SOME INDUSTRIAL APPLICATIONS OF ELECTRONICS

By A. F. McCULLOCH.

Introduction.

1. It is only recently that the application of electronic engineering techniques in the industrial field has become established. Formerly the applications of electronics were associated mainly with radio broadcasting, wireless communications and television; but during 1939—1945, under the impetus of new developments such as radar and the production of radioactive materials, some remarkable advances were achieved which can be invaluable if applied to the gentler arts of peacetime industry. But the comparative slowness with which industry is making use of the techniques may be due to the reason that the scope and possibilities of these new tools are not adequately realised.

2. Electronics is a product of scientific effort and research and modern developments have provided a tool of versatility and precision which yields results unattained previously by applications of older and more widely-known techniques. During the present circumstances of industrial expansion, of demands for increasing productivity and of rising costs and scarcity of labour, every effort should be made to achieve a very high standard of industrial efficiency. The scope of the applications of electronics for such a purpose is boundless and substantial process improvements and reductions of manufacturing costs could be achieved if sufficient thought be given to utilising the possibilities offered.

If an interest in the applications of electronics to industrial problems is encouraged, the purpose of this paper will have been served.

3. In all electronic components such as thermionic valves, photo-electric cells, gas and vapour-filled tubes, cathode ray tubes, etc., a moving stream of electrons is caused to flow between two or more elements by the application of a voltage. This stream has a negligible inertia owing to the minute mass of the electronic particles, and this property enables control of the motion of the stream to be achieved with an instantaneous response by insignificant changes of energy. For instance, in the photo-electric cell, the flow of power is controlled merely by changes of illumination. The commonest types of components used, their construction and the methods of utilising their characteristics are described. When properly selected, arranged and connected, these components may rectify, amplify, measure, control, time and perform many operations of a similar nature which are an essential part of some manufacturing process.

Typical Electronic Components and their characteristics.

4. (*a*) **Thermionic Diode.** This is a two-element tube or valve and is illustrated in Fig. 1. A glass

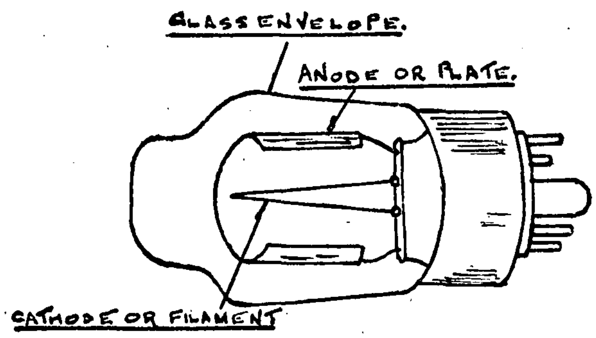

Fig. 1. Thermionic diode. Filament heater is not shown.

envelope which is exhausted to a high vacuum contains the two elements known respectively as cathode (or filament) and anode (or plate).

The cathode is generally coated with a thoriated material or barium oxide and will eject electrons when heated. If a closed external circuit is made by connecting the two elements through a battery or generator, the electrons will flow from cathode to anode and the intensity of this flow will vary with the voltage applied by the battery as indicated by the characteristic of Fig. 2. Electrons will flow

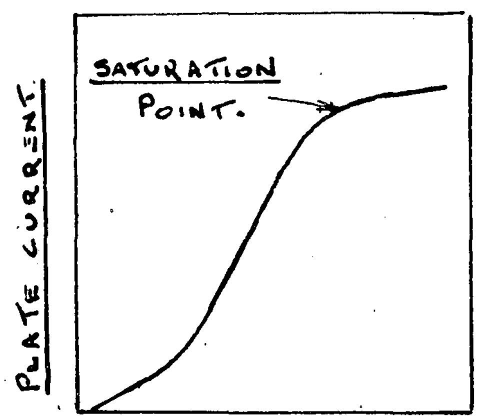

Plate voltage.
Fig. 2.

only if the anode is connected to the positive (+ve) side of the battery and the cathode to the negative (—ve) side. In practice, great care must be taken in designing the form of the cathode heater in order to suppress any magnetic fields which may cause spurious signal effects. The diode has rectifying properties; i.e., if the battery is replaced by an alternating current generator only the +ve half of the voltage wave is passed through the circuit and the —ve half is suppressed as shown in Fig. 3. By

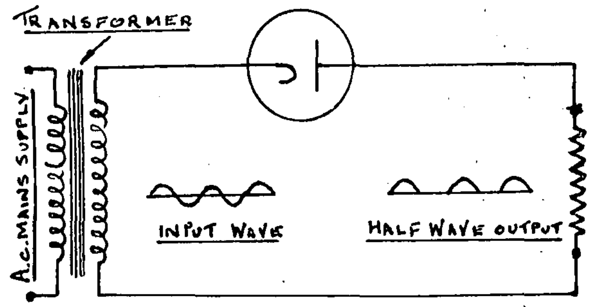

Fig. 3. Rectifier effect of diode.

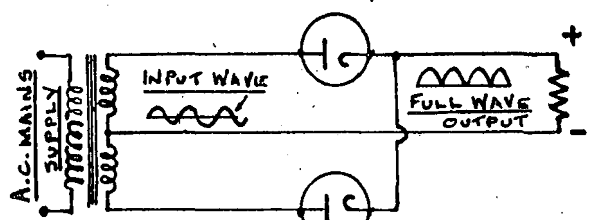

Fig. 4. Two diodes used for full wave output rectifier.

connecting two diodes as shown in Fig. 4 full wave output is achieved and, if suitable filter circuits are added to the arrangement, an output scarcely distinguishable from a steady direct current may be obtained, as shown in Fig. 5.

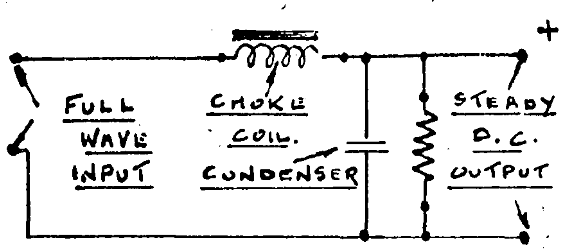

Fig. 5. Use of filter circuit to produce steady D.C. from full wave supply.

(*b*) **Thermionic Triode.** This is a three-element valve and is shown in Fig. 6. With the exception of the third element, known as the control grid, this valve is similar to the diode. The control grid has very important effects on the valve characteristics, since by varying the grid voltage a wide range of

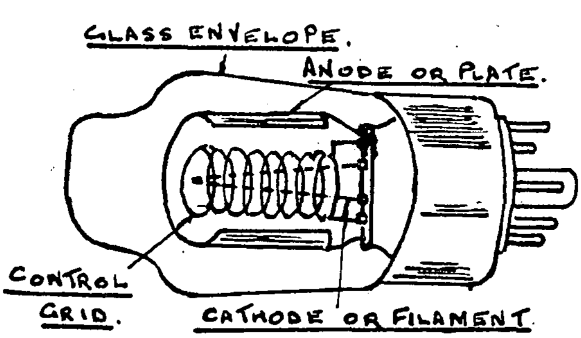

Fig. 6. Thermionic triode. Filament heater is not shown.

control may be achieved over the current passing between the anode and the cathode. The reason for the spiral construction of the grid is that electrons from the cathode may flow through it on to the anode. There are other types of valves—tetrodes and pentodes—which have two and three grids respectively. These perform similar functions to the triode, but differ in their characteristics.

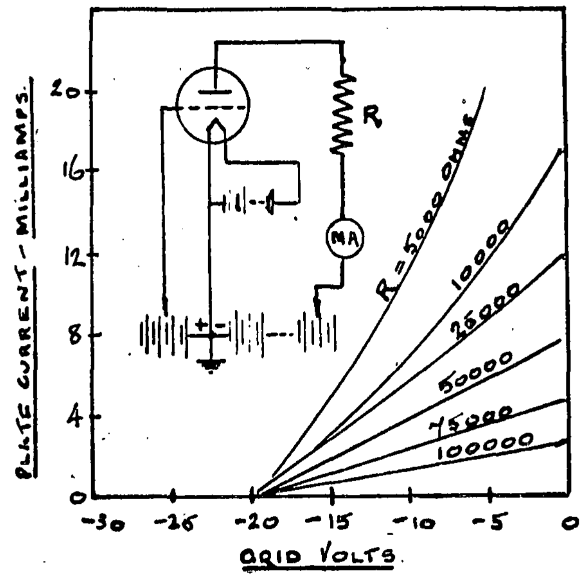

Fig. 7. Change of plate current with change of grid voltage and load resistance.

A typical triode characteristic is shown in Fig. 7, which reveals how the anode current changes with grid voltage and with the load resistance R. For relatively small values of R the plate current changes more rapidly than for relatively large values, so that in the latter case the curve is straighter. The amplifying effect of the triode is shown in Fig. 8,

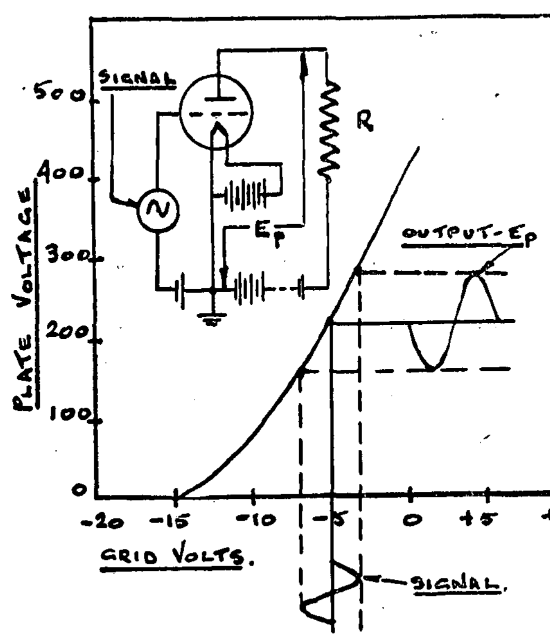

Fig. 8. Voltage amplication effect of a triode.

where a signal voltage is shown applied between grid and cathode and the corresponding change in output voltage Ep. Thus if the operating grid voltage changes from -5 volts to -3 volts due to the signal, the plate voltage Ep changes from 210 volts to 280 volts. Similarly, if the signal changes the grid voltage to -7 volts, Ep changes to 140 volts. This yields a voltage amplification of $(280-140)$-$(7-3)=35$; i.e., the signal has been amplified 35 times by the valve.

A $-$ve grid voltage is important for two reasons. Firstly, in order to obtain undistorted amplification, the straight part of the characteristic only must be used. If the curved portion of the characteristic is used, the output will not have a shape similar to the input. Secondly, if the grid is kept $-$ve, no electrons flow between grid and cathode; i.e., there will be no grid current and hence no power is taken from the signal source.

(*c*) **Cascading of triode amplifiers.** A single triode does not always provide adequate amplification and, when large amplifications are required, it is necessary to couple several stages. The most common methods of achieving this coupling are resistance coupling, impedance coupling and transformer coupling. Circuit diagrams for these couplings are shown in Figs. 9, 10 and 11. In Fig. 9 the voltage developed

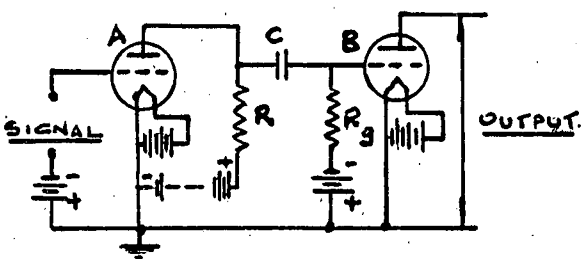

Fig. 9. Resistance coupled amplifier.

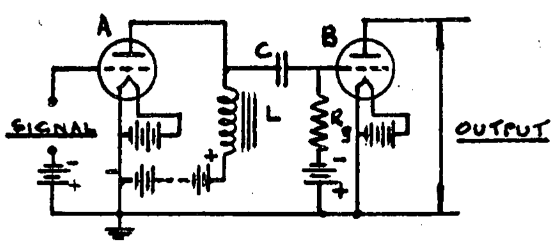

Fig. 10. Impedance coupled amplifier.

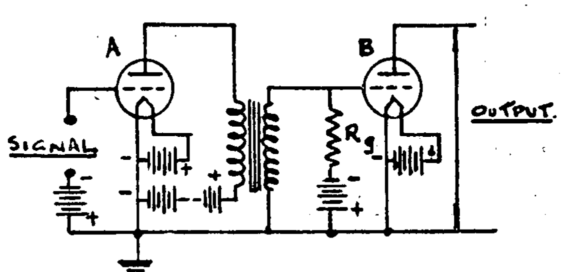

Fig. 11. Transformer coupled amplifier.

across R is applied across Rg through a condenser C. This condenser prevents the plate voltage of the valve A being applied to the grid of valve B, so that the $-$ve voltage bias of the grid is maintained. No current flows in the grid circuit of valve B and the full voltage of the bias battery is applied to the grid. The advantage of impedance coupling, Fig. 10, as compared with resistance coupling, is that direct current is more easily passed and alternating current components are more readily suppressed, which enables a high load impedance to alternating current to be obtained without excessive direct current voltage drop that would diminish the plate voltage.

Transformer coupling has an advantage over resistance coupling similar to impedance coupling. Since there is no direct connection between the two windings of the coupling transformer, valve A plate voltage is isolated from valve B and the coupling condenser C is not required. There is also the advantage that the primary winding output voltage may be stepped up proportionally to the turns ratio of the transformer.

Resistance and impedance couplings are used mainly for voltage amplification, and transformer coupling mainly for power amplification. Voltage amplification is required where the output of one valve is applied to a second valve. On the other hand, power amplification is required when the valve output is used to drive a control mechanism or where power has to be delivered to some form of load. In power amplification grid current flows wholly or partly during the cycle of operations.

5. **Gas-filled Tubes.** (*a*) *Gas-filled Thermionic Diode.* In the valves described in para. 4 there is a high vacuum inside the glass envelope. If the envelope is filled with a suitable gas or mercury vapour the resistance to flow of current between the cathode and anode is reduced under certain conditions and the tube is then capable of carrying large currents. When a voltage is applied to the electrodes, Figs. 12 and 13, only a small current flows until a certain critical voltage is reached at which the gas becomes a good conductor and a luminescent glow is initiated

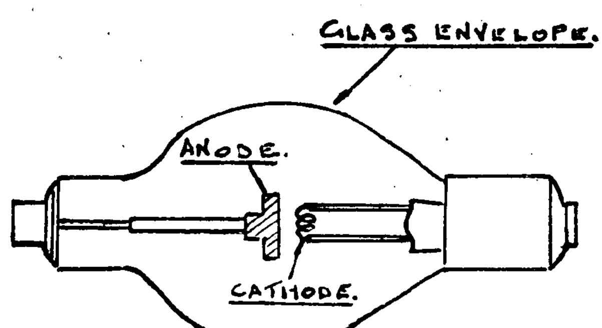

Fig. 12. Gas filled diode.

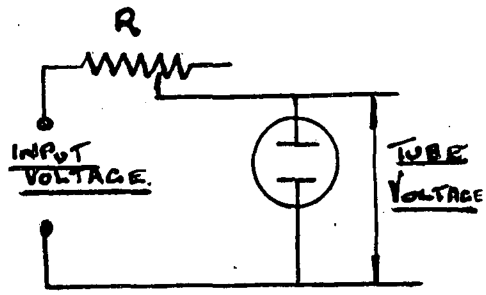

Fig. 13. Gas--filled diode connections.

at the cathode. This effect is called ionisation and the magnitude of the current is only limited at this point by the resistance R. If R is gradually reduced, the glow area increases in size and intensity and finally takes on the characteristics of an arc in which the voltage drop across the electrodes is substantially less than in the glow discharge, and for this reason the gas-filled diode may be used as a most efficient alternating current rectifier.

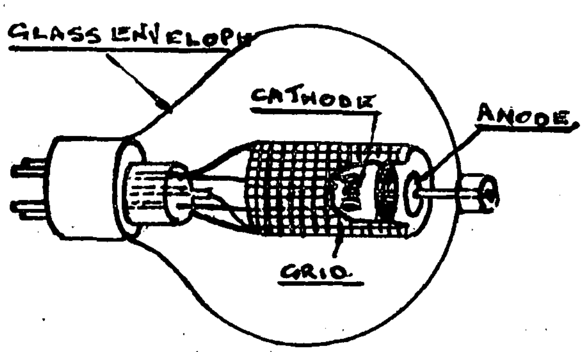

Fig. 14. Gas-filled triode. (Thyratron).

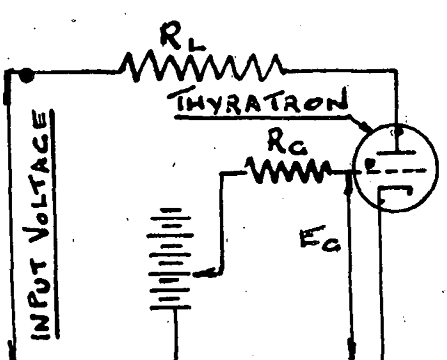

Fig. 15. Thyratron connections. For a given input voltage the tube fires suddenly at a critical value of Eg.

(*b*) *Gas-filled Thermionic Triode or Thyratron.* A typical gas-filled triode is shown in Fig. 14 and the characteristics of this tube are shown in Fig. 16. Flow of current through the tube may be prevented by maintaining the grid sufficiently —ve with respect to the cathode. In Fig. 16, as the negative voltage is changed, a certain critical voltage is reached at which an arc forms between the anode and the cathode. When this arc forms the grid has no further controlling effect and the current rises

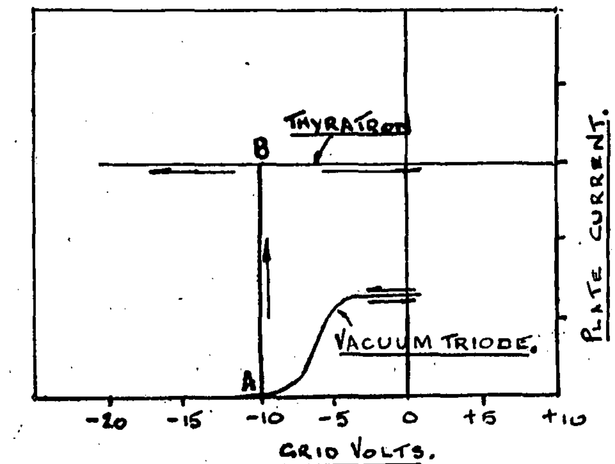

Fig. 16. Comparison of thyratron and vacuum triode characteristics.

instantaneously to a value determined by the input voltage and the circuit resistance. In order to stop the discharge the input voltage must be reduced to zero for an instant and when this is done the negative grid assumes control again. A comparison of the characteristics of a gas-filled triode and a vacuum triode is shown in Fig. 16. The sudden rise of current at the critical grid voltage is shown at AB and is usually referred to as the firing point. The value of the critical grid voltage depends on the input voltage as indicated in Fig. 11 (a).

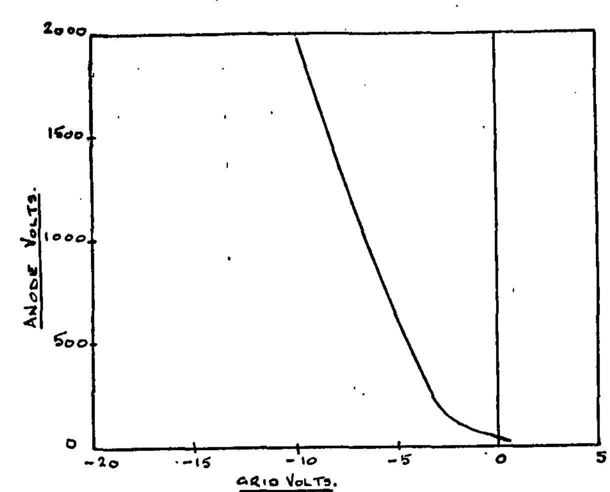

Fig. 11a. Variation of critical grid voltage with anode voltage.

6. **Photo-sensitive Cells.** (*a*) *Photo-electric Cells.* The photo-electric cell is a tube which permits an electric current to flow in a circuit when the tube is suitably illuminated by a source of light. The cell is a two-element tube and consists of an anode and a cathode which are sealed in a glass envelope as shown in Fig. 17. The action of the cell depends on the fact that certain metals, notably caesium, are photo-sensitive, i.e. emit electrons due to the effect of light. In most of the photo-electric cells used for industrial applications, the cathode is coated with

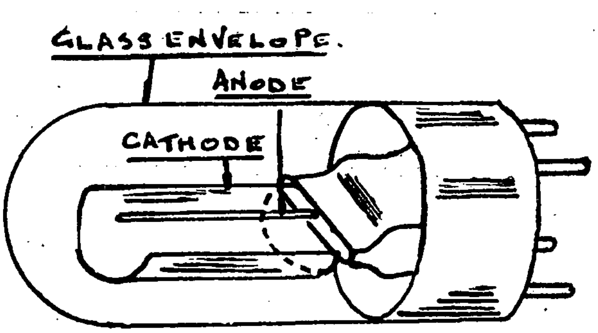

Fig. 17. Photo-electric cell.

a thin film of caesium-silver oxide which may vary in colour from light straw to dark chocolate. Other types of coatings may be used, principally caesium-antimony and caesium-bismuth, since these combinations have greater sensitivities to shorter wave-length light.

Like the vacuum and gas-filled tubes described above, photo cells may be either gas-filled or vacuum type and the characteristics of the two types of cell differ. Gas-fillings of argon and helium are often used.

If a cell is connected as shown in Fig. 18 and the lamp illumination is kept constant, characteristics as indicated in Fig. 19 are obtained which show that

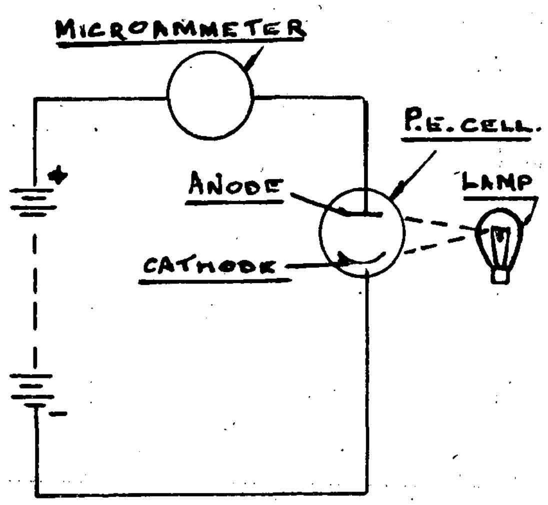

Fig. 18. Simple P.E. cell circuit diagram.

the vacuum cell is less sensitive than the gas-filled cell. At the same time the vacuum cell is seen to have a very stable characteristic when the applied voltage exceeds 20 volts, whereas the sensitivity of the gas-filled cell varies with the applied voltage.

If the voltage is increased sufficiently, a glow discharge is initiated; but a cell should never be used under these conditions, since the performance is changed completely.

If the applied voltage is kept constant and the intensity of illumination changed, the characteristics

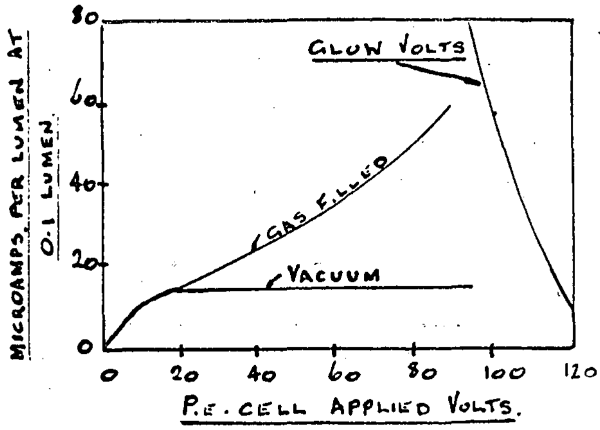

Fig. 19. Comparison of characteristics for constant illumination.

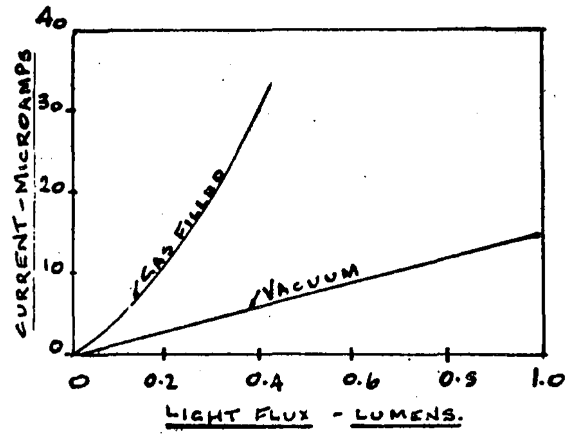

Fig. 20. Comparison of P.E. cell character for constant applied volts.

of Fig. 20 are obtained and show that, in the case of the vacuum cell, the current is directly proportional to the intensity of illumination. Photo-cell currents are always quite small and usually of the order of 10^{-6} ampere. For this reason a high insulation resistance between electrodes is vital, particularly where a cell is used in measurement work. Care should be taken to eliminate leakage paths between pin terminals when the cell is in use.

(*b*) *Photo-voltaic Cells.* The photo-voltaic cells consist of a sandwich formed of a light-sensitive surface, a semi-conducting material such as selenium and a ferrous base. The construction is shown in Fig. 21. The light-sensitive layer is usually covered with a thin transparent metal film and when it is illuminated a voltage appears across the external faces.

This cell differs from the photo-electric cell, since no external battery or source of electrical energy is required to drive the current through the circuit; and in this respect it may be regarded as a true voltage generator, since only the energy of the incident light is required to initiate the voltage. The cause of photo-voltaic action is not known with certainty.

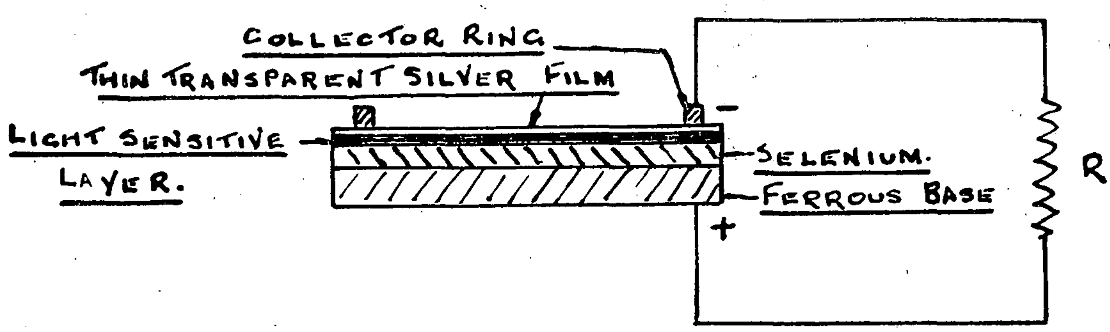

Fig. 21. Photo voltaic cell.

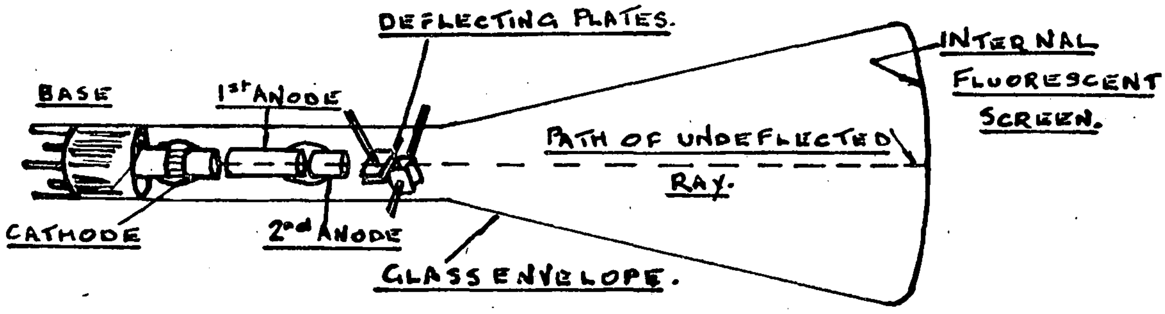

Fig. 22. Cathode ray tube.

7. **Cathode Ray Tubes.** The Cathode Ray Tube is one of the most useful electronic tools for the study of rapidly changing phenomena. A sketch of a typical tube is shown in Fig. 22. In the tube a beam of electrons is ejected from the cathode and is accelerated to high velocity by the two anodes. The anodes are hollow cylinders and the second has a small aperture at the end adjacent to the deflecting plates. The first anode operates at about 500 volts and the second between 1,500 and 3,000 volts. The intention of the second anode is to constrict the size of the electron beam in order to produce a fine intensely defined spot on the fluorescent screen.

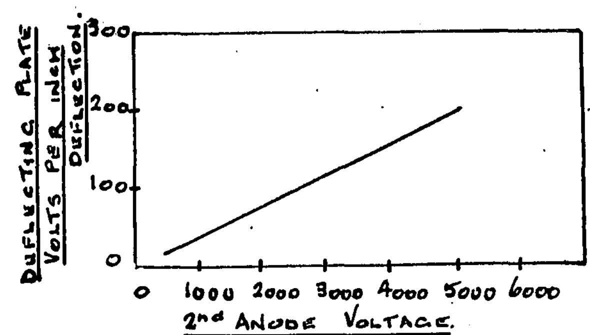

Fig. 23. Deflecting plate voltage required to displace the ray varies with anode voltage.

The beam is displaced from the axial path by two pairs of deflecting plates which are set normal to each other. By imposing a voltage of known frequency on one pair of plates the beam is deflected to produce a straight line time base; and by imposing a voltage to be studied on the second pair of plates a figure is produced on the screen showing how the latter voltage varies with time. By this means it is possible to study visually events lasting only for 1/20,000 sec. Control of the deflection of the beam may be attained by changing the voltage applied to the second anode as indicated in Fig. 23.

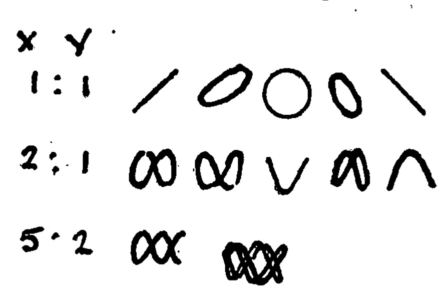

Fig. 24. Typical traces obtained on C.R.O. screen when voltages of different frequences are applied to the deflecting plates.

A series of screen traces obtained by imposing voltages of different frequencies to the deflecting plates is shown in Fig. 24.

One of the most recent and spectacular applications of the Cathode Ray Tube is in the television receiver, where the electron beam is swept at high speed in a series of successive horizontal lines across the screen by means of the deflecting plates. The intensity of the beam is controlled by the television broadcast signals. The high-speed sweep of the beam creates the illusion of a continuous single picture and the variation of the beam intensity creates the light and shade effect which is required for definition.

8. **Application Techniques.** (*a*) *Measurement of Displacements and Gauging.* In many engineering problems it is necessary to measure small displacements accurately or to make accurate measurements of components. The electronic micrometer[1] provides a very simple and accurate means of measuring displacements continuously. The principle of the micrometer is shown in Fig. 25. If a displacement is applied to the end of the lever the two anodes are displaced relatively to the cathode and a signal voltage is generated which is proportional to the displacement. By amplifying the signal and applying it to a cathode ray tube a visual record of the displacement can be exhibited and measured. The micrometer may be adapted to automatic gauging by applying the amplified signal to a machine which is controlled to separate undersize, standard and oversize components. If a very small mass is secured to the lever the micrometer may be used for measuring rapidly changing accelerations up to a maximum of 90 g at 10,000 cycles per sec.

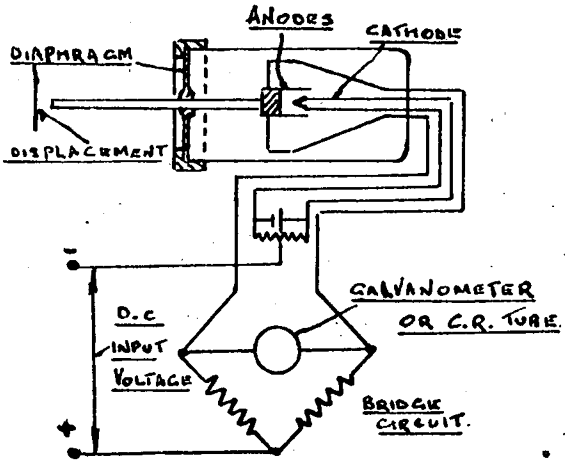

Fig. 25. Gunn micrometer. Electronic method of measuring displacements or accelerations.

(*b*) *Use of Photo-sensitive Cells.* Photo-sensitive cells are applied in many and various ingenious ways to industrial control problems. One great advantage of the photo-cell is that no constraint is imposed on the input source. For instance, in the application of the valve micrometer mentioned above, a very small force has to be applied to deflect the lever, but in some applications even a very small force cannot be tolerated and resort must be had to the photo-sensitive cell, which requires nothing more than a beam of light to excite it.

(*c*) *Water Level Control.* A very simple type of Water Level Control is shown in Fig. 26, where a beam of light from the source A is directed on to a glass tube B. If the water level exceeds height H, the light is refracted by the water on to a photo-cell at C which stops a pump-driving motor. If the water

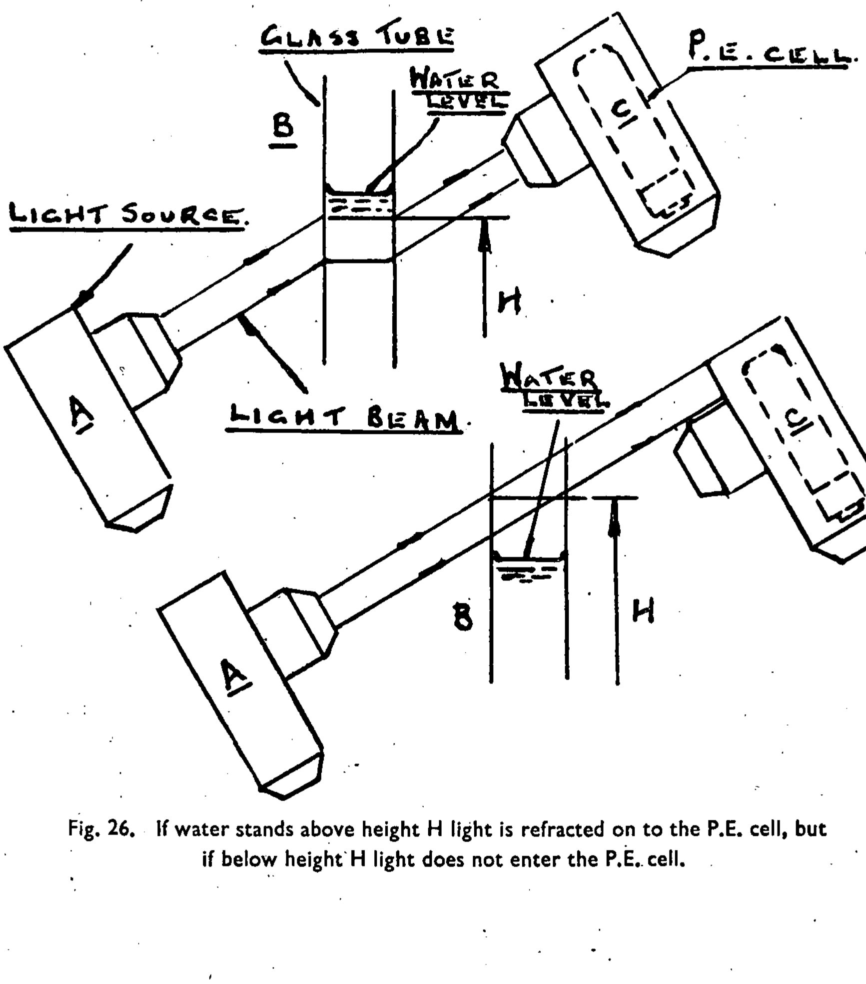

Fig. 26. If water stands above height H light is refracted on to the P.E. cell, but if below height H light does not enter the P.E. cell.

level falls below H the light is not refracted by the water and the light does not enter the photo-cell, which now starts the pump motor.

(*d*) *Continuous Gauging of Strip and Wire.* A method of continuous gauging of strip and wire has been developed[2] in which a photo-electric cell is used as a micrometer. Referring to Fig. 27 the material to be gauged is moved across a slit cut into a measuring plate which is illuminated by means of a lamp. The shadow of the material is projected on to the cathode of a photo-electric cell which initiates a voltage signal proportional to the area illuminated. Similar slits are cut into the measuring plate corresponding to the upper and lower size limits of the material and by means of a rotating scanning disc the three slits are exposed to the illumination in sequence. Signals corresponding to each slit are initiated and applied to a common amplifier circuit and on to the vertical deflection plates of a cathode ray tube.

A sweeping voltage synchronised with the scanning disc rotation is applied to the horizontal plates of the cathode ray tube, which exhibits traces on the screen corresponding to each slit of the measuring plate.

Each signal is exhibited simultaneously as a horizontal straight line which is shown without interruptions. If variation in the size of material occurs the test slit signal varies proportionately and the corresponding trace on the screen changes position relative to the limit traces, which do not change their positions.

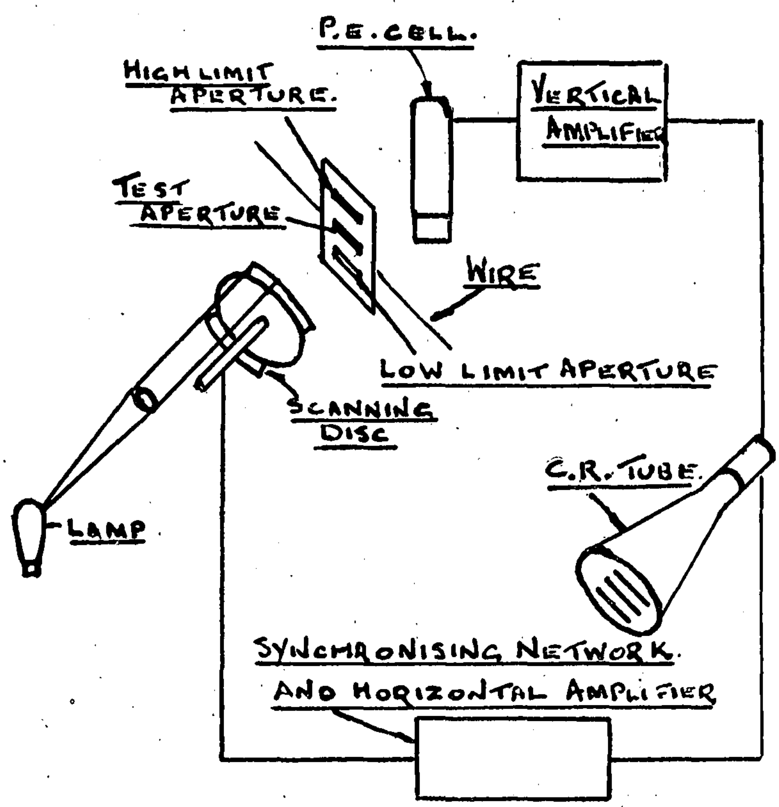

Fig. 27. Electronic micrometer for the continuous gauging of wire and strip.

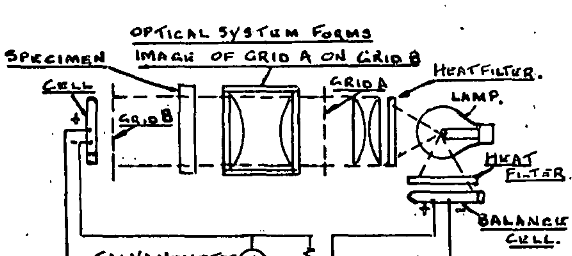

Fig. 28. Turbidity meter circuit diagram.

(*e*) *Turbidity Meter.* In turbid liquids light is scattered by the suspended particles and this effect is used to measure turbidity by electronic methods.[3] Referring to Fig. 28 a mesh grid A is illuminated by a lamp. The shadow of the mesh A is focussed by the optical system on to a similar mesh grid B. If no specimen is inserted for test, the grid B stops light from entering the specimen cell, but if a specimen is inserted the light-scattering effect occurs which illuminates the specimen cell and causes a galvanometer deflection. Since the relationship between turbidity and light-scattering is nearly linear, the galvanometer deflection is a measure of the turbidity.

(*f*) *Temperature Control.* A method of using a photo-electric cell for temperature control is shown in Fig. 29, which emphasizes the advantage of photo-electric systems not imposing any restraint on the input system.

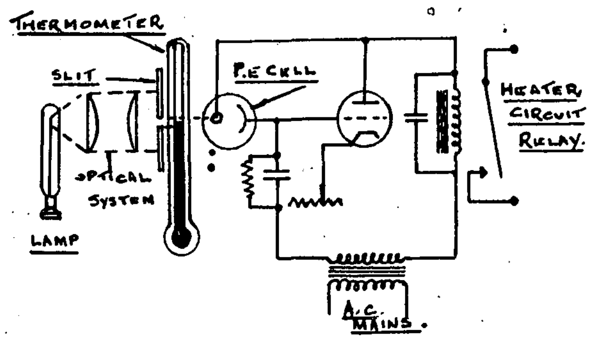

Fig. 29. Use of P.E. cell for temperature control.

In this application light is focussed through a narrow slit on to a transparent mercury-in-stem thermometer by means of an optical system. The temperature is controlled by the displacement of the mercury level in the stem, which permits or obstructs light from entering the cell. A sensitive control can be achieved by providing a carefully designed optical system and a narrow slit, and the control level may be regulated by raising or lowering the thermometer.

Since the energy available in the mercury stem is very small it will be clear that no system of electrical contacts could be operated directly.

9. **Use of high frequencies for detection of tramp metal.** The problem of foreign or tramp metal objects being mixed with process materials is a serious one for many industries, since stoppages and heavy damage may be caused to plant and machinery if such objects pass through fixed clearance rollers. Devices based on various effects have been developed in the past as safeguards and in one method recently introduced[5] the effect of metal causing distortion to the form of a high-frequency field associated with a coil has been exploited. The distortion effects arise from three causes, namely, eddy currents, hysteresis and dielectric losses; and the choice of the operating frequency and the design of the coil are such as to emphasize the effect of the foreign material and reduce the effect of the conveyer structure and the process materials.

The field is established in a large coil which is energised by a stable valve oscillator. The approach of foreign material to the coil, which is shown diagrammatically in Fig. 30, distorts the field and the effect is reflected back into an amplifier circuit as a change of resistance, which yields a voltage signal. If the signal has the appropriate sign and has sufficient steepness and amplitude, an alarm signal is given and the conveyer is shut down.

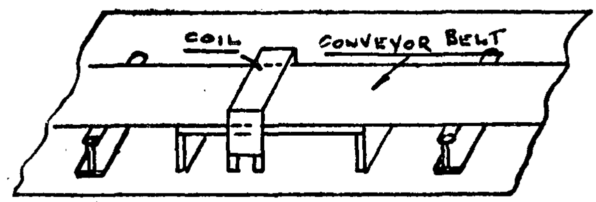

Fig. 30. High-frequency field method for detection of tramp material.

10. **Application to chemical measurements.** (*a*) *pH Meter.* Electric currents are frequently measured by the voltage drop across a resistance and this procedure is used in the pH meter or Hydrogen Ion Concentration Meter. Dissociation effects in solutions generate voltages which may be used to measure the pH value of the solution, but, in order to measure this voltage accurately and continuously, a glass electrode is necessary. The resistance of this electrode is very high—several hundred megohms—and the current is so minute that conventional types of sensitive galvanometers are inadequate.

The measurement problem has been successfully overcome by using a low grid current valve or electrometer valve which is adequate for measuring currents of the order of 10^{-15} amp or even less. The pH meter is well known, but it may not be clearly recognised that in measurements involving very high resistances the effects of electrical leakages which would be of no significance with resistances of a few thousand ohms may cause serious errors. This source of error often arises in electronic measurement techniques and it may be easily eliminated by use of a guard ring. The effect of the guard ring may be seen in Figs. 31 and 32, in which the unknown resistance R is measured by the deflection of the galvanometer G, which is in series with R and the battery. This deflection is compared with that obtained when R is replaced by a calibrated resistance. There is, however, a surface leakage resistance L present between the terminals T_1 and T_2 to which R is connected, and this will affect the deflection. By securing a metal ring to the insulator on which T_2 is mounted and connecting this to the —ve side

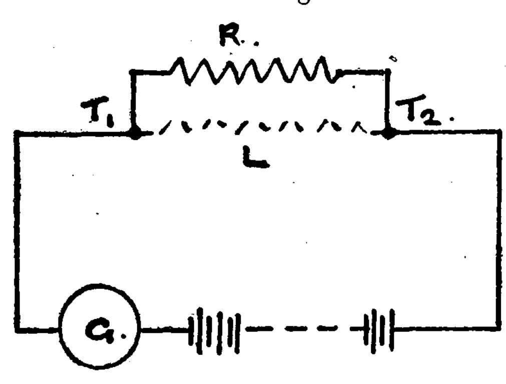

Fig. 31. Circuit diagram for resistance measurement. Leakage currents may flow from T_1 to T_2 through the leakage resistance and yield erroneous results.

of the galvanometer two resistances L_1 and L_2 are substituted for L. L_1 is in parallel with the battery and now has no effect on the deflection; L_2 is in parallel with G but, since it is large compared with the resistance of G, the shunting effect is negligible. It is also possible for leakage to arise from the battery directly to T_1, which may again cause errors; but, by mounting the battery on a metal plate and connecting the latter to the guard point P, the effect of the leakage on the measurement is also negligible.

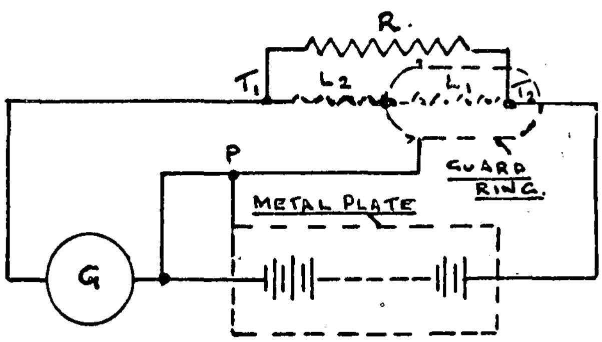

Fig. 32. Leakage currents through L_2 are conducted through the guard ring to the −ve terminal of the battery and do not affect the galvanometer: since the resistance of this part of the circuit is small, the effect of L_1 is negligible. The effect of battery leakage currents is eliminated by connecting the metal plate to point P.

In the pH meter the electrode voltage is applied to the grid circuit of the electrometer valve and affects the voltage drop across the plate circuit resistance. This voltage drop is measured by means of a conventional type galvanometer. The valve thus greatly amplifies the electrode voltage and it is important to ensure that the grid circuit connections and all points from which leakage currents may arise are adequately guarded.

(*b*) *Polarographic Method of Analysis.* A system for displaying the polarographic curve (or current-voltage curve) of a chemical solution on the screen of a Cathode Ray Tube has brought this method of chemical analysis within the range of electronic technique.[6] A study of the traces exhibited on the Cathode Ray Tube Screen enables different substances in dilute solution to be identified.

Referring to Fig. 33 the solution to be analysed is placed in an electrolytic cell. The upper electrode or cathode contains mercury and terminates in a capillary tube from which droplets of mercury flow at intervals of 2 to 4 seconds and the lower electrode or anode is a pool of mercury. When a direct current voltage is applied to the electrodes, a galvanometer reading is made and observations are repeated for different applied d.c. voltages. If the results are plotted, a curve of the form shown in Fig. 34 is obtained from which both the identity and concentration of the substance present may be deduced.

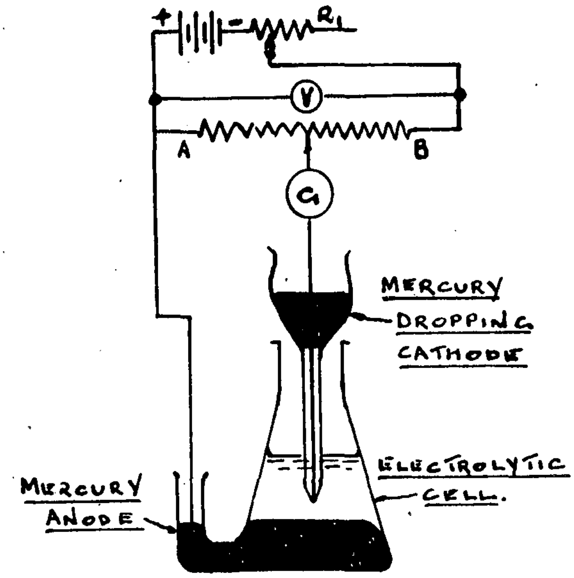

Fig. 33. Basic circuit for polarographic analysis.

Referring to Fig. 34, when the applied voltage is gradually increased there is a small increase of current as shown at a-b. When the voltage reaches the decomposition potential b the current increases suddenly with voltage and reaches a limiting value d-e. If several substances are present in the

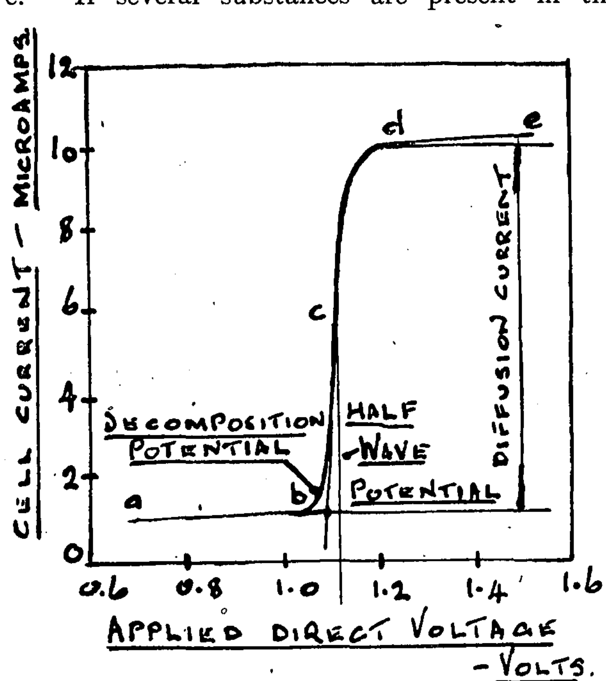

Fig. 34. Example of current/voltage curve obtained by polarograph.

solution the curve obtained will have a number of steps similar to Fig. 34, and the widths of the steps will be determined by the decomposition potentials of the respective substances; the heights of the steps will represent their concentrations.

Polarographic curves are symmetrical with respect to the applied voltage, at which one-half the limiting current flows, and this voltage is called the half-wave potential. This value is characteristic of the electrolyte, is independent of the concentration and is sufficient to identify the ion present. The magnitude of the limiting current establishes the concentration.

The polarographic method was developed about 25 years ago, but was not widely adopted owing to the labour involved in plotting the observations. In the electronic development, Fig. 35, a d.c. voltage is applied to the anode by potentiometer R_2 and is measured on the voltmeter V. An alternating current voltage is also applied from the transformer T_1 by means of the potentiometer R_5, and the resultant current is passed through the primary winding of a transformer T_2, which initiates a signal to the deflection plates of the Cathode Ray Tube. When the polarographic curve has linear characteristics as at a-b, c and d-e, the superposition of the a.c. wave on to the applied direct current will not change the shape of the wave; but where the curve is not linear, as at bc and cd, the wave shape will be distorted.

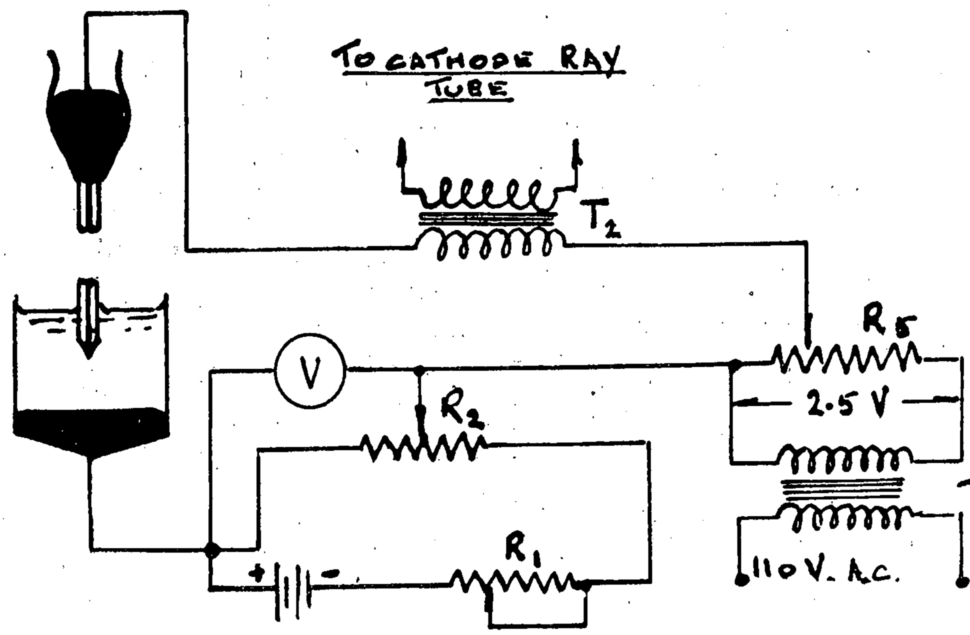

Fig. 35. Polarograph circuit permitting the use of a cathode ray tube for the identification of ions in a solution.

By applying the a.c. voltage to the horizontal pair of deflecting plates and the signal voltage to the vertical plates, the traces indicated in Fig. 36 may be obtained.

The trace a is symmetrical and indicates that the voltage is less than the decomposition potential. Trace b is unsymmetrical and corresponds to the region b-c, Fig. 34. Trace c is symmetrical and indicates that the half-wave potential has been reached. Traces d and e show the effect of changing the direct voltage hy ± 0.2 volts compared with c.

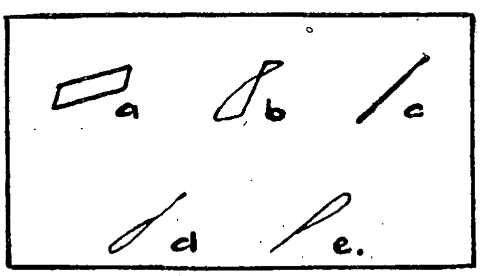

Fig. 36. Traces obtained on the C.R. tube as the direct voltage is increased in steps. The potentiometer is adjusted until the pattern C is obtained and the direct voltage giving this pattern is the characteristic half-wave voltage of one substance of the solution. Complex solutions may be analysed in a few minutes by this method.

11. **Automatic Moisture Control.** In textile weaving the warp threads must be moistened to withstand the effects of abrasion and flexing, and control of the moisture content of these threads is necessary, since too little may cause breakage and too much may cause mildew. The moistened threads pass over a steam-heated roller and the moisture content is regulated by controlling the speed of the roller. Electronic control is achieved by measuring the electrical resistance of the threads on the roller.[8]

Referring to Fig. 37, the threads are passed between two rollers at A; the lower roller is earthed and the upper roller is insulated. If the moisture content of the threads changes, the grid voltage of the triode B changes and a direct current signal voltage is initiated across CD which is applied to the converter and changed to an alternating current signal. This a.c. signal is amplified and applied to the motor M_1 which drives the indicator pointer to a new position on the scale, drives the slider on R_5 to a position which will restore balance to the bridge circuit BCD and displaces R_1 to initiate a change of roller speed. Since the moisture content/resistance relationship is not linear, a cam has to be used to drive the indicator pointer and R_5 has to be tapered.

If the roller speed were controlled directly by M_1, wide speed oscillations or hunting would occur owing to the sensitivity of the bridge circuit; and, in order to prevent this, a speed adjustment is applied which is proportional to the moisture content deviation.

As the position of R_1 is changed by M_1 a signal is applied to the a.c. amplifier which energises motor M_4. This motor changes the speed of the rollers and also drives the slider of R_3 to a new position from which a signal is applied to the a.c. amplifier to balance out the signal from R_1, and the system is restored to equilibrium at a new speed.

Final restoration of the speed to yield the desired moisture content is achieved by means of the floating switch SW_3, which is pre-set by manual control knob. When the moisture content differs from the pre-set value, SW_3 closes and energises motor M_2, which drives a slider on R_4 and unbalances the bridge $R_1R_2R_3R_4$ so as to correct the drift from the pre-set value. Thus the rotation of M_4 is initiated not only by the position of R_1 but also by the relative positions of the sliders on the four resistances R_1, R_2, R_3 and R_4; and any unbalance in this circuit causes M_4 to rotate until a speed is reached which produces the pre-set moisture content.

If manual control is required, the speed may be set by a control switch. The change from automatic to manual control is achieved by moving the switches SW_1 and SW_2 over, which changes the a.c.

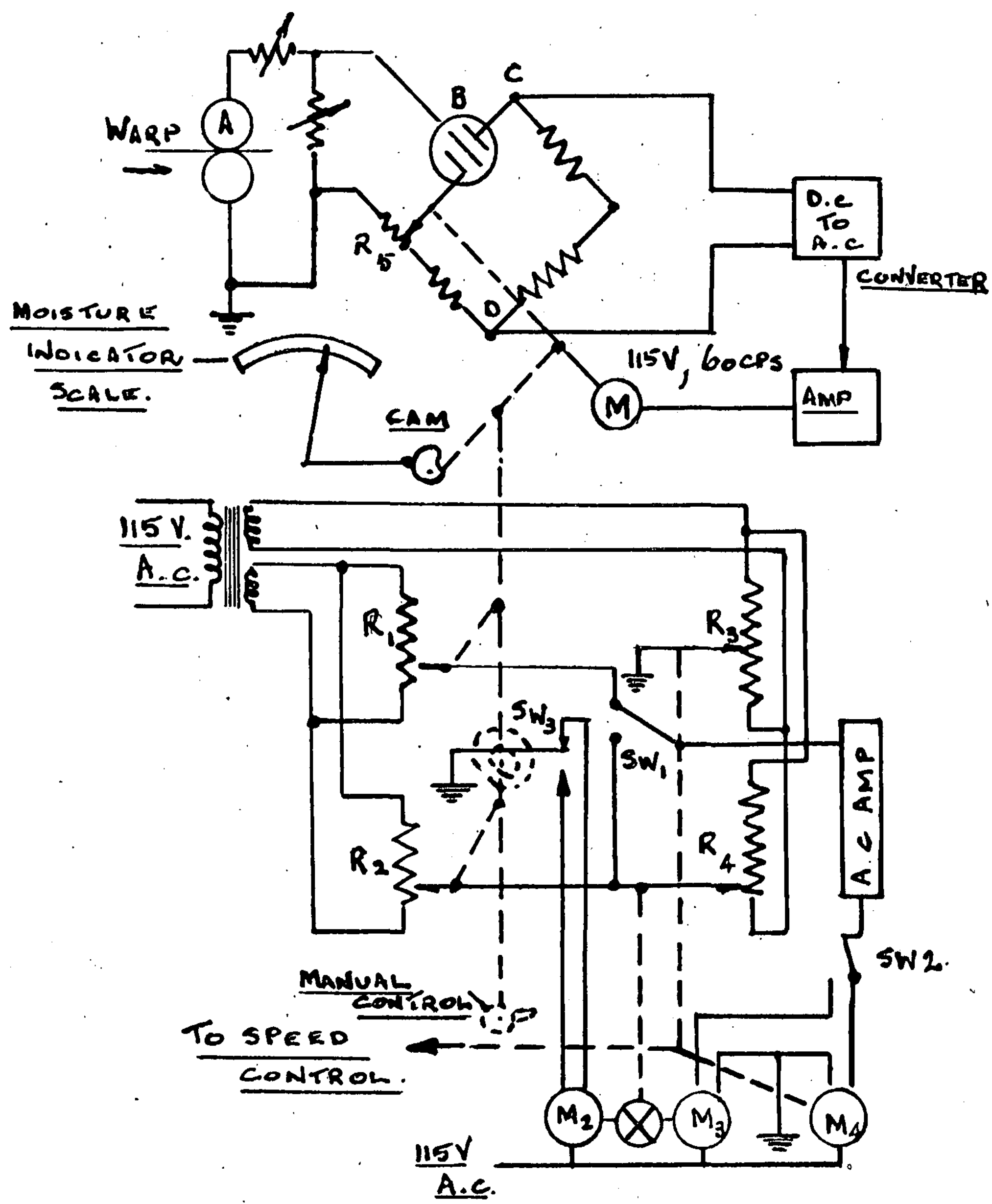

Fig. 37. Automatic moisture content control. Circuit diagram.

amplifier input connections to R_3 and R_4 and the output connections to Motor M_3. The operator adjusts the speed until the indicator shows that the pre-set moisture content has been attained, at which point R_1 and R_2 are in balance; at the same time M_3 is energised to drive the slide of R_4 to retain a balance with R_3. By this means the bridge is kept accurately adjusted and ready to take charge again as soon as the control switch is restored to automatic operation.

12. **Automatic Control of Machine Tools.** An electronic contour controller enables the manufacture of variable shapes and contours, e.g. cams, dies and roller forms to be achieved automatically by duplicating the contours of a master template.[9] The equipment consists of an electronic system, a tracing head and two motors which are geared to the longtitudinal and cross slides of the machine tool and rotate independently of each other.

The tracing head is shown in Fig. 38 and is secured so that the stylus may keep in contact with the template. A small force is adequate to deflect the stylus and templates made of wood or plaster may be used.

When the stylus is displaced by the motion of the template, signals are generated and applied to the electronic system which drives the motors so as to reproduce the motion required by the signal direction at the cutting tool. Referring to Fig. 39, a voltage of 2,000 cycles per sec. frequency is applied to inductances 1 and 3 and a similar voltage displaced in phase by a quarter-cycle from the former is applied to inductances 2 and 4. The inductances 1, 2, 3 and 4 form the arms of a bridge circuit. When the stylus is deflected the inductance air-gaps change and signals are generated in either or both of the coils as indicated. The electronic system is devised so that the drive to the motors ensures that the stylus is always kept in contact with the template.

The method is capable of providing very accurate reproductions of complicated forms.

13. **Speed and Performance control of Electric Motors.** In many industrial applications of motor drives, e.g. the textile, chemical and paper-making industries and machine tools, a wide range of driving speed is required which is usually provided by the use of direct-current motors. Generally, public power supplies are alternating current and means have to be provided to change this to direct current. The requirements are easily achieved by an electronic system which is capable of providing a speed range of 1 : 10 or 1 : 100 on the motor if desired.

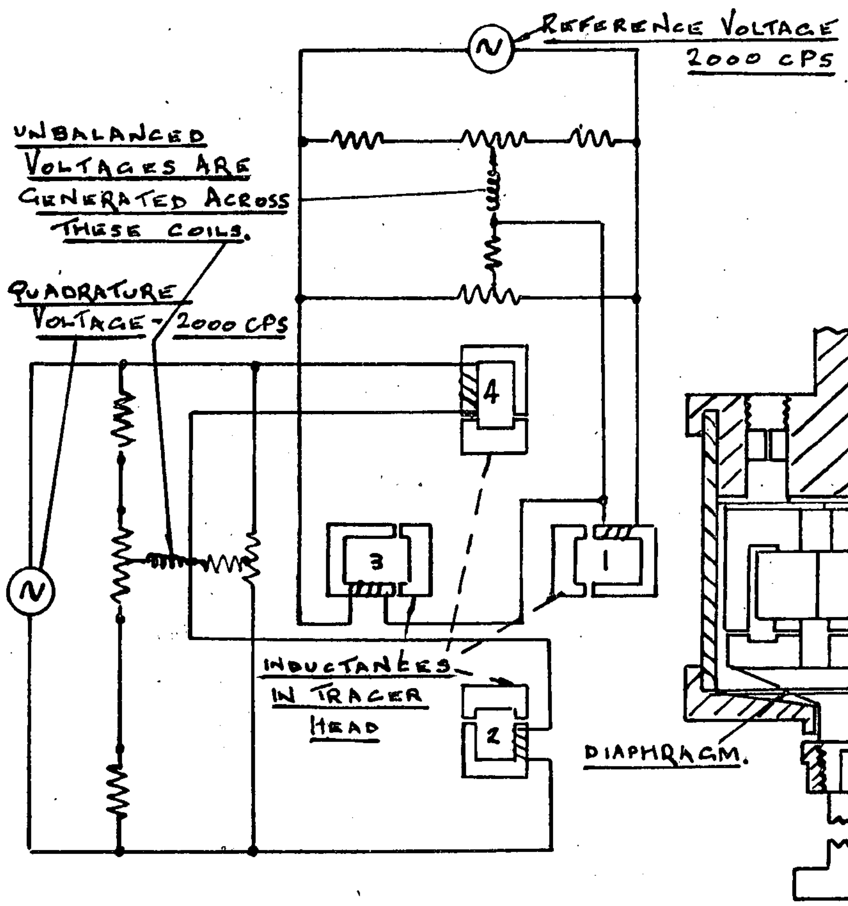

Fig. 39. Tracer head bridge circuit.

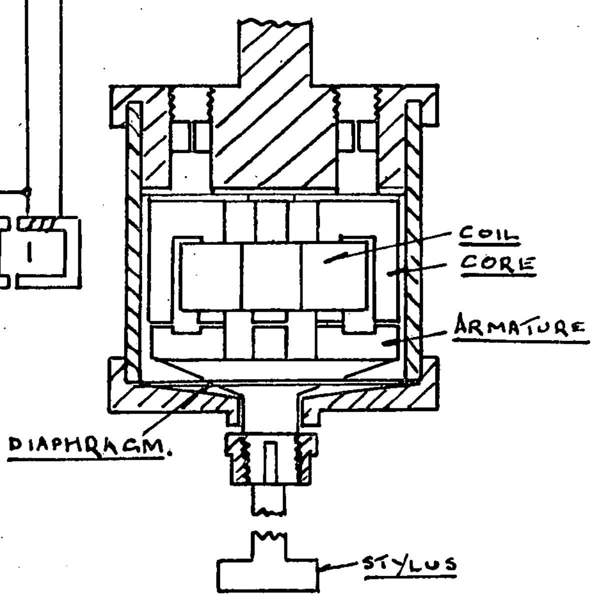

Fig. 38. Magnetic tracing head.

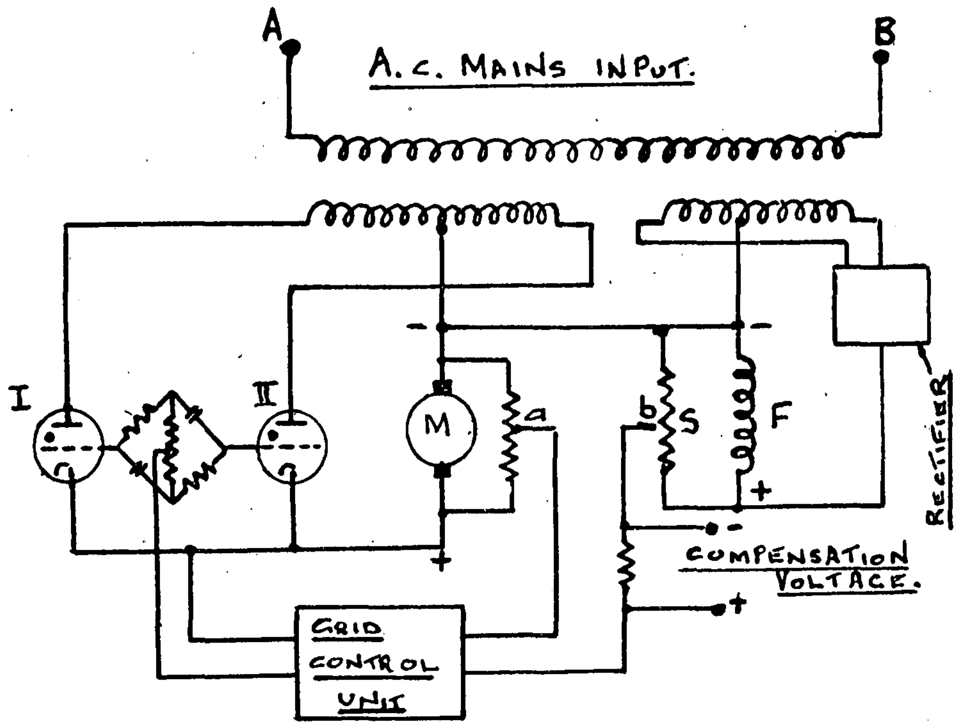

Fig. 40. Thyratron control of direct current motor. Circuit diagram.

Referring to Fig. 40, the a.c. supply voltage is applied to the transformer terminals A, B and the output is applied to the thyratrons I, II, which are connected to provide full-wave rectification. The thyratrons are connected to the motor armature M and the power supply for the motor shunt field F and the speed regulator S is provided from a separate rectifier.

By changing the incidence of the grid voltage with respect to the anode voltage, the thyratron firing point is changed and the output voltage also changes, which enables the motor speed to be adjusted. This effect is illustrated in Fig. 41 (*a*), (*b*) and (*c*). In Fig. 41 (*a*) the anode voltage is represented by the sine wave ACDB and the critical grid voltage by the horizontal line AHB. If a grid control voltage EFG is applied, the thyratron will fire at point 1 and continue firing for the interval 1H. In other words a rectified voltage is applied to the motor armature for a period 1H in each half-cycle of the anode voltage. This is illustrated in Fig. 42.

Referring to Fig. 41 (*b*) the grid control voltage is displaced by applying a d.c. voltage to it and under these conditions the thyratron fires at point 2 and continues firing for the interval 2H. By displacing the grid control voltage as illustrated in Fig. 41 (*c*) firing is delayed until point 3 and the armature voltage is applied only for the short interval 3H. The second thyratron is controlled similarly and a continuous control between zero and maximum of the output voltage is obtained.

Referring to Fig. 40, by connecting the points a and b to an amplifier in the grid control voltage unit very sensitive control of speed is obtained, since the voltage at point a is always proportional to the motor armature voltage. Any small variation of the

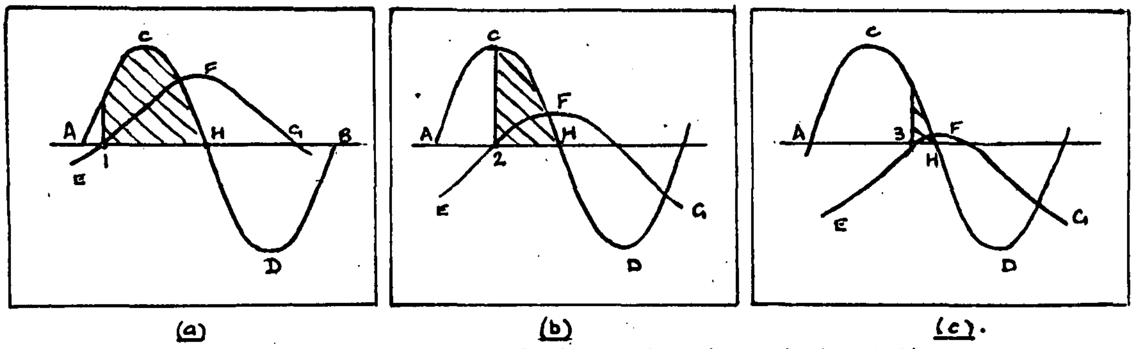

Fig. 41. Control of thyratron point by changing the grid control voltage incidence.

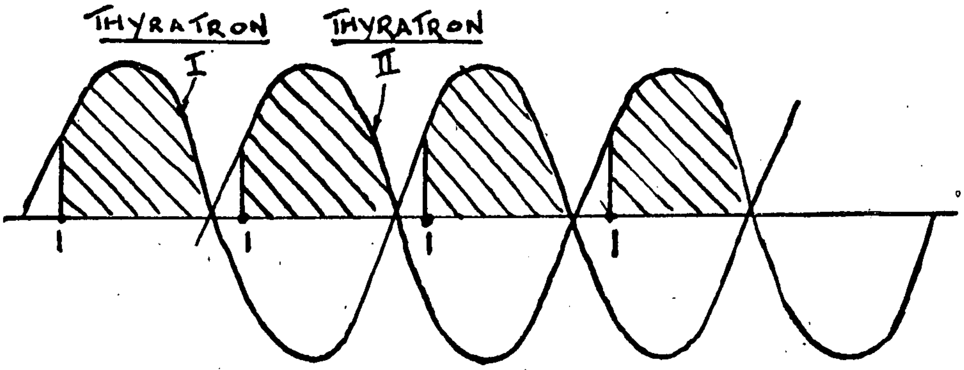

Fig. 42. Shaded areas show voltage applied to motor armature.

voltage between a and b is amplified and changes the incidence of the grid control voltage EFG substantially.

In the shunt-connected direct-current motor the speed falls as the load is increased, but this effect may be corrected with the electronic system by applying a compensating voltage to the armature, proportional to the armature current. Speed-load curves showing the effect of compensation are shown in Fig. 43.

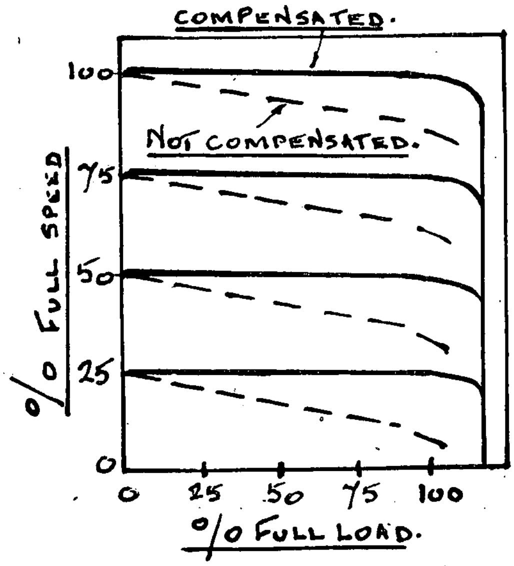

Fig. 43. Load-speed characteristics of a thyratron controlled D.C. motor with load compensation.

Conclusion.

14. The modern application of electronics to industrial processes has opened up a new perspective for the future and provides a means for achieving substantial progress in accuracy of control and making many operations fully automatic. By the advantages it possesses in sensitivity and rapidity of response, process lag can be eliminated. Future applications will become increasingly diverse and limited only by a lack of ingenuity in devising the methods of application and unwillingness to make use of them.

Summary.

15. The introduction of electronic methods to industrial processes is only of recent growth, but many successful applications of the technique have been made. This paper introduces a description of some typical electronic components and their characteristics and then discusses a few applications. The method possesses great versatility and a development of the applications described will be made increasingly as the advantages become better known and recognised.

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Sugar Milling Research Institute,
Howard College,
Durban.
February, 1950.

The author illustrated the paper by means of epidiascope slides, and then showed a film demonstrating several industrial uses of electronic devices.

The PRESIDENT asked if the author knew of any applications of such devices in sugar factories or refineries.

Mr. McCULLOCH replied that, with the exception of the pH indicator, he was not aware of any other applications at the present time.

Mr. McKENNA thought that a number of factory operatives would welcome automatic control of juice heating and of pan boiling, and he enquired if such control could be effected through electronic means.

Mr. McCULLOCH considered that such control could be comparatively cheaply and simply evolved. A temperature control method was described in the paper and this could easily be applied. Without having seen such devices at work it was difficult to realise the extent to which they could be utilised.

The PRESIDENT said that while it was possible to imagine all kinds of possible uses for such apparatus, it was evident that much development was required before full advantage could be taken of electronics in sugar factories and refineries.