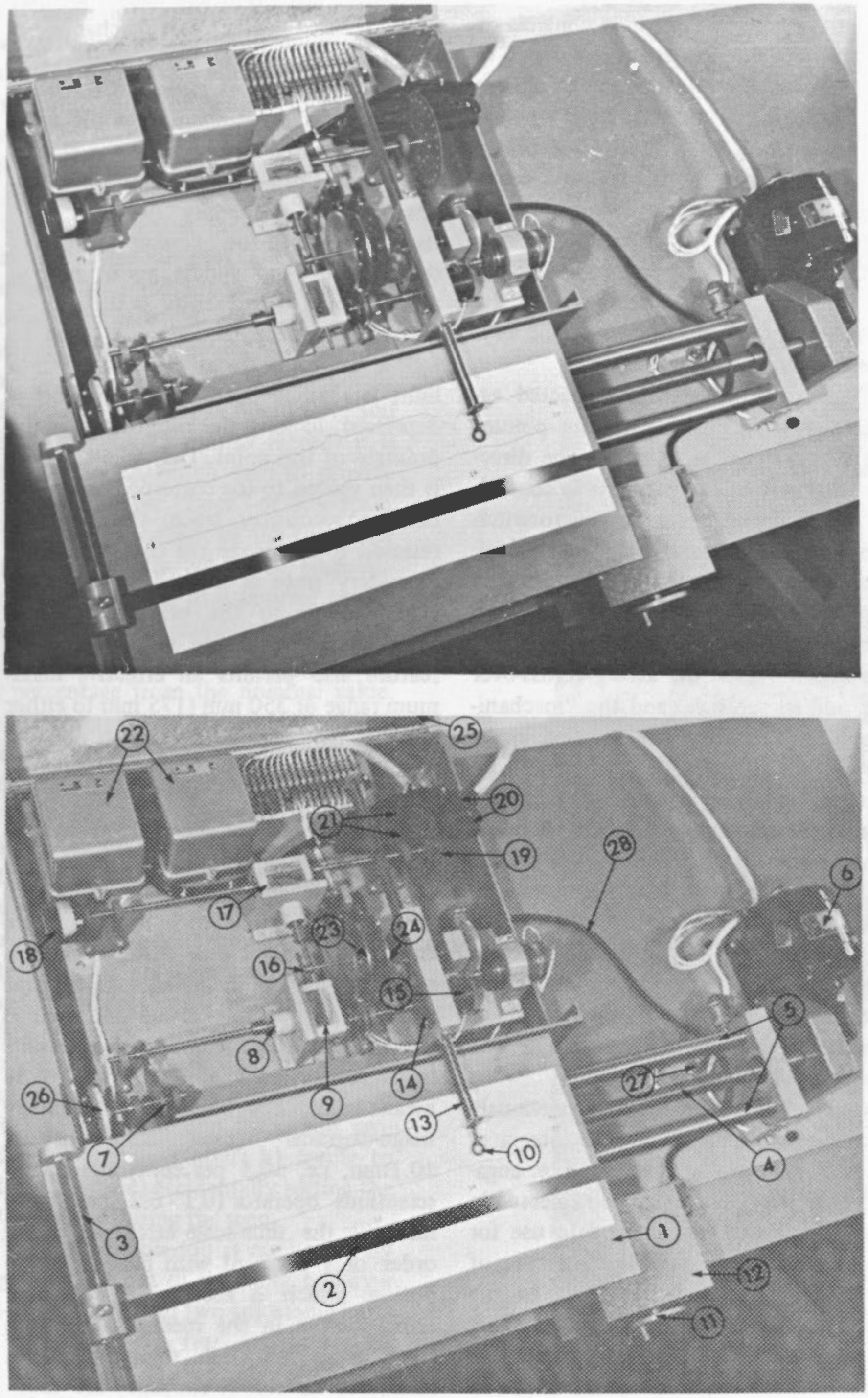
Full technical details of the separate sub-systems (mechanical, control, output) are given in the next three sections. A discussion of accuracy and operating reliability is given at the end of the paper.

Mechanical system

The mechanical system is shown in Figure 3. The magnetogram is taped to the carriage plate (1), using the baseline (zero) setting bar (2) to determine its position; the setting bar itself can be moved up or down over the hinged rod (3), to accommodate different types of magnetogram layout. Once the magnetogram has been positioned, the setting bar is swivelled out of the way, to give unimpeded view of the entire magnetogram. The carriage itself consists of a heavy (0.5-in. thick) aluminum plate; it is driven by a 0.875-in. diameter lead-screw (4), but its weight rests on two 1.125-in. diameter polished steel bars (5) along which it can slide on linear-motion (ball-slide type) bearings. This provides minimum wear on the lead-screw mechanism. The entire system is sufficiently massive, and the motor (6) sufficiently geared down (54 in.-lb output torque), to permit the operator to rest his arm on the plate and "travel along" with the carriage, for maximum comfort and minimum fatigue. The operator can also do work on the carriage while it is moving, such as for example exchange magnetograms during the carriage return.

The free end of the lead-screw is geared (7) to the time input (8) of the first ball and disc integrator (9); this provides the "time-scale" (dt) input to the system. The carriage can therefore be driven at variable speed, to accommodate different degrees of trace disturbance or operator competence. The speed is controlled by a foot-pedal which varies (via a control circuit) the armature voltage of the 1/8 HP DC motor (6), providing smooth variation from virtually motionless creep to a maximum speed of about 5 mm/sec. A switch built into the foot-pedal also provides "dynamic braking" of the motor, to provide instantaneous stop without coasting. The motor can be reversed for backing up in case of overshoot or tracking error; since counting direction is reversed by the same circuit, the overshoot error is corrected if the operator retraces over the same path, i.e. correct algebraic reading is maintained.

The pointer itself consists of a small black dot engraved on the underside of a plexiglass disc (10) fixed to the pointer bar (13). The disc slides just above the magnetogram, providing a parallax-free optical system without the need for rigidly fixed location of the operator's eyes. This permits the use of auxiliary lighting or visual aids to suit the particular operator's convenience and eyesight, such as the ring-lighted magnifying lens shown in Figure 1. The pointer is normally guided to follow the trace by means of a rotary handle (11), at a rate of 3 mm per turn. However, it can also be guided directly by hand if the trace excursions are very steep or if it otherwise suits the operator's convenience. The guide crank box (12) containing the transmitter synchro is removable and can be relocated for maximum operator convenience; in particular it can be located to the left of the pointer bar (as shown in Figure 1) for use by a left-handed operator. This provides a significant increase in operating efficiency and accuracy when used by left-handed operators (about 10 per cent of the population)–a point often overlooked in the design of equipment of this type. The synchro-receiver is geared to the rack of the



(1) Carriage plate
(2) Base-line setting bar
(3) Hinged rod
(4) Lead-screw
(5) Support bars
(6) Carriage motor
(7) Gear linkage to lead-screw
(8) Time-scale input of integrator
(9) Ball and disc integrator
(10) Pointer dot
(11) Guide crank
(12) Guide crank box (shown mounted for right-handed operator)
(13) Pointer bar
(14) Input gear of clutch
(15) Clutch
(16) Ordinate input of integrator
(17) Ball and disc multiplier
(18) Scale-factor dial
(19) Rotating disc
(20) Light sources
(21) Photo-cells
(22) Photo-cell amplifiers
(23) Cam, direction of count control
(24) Cam, integrator limit alarm
(25) Hinged metal cover
(26) Time-scale cam
(27) Carriage return microswitch
(28) Servo linkage, guide crank

Figure 3. Mechanical (analogue) system of magnetogram reader. Component numbers are referred to in text.

pointer bar, rather than directly to the input of the integrator; this means that the servo linkage and gearing need not be particularly tight or accurate, as long as it drives the pointer with acceptably low slippage. The gearing needs to be backlash-free only between the pointer bar and the integrator input.

The pointer bar (13) consists of two parallel rods spaced 1 in. apart, riding in two sets of linear-motion bearings in a 5.5-in. wide bracket. This prevents rotation or sideways motion of the pointer which would reduce tracking accuracy. The lower shaft is a 0.375-in. diameter round-stock rack, which rides directly over the input gear (14) of an electrically-operated clutch (15). The output shaft (inner concentric) of the clutch drives the linear-motion (y-ordinate) input (16) of the integrator through a gear and pinion/rack set. The output of the integrator is directly linked to the input of the second ball and disc integrator (17), which is used as a multiplier. The multiplying factor is entered by a 4-digit, 100-turn, digital dial (18) with locking brake. The dial rotation is converted to the linear motion of the ball slide by a pinion/rack drive within the integrator. With the chosen gear-ratios and other parameters, the dial setting is twice the desired scale-factor for a time-scale of 20 mm/hr; it can be set to within 0.005 units of scale factor, although 0.01 units is generally adequate. For example, dial setting 1602 represents 8.01γ/mm or 0.801′/mm. The dial range is 0000 - 3000, i.e. scale-factor ranges 0 - 15γ/mm or 0 - 1.5′/mm. Lower sensitivities (i.e. higher scale factors) can be accommodated by increasing the number of holes in the output disc (see farther on), with a corresponding decrease in setting resolution.

For magnetogram time-scales other than 20 mm/hr, an appropriate proportionality factor has to be applied to the dial settings. For example, if T = 15 mm/hr, a speed common in La Cour magnetographs, a dial setting of (20/15) X 1602 = 2136 would be required to obtain a scale factor of 8.01γ/mm. The machine can readily be used with acceptable accuracy (1 - 2 per cent) to about 10 mm intervals, but for shorter intervals it becomes progressively less satisfactory.

The output of the multiplier directly drives a light-weight fibre disc (19); with such minimal inertial loading the accuracy and lifetime of the ball and disc integrators is very high. The analogue-to-digital conversion is performed by the rotation of this disc between a light-source (20) and photo-cell (21). An outer ring of 24 holes drives a photo-cell at 24 counts per rotation, to provide the accumulated hourly mean value on a totalizing counter, in integer units (gammas, or minutes of arc for declination). A second ring of 10 holes can be used to drive a separate photo-cell, to provide an accumulated daily mean value, to the nearest 1/10 unit (0.1γ or 0.01′). The use of two independent channels permits a double check of the complete following, electronic, control, and read-out system.

The output of the photo-cells is processed by amplifiers (22) which provide uniform-width pulses regardless of the rate of rotation of the disc. The output of the amplifiers is fed directly (DC coupling, and with no intervening controls or reversals) to the inputs of two separate bi-directional counters. The amplifiers provide large-amplitude (24-volt) pulses at very low impedance (under 100-ohm); the counter input impedance and sensitivity can therefore be kept very low (and shunted by large capacitors), to provide immunity from noise pick-up, in spite of the heavy transients originating in the electromechanical components (the key-punch in particular).

Counts are added or subtracted according to the position of the pointer with respect to the baseline. The direction of count of the counters is controlled by a low-differential microswitch riding on a 4-in. diameter cam (23) which is geared to the y-ordinate system. The cam is fixed to its shaft by means of an adjustable hub-clamp. Coincidence between the "electrical zero" (cross-over from add to subtract) and the "mechanical zero" (stationary position, i.e. cross-over from clockwise to anti-clockwise rotation) is carried out on initial installation by adjustment of this hub. A second microswitch and cam (24) on the same shaft operate an alarm buzzer to indicate that the travel limit of the integrator is being approached. Although end-stops are provided as well, this alarm protects against possible distortion of components by forcing against the end stops.

The clutch (15) mentioned previously connects the pointer bar to the integrator input. It is normally energized (i.e. engaged) and its existence can be neglected in normal operation. It comes into use for two special functions: a) initial setting of the "zero" of the mechanism to the magnetogram baseline, and b) tracking secondary (off-scale) traces without loss of continuity. The zero setting needs to be carried out only once at the start of each day's run, or after any power-line interruption. The pointer is moved until zero is reached, as indicated by an audible click of the relay which operates on crossing between "add" and "subtract" (see relay L_{15} of Figure 5a). The clutch foot-pedal is then depressed, disconnecting the pointer from the mechanism. The clutch is of the "spring brake" type, i.e. the output shaft is locked when the input shaft is disconnected. The mechanism is therefore "frozen" in the zero position, the "free" pointer is moved to the baseline on the magnetogram, and the foot-pedal is released to re-engage the clutch. Coincidence of the baseline and mechanism "zero" is thereby obtained, and remains set until the operator or a power cut releases the clutch again. Setting accuracy and repeatability is 0.2 mm or better. A similar procedure is used to follow off-scale traces: when the trace limit is reached the clutch foot-pedal is depressed, locking the mechanism at the ordinate of this point. The "free" pointer is then moved to the corresponding point on the secondary trace, the pedal is released to re-engage the clutch, and the secondary trace is tracked in the usual way. Return to the primary trace is achieved by the same procedure. This feature also permits an effective maximum range of 350 mm (175 mm to either side of the baseline), in excess of the actual 300 mm mechanical travel range of the pointer bar.

The accuracy of the analogue system is limited almost entirely by the accuracy of the time scale, since the output is directly proportional to it. Any departure from the nominal time scale, whether a real irregularity in magnetogram time scale or an operator-caused one such as uncorrected over- or under-shoot, results in a proportional error in the hourly mean value. For standard observatory magnetograms (time scale usually ±0.1mm, i.e. ±0.5 per cent) and a conscientious operator (0.1 - 0.2 mm "resolution"), the time-scale errors are of the order of 1 per cent with random distribution, which is acceptable. All other error sources in the mechanical system (such as gear backlash, shaft distortions, integrator or clutch slippage) are negligible compared to the above figure. For records obtained from portable instruments and other magnetograph installations with irregular time scales, or for careless operators, the time-scale error could become prohibitive. An optional "time-scale interlock" has therefore been incorporated, to block read-out if the time scale is incorrect. A microswitch is operated by a notched cam (26) geared to the carriage lead-screw; the counts are accumulated on an electromechanical counter with decimal read-out contacts. This reading is a measure of the carriage travel. The counter is bi-directional, the direction of count being switched when the direction of carriage travel is reversed; the time-scale counter therefore provides a true measure of net carriage travel, regardless of reversals. The counter is automatically reset to zero during each hourly-mean print-out. With a 15-notch cam, 20 mm of carriage travel provide 94.5 counts; the cam is removable, and when processing 15 mm/hr records it is replaced by a 20-notch cam to provide the same count per "hour" of time scale.

The decimal output of the time-scale counter (nominally 94.5 per magnetogram hour) is wired to a control circuit which inhibits the read-out command if the reading differs by more than a specified percentage from the nominal value. The percentage can be set by a front-panel switch (see Figure 4) to 1, 2, 3, or 4 per cent. For example, with the switch set to 1 per cent, read-out cannot be obtained unless the time-scale counter reading is 93, 94, or 95; for 2 per cent the allowable range is 92 - 96. Use of the time-scale interlock therefore provides protection not only against inaccuracies caused by magnetogram time-scale irregularities or operator carelessness in overshooting the time-mark, but also against major operational errors such as: a) forgetting to read out one value and proceeding to the next hour; b) trying to read out twice; c) accidentally hitting the read-out pedal during the scan.

The entire table-top is connected by hinges to the front of the table, and by a lead-screw crank and two adjustable locking brackets at the rear. Its tilt can be adjusted to suit the operator's size and convenience, from horizontal to a maximum of 45°; about 30° is found to be the most comfortable position in most cases. Since the pointer moves just above the trace, i.e. is virtually parallax-free, the operator can use any lighting or vision aids he chooses, either permanently or occasionally. He can use just the general room lighting, or an additional fluorescent lamp clamped to the table, or (as

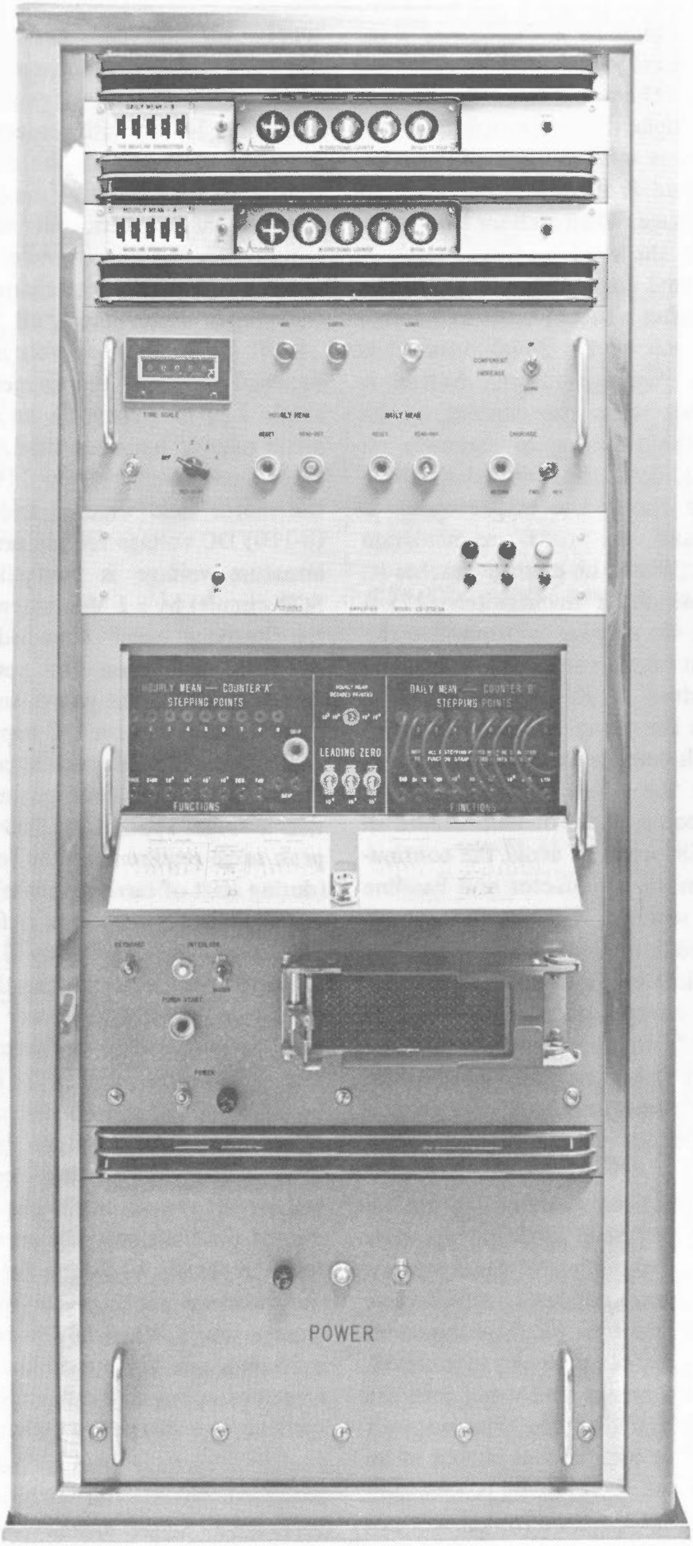


Figure 4. Control assembly, containing (from top to bottom): daily mean counter, hourly mean counter, main control unit, storage relays, print control unit (shown with opened access door to patch-board), punch control and power supply.

shown in Figure 1) a ring-lighted 5-in. diameter magnifying lens, which can be swung out of the way if not required.

Actual operation is very simple: the zero-set bar is swivelled out of the way, and the speed foot-pedal is depressed to run the carriage. When an hour time-mark is reached, the read-out foot-switch is depressed, and scanning continues to the next hour after a short ($\sim$ 0.1 sec) delay. When the end of the 24-hour record is reached, a "carriage return" button is pressed; this starts the carriage on its return, without having to manually reverse or hold down the foot-pedal. During this return travel, the magnetogram is removed and the next magnetogram positioned. When the carriage reaches its "start" position, a microswitch (27) is struck and the carriage is stopped, ready for the next record's scan. The time taken for the return is 90 seconds, which is ample time for changing of the magnetograms. Each component is processed separately for the whole year, rather than the three components of each record in sequence, in order to avoid the continuous changes in scale-factor and baseline correction settings. If the magnetograms are recorded from 0 to 24 U.T. (as is the case for Victoria), a toggle switch at the rear of the control unit can be pre-set to "automatic"; in this case the carriage return cycle is automatically triggered by the "daily mean" read-out. No further controls need be used in normal operation.

An experienced operator can process comfortably, without particular pressure, an average of about eight magnetograms (one component) per hour. An effective rate of well over one month/component per working day can easily be maintained, even if some breaks and other jobs are interspersed to reduce the monotony of the work. The total annual output of an observatory can therefore be processed in about 6 - 7 weeks—a considerable saving in time over manual methods.

Main control assembly

A) Power and count control circuits (Figure 5a). The power supply is mounted on a separate chassis and consists of: a) two unregulated 24-volt–3-amp DC supplies, and b) a modular variable-speed supply for the DC motor. The two 24-volt supplies are connected in series with centre grounding, providing +24-volt and −24-volt with respect to ground (denoted as 0 volt in the drawings), as well as 48 volts. Most of the components operate on 24 volts, but 48 volts are required for the output writer circuits. In order to maintain interchangeability of the plug-in components, all relays have 24-volt coils; where 48-volt operation is imposed by circuit requirements (for example L_{30} on Figure 6), an appropriate series resistor has been used. The motor controller provides fixed 110 VDC for the motor field winding and a variable (0-110) DC voltage for the armature; the armature voltage is controlled (via an SCR circuit) by a 1 Meg potentiometer in the "carriage speed" foot-pedal. A main ON-OFF switch on the power supply chassis switches the power to the entire system, i.e. the above DC supply units as well as the AC loads such as counters and typewriter motor. Total power consumption averages about 150 - 200 watts, with peak surge requirements up to 300 watts (during start of carriage return).

The armature voltage is fed through the "forward-reverse" relay (L_{11}), which is normally not energized, to the "power" relay (L_{10}); with the power relay energized it is then fed to the motor armature. The power relay (L_{10}) is energized by 24 volts either from the microswitch in the foot-pedal, or from the "carriage return" relay (L_{17}); however, the relay coil circuit 0 volt end is cut a) if either one of the limit switches on the carriage frame is struck, b) during the transfer of the counter readings to the read-out storage relays. When L_{10} is de-energized, a 10-ohm resistor is switched across the armature, acting to dynamically brake the carriage to a sharp stop without coasting.

The "carriage reverse" relay L_{11} is energized by 0 volt either from the FWD-REV toggle switch on the front panel, or from the "carriage return" relay L_{16}. It reverses a) the direction of rotation of the motor (by reversing the armature voltage polarity), and b) the direction of count of the main counters.

Relays L_{16} and L_{17} are energized and self-locked either by the manual RETURN push-button on the front panel, or (if the rear mode control switch is on "automatic") by a pulse from the "daily mean read-out" cycle. These two relays perform the following functions: a) energize L_{11} to reverse the carriage travel direction; b) energize L_{10} to provide carriage power; c) switch the speed control from the foot-pedal potentiometer to a fixed-setting locking potentiometer on the rear panel. They also energize an auxiliary "carriage return" relay L_{21}, which locks the counters at their preset reading, and which has delayed release by means of a 120-mfd capacitor across the coil. All three relays remain locked until the carriage return microswitch is struck, opening the 0 volt line to the upper ends of L_{16} - L_{17} and releasing these two relays to stop the carriage travel. The release of L_{16} also de-energizes L_{21}, which releases with a time delay of about 0.1 second. This ensures that the carriage has come to a complete stop before the GRD is removed from the counter RESET inputs, so that the counters remain accurately at the preset (baseline correction) setting, ready to start scanning of the next record.

The counting direction control lines (115 VAC from the microswitch on the mechanical assembly) can be reversed either by the "carriage reverse" relay L_{11}, and/or by a front-panel toggle switch which is set for the direction of component increase on the magnetogram (UP or DOWN). If the counter function is ADD, only the "add" pilot light is energized. If the function is SUBTRACT, relay L_{14} is energized in addition to the "subtract" pilot light. In order to maintain maximum lifetime for the low-differential microswitch, all switching is carried out on the AC line, with subsequent rectifying to operate the DC relay L_{14}. A small (0.01-mfd) capacitor provides additional protection for the contacts. This "subtract" relay (L_{14}) applies the bias voltage (+25 VDC) from the counters to the "direction control" terminals of the counters, thereby switching the counters into the "subtract" mode. When these terminals are open-ended or grounded, the counters remain in the normal "add" mode. The counters fea-

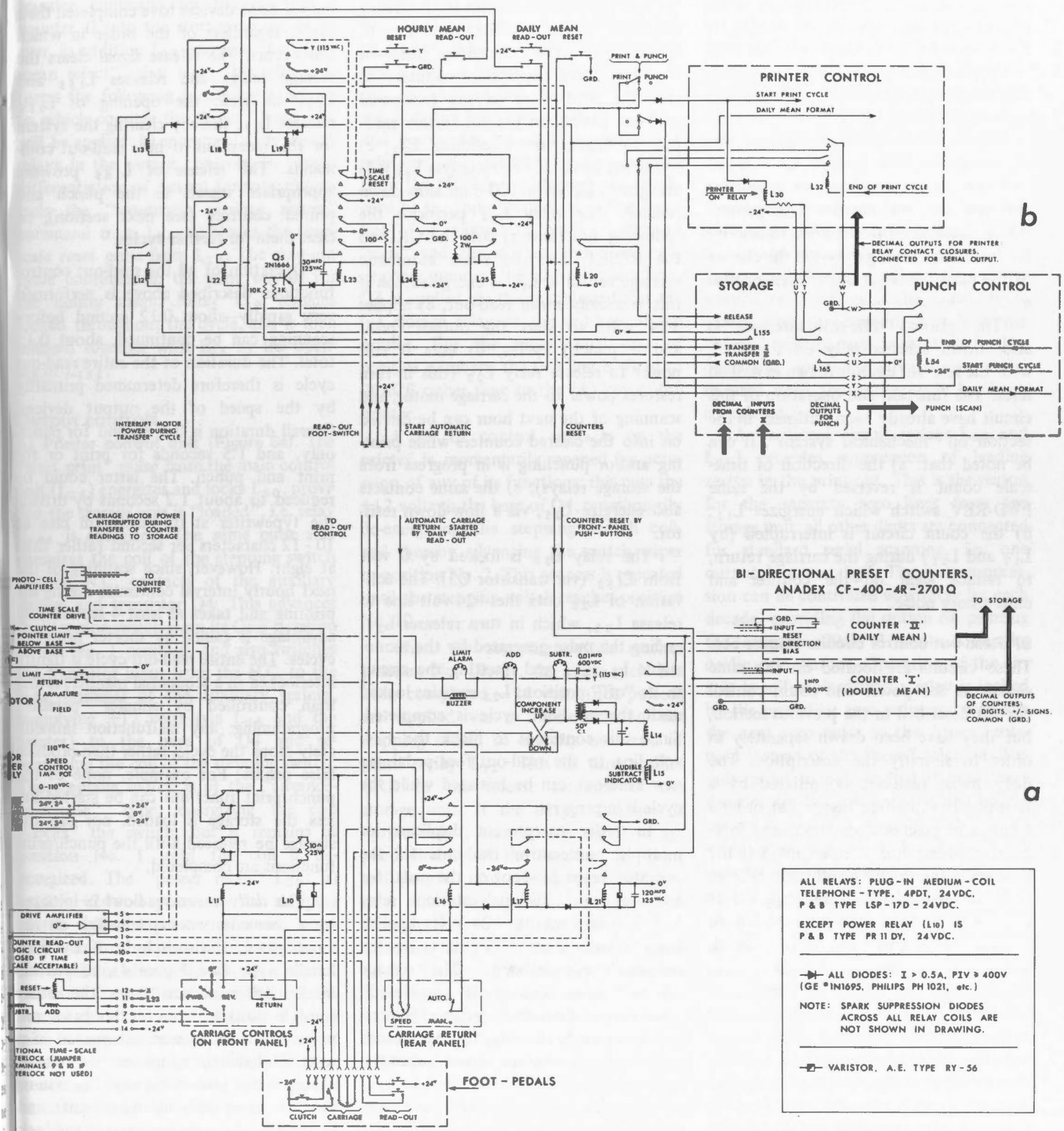


Figure 5. Main control assembly: a) power and count control circuits, b) read-out control circuits.

ture automatic internal reversal when counting through zero, e.g. 5, 4, 3, 2, 1, 0, −1, −2, −3. . . .

The subtract relay L_{14} also energizes L_{15}. This is a relay of the general-purpose type which is very noisy in its operation. It is not used as a load-carrying relay, but it provides a loud audible click when energized or released, i.e. on cross-over between add and subtract. This permits the operator to set the baseline to zero by ear instead of having to watch the change of the pilot lights out of the corner of his eye.

The optional "time-scale interlock" is also shown schematically on Figure 5, with the relevant circuits drawn in dashed lines. The function and operation of this circuit have already been outlined, in the section on "mechanical system". It can be noted that: a) the direction of time-scale count is reversed by the same FWD-REV switch which energizes L_{11}; b) the count circuit is interrupted (by L_{17} and L_{21}) during the carriage return, to reduce wear on the counter and unnecessary noise.

B) Read-out control circuits (Figure 5b). These circuits are located on the same chassis as the power and count control circuits described in the previous section, but they have been drawn separately in order to simplify the description. The daily mean read-out is initiated by a foot-pedal switch (see Figure 5a), or by a front-panel push-button switch; the foot-pedal read-out line is interrupted if the time-scale interlock is activated (Figure 5a). Provided both L_{23} and L_{25} are at rest, +24 volts is thereby applied to energize L_{22}. This relay is self-locked, and also a) cuts power to the coil of L_{10}, i.e. the carriage cannot be driven; b) energizes L_{12}. L_{12} in turn applies GRD to the "transfer I" terminal of the storage unit; the reading from counter I is thereby transferred to the storage relay matrix. A control relay on the storage unit (L_{155}) is also energized and a) releases L_{12}, thereby stopping the transfer command; b) energizes L_{23} (via transistor Q5). The pair of relays L_{23} - L_{24} (with assistance from L_{25}) forms a monostable (single-shot) circuit which provides a single pulse of duration 0.1 second.

The relay L_{23} performs the following functions: a) applies GRD from L_{24} to the counter RESET terminals (directed by L_{19} to the appropriate counter); b) cuts the +24 volts to the foot-pedal read-out switch, to prevent further read-out commands from reaching L_{22}; c) resets the time-scale counter (via L_{19}); d) energizes L_{24} via a 100-ohm slow-down resistor. The relay L_{24} performs the following functions a) cuts the GRD to the RESET lines; b) starts automatic carriage return if L_{19} is energized, i.e. if this is a *daily* mean read-out; c) applies +24 volts to start the output (print and/or punch) cycles; d) cuts 0 volt power to release relay L_{22} (this in turn restores power to the carriage motor, and scanning of the next hour can be carried on into the cleared counters while printing and/or punching is in progress from the storage relays); e) the same contacts also energize L_{25}, via a slow-down resistor.

The relay L_{25} is locked by 0 volt from L_{155} (via transistor Q5). The activation of L_{25} cuts the +24-volt line to release L_{23}, which in turn releases L_{24}, ending the pulse generated by the monostable L_{23}/L_{24} and resetting the circuit to its "off" position. L_{25} remains locked until the read-out cycle is completed. Since this continues to block the +24-volt line to the read-out foot-pedal, no new read-out can be initiated while the cycle is in progress.

In order to prevent duplicate or multiple consecutive read-outs (if the operator keeps his foot on the pedal for too long), an additional interlock relay L_{20} is energized by +24 volts applied from a second set of contacts on the read-out foot-pedal switch. The "storage release" pulse (i.e. "cycle completed" signal) from the output device(s) is interlocked through this relay; no release can occur and L_{25} remains locked unless the foot-pedal has been lifted.

Once the output device(s) have completed their cycle (see next section), GRD is applied to the RELEASE terminal of the storage unit. A switch at the rear of the control unit selects the mode of operation: print only, punch only, or print and punch simultaneously. In the latter mode, the release signal is applied only if *both* devices have completed their cycle, regardless of the order in which this occurs. The release signal clears the storage relays and releases L_{155} and L_{165} as well; the opening of L_{155} releases L_{25}, thereby clearing the system for the reception of new read-out commands. The release of L_{165} provides appropriate signals to the punch and printer controls (see next section), to clear them for further cycles.

Operation of all the read-out control functions described above is performed very rapidly—about 0.12 second before scanning can be continued, about 0.15 total. The duration of the entire read-out cycle is therefore determined primarily by the speed of the output devices. Overall duration is 0.3 second for punch only, and 1.5 seconds for print or for print and punch. The latter could be reduced to about 1.2 seconds by driving the typewriter at its maximum rate of 10 - 12 characters per second rather than at eight. However, since scanning of the next hourly interval continues during the printing and takes at least 4 seconds, no advantage is gained by shorter print-out cycles. The entire read-out cycle is tightly interlocked in a sequential manner, rather than controlled by simpler "parallel" programming; any malfunction immediately stops the cycle, rather than produce false results. For example, none of the punch/print functions can be started unless the storage is loaded, nor can the storage be released until the punch/print functions are completed.

The *daily* mean read-out is initiated by a momentary-contact switch on the front panel; the switch is of the bat-handle type (see Figure 4), to provide tactile differentiation from the other (push-button) switches on this panel and prevent accidental read-out instead of a reset. This switch: a) applies +24 volts to energize the interlock relay L_{20} (same function as in daily mean read-out), and b) applies +24 volts to energize and lock L_{18} and L_{13} (provided L_{23} and L_{25} are at rest, i.e. no read-out cycle is in progress). The relays L_{18} and L_{13} perform the same functions as L_{22} and L_{12} respectively in the hourly mean read-out, i.e. initiation of read-out controls and transfer command for the reading of counter II into the storage relays. However, in addition L_{18} energizes the "daily mean select" relay L_{19}. This relay performs the following functions: a) selects to which counter the "reset" from L_{23} will be applied; b) energizes "daily mean" relays in the output controls, to permit differentiation of output formats; c) controls the "automatic carriage return" command from L_{24}; d) blocks the time-scale reset pulse from L_{23}. The read-out cycle continues in the same way as for the hourly mean. Relay L_{19} remains locked throughout the cycle, and is then released together with L_{25} by the opening of L_{155}.

Output controls

A) Printer control unit (Figure 6a). The "start print" pulse from the main control unit (L_{24}) energizes and locks L_{30}, provided the storage unit is "loaded", i.e. relay L_{165} is energized. The same pulse also energizes the coil of the stepping switch via the N.C. contacts of the auxiliary springs and transistor Q4. This advances the stepping switch from its OFF position to the No. 1 position, and also switches the transistor input from the N.C. to the N.O. terminal of the auxiliary springs, reapplying +12 volts (via L_{34} and the printer) to the base of Q4 and re-energizing the coil of the stepping switch. The stepping switch is of the "advance-on-release" type: energizing the coil "cocks" the switch, but it remains at position No. 1 until the coil is de-energized. The "power relay" L_{30}: a) applies +24-volt power to the stepping switch coil, the printer solenoid "common", and other circuits; b) switches on the oscillator circuit Q_1 - Q_2. The output pulses of the oscillator are of about 0.030 second duration (controlled by R_2) and with a repetition rate of about eight pulses per second (controlled by R_1); neither of these parameters is critical, and variations over a wide range (±30 - 40 per cent) do not disrupt performance.

The pulses from the oscillator are applied through transistor Q3 and relay L_{31} to the wiper of one of the stepping switch decks. With L_{31} at rest they are applied to the hourly mean deck; if L_{31} is energized they are applied to the daily mean deck. The stepping switch points (1 to 9) are wired to a patchboard-panel, which can be wired by plug-in cords to control the desired print-out format: space or tab functions, insertion of decimal points, line return after daily mean print-out, etc. The pulse is thus applied from the No. 1 point through the patch-cord to the appropriate function or "scan line". For example, if "No. 1" is wired to "sign" and the storage unit contains a negative number, the −24-volt pulse from Q3 is applied via the patchboard and the (−) storage relay to the (−) key of the printer. For the more usual case of positive numbers, the (+) line is wired to SPACE rather than to the (+) key of the printer.

A set of control contacts on the printer is momentarily opened by actuation of any of its functions; this cuts the +12 volts to the base of Q4, momentarily de-energizing the stepping switch coil, and thereby advancing the switch wiper to position No. 2. This process is repeated until the stepping switch reaches position No. 10.

When the stepping switch reaches position No. 10, i.e. the print cycle has been completed, −24 volts (not pulsed) are applied via a third deck on the stepping switch to energize the "end of print" relay L_{32}. This in turn applies GRD to the release terminal of the storage unit. If the output function is "print only", this release signal is applied directly; if the function is "print and punch", the release signal originating from the punch unit is taken through the normally-open upper contacts of L_{32}, i.e. release cannot occur until both output devices have completed their cycle. The release signal clears the storage unit; L_{165} is released as well, de-energizing L_{30}. This in turn cuts the +24-volt power of the stepping switch coil, thereby advancing the switch from No. 10 to its OFF position, ready for the next cycle.

Again, the entire cycle is interlocked in a serial sequence for reliable fail-safe control. If for any reason a pulse failed to operate the typewriter function (for example, if only a fraction of the pulse duration was applied on the first pulse), the printer control contacts would fail to open and the stepping switch would not advance; it would not move to the next position until the next (or any) pulse had fulfilled the function required at this position. This in turn means that performance is not critically affected by reasonable changes in parameters such as mechanical condition of the stepping switch or printer, or oscillator pulse length and repetition rate. Similarly, any data gap (failure of a decade digit in the counter or of a relay in the storage unit) would stop the stepping switch in the "blank" position and prevent all further operation, since the storage cannot be released until the entire cycle has been completed.

An optional circuit (relays L_{36} and L_{37}) provides suppression of leading zeroes in the print-out. This is the reason for the separate zero lines from the storage unit; all other digits are connected for standard serial scanning, i.e. one output line per digit. The zero suppression can be controlled separately for each decade, providing the option of printing for example 00.3, 0.3, or .3 in the declination output. Operation of the circuit is self-explanatory; a relay is locked by the preceding zero pulse and redirects the next zero pulse to the "space" solenoid instead of the "zero" solenoid. The only point to note is that if only three decades are being scanned in the hourly mean, the relay L_{36} is locked by −24 volts via the toggle switch and L_{31}, i.e. a dummy first-decade zero is assumed.

B) Punch control unit (Figure 6b). The Type 526 Summary Punch has internal scanning and logic, so that the control circuits need to provide only through-wiring from the storage unit to the punch terminals and basic controls. The "start punch" pulse energizes L_{53}, which initiates the punch cycle. An interlock relay, L_{55}, is normally energized; it is released by punch failures such as power off, empty input card hopper, or over-full output card stacker. When de-energized, it operates an alarm buzzer, and also blocks the "start punch" pulse from reaching L_{53}.

A "scan end" signal to the keypunch

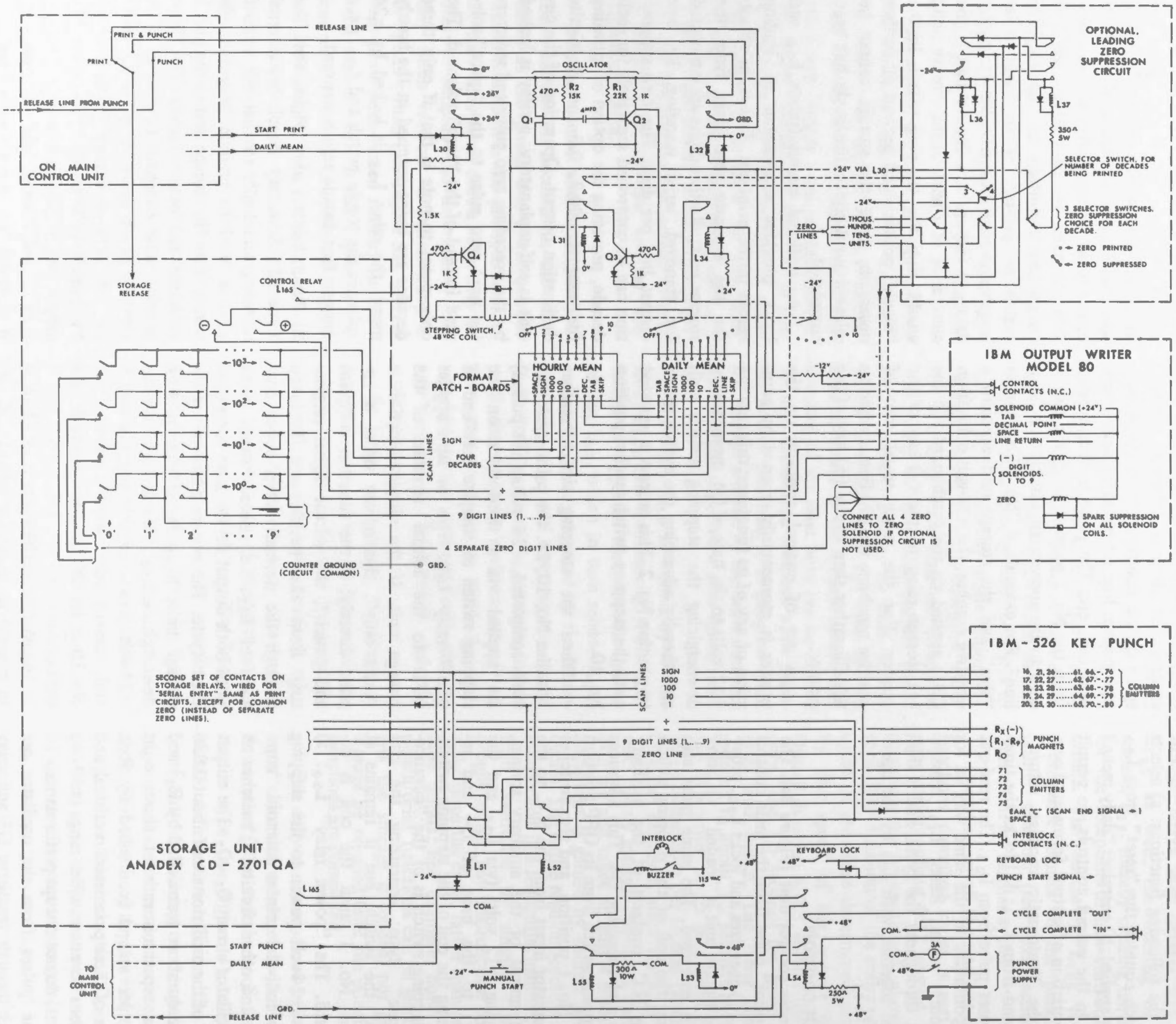


Figure 6. Output control circuits for a) printer and b) card punch.

is initiated by wiring the "units" scan line to the EAM–C hub; an internal "cycle complete in" signal is thereby generated within the punch to energize L_{54}, which is locked via L_{165} in the storage unit. This "cycle completed" relay, L_{54}, performs two functions: a) it disconnects the +48-volt line from the "cycle complete out" terminal of the punch, thereby terminating the cycle and preventing further punching; b) applies GRD to the release terminal of the storage unit; this clears the storage and opens L_{165}, which in turn releases L_{54} to leave the punch ready for its next cycle.

The punch keyboard is automatically locked during the cycle (see diode connection between the "punch start" and "keyboard lock" terminals). It can also be locked continuously by a toggle switch on the control unit, to prevent accidental manual punching by the operator, or unauthorized manual use during the operator's absence. The latter is particularly important because the data is entered into card decks which are pre-punched with date and serial numbers.

The unit was wired for five-digit fields (sign and four decades); the layout of these fields on the card can be controlled by the plug-in patch-cords on the control panel and by the standard program card of the punch. At present columns 16-80 of each card are used for the data, leaving columns 1-15 for non-data information (station and component identification, date, sequential card serial numbers). During daily mean read-out, relays L_{51} and L_{52} are energized, and change the output format by skipping five columns (71 - 75 in this case) before punching the daily mean (in columns 76 - 80). This permits easy visual identification of the daily mean on the card, and also clearly differentiates between the first and second card of each day.

The entire output deck is subsequently computer-processed in two steps. At present the printer output sheets are not used for the Victoria publications; these are now produced from the computer print-outs. The first-pass program performs two functions: a) checks the card order (sequence of serial numbers), and b) computes the daily mean from the 24 hourly means, compares it to the punched daily mean, and provides a warning print-out if they differ by more than a specified limit (usually set to 0.25 or 0.30 gamma). In the second-pass program, all auxiliary computations are carried out: means of the hour for each month, summary means (for all days, Q-days, and D-days) by month and season, and various cross-checks. The final results are output-printed in a format suitable for direct photo-offset reproduction in publications (for example Auld and Andersen, 1968).

Reliability and accuracy

As mentioned at various points in the description of the circuits, the primary consideration in the design has been high reliability, both in terms of service-free operation and in terms of data output. It is hoped that this reliability can be maintained over the lifetime of the machine (estimated at well over 200 observatory-years of data), as all components have been carefully selected to operate well within their rated capabilities. The mechanical components of the analogue system operate at very slow speeds under virtually no-load conditions and should last indefinitely without wear-caused inaccuracies. The two ball/disc integrators are the critical components of the system. Their lifetime expectancy of 5,000 - 10,000 hours of operation at the rated 0.05 per cent accuracy, i.e. about 20 observatory-years of data, is available only for high-speed (400 rpm) full-load conditions; at the actual speeds used (variable from 0 to 60 rpm maximum) and virtually no-load conditions, the rated accuracy should be maintained for at least 10 times that long.

The electromechanical components should similarly maintain their reliability for a long time. The control relays are of the medium-coil telephone type, with bifurcated twin contacts rated 4 amps at 28 VDC. They operate very quietly and feature very long lifetime: 10^8 mechanical operations minimum, contact life estimated at over 5×10^6 cycles with the loading and spark suppression used, i.e. at least 200 observatory-years of data for the hourly mean relays, indefinitely for all others. Trouble-free operating life can be lengthened by an interchange between the more frequently operated relays (hourly mean read-out) and the daily mean relays; since the relays are plug-in types such exchanges can be easily carried out. Similar specifications apply to the other electromechanical components such as stepping switch and storage relays.

The electronics are all solid-state, and so far have not caused any servicing problems. The two counters are identical, so that operation can continue on the basic hourly mean system if one of the counters is removed for servicing. The light-bulbs for the photo-cell actuation are operated well below their ratings and have so far not required replacement. In fact the only difficulties which have developed over the last three years of operation concerned peripheral equipment: routine servicing of the printer, key-punch, and counter, and failures in the speed foot-pedal. In the foot-pedal case, the original pulley system has been replaced by a commercial foot-pedal with a gear-driven potentiometer.

As far as the data output is concerned, "high reliability" simply means the absence of *large* (random or consistent) errors caused by either equipment malfunction or by operator carelessness. This is ensured by the fail-safe type of interlock circuitry, and by the automatic double-check provided by the two separate channels. No large errors have so far been detected in any of the data processed on this machine; this is in contrast to manually processed data where such errors occur with embarassing regularity, the most usual being reading or copying errors of one digit in a particular decade, i.e. 1, 10, or even 100 gammas.

Accuracy of the machine is limited primarily by two factors: a) time-scale inaccuracies, and b) digital resolution. The time-scale inaccuracies include genuine irregularities in magnetogram time scale as well as operator-caused ones such as uncorrected over or under-shoot of the hour mark. For observatory-quality magnetograms (time scale usually ±0.1 mm, i.e. ±0.5 per cent) and a conscientious operator (0.1 - 0.2 mm resolution), the combined time-scale errors are of the order of 1 per cent, with a maximum of 1.5 per cent. It should be noted that this error is strictly proportional to the ordinate. In most cases magnetograms are laid out so that each trace runs near its baseline, i.e. mean ordinate usually under 100 - 200 gammas; the percentage error of 1 per cent is therefore acceptably low when expressed in gammas. However, for magnetogram layouts where the traces are distant from the baseline, the percentage error could become prohibitive, in contrast to manual processing where the scaling accuracy is independent of amplitude. On the other hand, the accuracy of the magnetogram reader is independent of the degree of disturbance; this contrasts with manual scaling where the accuracy of the visual hourly mean estimate deteriorates markedly for disturbed periods.

The time-scale errors are not cumulative; an overshoot in one hour means an equivalent reduction in the next hour, so that the average value over any group of hours is correct to a much higher percentage accuracy. In the daily mean for example, a time-scale accuracy of 0.1 per cent can readily be achieved. Consistent time-scale differences in magnetograms from a particular observatory, i.e. *mean* time scale differing from the nominal 20 mm/hr, can of course be corrected for by an appropriate adjustment in the scale-factor dial setting, leaving only the superimposed random irregularities.

The digital resolution error of the system, i.e. a potential error of one unit (1 gamma or 0.1′), is inherent in the analogue-to-digital conversion. If the rotating disc is stopped for an hourly read-out just before a hole reaches the light-beam, the output value can be too low by almost one unit (e.g. true analogue value 10.9, digital output 10). Again, these errors are not cumulative; if the disc is stopped just below a hole on one hour, it will tend to give a correspondingly higher reading on the next hour. The maximum resolution error in the average of a group of n hours is therefore only 1/n. In the daily mean channel, in which the unit is 0.1 gamma or 0.01′, the resolution error is entirely negligible.

Potential accuracy of the entire process is therefore ±1 per cent of mean ordinate ±1 unit. For a medium-latitude observatory such as Victoria, with scale-factors of 3 - 4 gammas/mm and mean ordinates around 100 gammas, this means errors of ±1 - 2 gammas in individual hourly means (independent of the degree of disturbance). Additional errors of the order of 1 gamma can be expected occasionally, caused by operator tracking inaccuracies. The actual accuracy achieved in operational use is discussed in the next section.

Operational performance

A detailed test was carried out on three months of data in two components, i.e. 4,400 hourly mean values. A comparison was made between a data set which had been previously processed by hand, and the same data processed on the machine without the operator's knowledge that a test was involved. All values which differed by 3 gammas or more were checked out in detail; in most cases it was found that the difference was "split", i.e. a 1 - 2-gamma error in the machine values and a 1 - 2-gamma error of opposite sign in the manual values added up to a ⩾3-gamma difference. The remaining discrepancies have been summarized in Table I below, showing the percentage of the hourly values which were in error by the stated amounts.

All the ±4-gamma errors and all except one of the ±5-gamma errors in the machine-processed data correspond to time-scale irregularities in the magnetogram. Nevertheless, the accuracy which was obtained for the individual hourly means (3 per cent of values in error by ±3 gammas) was lower than could be expected from the theoretical design considerations. Some "legitimate" causes were recognized: curved baselines and minor time-scale irregularities. However, a significant residue of the 3-gamma errors can only be ascribed to operator causes, i.e. careless tracking. It is an unfortunate fact that no amount of circuit design care and other safeguards can protect such processing from careless operation, and the same applies to manual scaling and processing. This is perhaps the strongest argument in favour of fully automatic systems. Operational discipline has since been tightened up (by periodic spot checks), and generally only 2 per cent or less of the machine-processed values are now in error by ±3 gammas.

The most striking difference between the results of the two processes is the absence of large errors in the machine data, i.e. high data reliability. By comparison, the magnitude of the errors in the manually-processed data (26 errors larger than 4-gamma, out of 4,400 values) came as an unpleasant surprise, and impressed us with the need for duplicate processing rather than just spot-checking of manual data. Eighteen of these errors were very large (> 10-gamma), and at least some of them would probably have been noticed as "out of place" by simple visual inspection of the monthly sheets (for example a 100-gamma copying error in the addition of the baseline correction). The rest of the errors included some "legitimate" scaling errors during very disturbed sections, several 10-gamma copying errors, one 65-gamma error caused by use of the wrong baseline, a 75-gamma cross-over tracking error during minor disturbance, a 30-gamma copying error (writing 15 instead of −15) and a 45-gamma copying error (writing 5 instead of 50).

The comparative performance of the two methods is outlined in Table II.

Table I

Error (Gammas)	Percentage of Values a) Machine	b) Manual
±3	2.90	0.50
±4	0.91	0.23
±5	0.18	0.14
±6–9	0	0.04
±>10	0	0.41

Table II. Comparison of different magnetogram processing methods

		Manual processing	Duplicate manual processing	Magnetogram reader
Theoretical accuracy		resolution ($\pm 0.5\gamma$)	resolution ($\pm 0.5\gamma$)	1 per cent $\pm 1\gamma$
Potential	$K = 0$–2	$\pm 1\gamma$	$\pm 1\gamma$	± 1–2γ
practical	$K = 3$–5	± 1–3γ	± 1–2γ	± 1–2γ
accuracy	$K \geqslant 6$	± 2–10γ	± 2–5γ	± 1–2γ
Achieved	$K = 0$–2	$\pm 1\gamma$	$\pm 1\gamma$	$K = 0$–9:
practical	$K = 3$–5	± 1–3γ	± 1–3γ	any value ± 1–2γ
accuracy	$K \geqslant 6$	± 2–10γ	± 2–5	<3 per cent of values $\pm 3\gamma$ (random distribution)
Reliability: number of large errors ($>10\gamma$) in one year		variable, typical: 12 (10–100γ)	Nil	Nil
Daily mean value accuracy		$\pm 0.5\gamma$	$\pm 0.5\gamma$	$\pm 0.5\gamma$
Time (man-months) to process one year in three components completely ready for publication		4 - 6	8 - 12	2
Output also available on cards or tape?		No (Unless manually punched)	No	Yes

Based on records from a mid-latitude observatory (Victoria, 54°N geomagnetic), scale factors 3–4γ/mm, variograph time scale reliable ± 1 per cent, mean ordinates usually under 100γ.

Briefly summarized, duplicate manual processing provides the most accurate and reliable results, provided one can afford the manpower. Single manual processing is still more accurate than machine processing (0.5 per cent of values ±3-gamma, compared to 2 - 3 per cent). However, it is far less reliable; the machine data contains no large errors. Accuracy of the daily mean value is about the same for both methods, except in manual processing during the few days which contain the aforementioned large errors. The salient point is of course the saving in manpower with the machine processing.

Alternative versions

The basic feature of the machine is the mechanical analogue system; it can naturally be adapted to work into different digital output systems. For example, if digital recording facilities are already available, the output from the photo-cell amplifiers can be fed into any other equivalent counters (bi-directional with preset capability) which would be compatible with the available digital recorders. In particular, a complete range of commercial output processors is available to link BCD outputs from counters to a variety of output devices–magnetic tape or punched tape as well as punched cards or printers.

At the other extreme, a low-cost version can be built with electromechanical counters such as the Whittaker/Neuron Type 7005-D24-AS which is presently used for the time-scale interlock. This counter is bi-directional and has decimal contact-closure outputs which can operate the typewriter or key-punch directly, without the need for a relay storage unit; the one-second wait for the print-out is not prohibitive. The operating speed of these counters (40 counts per second) is adequate for scanning, although the clicking noise at high speeds could become objectionable. The main limitation on the use of this system is the fact that no instantaneous reset to a dialed-in "preset" value is available; reset to the baseline correction therefore has to be obtained by first resetting to zero and then counting up to the desired value (with the counting pulses gated by an output from the decimal contact closures). This method has been successfully used for the *daily* mean channel in the original home-made prototype; the counting time for the baseline reset was irrelevant since it could be carried out during the carriage return. However, for the hourly mean system this reset-by-counting would cause a prohibitive slowing-down of the entire process; for example, 1.2 seconds for print-out plus 4 seconds for reset to a baseline correction of 150 gammas. Nevertheless, if cost is an overriding consideration, such a low-cost version should be investigated in more detail. In particular, bi-directional counters with decimal read-out are now becoming available in single-decade modules. By disconnecting the "carry" between decades during reset, such a system could be rapidly reset by counting each decade separately to its desired value. Such an entirely electromechanical version would provide acceptable (though somewhat noisy) low-cost equivalence to the hybrid electromechanical/electronic system described in this paper.

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