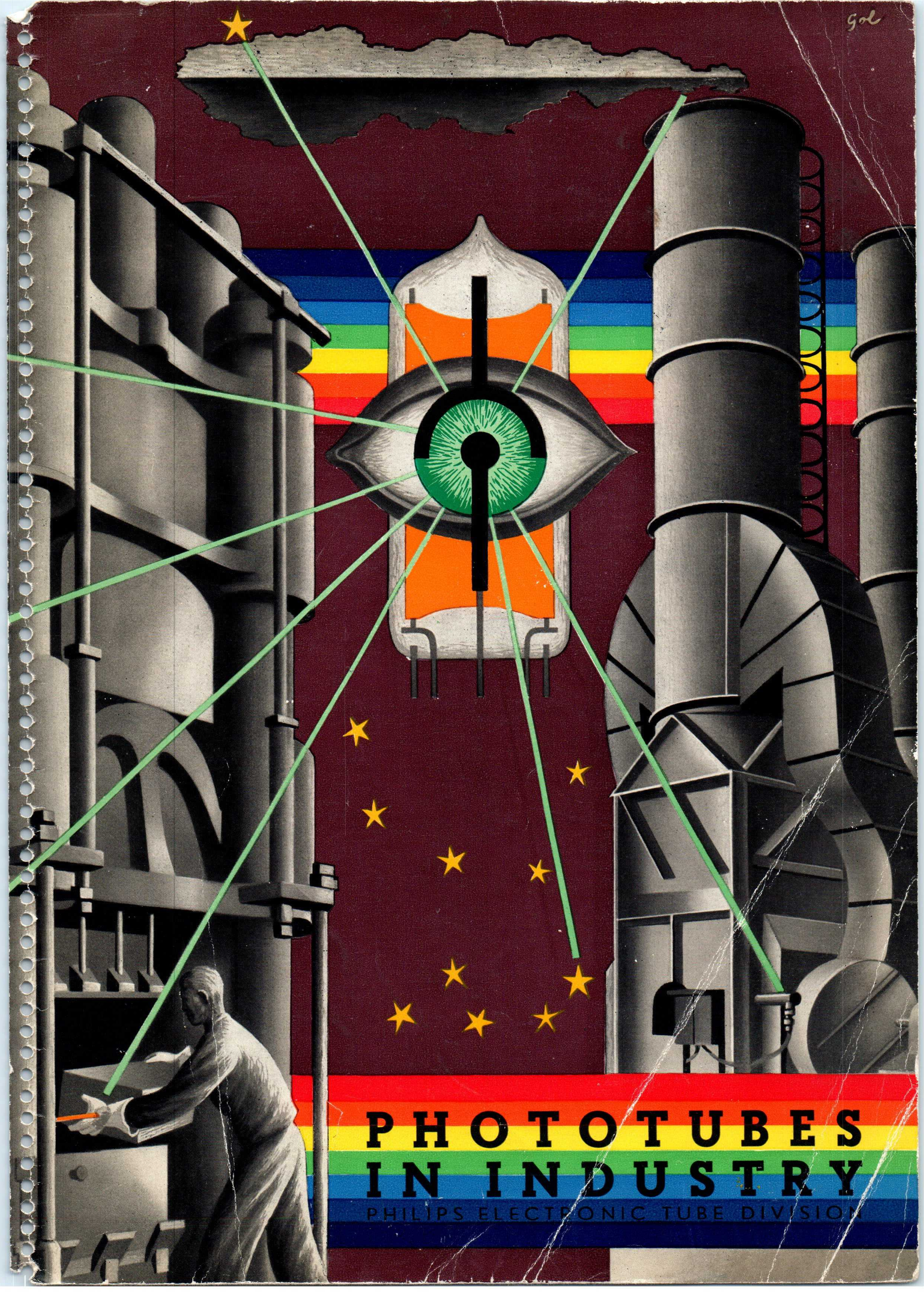
PHOTOTUBES
IN INDUSTRY
PHILIPS ELECTRONIC TUBE DIVISION

PHOTOTUBES IN INDUSTRY

PREFACE

Most inventions of this technical age serve to assist or replace human effort, be it physical or intellectual. There are several mechanical and electrical devices for amplifying human strength or replacing human labour. Microphones and amplifiers augment the sense of hearing, while loudspeakers amplify the power of the human voice. Telescopes and microscopes are an aid to the sense of sight, while photo- and film cameras in a certain way further the ability of visual memory.

All these devices are a reinforcement to man. He uses them in cases where a given task can be performed in a more efficient way with the aid of mechanical or physical implements.

The phototube with its supplementary electronic equipment constitutes a device of a higher order, because it acts by itself. It looks and watches; it even partially replaces the reflex actions of the human nervous system, without human aid. Once it is installed and directed in its duty, it is a never tiring and never sleeping electronic supervisor, and when the phenomenon it is to watch for occurs, it *can give a signal or make a huge machine stop or be set in motion, according to the work it is required to do.*

The phototube is no novelty. It started its career some twenty years ago. This magic device, made of a little glass, some metals and a tremendous amount of skill, which revolutionized the sound film in one stroke, was bound to penetrate into industry. Here, however, its application was a more gradual evolution because in the beginning even the most progressive of mechanical engineers only hesitatingly introduced the phototube into their kingdom of force and power. Men were needed with an interest in, and with a knowledge of, both mechanics and electronics; teams of mechanical and electronic engineers had to be formed, before the younger technique could take its place on an equal footing with the mechanical and electrical industry.

Especially during the last decade, when tremendous industrial problems had to be solved in the shortest and most efficient way, co-operation between mechanical and electronic engineers came to full development. Due to electronics, which proved a formidable ally, production could be accelerated and multiplied in an unprecedented way. With electronics, general interest focuses in particular on the phototube, because its application brought the solution of hitherto insoluble technical problems. This documentation, which contains information, circuits and suggestions on industrial phototube applications, is offered to the progressive electronic equipment maker in order to direct his attention to this but partially explored field of action and source of profit. Additional and specific assistance for solutions of problems that might arise during development of phototube apparatus will be gladly given.

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PART 1 GENERAL INFORMATION

HIGH-VACUUM PHOTOTUBES

Phototubes are photo-electric devices of the emissive type, as distinct from the barrier-layer and photo-conductive cells. They may be divided into two classes:

(1) high-vacuum phototubes;

(2) gas-filled phototubes.

Each of these groups can be subdivided into red-sensitive and blue-sensitive phototubes, the spectral response depending upon the cathode material.

The cathode

The cathode of a phototube is made of a material with a low work function. In fact, this work function is so low that, when the cathode is struck by a beam of light, free electrons are emitted. It is known that in this respect caesium is sensitive to red and infra-red rays, whereas for instance potassium is sensitive to the electro-magnetic waves of shorter wavelength, i.e. blue, violet and ultra-violet.

In the course of development of photo-emissive cathodes it proved that very good red-sensitive cathodes could be made with caesium on a layer of oxidized silver, this being called the "C" type of cathode. A very good blue-sensitive cathode is made of caesium on antimony and is called the "A" type of cathode.

In fig. 1 the spectral response curve is shown of a phototube with the "A" type of cathode. It is seen that the greatest sensitivity lies in the region between wavelengths of 3850 Å and 4500 Å, thus in the range of violet and blue light. Ultra-violet rays, having a wavelength below 3850 Å, are absorbed by the glass envelope of the tube; so the curve does not extend below this wavelength. If phototubes sensitive to ultra-violet rays are desired, the bulb must be provided with a quartz window, to let these rays pass on to the cathode.

Fig. 2 shows the spectral response curve for the "C" type of cathode. Maximum sensitivity lies between 7,000 Å and 9,000 Å, which is the region of red and infra-red light.

The photo-cathode can be applied on a silver plate, in which case the entire bulb is transparent (for instance the phototube 90 CV). In other cases the cathode is applied to the inner side of the glass envelope, the bulb then being only partly transparent; the space where the beam of light enters the phototube is then called the window.

A value for the maximum permissible cathode

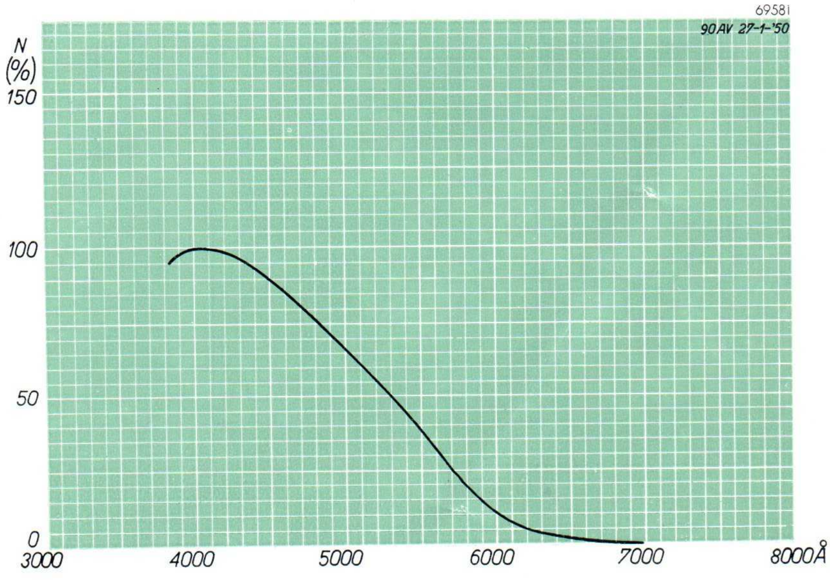
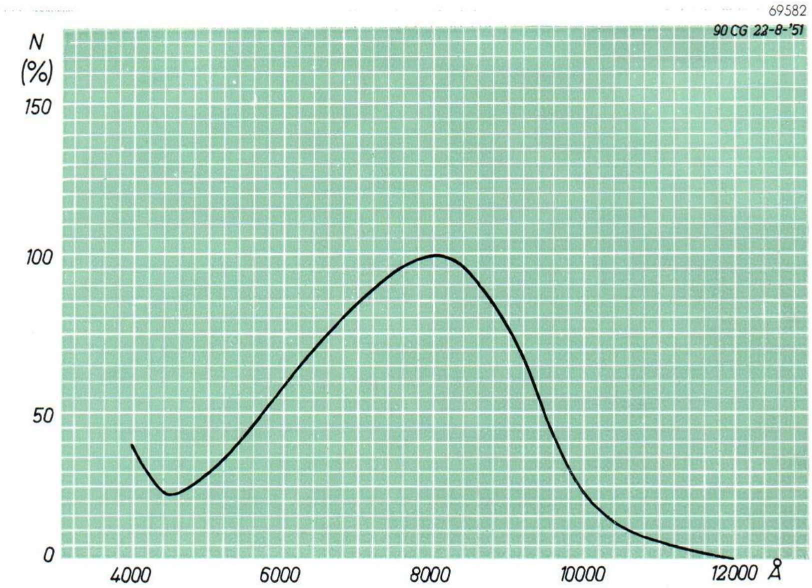


Fig 1. Spectral response curve of phototube with "A" type of cathode.

Fig. 2. Spectral response curve of phototube with "C" type of cathode.



current is given in the tube data. This value holds when the entire cathode surface is illuminated uniformly. If, however, only part of the cathode surface is illuminated, the cathode current must be kept correspondingly lower.

Dark current

Even if a photo-cathode is not illuminated it will emit some electrons, if only as a result of the ambient temperature. The work function of the cathode surface is so low that even at room temperature some thermionic emission can be observed. The current resulting from this thermionic emission is called the dark current and is rather low, in the case of ceasium cathodes this being of the order of 10^{-8} A/cm². For the 90 AV or the 90 CV phototubes the dark current at an anode voltage of 100 V is about 0.05 μA.

Sensitivity

The sensitivity of a phototube depends on the type of cathode used and is expressed in μA/lm. It must be noted that this value has no significance if the spectral energy distribution of the light source used to measure the sensitivity is not known.

Especially for phototubes sensitive to the invisible infra-red radiation, the sensitivity depends largely on the spectral composition of the light. The eye cannot distinguish between a large and a small component of infra-red radiation. If there are two sources of light radiating an equal number of lumens, it is possible that one radiates far more of the invisible infrared than the other. The sensitivity of a "C" cathode will be much greater for the first light source than for the latter. For instance the sensitivity of a phototube with a "C" type cathode is, for incandescent light with a colour temperature of 2700 °K, 20 μA/lm, but for daylight, which usually has a much smaller infra-red component the sensitivity is only 4 μA/lm. The daylight sensitivity of a phototube with an "A" type cathode, however, is about 80 μA/lm, whilst for a lamp with a colour temperature of 2700 °K it is 45 μA/lm.

Since phototubes are normally employed in combination with incandescant lamps, the sensitivity of phototubes is measured with a lamp with tungsten filament operating at a colour temperature of 2700 °K.

The anode

The anode may consist of a single rod or a bent wire, the so-called hair-pin anode. Where the total electronic current is only very small (5 - 10 μA), there is no need of a large anode surface for cooling. The anode, having to be placed between the light source and the cathode, is made small and thin, so that only very little of the light beam is intercepted.

Characteristics of high-vacuum phototubes

In fig. 3 the saturation characteristic of a high-vacuum phototube is represented. The anode

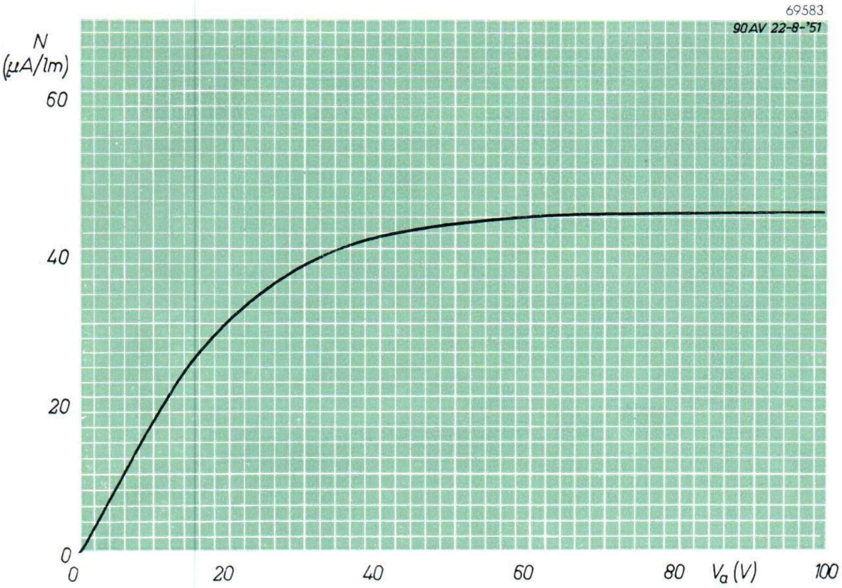


Fig. 3. Saturation characteristic of a high-vacuum phototube.

current depends on the quantity of light falling on the cathode, and so the sensitivity is indicated in µA/lm. It is seen that only the lower anode voltages affect the anode current, this being due to the fact that not all the emitted electrons are drawn towards the anode. Above a certain value the anode current is practically independent of the anode voltage. When all free electrons impinge upon the anode, saturation is reached. The voltage where the curve becomes flat is called the saturation voltage.

The high-vacuum phototube may be compared with normal thermionic diode in which the heater cathode is replaced by a photo-electric cathode. The high-vacuum phototube thus having fundamentally the same properties as those of a thermionic diode with respect to frequency etc., its sensitivity is therefore constant for frequencies up to those at which transit time limitations occur.

If high-vacuum tubes are operated under the conditions recommended, their characteristics remain substantially constant over long periods of time.

Types of high-vacuum phototubes

The high-vacuum phototubes dealt with in this documentation are:

58 CV . . . . red-sensitive
90 AV . . . . blue-sensitive
90 CV . . . . red-sensitive
3545 . . . . red-sensitive.


70642

Fig. 4. Phototube 58 CV

PHOTOTUBE 58 CV

The phototube 58 CV is of the vacuum type and is provided with a caesium-on-oxidized-silver cathode. It is most sensitive to incandescent light sources and to near infra-red radiation.
This phototube is designed for end-on incidence of illumination and its small dimensions make it suitable for applications where space is a limiting factor, or where it is desired to have multiple banks of phototubes in operation.

Cathode

Surface	caesium-on-oxidized-silver
Projected area	1.1 cm² = 0.171 □″

Mounting position any

Capacitance

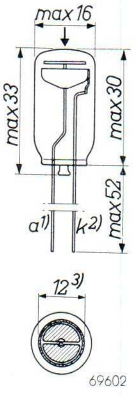
between anode and cathode	3.0 pF

Characteristics and recommended maximum operating conditions

Dark current at 50 V	max. 0.05 μA
Anode supply voltage	50 V
Sensitivity (V_a = 50 V, T = 2700 °K)	20 μA/lm
Anode resistor	1 MΩ

Limiting values

Anode supply voltage	max. 100 V
Cathode current (per mm²)	max. 30 mμA
Ambient temperature	max. 100 °C



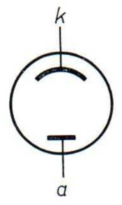


Fig. 5 Dimensions in mm and electrode connections.

1) Red lead
2) Black lead
3) Sensitive cathode area

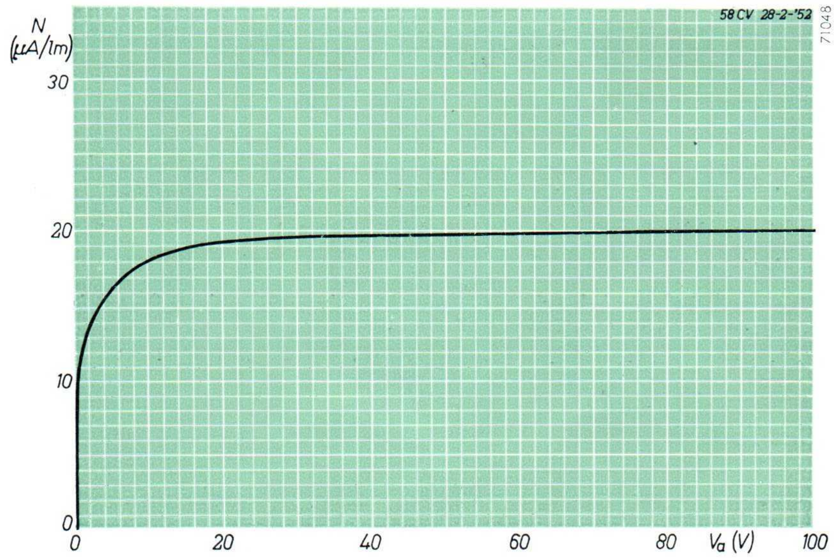


Fig. 6. Saturation characteristic.

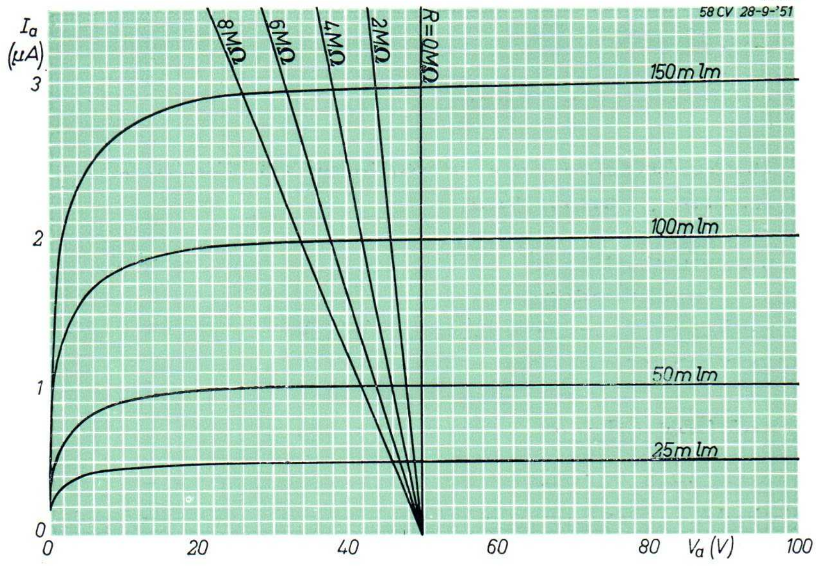


Fig. 7. I_a/V_a characteristic.

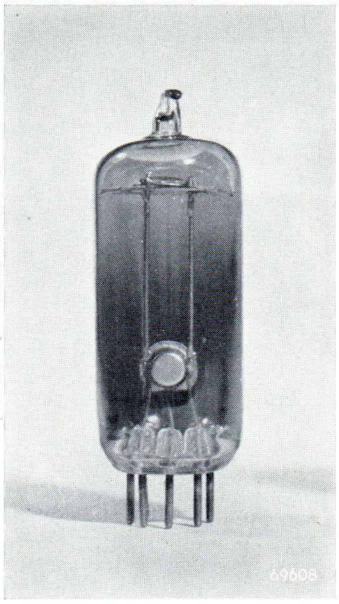


Fig. 8. Phototube 90 AV

PHOTOTUBE 90 AV

The phototube 90 AV is of the vacuum type with a caesium-on-antimony cathode. It is most sensitive to daylight and light radiation having a blue predominance. It has negligible response to infra-red radiation.
The use of the miniature all-glass technique permits of a rigid construction and a maximum exposed cathode area for a phototube of these small dimensions.

Cathode

Surface	caesium-on-antimony
Projected area	4 cm^2 = 0.620 □″

Mounting position any

Capacitance

between anode and cathode	0.9 pF

Characteristics and recommended maximum operating conditions

Dark current at 85 V	max. 0.05 μA
Anode supply voltage	85 V
Sensitivity (V_a = 85 V T = 2700 °K)	45 μA/lm
Anode resistor	1 MΩ

Limiting values

Anode supply voltage	max. 100 V
Cathode current (per mm^2)	max. 12,5 mμA
Ambient temperature	max. 70 °C

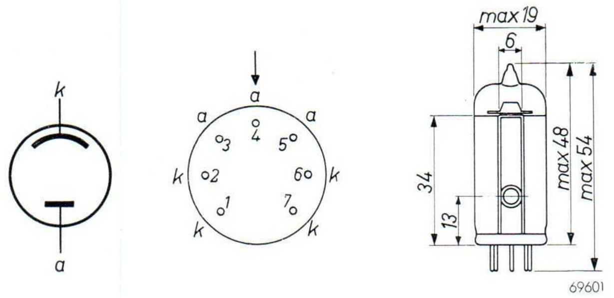


Fig. 9. Dimensions in mm and electrode connections.

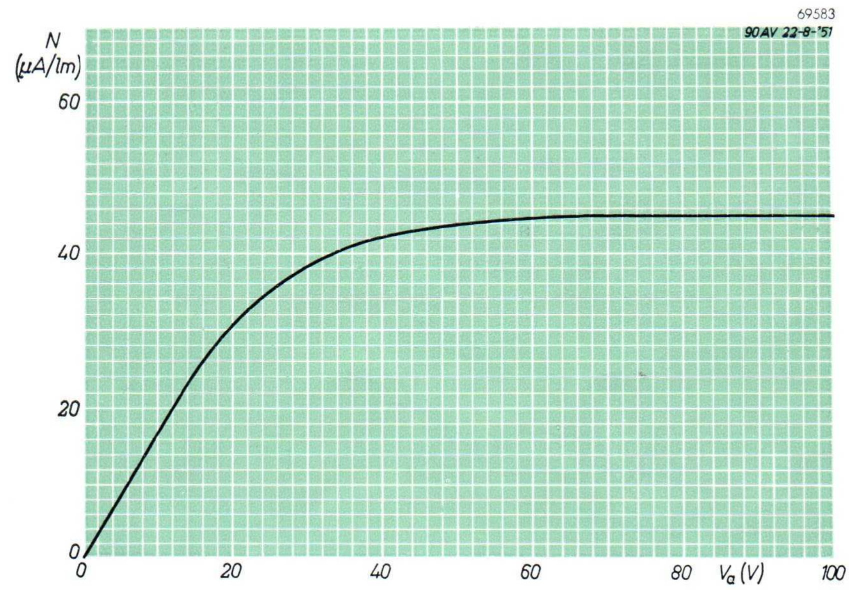


Fig. 10. Saturation characteristic.

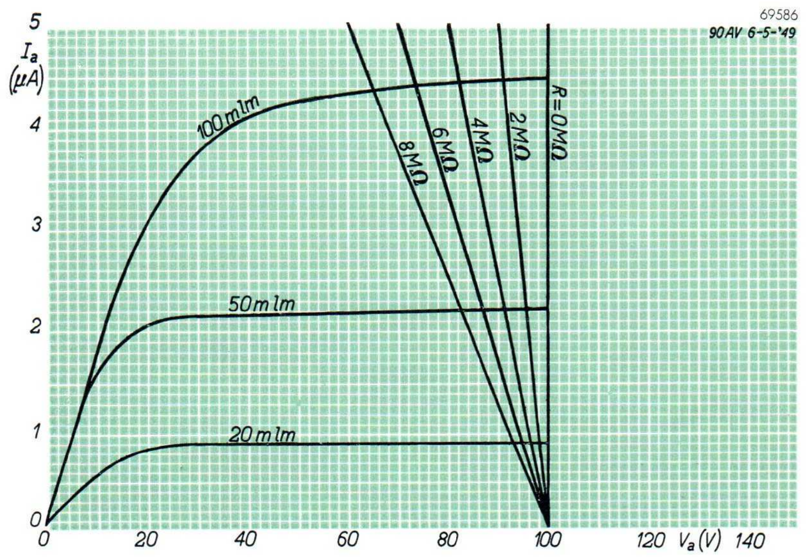


Fig. 11. I_a/V_a characteristic.

PHOTOTUBE 90 CV

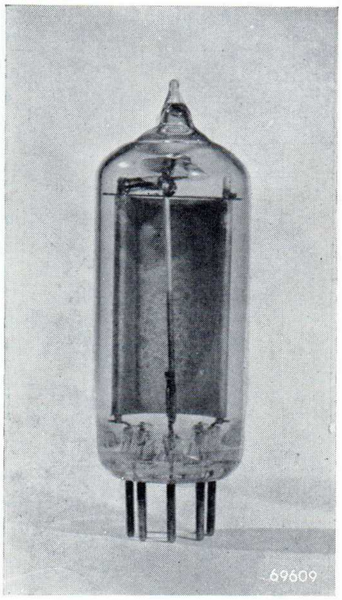


Fig. 12. Phototube 90 CV.

The phototube 90 CV is a vacuum tube with a caesium-on-oxidized-silver cathode, thus most sensitive to incandescant light sources and to near infra-red radiation. The use of the miniature all-glass base permits of a rigid construction and a maximum exposed cathode area for a phototube of this size.

Cathode

Surface	caesium-on-oxidized-silver
Projected area	2.4 cm² = 0.372 □″

Mounting position any

Capacitance

between anode and cathode	1.1 pF

Characteristics and recommended maximum operating conditions

Dark current at 50 V	max. 0.05 μA
Anode supply voltage	50 V
Sensitivity (V_a = 50 V, T = 2700 °K)	20 μA/lm
Anode resistor	1 MΩ

Limiting values

Anode supply voltage	max. 100 V
Cathode current (per mm²)	max. 30 mμA
Ambient temperature	max. 100 °C

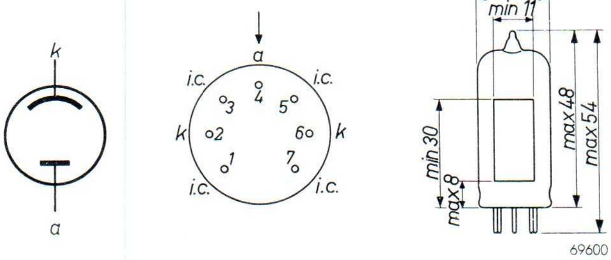


Fig. 13. Dimensions in mm and electrode connections.

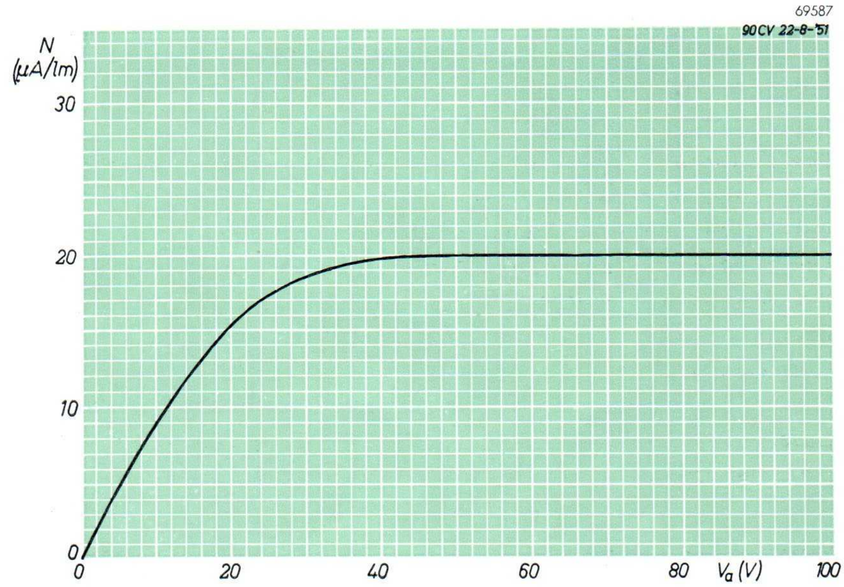


Fig. 14. Saturation characteristic.

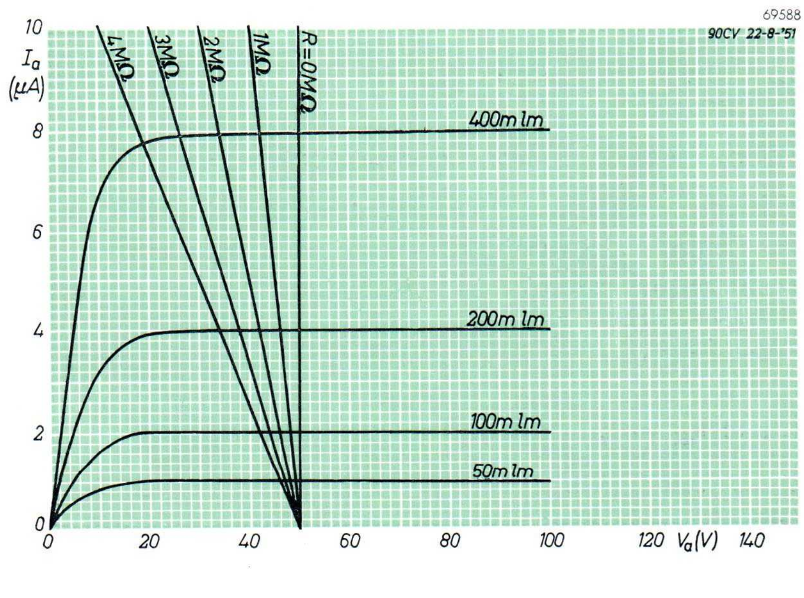


Fig. 15. I_a/V_a characteristic.

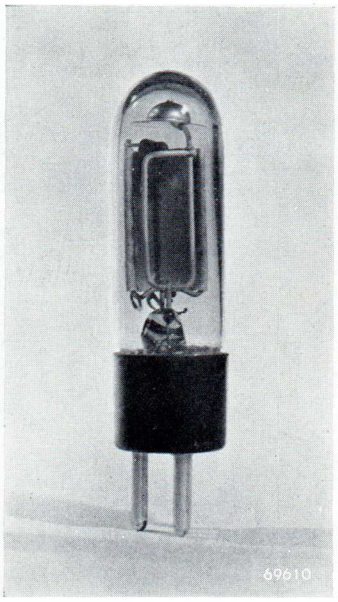


Fig 16. Phototube 3545.

PHOTOTUBE 3545

The phototube 3545 is of the vacuum type with a caesium-on-oxidized-silver cathode, most sensitive to incandescent light sources and to near infra-red radiation.
In order to prevent microphony if the tube is used in equipment which is subjected to vibration, special measures have been taken to obtain a rigid electrode structure. The top ends of anode and cathode, for example, are interconnected mechanically via a glass bead to prevent vibration of these electrodes as a result of impact excitation.
The 3545 can be supplied with a standard PeeWee or with a two-pin base.

Cathode

Surface	caesium-on-oxidized-silver
Projected area	0.8 cm² = 0.124□″

Mounting position any

Capacitance

between anode and cathode	2 pF

Characteristics and recommended maximum operating conditions

Dark current at 90 V	max. 0.01 μA
Anode supply voltage	90 V
Sensitivity (V_a = 90 V. T = 2700 °K)	20 μA/lm
Anode resistor	1 MΩ

Limiting values

Anode supply voltage	max. 250 V
Cathode current (per mm²)	max. 50 mμA
Ambient temperature	max. 50 °C

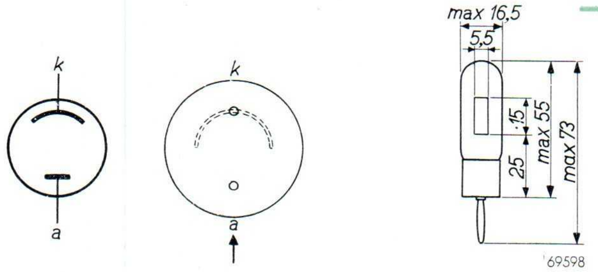


Fig. 17. Dimensions in mm and electrode connections.
(For dimensions and connections PW-base see fig. 32, page 21.)

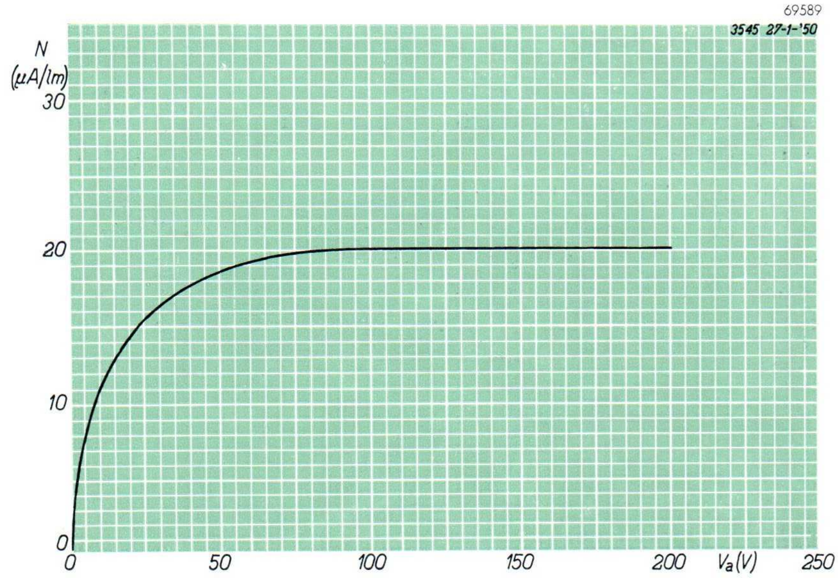


Fig. 18. Saturation characteristic.

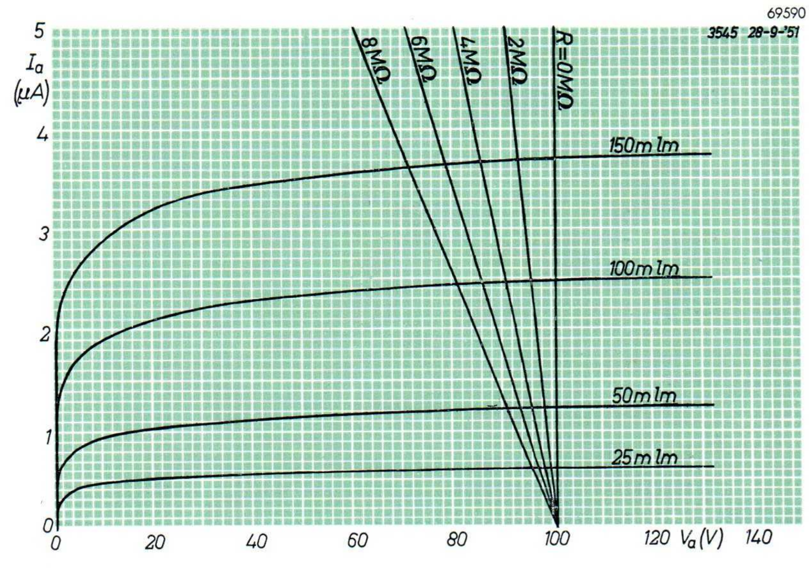


Fig. 19. I_a/V_a characteristic.

GAS-FILLED PHOTOTUBES

In the course of the last ten or twenty years the sensitivity of particularly the blue-sensitive high-vacuum phototubes has been improved quite remarkably. This is illustrated by comparing the old blue-sensitive tube type 3510, having a sensitivity of 3 µA/lm, with the newer type 90 AV which has a sensitivity of 45 µA/lm. Red-sensitive tubes have not been improved to the same extent.

For several purposes a much greater sensitivity is required and this can be reached in a rather simple way by letting a small quantity of inert gas into the bulb.

The gas amplification can be explained as follows: When the electrons pass from the cathode to the anode in a gas-filled tube, on their way they will meet the gas atoms. If the velocity of the electrons is only small, this will be of no influence on the photo current. If, on the other hand, an electron traverses a potential which exceeds the ionization voltage of the inert gas concerned, it has a velocity sufficiently high to ionize gas atoms by collision. Through this collision a positive ion is formed, which goes to the cathode, and a free electron is released, which, together with the original electron, passes to the anode. These two electrons may cause the ionization of other gas atoms so that for one electron released from the cathode by the beam of light, several electrons may arrive at the anode. The positive ions resulting from the ionization, impinge on the cathode and may release other electrons from its surface, which, on their way to the anode, ionize other gas atoms, and so on. It will be clear that in this way the photo-current can be amplified several times, and this amplification increases with the anode voltage, since the velocity of the electrons is directly proportional to the voltage gradient traversed. The number of collisions resulting in ionization therefore increases with the anode voltage.

The anode voltage, however, may not be increased indefinitely because at too high an anode

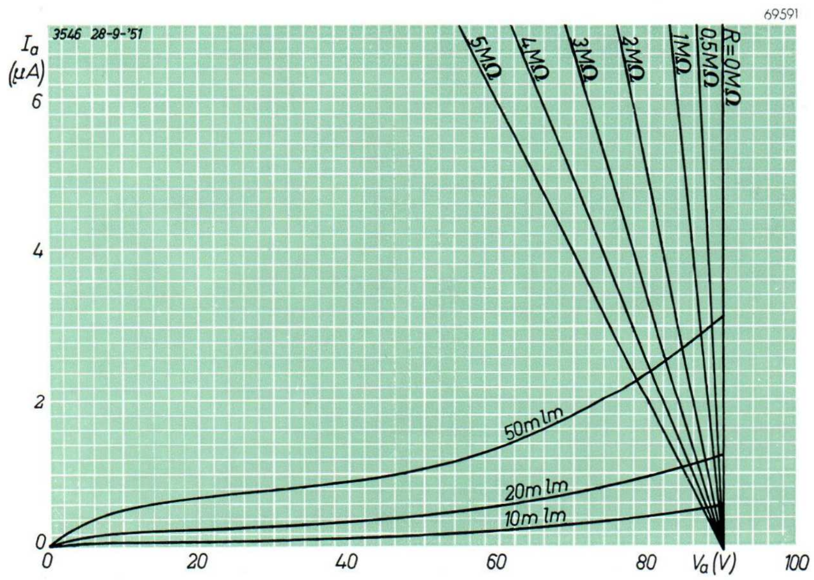


Fig. 20. I_a/V_a characteristic of gas-filled phototube.

voltage gas-glow would occur. To limit the effect of accidental over-running a protective resistor of at least 0.1 MΩ should be inserted. The ignition voltage of gas-filled phototubes is about 100 to 150 V for the different types and the anode voltage has to be made much lower, for instance, 75 to 100 V. The gas amplification that can be obtained in this way ranges between 5 and 10 times.

A typical I_a/V_a characteristic of a gas-filled phototube is shown in fig. 20. In the curved parts of the characteristic the voltage across the load resistor will not be exactly proportional to the amount of light falling on the cathode. For this reason gas-filled phototubes are not very suitable for exact measurement purposes; they are, however, excellent for sound reproduction, because at the usual value of the load resistor in sound-film apparatus, the bend in the characteristic is of negligible influence.

For industrial purposes where a great sensitivity prevails over exactness, the gas-filled phototube is very useful.

The gas amplification decreases at higher frequencies. This is due to the fact that the ions formed in the gas are much heavier than the electrons, so that their velocity is relatively low. When the light is suddenly interrupted there are still some ions moving to the cathode which release some electrons, ionizing other gas atoms, and so on. The number of newly formed ions, however, is too small to keep the anode current flowing and so this is gradually decreasing. Likewise the anode current will not reach its final value immediately after the cathode is illuminated.

Thus at higher frequencies the gas amplification is not able to follow the fluctuations of the light, and the result is that above 1000 c/s, the amplification decreases, but up to 10,000 c/s this decrease is so small as to be of no influence for practical applications. A typical example of a frequency characteristic of a gas-filled phototube is given in fig. 21.

The types of gas-filled phototubes dealt with in this documentation are:

58 CG	red-sensitive
90 AG	blue-sensitive
90 CG	red-sensitive
3546	red-sensitive
3554	red-sensitive.

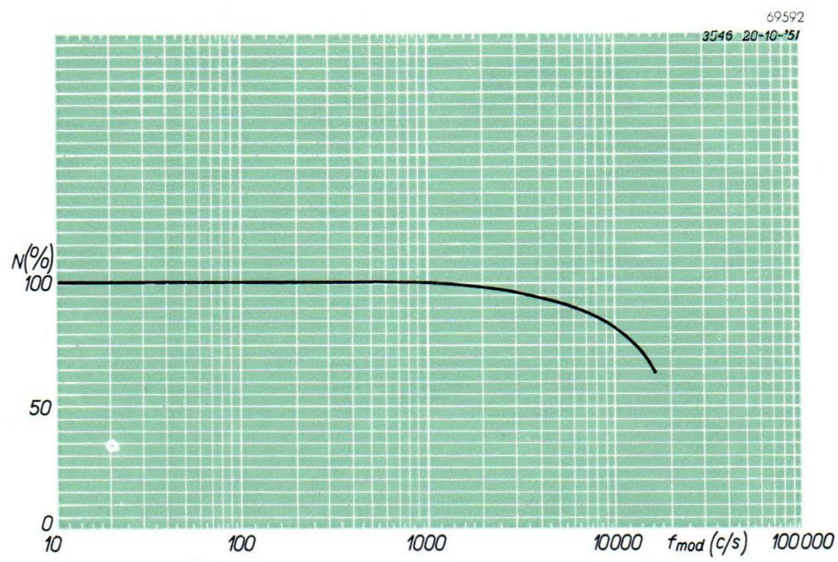


Fig. 21. Frequency characteristic of gas-filled phototube.

PHOTOTUBE 58 CG

Fig. 22. Phototube 58 CG.

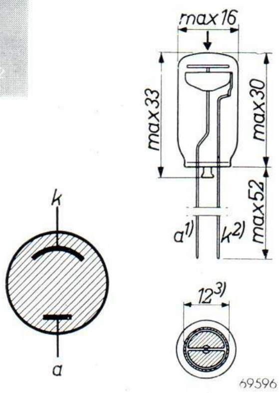


Fig. 23. Dimensions in mm and electrode connections.

1) *Red lead.*
2) *Black lead.*
3) *Sensitive cathode area.*

The phototube 58 CG is of the gas-filled type, with a caesium-on-oxidized-silver cathode, thus most sensitive to incandescent light sources and to near infra-red radiation.

This tube is designed for end-on incidence of illumination and its small dimensions render it suitable for applications where space is a limiting factor or where it is desired to have multiple banks of phototubes in operation.

Cathode

Surface	caesium-on-oxidized-silver
Projected area	$1{,}1\ cm^2 = 0.171\square''$

Mounting position any

Capacitance

between anode and cathode	3.0 pF

Characteristics and recommended maximum operating conditions

Dark current at 85 V	max.	0.1 μA
Anode supply voltage		85 V
Sensitivity (V_a = 85 V, T = 2700 °K)		85 μA/lm
Anode resistor		1 MΩ

Limiting values

Anode supply voltage	max.	90 V
Cathode current (per mm²)	max.	15 mμA
Ambient temperature	max.	100 °C

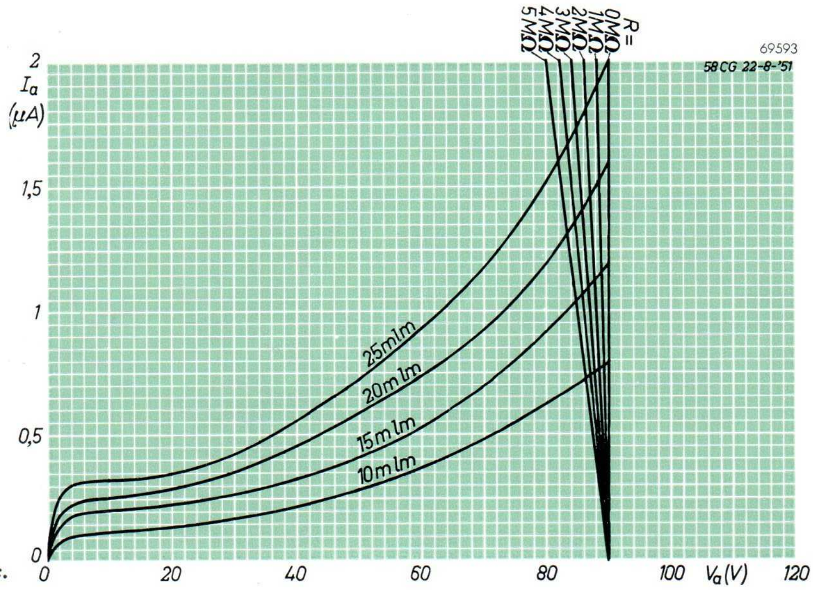


Fig. 24. I_a/V_a characteristic.

PHOTOTUBE 90 AG

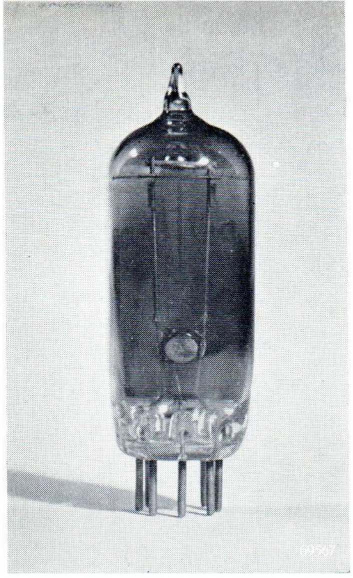


Fig. 25.
Phototube 90 AG.

The phototube 90 AG is of the gas-filled type with a caesium-on-antimony cathode. It has a high sensitivity to daylight and to light sources predominating in blue radiation. Its response to infra-red radiation is negligible. The use of the miniature all-glass technique permits of a rigid construction and a very large sensitive surface for a phototube of such small dimensions.

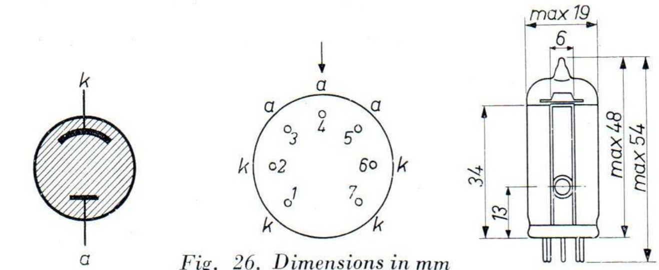


Fig. 26. Dimensions in mm and electrode connections.

Cathode

Surface	caesium-on-antimony
Projected area	4 cm² = 0.620 □″

Mounting position

any

Capacitance

between anode and cathode	0.9 pF

Characteristics and recommended maximum operating conditions

Dark current at 85 V	max.	0.1 μA
Anode supply voltage		85 V
Sensitivity (V_a = 85 V, T = 2700 °K)		130 μA/lm
Anode resistor		1 MΩ

Limiting values

Anode supply voltage	max.	90 V
Cathode current (per mm²)	max.	6 mμA
Ambient temperature	max.	70 °C

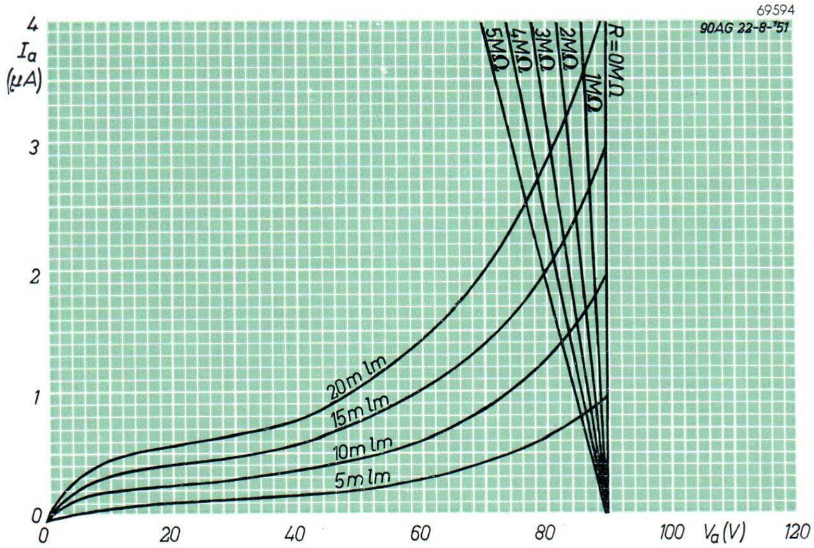


Fig. 27. I_a/V_a characteristic.

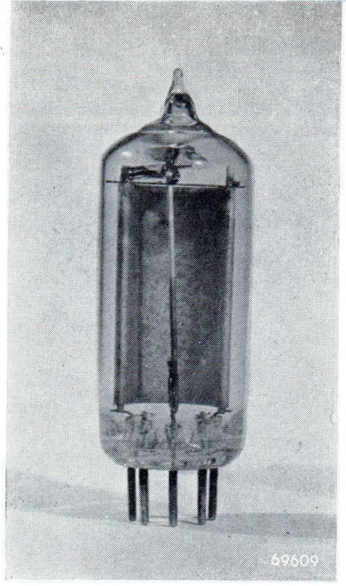


Fig. 28. Phototube 90 CG.

PHOTOTUBE 90 CG

Type 90 CG is a gas-filled phototube with a caesium-on-oxidized-silver cathode, so it is most sensitive to incandescent light sources and near infra-red radiation.

The use of the miniature all-glass technique permits of a rigid construction and a very large sensitive surface for a phototube of this size.

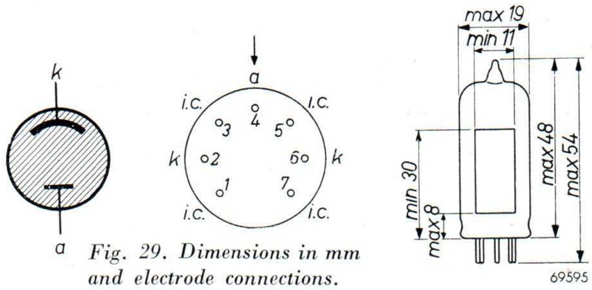


Fig. 29. Dimensions in mm and electrode connections.

Characteristics and recommended maximum operating conditions

Dark current at 85 V	max. 0.1 μA
Anode supply voltage	85 V
Sensitivity (V_a = 85 V, T = 2700 °K)	125 μA/lm
Anode resistor	1 MΩ

Limiting values

Anode supply voltage	max.	90 V
Cathode current (per mm²)	max.	7 mμA
Ambient temperature	max.	100 °C

Cathode

Surface	caesium-on-oxidized-silver
Projected area	2.4 cm² = 0.372□″

Mounting position

any

Capacitance

between anode and cathode 1.1 pF

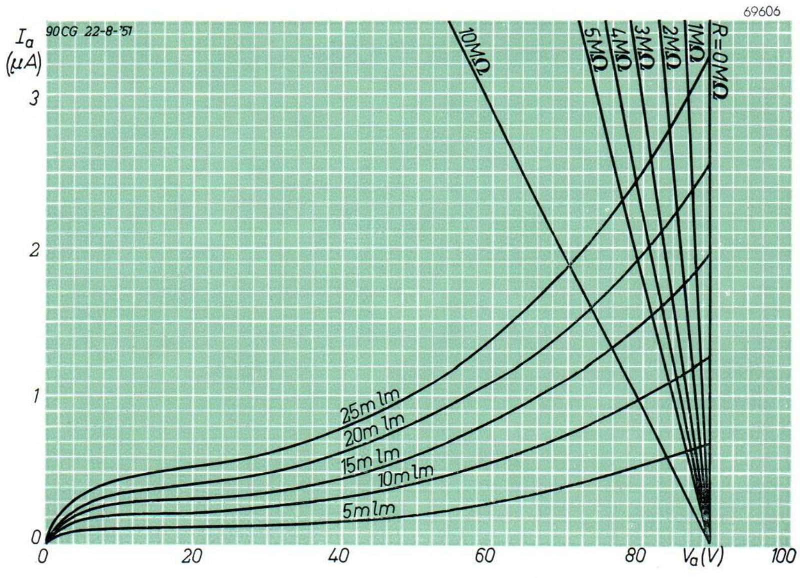


Fig. 30. I_a/V_a characteristic.

PHOTOTUBE 3546

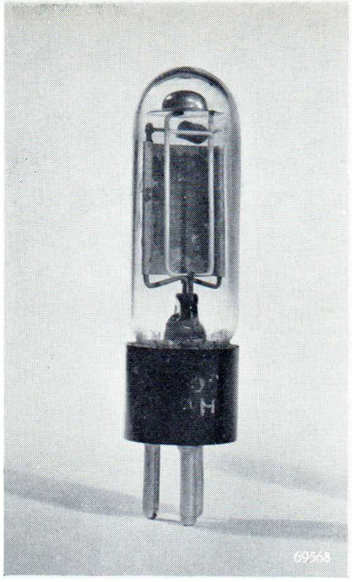


Fig. 31.
Phototube 3546.

The phototube 3546 is of the gas-filled type with a caesium-on-oxidized-silver cathode, thus most sensitive for incandescent light sources and near infra-red radiation. The small dimensions make it very useful in standard sound-film projectors and in such light-operated relays where small dimensions are of paramount importance.
In the construction of the electrode system great care has been taken to avoid occurrence of microphony, the top-ends of the anode and the cathode are connected to each other by means of a glass bead so that the tube is quite insensitive to vibration of the apparatus in which it is mounted.

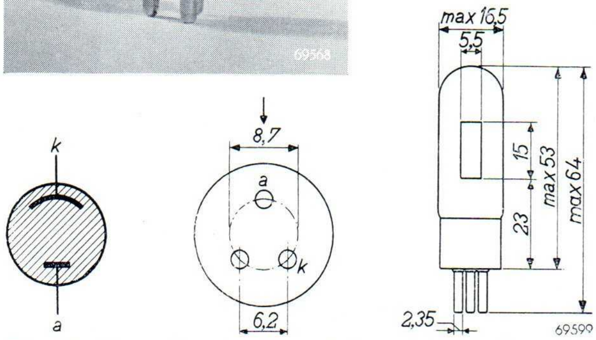


Fig. 32. Dimensions in mm and electrode connections. (For dimensions and connections two-pin base see fig. 17, page 15.)

Cathode

Surface	caesium-on-oxidized-silver
Projected area	0.8 cm² = 0.124□″

Mounting position any

Capacitance

between anode and cathode	2 pF

Characteristics and recommended maximum operating conditions

Dark current at 90 V	max.	0.1 μA
Anode supply voltage		90 V
Sensitivity (V_a = 90 V, T = 2700 °K)		150 μA/lm
Anode resistor		1 MΩ

Limiting values

Anode supply voltage	max.	90 V
Cathode current per mm²	max.	75 mμA
Ambient temperature	max.	50 °C

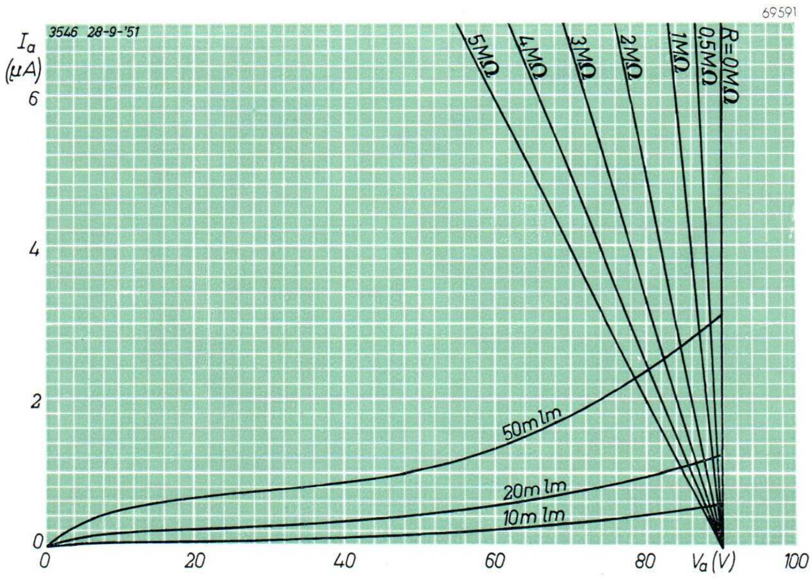


Fig. 33. I_a/V_a characteristic.

PHOTOTUBE 3554

Type 3554 is a gas-filled phototube with a caesium-on-oxidized-silver cathode. It has maximum response for incandescent light and near infra-red radiation. Its high sensitivity renders it suitable for use in standard cinema installations and in such light-operated relays where a relatively great cathode surface is wanted.

The tube is equipped with a medium four-pin base.

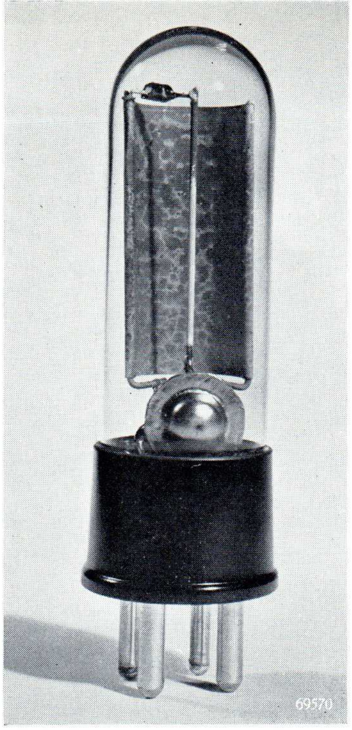


Fig. 34. Phototube 3554.

Cathode

Surface	caesium-on-oxidized-silver
Projected area	4.5 cm² = 0.698 □″

Mounting position

any

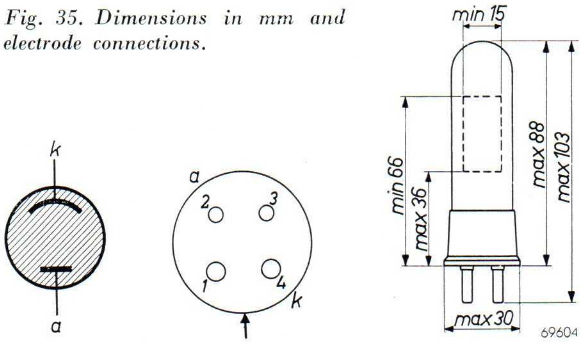
Capacitance

between anode and cathode	3.4 pF

Characteristics and recommended maximum operating conditions

Dark current at 90 V	max.	0.1 μA
Anode supply voltage		90 V
Sensitivity (V_a=90 V, T_a=2700 °K)		150 μA/lm
Anode resistor		1 MΩ

Fig. 35. Dimensions in mm and electrode connections.



Limiting values

Anode supply voltage	max.	90 V
Cathode current (per mm²)	max.	75 mμA
Ambient temperature	max.	50 °C

(Provisional data).

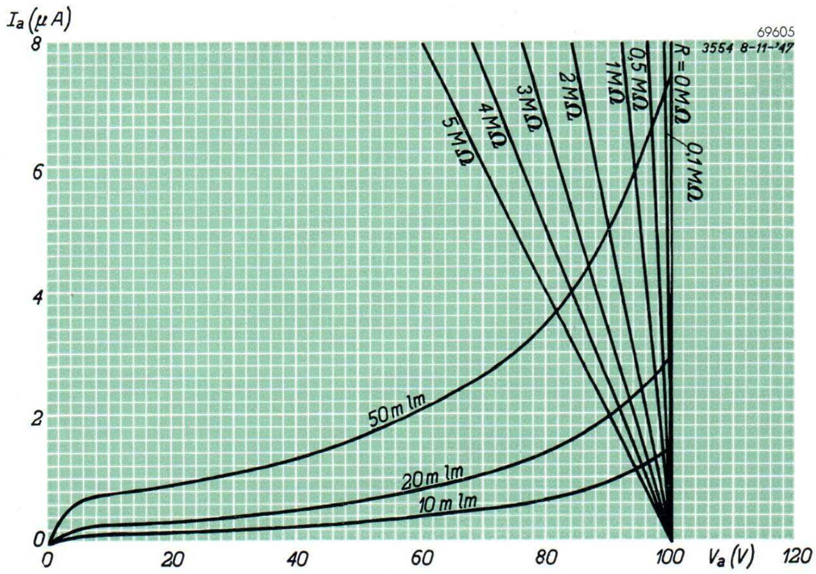


Fig. 36. I_a/V_a characteristic.

CLASSIFICATION OF PHOTOTUBE APPLICATIONS

Phototubes are applied for measuring or indicating a quantity or a variation of light or colour. The measurement can be very rough and only indicate whether there is light or not; this may be called on-off action. A more refined measurement is possible when the phototube indicates a certain increase or decrease of light. Finally, exact quanta of light can be measured. It is not necessary for the light beam to strike the cathode directly; in several cases it will only be possible to use reflected light. Then there is no question of on-off action because every surface, even if it is apparently black, reflects some light, it then being only a matter of a maximum or minimum of reflected light; this may be called contrast action.
Thus we can divide the application of phototubes into two main groups:

(1) with direct light,
(2) with reflected light.

Each group is subdivided into three groups, viz.:

direct light
1. **on-off action**
2. **action after certain increase or decrease of light,**
3. **quantitative or spectral measurement of light**

and

reflected light
1. **contrast action,**
2. **action after certain amount of increase or decrease of reflected light,**
3. **quantitative or spectral measurement of reflected light.**

Every application of phototubes falls under one of these headings.

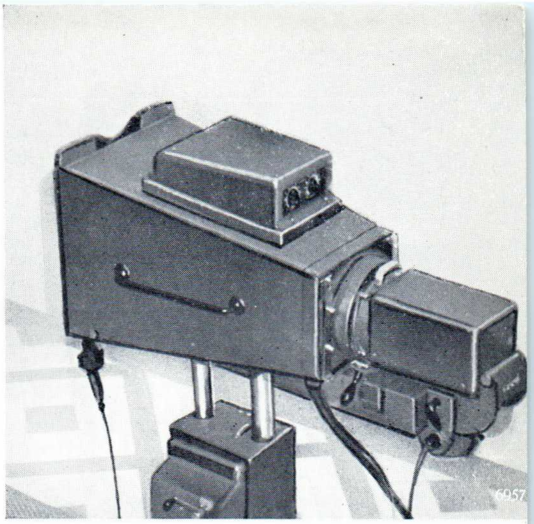


Fig.37. Camera part of X-ray apparatus for medical mass chest examination. The phototube installation measuring the light intensity on the luminescent screen (the photo timer) is mounted in the hood.

The information obtained from the phototube can be utilized in several ways. For on-off and contrast action the usual method is as follows: After due amplification the information of the phototube commands a relay. The relay can either activate some signalling system or it can switch on some auxiliary or servo-mechanism to control a machine.
When a gradually varying phenomenon of light is "observed" by a phototube and a predetermined limit is reached, the tube can bring about the same action as in the case mentioned before. Finally, the amount of light can be measured, and the results can either be registered directly or communicated to other electronic apparatus and to servo-mechanisms. A practical example of the last method is the use of phototubes for automatic exposure control in X-ray film cameras such as are used for medical mass examination in the Army, big factories and for examining the entire population of a district. Owing to the phototube apparatus incorporated in the cameras, the examination can be carried out at a rate of 500 persons per hour. Fig. 37 shows a photograph of such a camera, with the photo-timer mounted on the hood. On page 24 a schematic survey is given of various applications of phototubes, grouped according to the classification mentioned above, followed by a list of explanations in alphabetical order.

SURVEY OF PHOTOTUBE APPLICATIONS

- Applications of phototubes
  - Direct light
    - On-off action
      - Excitation of relays
        - Alarm
        - Air doffer
        - Counting
        - Flame control
        - Filling
        - Folding
        - Inspection
        - Level control
        - Pin hole detector
        - Safeguard
        - Switching
        - Weighing
      - Excitation of transductors
        - Switching of heavy currents
        - Temperature control
      - Excitation of gas-discharge lamps
        - Calibration of gas and water meters
    - Gradual increase or decrease
      - Excitation of relays at predetermined level
        - Automatic light switching
        - Density control
        - Fire alarm
        - Mercury vapour detectors
        - Smoke detectors
      - Reproduction
        - Image
        - Sound
      - Measuring
        - Absorption meters
        - Astronomy
        - Dust detection
        - Exposure control (X-ray)
        - Meteorology (cloud density)
        - Optical pyrometers
        - Photographic density
        - Saturation of a solution
    - Spectral response
      - Excitation of relays at predetermined level or colour
        - Chlorinization of water
        - Control over mixture of solution
        - Colour inspection rough tempering
        - Discolouring during chemical reactions
        - Gas detector
      - Measuring
        - Colorimeters
        - Flame photometers
        - Spectral analysis
  - Reflected light
    - Contrast action
      - Excitation of relays
        - Examination for: double printing
          - cracks
          - leaks
          - insulation
          - seams
        - Register control
      - Excitation of transductors
        - Register control
        - Switching of heavy currents
    - Gradual increase or decrease
      - Excitation of relays at certain level
        - Baking colour control
        - Grinding machines
        - Polishing machines
        - Spraying machines
      - Reproduction
        - Facsimile
        - Sound
      - Measuring
        - Exposure meters
        - Integrating photometers
    - Spectral response
      - Excitation of relays
        - Final inspection
        - Mixing of paints or ink
        - Sorting to colour
      - Measuring
        - Chemical analysis
        - Colour comparison
        - Spectrometers

ALPHABETICAL LIST OF PHOTOTUBE APPLICATIONS

ABSORPTION METER

Photometer used for measuring the light transmission of liquids and translucent materials for comparison or standardization.

AIR DOFFER

Photo electric air-jet device used in laundries. The laundered articles coming from the ironer on a conveyer intercept a light beam striking a phototube. This operates an air-jet device, which is mounted in such a way that the articles are blown onto a horizontal bar and stacked there until removed.

ALARM

A light beam (visible or invisible) striking a phototube is intercepted and an alarm signal is given. The light beam can be lengthened by means of mirrors. The interception may be caused by persons, approaching trains, traffic, etc.

ASTRONOMY

Photometers are used in this science for measuring light intensities or spectral emission of stars or other celestial bodies.

AUTOMATIC LIGHT SWITCHING

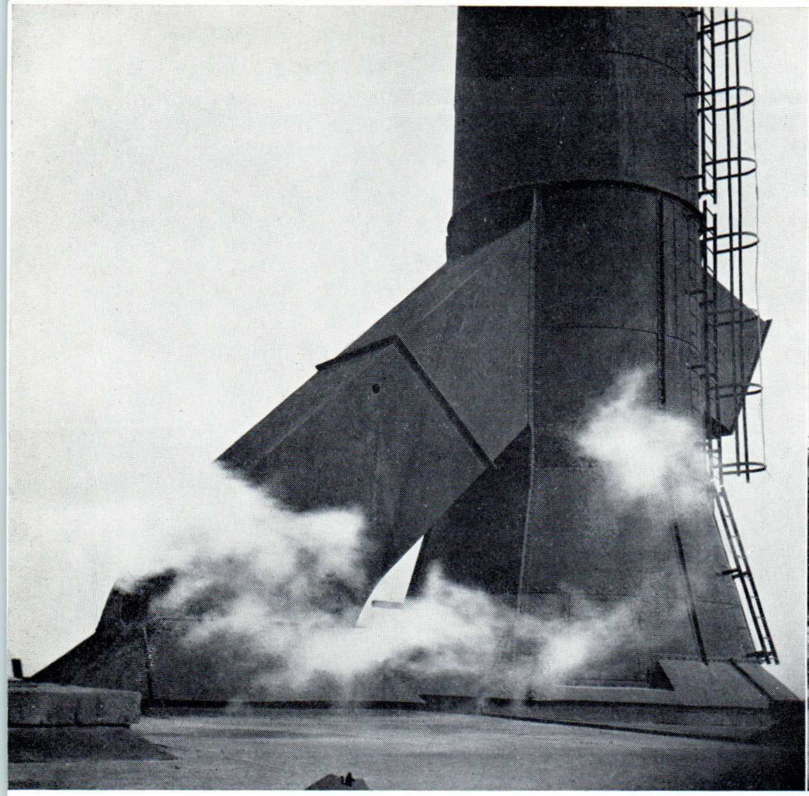
One or more phototubes operating relay circuits, biased at a certain level, are directed towards the sky. As soon as daylight decreases to a certain level, artificial illumination is switched on by the relay. When daylight increases the illumination is automatically switched off. Some delaying device is incorporated in the circuit, to prevent the relay from being operated as a result of passing foreign bodies intercepting the light received by the phototubes.

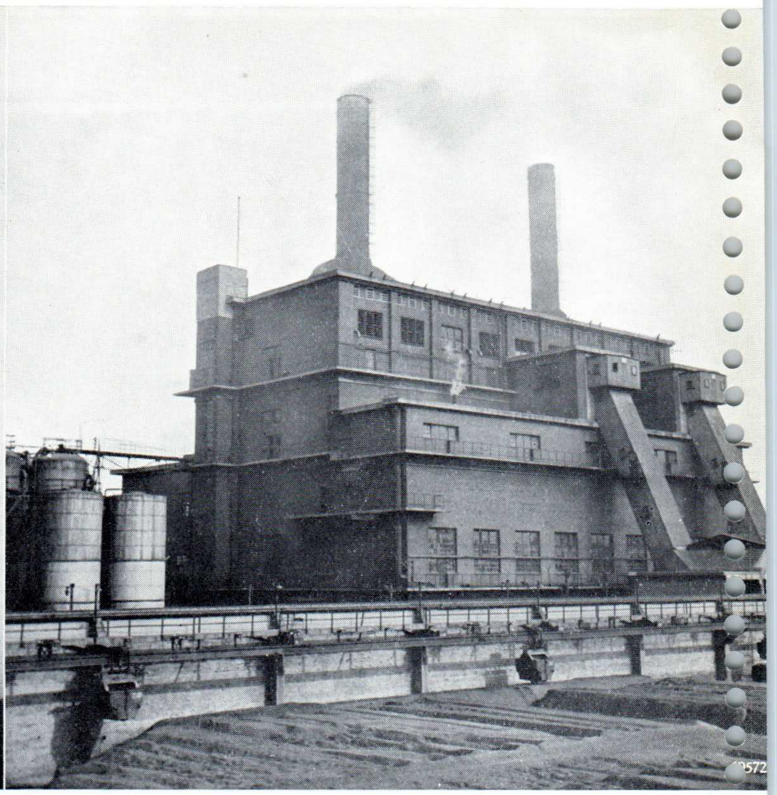
BAKING COLOUR CONTROL

In order to obtain baked products of uniform quality and to prevent burning, phototubes are installed in ovens in large bakeries or hotels. As soon as the colour of the products reaches a certain degree the current is switched off and a signal is given.

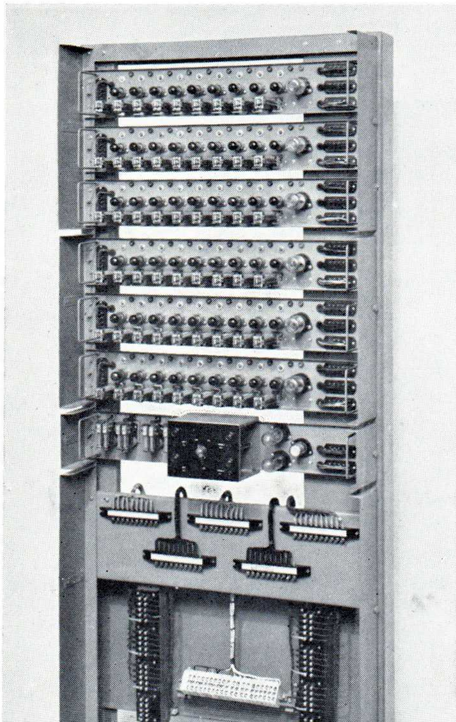
CALIBRATION OF GAS AND WATER METERS

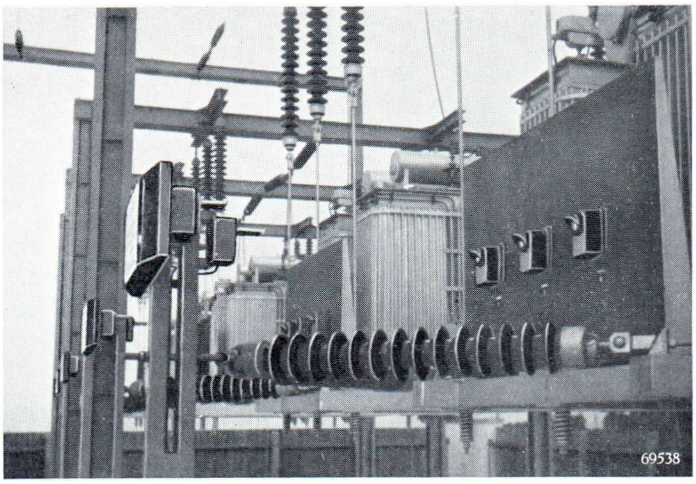
In gas and water meters the quantity used is measured by registering the number of revolutions of a small propeller or vane, which is driven by the gas or water flow. When a meter has to be calibrated the vane revolutions are compared with those of a standard meter of the same type. The vane of the standard meter intercepts a light beam to a phototube (or reflects light to it). The pulsating voltage on the load resistor is amplified and fed to a gas-discharge lamp. This lamp illuminates the vane of the meter to be tested, and by the stroboscopic effect it is easy to regulate the number of revolutions to correspond to that of the standardmeter.





Smoke detector in use with power plant (right). On the left photograph the light projector and the phototube receiver are to be seen on both sides of the funnel-uptake.





Phototube protection against overheating of a 110 kV capacitor battery in use with the „Austrian Power Supply Cy.", Vienna. Thermo relays switching-on light projectors ingeniously fed from the 110 kV supply are mounted on the housing of the 54 capacitors which are on 110 kV against earth. Phototube receivers on earth potential receive the light signal when the temperature of a capacitor might rise above a predetermined degree. These signals are fed to a central point where a group of 54 relay amplifiers is mounted in one rack. Here the alarm signals are switched-on.

Above: Part of the capacitor battery.
Left: The amplifier and relay rack.

(By courtesy of Fa. Dipl. Ing. Kühnel, Vienna).

CHEMICAL ANALYSIS

In chemical analysis the phototubes can be used in flame photometers, colorimeters etc.

CHLORINATION OF WATER

Drinking water is treated with chlorine to ensure its freedom of organic impurities. This process needs careful control since insufficient chlorine fails to render the water safe for drinking, while too much chlorine gives it a disagreeable taste. A reagent can be added to samples of the water, and if the discoloration reaches a certain degree the chlorine supply can be cut off. If the required degree of discoloration is not reached extra chlorine can be added to the water. When operated by phototubes the process can be made fully automatic.

COLORIMETER

Photometer of special construction, used to analyse colour radiation either by comparison with a standard or by an absorption method.

COLOUR COMPARISON

To ascertain whether a newly made paint, ink or dye has the same colour value as that of a product previously made, a comparative measurement can be made with a spectro-photometer (see spectro-photometer).

COLOUR INSPECTION ROUGH TEMPERING

In the rough tempering of metals the process can be followed by an optical pyrometer for measuring the temperature. When the correct temperature is reached, a phototube relay circuit can either give a signal or modify the process.

CONTROL OF MIXTURE OF SOLUTIONS

When a mixture has to be made of two solutions of different colour or density, the flow of the liquid can automatically be stopped when the required colour is reached. A phototube, a relay amplifier and a solenoid valve are required for this purpose.

COUNTING

Objects carried along on a conveyer, or traffic on a highway, can be counted by interception or reflection of a light beam striking a phototube. The phototube signals are amplified and passed on to an electrical counting mechanism or circuit.

DENSITY CONTROL

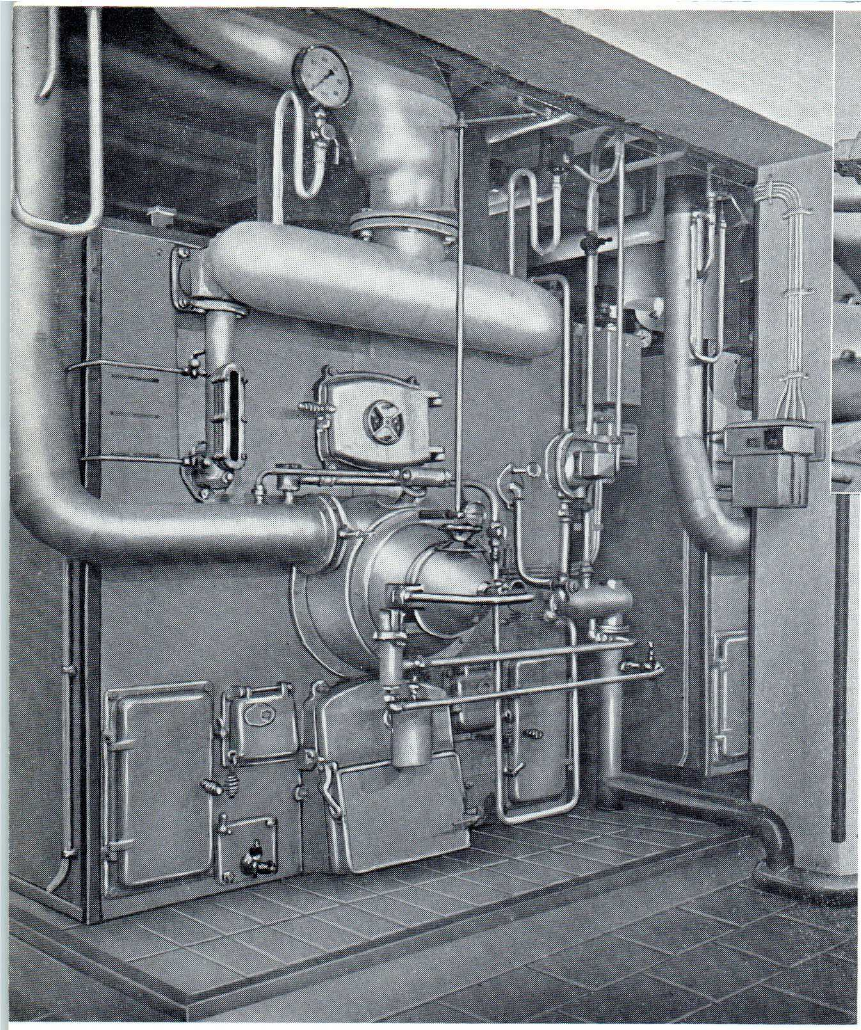
Corresponds to "Control of Mixture of Solutions" and to "Smoke Detection" (q.v.).

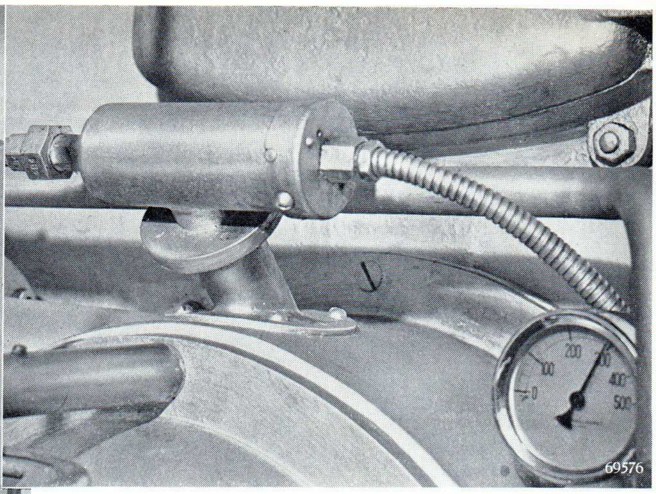
DISCOLORING DURING CHEMICAL REACTIONS

See "Chlorination of Water" and "Control of Mixture".

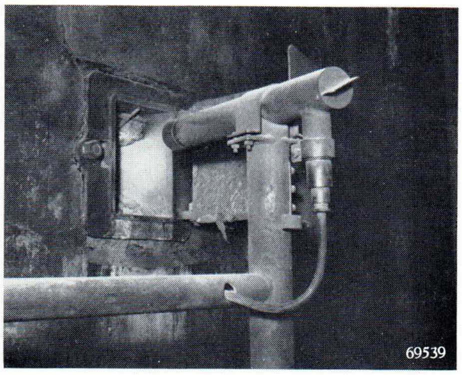
DUST DETECTION

In some factories too high a dust content in the air can be dangerous to workers or may spoil production. The air is drawn off by fans and the dust content determined in the same way as with the smoke detector.





Mounting of the phototube holder on the boiler. The tube is protected against possible damage by cast iron container.

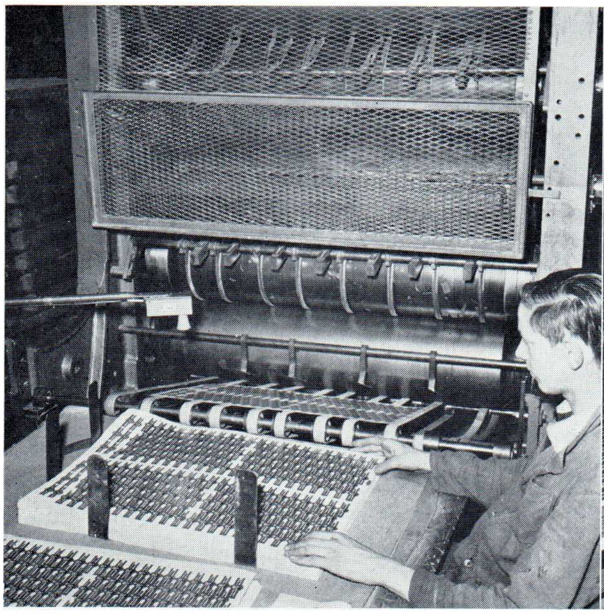


Flame control with phototube. A phototube „watches" the fire in the boiler. When the fire extinguishes the fuel supply is stopped and an alarm signal is given, so explosion is prevented.

A simpler method of mounting a phototube system for flame control.

Counting of printed sheets coming off a rotary press, by means of a phototube

Close up of the scanning head of the photo-electric counter. Underneath the belt part of the light-projector can be seen.



EXAMINATION FOR:

CRACKS	In paper fed to printing machines.
DOUBLE PRINTING	With printing presses.
GRINDING	With grinding machines.
INSULATION	Of enamelled wire with machines for winding coils or transformers.
LEAKS	In the latex rim in the lid of tins in canneries.
PIN HOLES	In thin plates made in rolling mills.
POLISHING	With automatic polishing machines.
SEAMS	With textile machines.
SPRAYING	With automatic spraying machines. Can be carried out with the aid of phototubes either with direct or with reflected light.

EXPOSURE CONTROL (X-Ray)

In X-Ray apparatus for mass examination automatic exposure control is built in. A phototube measures the amount of light on a fluorescent screen and via auxiliary apparatus controls the exposure.

EXPOSURE METER

Exposure meters are used in photographic reproduction. The phototube measures the light intensity, and automatic exposure control can be incorporated in the installation.

FACSIMILE

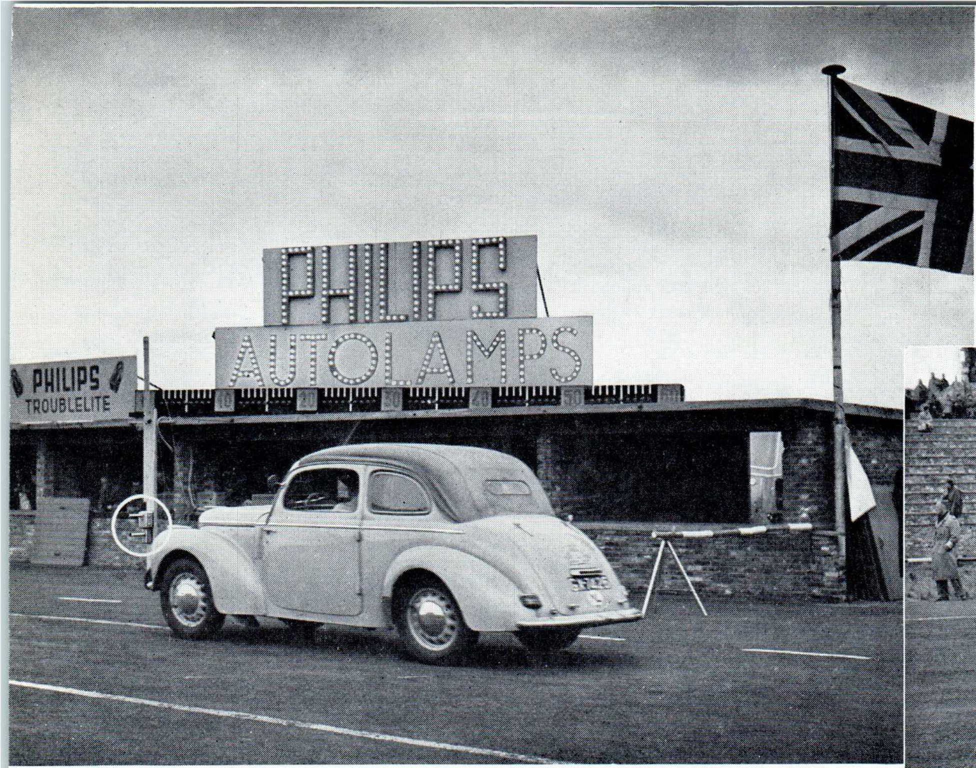
A scanning head comprising a phototube "reads" a text or photograph mounted on a rotating drum. It translates the reflected light intensities of the original in current variations which are amplified and used for modulating a transmitter.
At the receiver end a drum rotating in synchronism with that of the transmitter drum is used. The modulation is transferred by chemical means to a specially prepared paper.

FILLING CONTROL

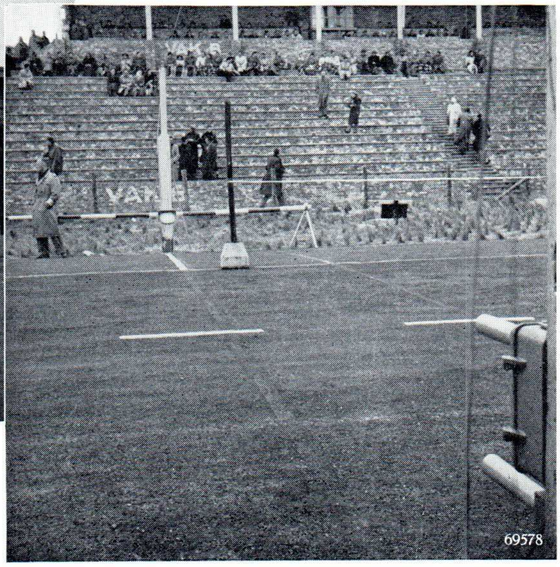
In a filling machine a phototube "watches" the filling of bottles or jars. When the required level is reached the phototube signal causes the flow of liquid to stop. The filled bottles are usually automatically replaced by empty ones.

FINAL INSPECTION

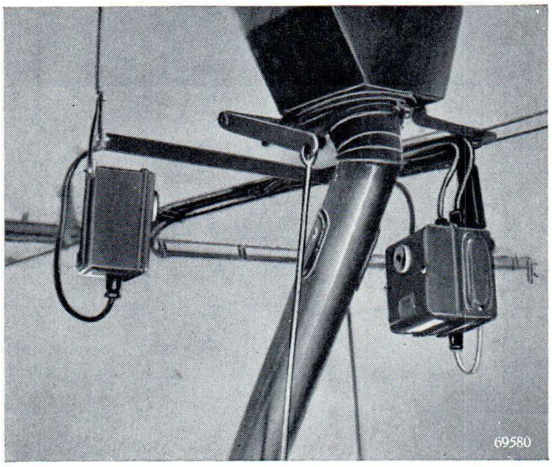
Finished products often have to be examined to make sure that they are not sent out without labels, trade marks, etc. This inspection can be carried out with the aid of a phototube installation.

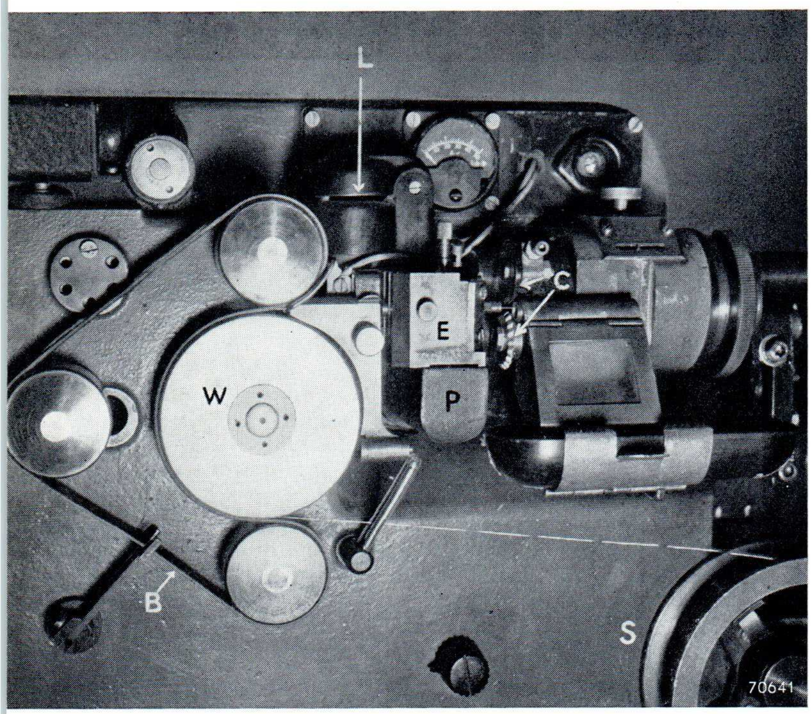


Accelerating contest for motor cars. The car starts at a given point and at the 'starting signal lamps are successively automatically lit behind the time scale on the stand. Each second is counted. The counting mechanism stops as soon as the motor car passes the line from the light projector to the phototube and the public can easily read the time made by each car.



Phototube and light projector on both sides of the feeder of an automatic filling machine. As the feeder is emtpy light passes to the phototube and the machine is stopped. (By courtesy of Fa. Dipl. Ing. Kühnel, Vienna.)





Cutting machine for spirals for incandescent lamps. The spirals are fed to the machine from the spool S and are moved by the big wheel W. They pass the box E where the light beam of a lamp in the holder L passes a narrow slit. As soon as the new spiral comes in front of the slit, the light falling on the phototube in the box P is intercepted which causes the transporting wheel to stop. The spiral is cut off by the cutting wheels C and falls in a container. The machine then moves the next spiral to the cutting wheels.

FIRE ALARM	Normally there is a considerable development of smoke before a blazing fire starts. A phototube smoke detector placed in an air-conditioning duct is used to give a fire alarm (see "Dust Detection" and "Smoke Detection").
FLAME CONTROL	When in boilers or furnaces the fuel is oil or coal dust, extinguishing of the flame may cause an explosion if the fuel supply is not immediately stopped. A phototube watches the fire and in the absence of a flame a signal is given and the fuel supply is cut off.
FLAME PHOTOMETERS	To detect whether a material contains a certain element, a small amount of it is burned in a flame. If it shows the characteristic spectral line, which can be observed by a selective photometer, the element in question must be present in the material.
FOLDING	In laundries, printing offices, etc. goods have to be folded. When the leading edge of the material intercepts the light beam to a phototube, the latter brings the folding mechanism into operation.
GAS DETECTION	To detect the presence of dangerous gases in air, the air can be drawn off and compressed. The compressed air can be compared with pure air in different containers (phototube bridge circuit) or it can be lead through a liquid which changes colour when poisonous gas is present. The chemical reaction can be observed by a phototube.
GRINDING INSPECTION	See "Examination".
IMAGE REPRODUCTION	In the so-called flying spot scanning system for televising films a phototube is used to convert the light variations into current variations.
INTEGRATING PHOTOMETER	Photometer used to obtain integration of light exposures over a certain period.
LEVEL CONTROL	Level control can be either obtained by watching a gauge glass by means of a light beam on a phototube or in the manner described under "Filling Control".
MERCURY-VAPOUR DETECTOR	See "Gas Detection".
METEOROLOGY	The extent to which clouds or haze intercept the sunlight is a measure for their density or composition. These factors can be measured with a photometer.

MIXING COLOUR

When inks, paints or dyes have to be mixed, to obtain a certain colour as previously used, the eye is not sufficiently sensitive to distinguish fine differences in colour. When the new mixture is compared with the former one with the aid of a spectrometer, the analysis into different components shows whether the new mixture is identical and, if not, which colour has to be added.

OPTICAL PYROMETER

This is used for ascertaining the surface temperature of heated metals or ceramics. Means are usually provided for registering the temperature automatically on a chart. The energy radiation of an incandescent body is approximately proportional to the fourth power of the absolute temperature.

PIN HOLE DETECTOR

Thin metal sheets coming from the rollers can be examined for pin holes by passing them over a light source and inspecting the surface with the aid of a row of phototubes or what is called an aniseikon*). Faulty sheets can automatically be removed.

PHOTOGRAPHIC DENSITY

The density on film can be measured by testing it with light from a gas-discharge lamp. The light, having a pulsatory character, causes an A.C. voltage across the load resistor of a phototube. The meter indicating the A.C. voltage can be directly calibrated in degrees of density or be used for comparison only.

POLISHING MACHINES

See "Examination".

REGISTER CONTROL

Phototube method for controlling rotary presses, for cutting, glueing, labelling, folding, etc. at the correct place on the already printed material.

SAFEGUARD

When heavy presses, punches, drills, etc. are fed with the material by hand, a phototube locking device can be used to prevent the operator from being seriously hurt by the machine. As long as a light beam to the phototube is interrupted by the hands or other parts of the body the machine is locked. Failure of phototube or light source locks the machine too.

SATURATION MEASURING

If a solution is saturated the density has a certain value, which can be measured with a photometer.

SMOKE DETECTION

Since smoke indicates waste of fuel, it saves money to be warned when the fire produces smoke. A phototube and light source are mounted opposite each other in the chimney stack. As soon as the smoke reaches

*) See page 43.

a certain density, the phototube brings a relay into action and a bell or buzzer is heard. The stoker regulates the fire and the signal stops as soon as it burns properly.

SORTING TO COLOUR

Different methods are used for sorting with the aid of phototubes. Cigars can be sorted to colour, coffee beans, oranges, etc. according to their quality. Filters are used to make the phototube sensitive for one special colour. Faulty specimens of the products under inspection are automatically removed.

SOUND REPRODUCTION

Recording of sound on film is either done photographically (sound film) or mechanically by cutting a track with variable width in blackened tape (Philips Miller). The reproduction is possible by moving the film or tape at uniform speed between a light source and a phototube.

SPECTRAL ANALYSIS

See "Colorimeter", "Flame Photometer" and "Spectrometer".

SPECTROMETER

Phototube instrument for measuring the amount of direct or reflected light of a certain colour. The different colours can be selected by selective filters or by using monochromatic light sources.

SWITCHING OF HEAVY CURRENTS

The phototube circuit can control not only relays but transductors as well. This is of importance when heavy currents have to be switched or controlled. Transductors have the advantage over heavy relay switches in that there are no moving parts of burning contacts. Furthermore they operate silently. For register control or temperature control transductors can be used.

TEMPERATURE CONTROL

A thermometer can be watched by a phototube to keep temperatures constant. See further "Colour Inspection", "Rough Tempering" and "Switching of Heavy Currents".

WEIGHING

Automatic weighing can be done with phototube circuits. The phototube watches the pointer of a weighing machine or scale.

PART 2 PRACTICAL APPLICATIONS AND CIRCUIT DESCRIPTIONS

PHOTOTUBE RELAY AMPLIFIERS

When a light signal has to be converted into a switch manipulation, a phototube offers a fairly simple solution. Unfortunately the anode-current variations of a phototube are too small to operate even the most sensitive relay, so that amplification is necessary.
Especially when phenomena of a slow character have to be registered or controlled, the amplifier can very often be of simple design. In such cases, the exciter lamp, the amplifier and even the phototube can be fed directly from the A.C. mains or from a simple and inexpensive mains transformer. In other applications, however, D.C. supply is often required for all elements in the circuit, even for the exciter lamp. Then a more complicated amplifier must be advised. In this chapter various phototube amplifiers and relay circuits will be described.

1. A SENSITIVE RELAY AMPLIFIER WITH TUBES EF 40 AND EC 50

In fig. 38 the circuit diagram of a sensitive relay amplifier is given. This is a D.C. amplifier, the cathode of the phototube being directly connected to the grid of the pre-amplifier tube EF 40, whilst the anode of the latter is connected directly to the grid of the relay tube EC 50. The relay is taken up in the anode circuit of the gas triode.
When the phototube is illuminated there is a voltage drop across R_1, and in this state the grid is biased slightly negative by adding a negative potential by means of the potentiometer P_1. The anode current of the EF 40 has such a value that there is a considerable voltage drop across R_4. The grid of the EC 50 is therefore negative with respect to the cathode, so that the gas triode does not ignite. When the illumination of the phototube decreases, the current through R_1 will also decrease and the control-grid voltage of the EF 40 will become more negative. The anode current of the EF 40 will then decrease and so does the voltage drop across R_4. The grid of the gas triode EC 50 becomes less negative with respect to the cathode, and, at a given grid voltage, the tube ignites. A considerable anode current is drawn and the relay is attracted. If the light intensity on the phototube now increases again, the EF 40 will draw more anode current and the voltage drop across R_4 increases. In this circuit the usual resistor in the grid circuit of the gas triode is omitted. In a normal circuit such a resistor is necessary to limit the grid current to a safe value. In this circuit, however, the grid current is limited by the tube EF 40. This has the advantage that, after the light on the phototube is restored, the EC 50 can be extinguished again. This would not be possible if a grid resistor of the usual value were inserted. Now the increase in anode current of the EF 40 makes the grid of the EC 50 negative again with respect to the cathode. The positive ions of the discharge are attracted by the grid and a negative grid current starts to flow via the EF 40. The anode current of the EF 40 will continue to rise; the grid of the EC 50 becomes more negative, fewer electrons will pass the grid, the space charge in the EC 50 increases, fewer ions are produced and suddenly the discharge ceases. The various currents and voltages regain their original values and the relay opens again.

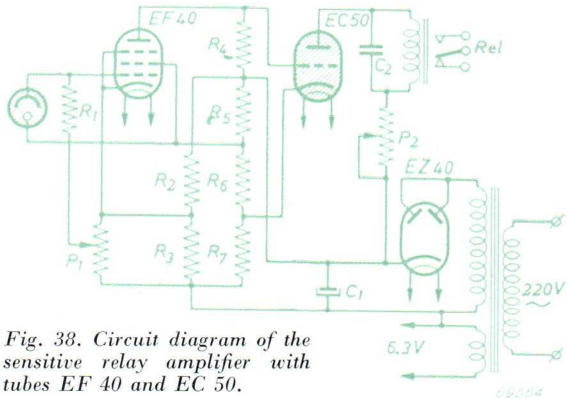


Fig. 38. Circuit diagram of the sensitive relay amplifier with tubes EF 40 and EC 50.

This circuit is very sensitive. If P_1 is adjusted minutely at such a value that the EC 50 is on the verge of firing, a decrease of light of less than 0.001 lm is sufficient to close the relay (with a gas-filled phototube of a sensitivity of 150 μA/lm). In this case, however, the relay will not open again when the light is restored to the original value. If the relay has to close and to open, the maximum sensitivity of this circuit is 0.004 lm.

Circuit details

The supply transformer is rather simple. Because of the use of a rectifier tube EZ 40, which has a V_{fk} of 500 V max., only one 6.3 V winding for 2.5 A is required. The winding for the anode supply voltage is not critical, 120-150 V, 20 mA being sufficient. In many cases an auto-transformer with taps for 6.3 V and 120-150 V answers the purpose.

The potentiometer P_2 serves for adjusting the anode current of the EC 50 within its limits. It can be a semi-adjustable wire-wound resistor of 5 kΩ, but for a given relay it can be replaced by a fixed resistor.

To prevent the relay from fluttering it is advisable to shunt it by a capacitor C_2 of which the value depends on the relay used.

Parts list

RESISTORS

Circuit ref.	Type	Value	Power rating (W)
R_1	carbon	1 MΩ	0.5
R_2	carbon	20 kΩ	1
R_3	carbon	1 kΩ	1
R_4	carbon	0.4 MΩ	0.5
R_5	carbon	5 kΩ	1
R_6	carbon	5 kΩ	1
R_7	carbon	22 kΩ	1
P_1	carbon potentiom.	0.5 MΩ	
P_2	wire-wound adjustable	5 kΩ	

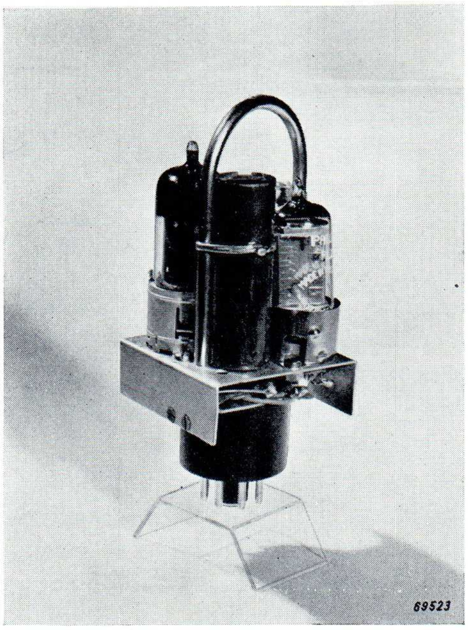


Fig. 39. Compact relay amplifier with tubes EF 40 and PL 21 mounted on an octal base.

CAPACITORS

Circuit ref.	Type	Value	Work volt. (V)
C_1	electrolytic	50 μF	300
C_2	paper	0.05 μF	500

TRANSFORMER AND COIL

T_1: see text. Relay ca. 10 kΩ.

2. A COMPACT RELAY AMPLIFIER WITH TUBES EF 40 AND PL 21

Fig. 39 is a photograph of a compact and very sensitive relay amplifier employing the tubes EF 40 and PL 21. The complete amplifier is mounted on an octal tube base, the base connections corresponding as far as possible to the usual tube connections. Amplifiers of this type are very useful in cases where multiple banks of phototubes and amplifiers have to be used, and they can be fed from one central supply source. Another application is where the amplifier has to be placed near the phototube to avoid long grid connections. As a rule there is no objection to connecting the relay or the supply unit by means of long cables.

The circuit of this amplifier is conventional. With the values of the various resistors in the circuit diagram of fig. 40 and a supply voltage of 250 V, the EF 40 has a gain of 180. The grid of the PL 21 is coupled to the anode of the EF 40 via a coupling capacitor C_4 of 2000 pF. Either the first or the second grid of the PL 21 may be used. In the latter case the sensitivity is about four times greater, but the pre-conduction current and the capacitance to the anode will have a higher value. This may be a disadvantage if the tube is operated with A.C. anode voltage and a grid resistor of a high value is used. The anode-voltage supply of the PL 21 can be

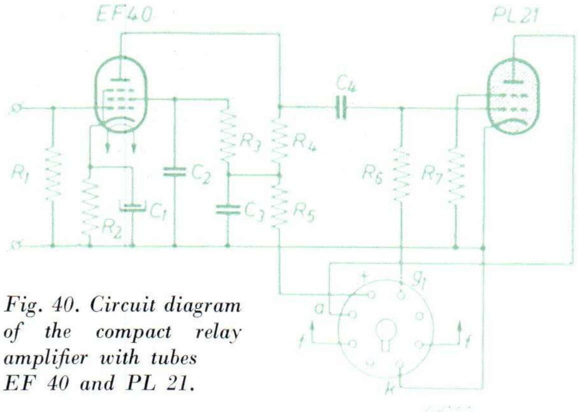


Fig. 40. Circuit diagram of the compact relay amplifier with tubes EF 40 and PL 21.

either D.C. or A.C. In the first case the PL 21 fires when a negative pulse of sufficient value reaches the grid of the EF 40 (approx. 3 mV). The PL 21 remains conductive until the anode-voltage supply is interrupted. With A.C. on the anode of the PL 21 and on the exciter lamp as well, the relay in the anode circuit of the PL 21 stays closed as long as the illumination of the phototube causes a current variation of $3\times10^{-3}\mu A$ in the grid resistor of the EF 40. When the illumination is interrupted the relay opens again.

Parts list

RESISTORS

Circuit ref.	Type	Value	Power rating (W)
R_1	carbon	1 MΩ	0.5
R_2	carbon	1.5 kΩ	0.5
R_3	carbon	1 MΩ	0.5
R_4	carbon	0.22 MΩ	0.5
R_5	carbon	10 kΩ	0.5
R_6	carbon	0.1 MΩ	0.5
R_7	carbon	0.1 MΩ	0.5

CAPACITORS

Circuit ref.	Type	Value	Work. volt. (V)
C_1	electrolytic	50 μF	12
C_2	paper	0.1 μF	500
C_3	paper	50,000 pF	500
C_4	paper	2000 pF	500

3. ELECTRONIC SWITCH WITH THYRATRON TYPE PL 21

In the circuit diagram of fig. 41 an example is given of a simple relay amplifier using only one thyratron type PL 21. To obtain maximum sensitivity the tube is used with screen-grid control and with A.C. supply, which simplifies the circuit.

In the screen-grid and first grid connections, resistors R_3 and R_4 are inserted to keep the grid currents below the permissible values. Grid bias is obtained from a selenium rectifier *Sl* and can be varied, by means of the potentiometer R_1, from 0 to approx. —30 V.

The transformer is rather simple. The voltage applied to the phototube, i.e. the voltage derived from $L_3 + L_4$, depends on the type of phototube

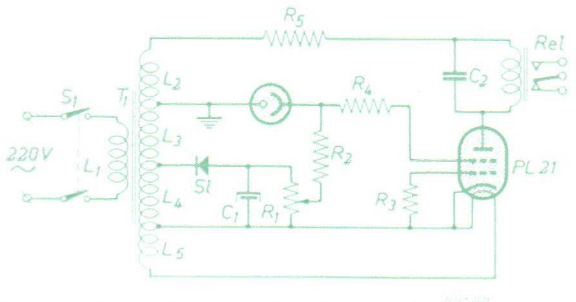


Fig. 41. Circuit diagram of an electronic switch with thyratron PL 21.

used. It must be remembered that the values for the maximum permissible anode voltages for phototubes refer to either D.C. or peak value A.C.; so theoretically the r.m.s. value of $L_3 + L_4$ should be: max. permissible anode voltage/$\sqrt{2}$. It very often happens nowadays that signals are transmitted via the mains supply, and so higher peaks may occur in the mains voltage. Therefore it is advisable to use no higher r.m.s. voltage on

the phototube than half the permissible max. anode voltage.
The resistor R_5 in the anode circuit is inserted to limit the current through the tube and the relay. In this circuit a 15 kΩ relay is used and the value of R_5 is 1.2 kΩ. To prevent the relay from fluttering, it is shunted by a capacitor C_2 of 0.5 μF.

Parts list

RESISTORS

Circuit ref.	Type	Value	Power rating (W)
R_1	wire-wound potentiometer	2 kΩ	1
R_2	carbon	8.2 MΩ	0.5
R_3	carbon	0.1 MΩ	0.5
R_4	carbon	0.1 MΩ	0.5
R_5	carbon	1.2 kΩ	1

CAPACITORS

Circuit ref.	Type	Value	Work. volt. (V)
C_1	electrolytic	25 μF	50
C_2	paper	0.5 μF	500

TRANSFORMERS AND COILS

T_1	mains transformer
L_1	220 V
$L_2+L_3+L_4$	195 V
L_3+L_4	see text
L_4	25 V 0.1 A
L_5	6.3 V 0.6 A
Rel	Relay. D.C. resistance 15 kΩ.

4. RELAY CIRCUIT WITH TUBE UL 41 FOR 110 V D.C. MAINS SUPPLY

When a phototube relay amplifier has to be used on 110 V D.C. mains, the amplifier of fig. 42 offers an attractive solution. Only one tube UL 41 is used and the 45 V, 0.1 A filament is directly fed from the mains. The exciter lamp can be connected in series with the filament, in which case the value of the resistor R_6 depends on the type of lamp used. Otherwise R_6 has a value of 650 Ω and must be a wire-wound 7.5 W resistor.

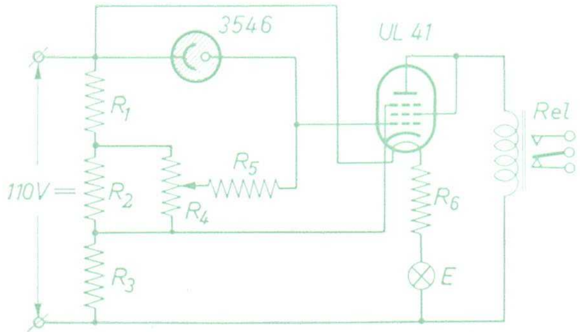


Fig. 42. Circuit diagram of 110 V D.C. relay amplifier with tube UL 41.

In this circuit the anode current of the UL 41 is only 4 mA, while the phototube is illuminated. When the illumination is completely interrupted, the anode current rises to 16 mA, the difference of 12 mA being sufficient to operate a relay.

Parts list

RESISTORS

Circuit ref.	Type	Value	Power (rating W)
R_1	wire-wound	300 Ω	12
R_2	wire-wound	30 Ω	2
R_3	wire-wound	500 Ω	15
R_4	carbon potentiometer	10 kΩ	
R_5	carbon	1 MΩ	0.5
R_6	see text		

5. PHOTOTUBE RELAY CIRCUIT WITH TRIGGER TUBE PL 1267

In many cases it is advantageous to use a cold-cathode gas-discharge tube (trigger tube) in a phototube relay circuit. Such a circuit, if correctly adjusted, takes minimum power from the mains supply, while a trigger tube has a long lifetime.
In fig. 44 a diagram is given for a circuit where the trigger tube ignites when the beam of light on the phototube is interrupted. Fig. 43 shows a circuit where the trigger tube starts conducting when light falls on the phototube. Both circuits are for A.C. mains supply of 117 V.
In fig. 43 the selenium rectifier charges the capacitor C_2. When the phototube is illuminated, it

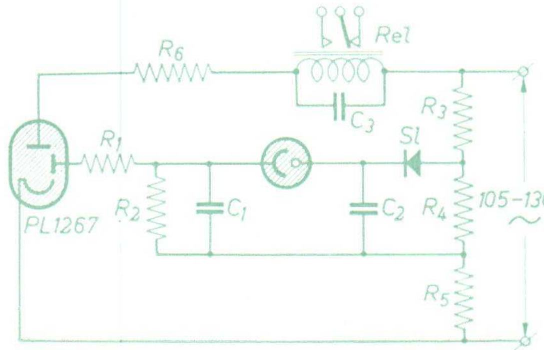


Fig. 43. Circuit diagram of relay amplifier with trigger tube PL 1267.

becomes conductive and C_1 is charged. The auxiliary anode of the PL 1267 obtains a positive voltage and the tube ignites during each positive half cycle of the A.C. voltage. The relay is attracted and if shunted by a capacitor it will not flutter during the non-conductive half cycle.

A limiting resistor R_6, the value of which depends upon the relay used, keeps the anode current below its maximum permissible value. The anode current of the PL 1267 may not exceed 25 mA.

The circuit diagram given in fig. 44 is for a similar apparatus, but here the PL 1267 ignites when the beam of light is interrupted. The circuit is practically identical to that of fig. 43, the position of the phototube and the resistor R_2 being interchanged, while in the circuit the resistor (R_{2a}) is 20 MΩ. When illuminated, the phototube draws an anode current via R_{2a} and there is a considerable voltage drop across this resistor. When the light is interrupted the anode current decreases and the voltage on the auxiliary anode of the PL 1267 rises, thereby causing the trigger tube to ignite.

Parts list

RESISTORS

Circuit ref.	Type	Value	Power rating (W)
R_1	carbon	3 kΩ	1
R_2	carbon	100 MΩ	1
R_{2a}	carbon	20 MΩ	1
R_3	carbon	15 kΩ	1
R_4	carbon	56 kΩ	1
R_5	carbon	47 kΩ	1
R_6	see text		

CAPACITORS

Circuit ref.	Type	Value	Work. volt. (V)
	mica or ceramic	1000 pF	500
C_2	paper	0.05 μF	500
C_3	paper	0.5 μF	500

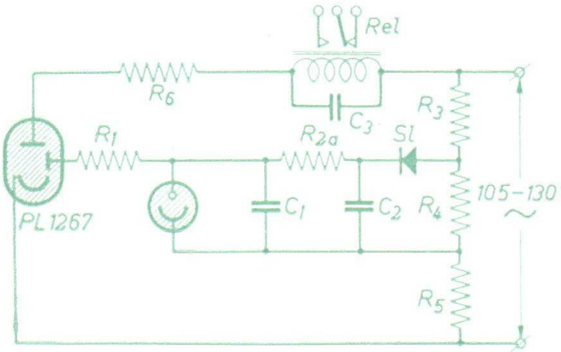


Fig. 44. Circuit diagram of relay amplifier with trigger tube PL 1267.

A SMOKE DETECTOR

Where fuel is both scarce and expensive the utmost economy in its use is required, but when looking around in an industrial centre it can be seen that precious fuel is recklessly blown into the air by a large number of smoking factory stacks.

This waste can easily be stopped by installating a phototube smoke detector. In a small factory where only one engine-man cum stoker was employed, the savings on the fuel bill, after the installation of a smoke detector amounted to £ 80.— monthly.

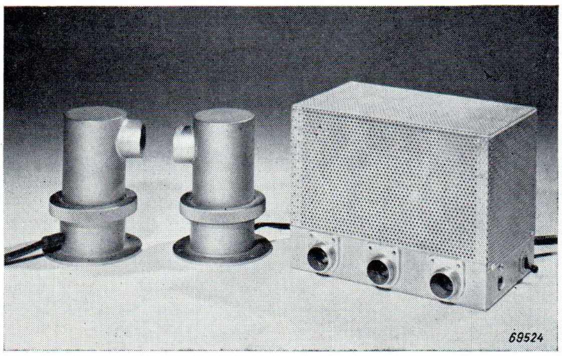


Fig. 45. Phototube amplifier for smoke detector with phototube receiver and light projector.

The smoke detector is a simple device. A light projector and a phototube are mounted opposite each other in the funnel uptake or the chimney stack. The phototube commands a relay by means of a sensitive relay amplifier, which may be arranged according to fig. 48. When the light beam is partly or wholly intercepted by smoke, the relay closes and operates a buzzer, warning the man in charge to look at his fire. The phototube and the light projector are mounted in separate housings as shown in fig. 46 and 47. These housings are described in some detail because they are also very useful in other applications where the phototube and the exciter lamp are used outdoors or in a humid atmosphere.

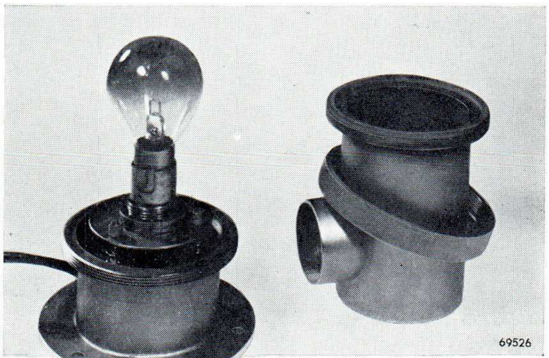
Provided sufficient care is taken in the mounting and assembly, they can even be used under water.

Fig. 46. Watertight phototube housing.

In one of the housings the phototube is mounted on a circular plate of plexi-glass, the diameter of which is 0.5 mm greater than the inner diameter of the housing. A slit is cut in this plate as shown in fig. 46. The sockets for the phototube base pins are placed on either side of the slit which ensures a long insulating distance. Both sides of the slit can be pressed together so that the plate fits into the housing and is secured by its own resilience.

In the light projector (see fig. 47) the fitting for the incandescent lamp is mounted on a plate of insulating material, which is fixed to the bottom of the housing by means of three bolts with spring loading. The lamp can be adjusted by means of nuts, and after adjustment the spiral springs keep the fitting in the right position. The hood of the housing is provided with a window in which a lens or a glass plate can be mounted. Watertight closing is ensured by means of rubber packing. The hood is fitted on the housing with a ring nut, and a rubber ring in the rim ensures watertightness.

Fig. 47. Watertight light projector.



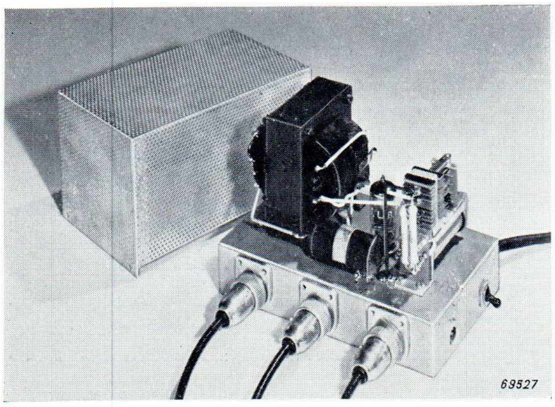


Fig. 48. Phototube amplifier for smoke detector with perforated hood removed.

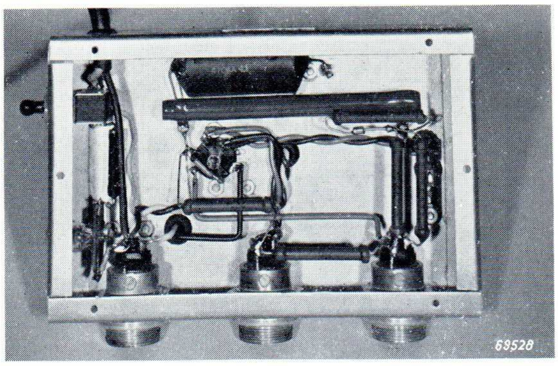


Fig. 49. Another view of the amplifier, showing the wiring.

The windows of the light projector and the phototube housing require continuous cleaning. This can be done either by providing for a natural draught or by means of a compressed-air system.

Natural draught can be obtained by connecting the light projector and phototube housing to the stack or funnel uptake via tubes of some length. Near the window holes are drilled in the tube; the draught through the holes passes through the tubes in the direction of the stack, thus keeping the windows free of dust. The compressed-air system consists of an air jet with a narrow slit in the immediate vicinity of the window. By blowing compressed air through the jet at certain intervals, the windows can easily be cleaned.

Parts list

RESISTORS

Circuit ref.	Type	Value	Power rating (W)
R_1	carbon	1 MΩ	1
R_2	carbon	0.4 MΩ	1
R_3	carbon	10 kΩ	2
R_4	enamelled	40 kΩ	5
R_5	carbon	1 MΩ	1
R_6	carbon	1 MΩ	1
R_7	carbon	2.2 MΩ	1

CAPACITORS

Circuit ref.	Type	Value
C_1	paper	0.5 μF
C_2	paper	0.5 μF

TRANSFORMERS AND COILS

T	Mains transformer	
L_1	220 V	
L_2	250 V	40 mA
L_3	6.3 V	5 A
Rel.	Relay	7.6 kΩ

LAMPS

E_1	Signal lamp green
E_2	Signal lamp red
E_3	Exciter lamp 6.3 V 3 or 4 A.

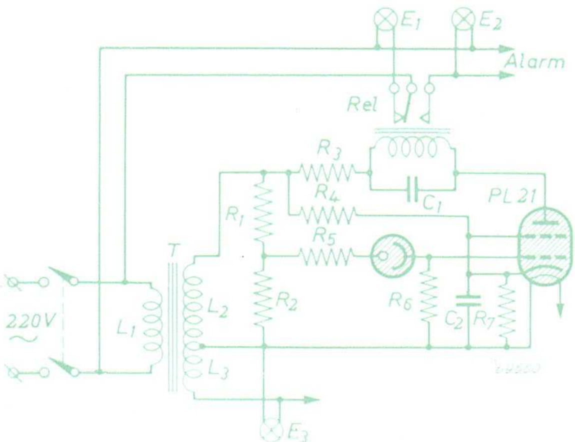


Fig. 50. Circuit diagram of the smoke detector.

AUTOMATIC LEVEL CONTROL

In chemical laboratories and factories it is often required to prevent a liquid in a tank from exceeding a certain level. For this purpose a phototube and exciter lamp can be placed on both sides of a gauge glass and a relay apparatus can be installed to give an alarm signal when the predetermined level is reached.

Automatic control is obtained by letting the phototube command a solenoid valve. Such a valve can be fitted either in the liquid supply and made to close when the level is reached, or it can be fitted in the outlet and made to open at the moment the level is exceeded. In the latter case the excess liquid flows off to some other container.

A photograph of a solenoid valve is given in fig. 51, cross-sectional drawings are shown in figs 52, a b, c and d.

In a plexi-glass cube holes are drilled as indicated in the drawing, and tube nipples can be glued to the sides. A screw cap contains a coil wound on a plastic or plexi-glass tube. This tube is fitted watertight into the screw cap. The plug controlling the liquid flow can move up and down in this tube, which is provided with grooves on the inner side to let the liquid pass. The plug is made of a plexi-glass rod, in the top of which an axial hole is drilled to take a loose iron core. The hole is plugged at the top. When the coil is energized the core is attracted, moves upwards and opens the valve suddenly, whilst, when the current in the coil is interrupted, the core drops, the valve is closed and the liquid flow stopped.

In some cases the liquid may be too clear to give sufficient reduction of illumination on the phototube. It is then advisable to use a floating opaque body intercepting the light completely.

The relay-tube switching apparatus as previously described is suitable for operating the valve.

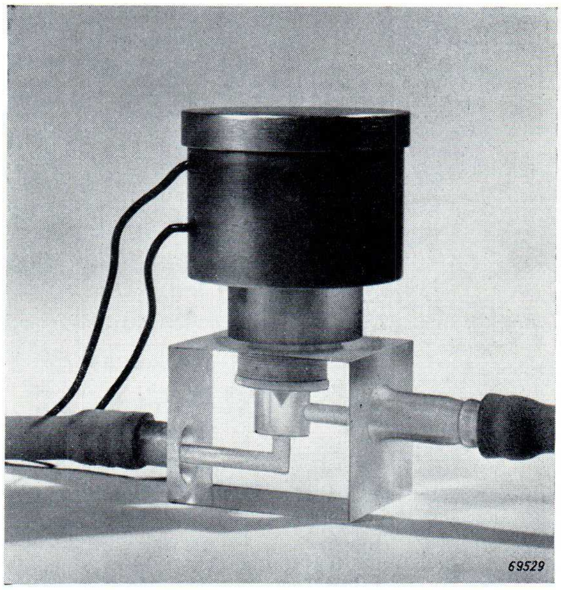


Fig. 51. A solenoid valve.

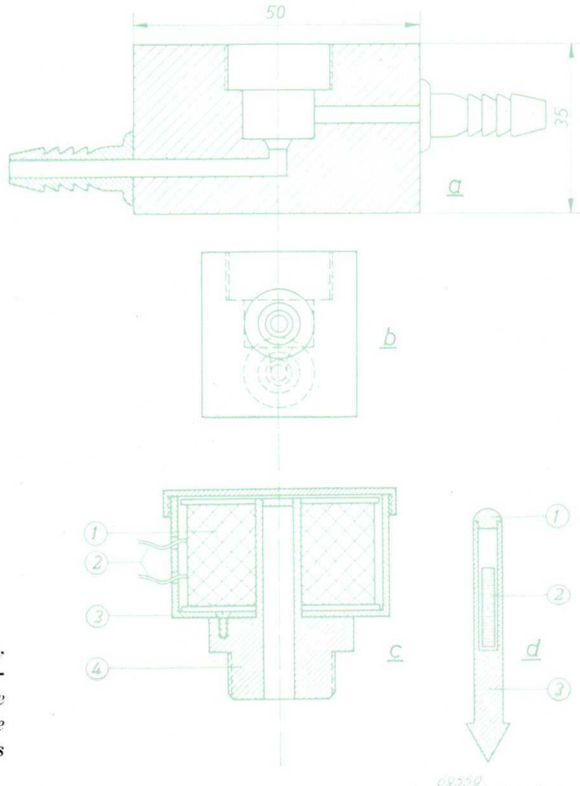


Fig. 52. Cross sectional drawings of the solenoid valve. a *and* b *— the plexi-glass holder;* c *the screw cap wherein* 1 *— the winding;* 2 *— the connection leads;* 3 *— the iron housing;* 4 *— the screw nut;* d *— the plug;* 1 *— the top plug;* 2 *— the loose iron core and* 3 *— the plexi-glass plug.*

SPATIAL PROTECTION

As a rule phototube supervision or phototube protection is possible in a small area only, i.e. along a line formed by a beam of light or a broken line when the light beam is reflected by a group of mirrors. Spatial supervision is usually performed by a scanner of the mechanical or electronic type, or a number of phototubes is employed each covering a section of the whole space to be protected. A method employing only two phototubes, called "Aniseikon" [1]) is described here. It may be used for:
detection of cracks and flaws in material being manufactured in continuous sheets, viz. sheet metal, rubber, plastic, paper, fabric, etc.;
detection of stains in paper, fabric, etc., moving at the usual speed through presses or dyeing tubs;
detection of objects or persons in a prohibited area or room;
protection of valuable plans, precious tools or stones, of open spaces, power plants, etc.
Not only can the installation be made automatically signalling intrusion, but it can also be so arranged that a photograph is taken of the intruder by means of infra-red light.
There are two types of Aniseikon. The oldest employs a combination of binoculars of different focal lengths and two phototubes connected in a bridge circuit. The binoculars are directed on a given scene and the circuit is then balanced. Intrusion in this scene by some object or other results in the latter being imaged at unequal sizes by the binoculars, and this upsets the balance of the circuit. Only objects or conditions alien to the original set-up can be detected, but movement of objects forming part of the scene cannot be detected.
The other type of Aniseikon employs binoculars of equal focal lengths, but between the lenses and the phototubes a grating is applied according to the pattern of fig.55 *a* and *b*, *b* and *c* or *a* and *c*. A. Fitzgerald interposed a screen of alternate opaque and transparent squares of a chequerboard pattern between the image and the phototube. This system, however, had several disadvantages which made its practical applica-

[1]) In Electronic Engineering of 1944 Dr. W. Sommer describes a form of spatial protection with only two phototubes, which is called Aniseikon. The name is derived from Aniseikonia, a pathological condition in which the images which reach the consciousness through the two eyes are not of identical shape and size.

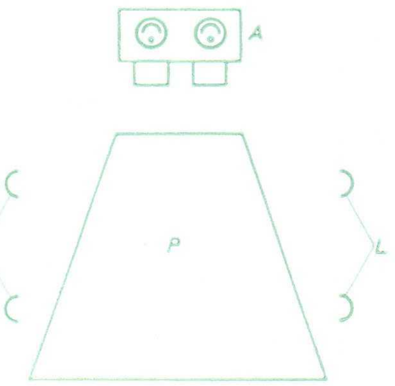


Fig. 54. Aniseikon protection of the area P. *The scene can be illuminated by the lamps* L.

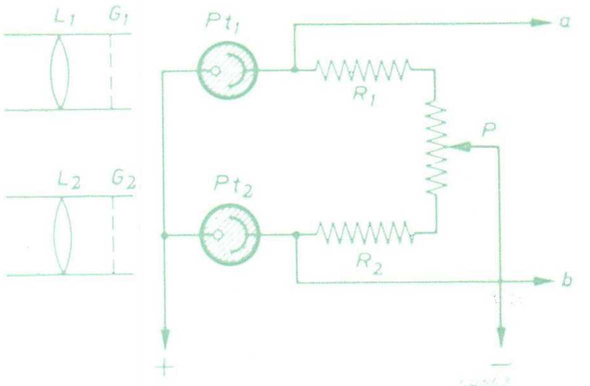


Fig. 53. Schematic diagram of and „Aniseikon". L_1 and L_2 form the binoculars with the gratings G_1 and G_2 behind. The scene is projected on the cothodes of the phototubes, Pt_1 and Pt_2, the photo current is balanced with the potentiometer P. *When something in the scene alters, the balance is upset and a voltage difference occurs between* a *and* b.

tion questionable. It might happen that movement of a part of the scene would not upset the balance of the circuit.
If two of the gratings of fig. 55*a*, *b* or *c* are used and the circuit is balanced, movement of any part of the scene will upset the balance, because the movement of an object will always cause a different change in photo current in the two phototubes. Therefore the pattern of the two gratings is distinctly different and it will be useful to arrange for the small elements of the one grating to be where the large elements of the other screen are positioned, thereby enhancing the sensitivity of the device.
The balance connection of the phototubes makes the circuit insensitive to changes in the illumination of the space under observation. It is claimed by different authors that, with a system according to this principle a person moving at 200 m distance can be signalled.

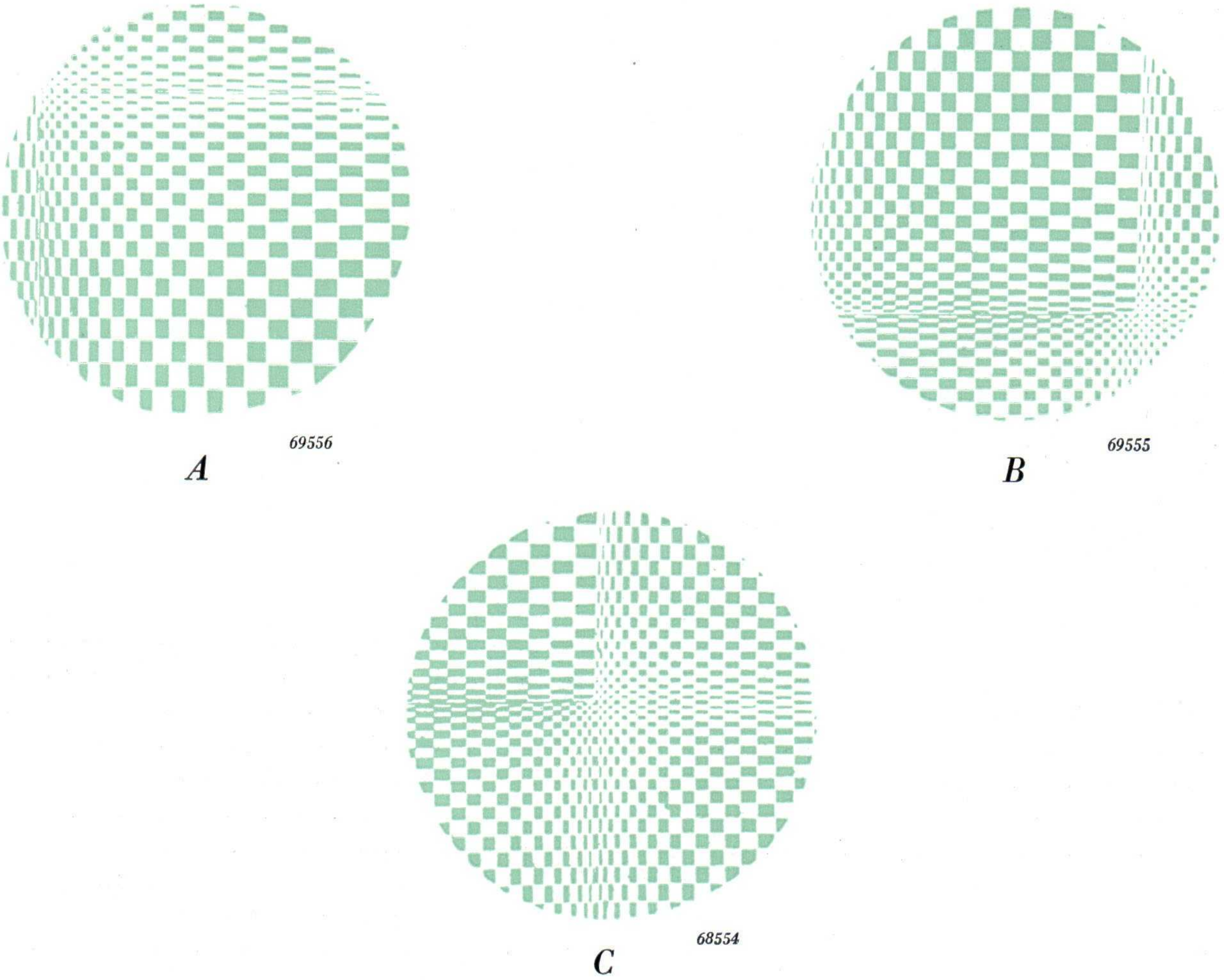


Fig. 55. Gratings to use in combination with an aniseikon. Any combination of two of these gratings will result in the aniseikonic effect.

A PHOTOTUBE AMPLIFIER FOR AUTOMATIC REGISTER CONTROL

In several plants, machinery is used for printing in two or more colours on paper or on textiles; for cutting, folding or glueing already printed paper to bags or wrappings. The material is fed into such machinery from a big roll, and because of irregular drying the material is stretched in some places, whilst in others it has shrunk. Due to these irregularities in the material the machine does not always come into operation at the right instant and this results in part of the production being lost through misprints or miscuttings.

If low-speed machines are used manual control is possible, but in modern high-speed machinery with a production rate up to one thousand items per minute, manual control is too slow in responding to the process; so large parts of the production have to be discarded and materials and time have been lost, while the selection of good and bad products demands extra labour. The electronic register control apparatus described here is fully capable of controlling high-speed machinery. As distinct from the usual apparatus for register control, this circuit uses only high-vacuum tubes; neither gas-filled tubes nor their additional electro-magnetic relays are employed. Instead of the latter, use is made of double triodes in Eccles-Jordan circuits.

General description

The requirements to be met by equipment for automatic register control may be formulated as follows:

If the material has stretched, the speed at which it is fed into the machine must be accelerated. If the material has shrunk, the speed must be decelerated. If the material is normal, it must move with normal speed.

It is practically impossible to control the speed of a powerful main motor within the time limits concerned. Only a motor with a small rotating mass can be sufficiently controlled in the time available. Therefore the main motor driving the rollers and the press runs at normal speed and is coupled to the machine by means of a transmission gear and to the rollers via a differential gear. The construction of such a differential gear is schematically shown in fig. 56.

The two gears *A*, *B* are locked on their respective shafts *M*, *E*, which can rotate independently of each other in bearings *G* and *K* of a wormwheel *T* and a mounting frame *F*. The pinion *C* and its shaft can rotate on a bearing in the frame *F*.

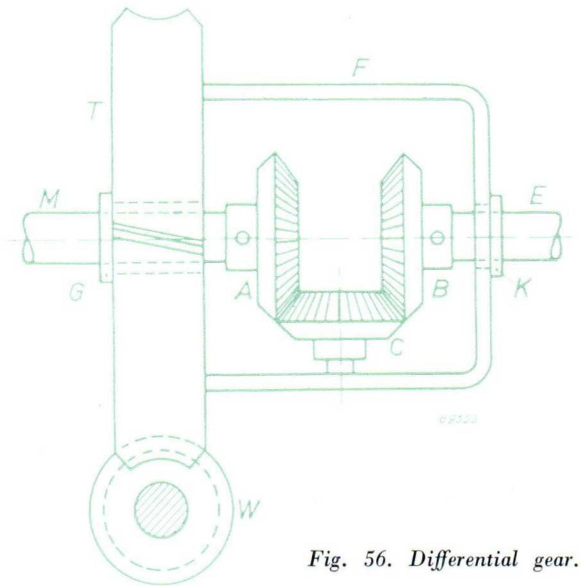


Fig. 56. Differential gear.

Suppose that under these conditions the frame *F* is held stationary, while the shaft *M* is driven by the main motor. The motion of gear *A* then causes the pinion *C* to rotate and so the gear *B* is set in motion in the opposite direction of the gear *A*, but with equal speed, the number of teeth on both gears being the same. (If rotation in equal direction is desired, supplementary gears can set another shaft in motion.)

If, now, the shaft *E* is kept stationary, then rotation of shaft *M* would cause frame *F* and wormwheel *T* to rotate in the same direction with half the speed of *M* if the worm W were decoupled. On the other hand, if the shaft *M* rotates and, by means of an auxiliary motor, shaft *W* is rotated in such a way that *T* rotates in the same direction with half the speed of *M*, then the

shaft E is stationary, whilst, if rotation of shaft W sets T in motion in opposite direction as M with half its speed, the speed of shaft E is double the speed of M in opposite direction.
The automatic register control described here is based on this property of a differential gear. For the relatively small errors as originate from shrinking and stretching of the material, it is not necessary that the wormwheel T is rotated at such a speed that the shaft E is completely stopped or that its speed is doubled. It will only be necessary to add or substract a small percentage of the number of revolutions of E. Therefore T may be driven by a wormshaft eonnected to the auxiliary motor by means of a reduction gear. The auxiliary motor can be small and of low power. Such a motor can easily be set in motion, stopped or made to reverse.
The auxiliary motor is a D.C. motor with two field coils wound in opposite directions. If one of the field coils is excited, the motor rotates in one direction, if the other field coil is excited the direction of rotation is reversed. The field excitation is supplied by the electronic control unit. The schematic diagram of the machine is shown in fig. 57.
The material W is fed into the operational part O of the machine by the roller. Marking spots T are printed on the material, but a significant part of the design can do just as well.
The machine is driven by the main motor MM via a reduction gear G. A fibre disc F operating the switch S and the magnetic pick-up M is mounted on the driving shaft of the machine. Since the switch S has to be closed and opened at a rate of up to 1000 times per minute, any normal switch would have to be replaced once a week. Therefore a special construction is necessary, the details of which are shown in fig. 58
The fibre disc has a copper strip R on part of its circumference. The switch is formed by two carbon brushes and is closed when both brushes are connected via the copper strip. In the disc is an iron pin I serving to excite the magnetic pick-up.
The driving shaft drives the roller via some pinions and the differential gear box D. The speed of the roller can be controlled by the auxiliary

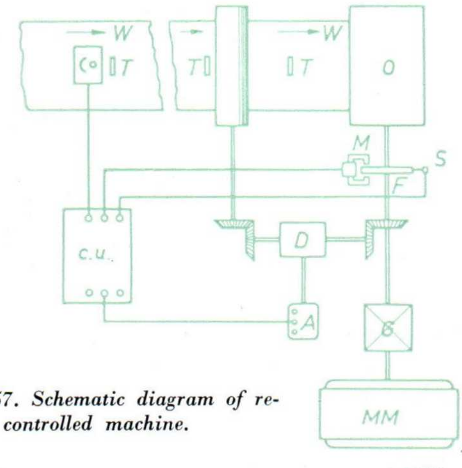


Fig. 57. Schematic diagram of register controlled machine.

motor A. The field coils of this motor are excited by the electronic register control unit CU, this obtaining its commanding signals from the phototube P and from the magnetic pick-up M, whilst it is brought into the control position by the switch S.

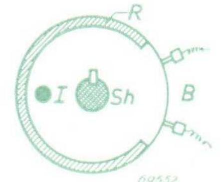


Fig. 58. Details of the rotary switch S *of fig. 57.*

Fig. 59 is a simplified diagram of the electronic part. This consists of a phototube, a magnetic pick-up, the pre-amplifiers P and M, two double triodes ECC 40 (V_4 and V_{10}) connected in monostable Eccles-Jordan circuits, the so-called flip-flop circuits and two double triodes ECC 40 (V_5 and V_{11}) connected in bistable Eccles-Jordan circuits. Furthermore, there are two tubes ECC 40 (V_6 and V_{12}) connected in a bridge circuit,

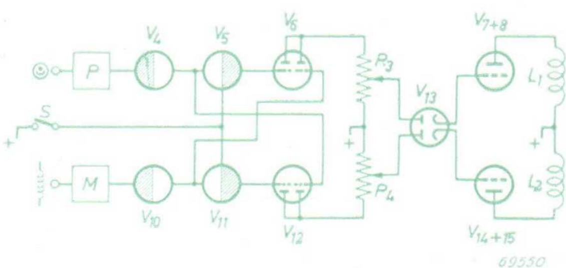


Fig. 59. Simplified diagram of the electronic part.

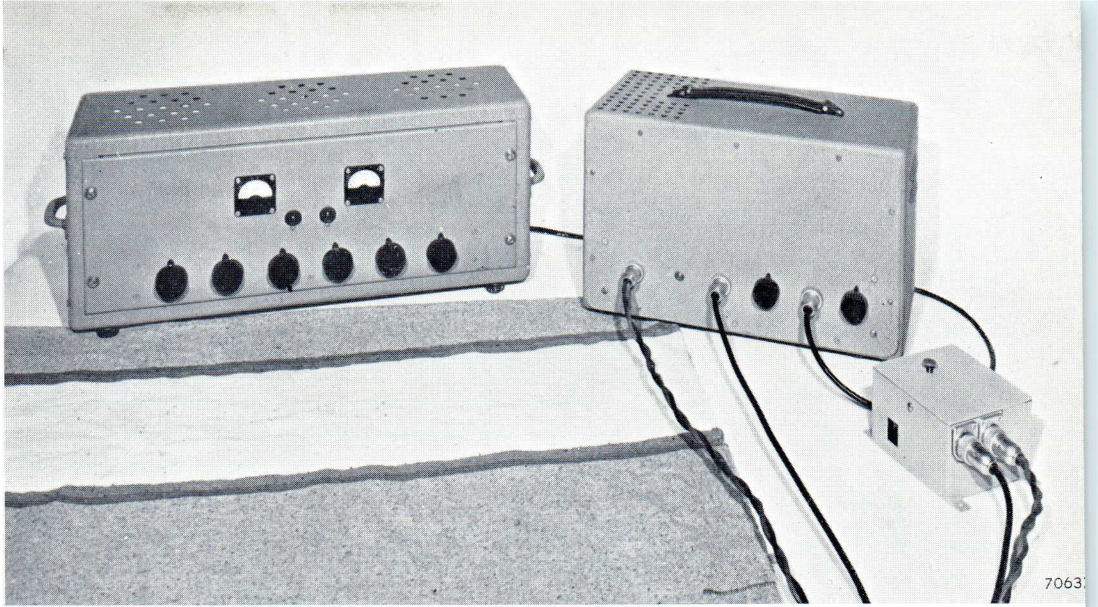


Fig. 60. The electronic part of the register control apparatus. Left: the electronic control apparatus; middle: the phototube amplifier; right: the scanner. In the foreground a colour printed blanket; note the marking spot (the dark stripe on the right side).

whilst the final stage V_{7+8} and V_{14+15} is coupled to the bridge circuit via a double diode EB 41 V_{13}.
The automatic register control may now be explained with the aid of the figures 57, 58, 59 and the circuit diagram, fig. 70. On the material W in fig. 57 marking dots T are printed. When these dots pass under the phototube the latter gives a signal to the control grid of the pre-amplifier. This amplifier is connected in such a way that a positive signal from the phototube results in a negative pulse on the grid of the conductive section of V_4 and causes the flip-flop to reverse. Where V_4 has only one stable position it returns to the initial state immediately, but in the meantime it causes V_5 to reverse, and since the latter has two stable positions it stays reversed. A similar explanation applies to the magnetic pick-up amplifier, to the flip-flop V_{10} and to V_{11}.
The closing of switch S brings V_5 and V_{11} into the initial position and keeps them there, no matter what stray signals might excite their grids. This arrangement blocks the electronic part during the greater part of a revolution of the main shaft and a "dead zone" is provided. Only when the marking spot comes in the vicinity of the phototube, the switch is opened and V_5 and V_{11} can reverse. If no provisions are made for a "dead zone" the machine can successively run at too high a speed, then at too low speed and so on, this phenomenon being called "hunting".
The double triodes V_6 and V_{12} in the bridge circuit are connected to V_5 and V_{11}. The grid of the first section of V_6 is connected to the grid of the conductive part of V_5 and the grid of the second section to the grid of the non-conductive part of V_{11}. The grids of V_{12} are connected to the remaining sections V_5 and V_{11}.
The anodes of both sections of V_6 and V_{12} are connected in parallel and fed via the potentiometers P_3 and P_4. In the initial position, the two potentiometers carry equal currents and the circuit is in balance. The control grids of the power tubes are connected to the potentiometers via a double diode in such a way that only positive signals can excite the final stage.
After this description of the mechanical and electronic parts the working of the entire apparatus can be explained. The magnetic pick-up is excited by the iron pin in the fibre disc, which at the same time operates the switch S. Both the pin and the switch are connected to the operating part of the machine and thus all three run synchronously.
The phototube is placed in such a position above the material that the marking spots pass at exactly the same moment that the magnetic pick-up gives a negative pulse to its corresponding amplifier. If the material is normal the mark passes the phototube at the same moment that the pulse from the magnetic pick-up is passed to the amplifier; so V_4 and V_{10} receive a negative pulse, they reverse and fall back in their initial position. Because the switch S has already been opened a short time beforehand, V_5 and V_{11} are released and the reversal of V_4 and V_{11} causes V_5 and V_{11} to reverse. V_5, V_{11}, V_6 and V_{12} have one cathode resistor in common, the interconnected grids being equally biased. V_6 and V_{12} are in balance when V_5 and V_{11} are in the initial condition. If both double triodes reverse simultaneously, the balance of V_6 and V_{12} is not disturbed and the grids of the final stage are not excited.
If the material has shrunk or stretched, however, then the signals from the phototube and the magnetic pick-up reach the grids of one of the amplifiers. If shrunken material passes, the phototube signal comes first and the grids of V_{7+8}

is excited, whilst in the case of stretched material the phototube signal is delayed and the magnetic pick-up signal comes first, exciting the grids of V_{14+15}. Suppose the material has shrunk, then the phototube signal causes V_4 to reverse, V_5 reverses and V_6 is completely blocked, whilst both sections of the double triode V_{12} become conductive. The bridge circuit is then out of balance, so that a positive pulse is applied via the diode to the control grid of V_{7+8}, resulting in the corresponding field coil of the auxiliary motor being excited and the motor rotating in such a way that the rollers are slowed down. After a short time has elapsed the signal of the magnetic pick-up comes in and V_{10} and V_{11} reverse. The balance in the bridge circuit is restored and the voltage on the control grid of V_{7+8} leaks away over the grid resistor. (This is one of the reasons why a diode is employed.) The auxiliary motor slows down but in due course the next signal comes through and the auxiliary motor is accelerated again.
If the material has stretched, the signal from the phototube is delayed. In this case the magnetic pick-up signal comes first and a similar explanation as given above applies, with the result that the control grid of V_{14+15} is excited and the auxiliary motor rotates in the opposite direction, accelerating the speed of the rollers.
As a rule the error in the material is uniform over comparatively long distances. Therefore, *RC* filters with a large time constant may be employed in the grid circuits of the final stage, while

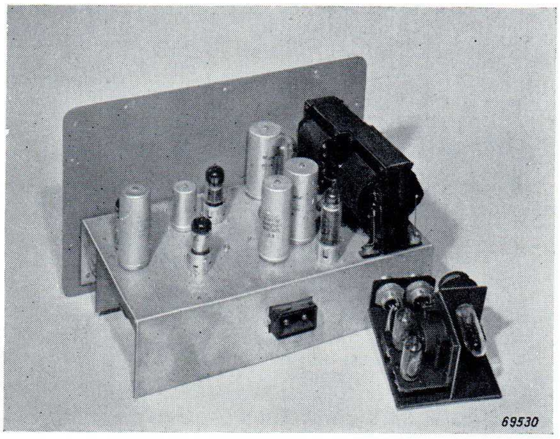


Fig. 61. The scanner (right) and the phototube amplifier opened.

the field coils of the auxiliary motor may be shunted by a capacitor. The result is that the motor rotates with nearly constant speed for the whole of the time during which correction is required. The speed depends on the duration of the pulses in the bridge circuit. If there is only a small interval between the arrival of the signals from the phototube and the magnetic pick-up, the pulses are weak. The longer the interval, the stronger the pulses. The decrease in negative grid bias of the power tubes, and therefore the current in the field coils, is proportional to the duration of the pulses. The peak value of the pulses depends on their duration; their influence on the final stage can be controlled by means of the potentiometers in the bridge circuit.

Circuit description

The electronic register control apparatus operates with reflected light on the phototubes. Since the surface of the material is not always flat, which causes straying of the reflected beam of light, two phototubes are employed in the scanner. If only one phototube were used, the straying would cause errors in the reading of the phototube. The scanner employed here safeguards the installation against these errors. In the scanner the two phototubes are mounted very near to each other and the beam of light from the exciter lamp passes between. The lamp is placed in the back part of the box (see fig. 61.) and is screened from the phototube compartment. The inner sides of the scanner are painted dull black. There is a hole in the screen for the light beam to pass, and a lens is applied just in front of this hole in the phototube compartment. The beam of light can be focused on the material by means of this lens and it can be adjusted by a screw on top of the scanner. A photograph of the complete outfit is given in fig. 60 (see also schematic diagram of the electronic part fig. 57).
The cabinet at the left contains the magnetic pick-up amplifier, the flip-flop circuits, the final stage and two supply units (see figs. 65 and 66). The other cabinet contains the phototube ampli-

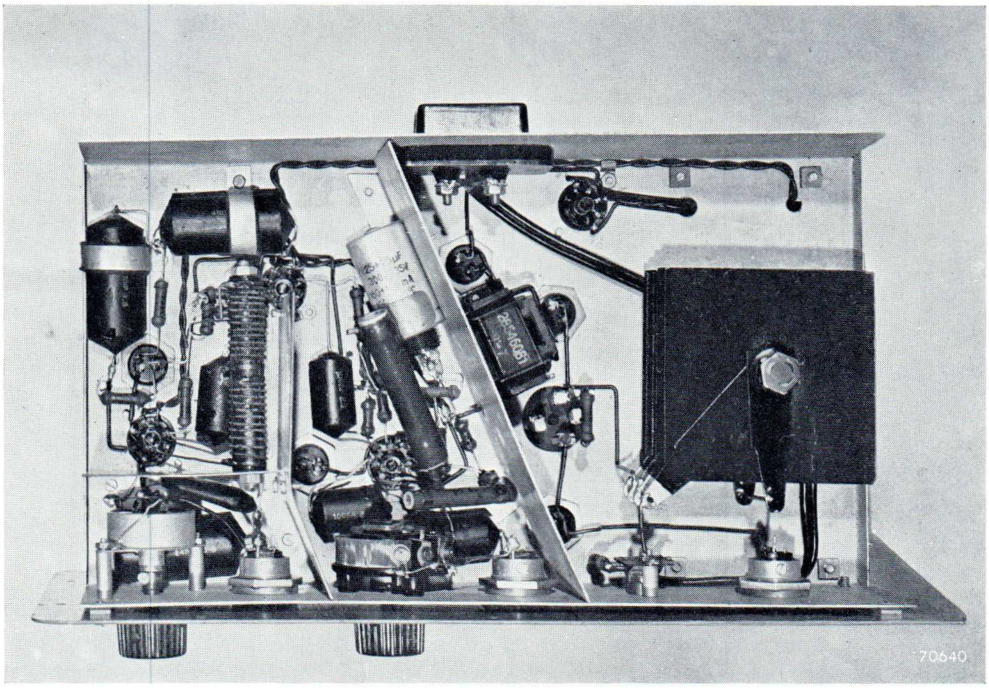


Fig. 62. Under-chassis view of the phototube amplifier.

fier with supply unit and the rectifier for the exciter lamp (see figs. 61 and 62).
The small box on the right is the scanner (see fig. 60), with the screw for focusing the light beam at the top, and on the left side of the scanner, the window through which the light beam passes and the reflected light enters. In the foreground is a colour-printed blanket, the marking spot on which may be seen at the right side (the dark stripe).

The phototube amplifier (fig. 61 and 62)

The signal of the phototubes is a positive pulse with a peak value of 8-15 mV, depending on the contrast between marking spot and background. This signal has the general form as represented in fig. 63*a*. Via a coupling capacitor C_2 and potentiometer P_1 it is applied to the control grid of the pre-amplifier tube EF 40 (V_1), at the control grid of which the pulse has the shape of fig. 63*b*.
The EF 40 (V_1) is connected normally and the gain of this stage is approximately 180; so the pulse arriving at the control grid of the EF 40 (V_2) has a peak value of approx. 1.5 V to 2.5 V. Since a negative pulse must be amplified, this second EF 40 tube operates without cathode bias, thus using the steepest part of the tube characteristic. Because of the grid current through the resistor R_8 the control grid is biased slightly negatively. The pulse form on this control grid is shown in fig. 63*c*. After due amplification it reaches the grid of the first section of the double triode ECC 40 in the form of a positive pulse as shown in fig. 63*d*. To obtain a pulse with a steep leading edge, as is necessary to operate an Eccles-Jordan flip-flop circuit, the ECC 40 (V_3) is equipped with a cathode resistor P_2 of high value, adjustable between 4.7 and 14.7 kΩ. In the absence of a signal the tube is in the cut-off position, as a result of which inter-

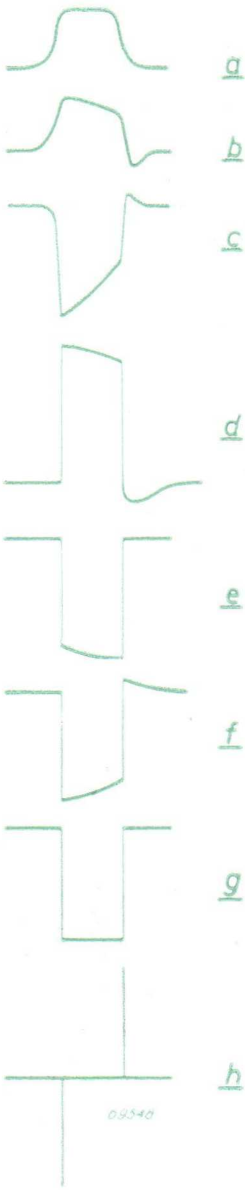


Fig. 63. Oscillograms of the phototube signal.

fering voltages due to coarse material remain below the cut-off point of the tube. The negative pulse reaching the anode of section I of the ECC 40 is applied to section II, which is connected as a cathode follower with high anode current. A negative pulse with steep leading edge and of a peak value between —60 V and — 90V is thus applied to the grid of the conductive section of the flip-flop No. 1 (V_4).

The pulse form on the cathode of the cathode follower is shown in fig. 63*e*, and fig. 63*f* shows the form in which it reaches the grid of the flip-flop. Fig. 63g shows the form of the pulse in the anode circuit of the flip-flop, while due to the small value of the coupling capacitor C_{14}, it excites the double triode V_5 in the form of fig. 63*h*.

The power supply unit is built on the same chassis as the amplifier. It has an entirely conventional circuit, employing an AZ 41 as a full-wave rectifier. In addition to the normal choke capacitor smoothing arrangement, the anode and screen-grid voltages of the pre-amplifier tube and the anode voltage of the phototubes are further smoothed by R_7 and C_5.

The anode voltage of the phototubes is taken from a potential divider consisting of two wire-wound resistors R_1 and R_2 of 0,1 MΩ and 40 kΩ respectively. It is necessary to use wire-wound resistors in the phototube circuit, because resistors of the carbon type would introduce too much noise.

The magnetic pick-up amplifier

The shape of the voltage of the magnetic pick-up approximates a sine curve with a peak value of about 5 V, the negative half cycle being used. A double triode ECC 40 (V_9) is used for amplification and for producing a square wave form. To obtain this result, cathode resistors of high value are employed, so that both sections operate in the bend of the characteristic.

The cathode resistor of the first section is shunted by a capacitor of 50 μF. The second section has no by-pass capacitor across the cathode resistor; so negative feedback is applied.

In the first section the anode current is interrupted during part of the negative half cycle of the grid signal, and in the anode circuit a voltage with a square positive half cycle and a sinusoidal negative half period appears. In the second section the positive square half period is amplified and the negative half sine wave is cut off. A negative pulse with large amplitude is therefore applied to the grid of the flip-flop (V_{10}). The pulse in the anode circuit of the second section of this flip-flop is similar in shape to that in the flip-flop V_4. The wave form in the various stages of the amplifier is shown in fig. 64 *a* to *e*. The voltage gain of the magnetic pick-up amplifier amounts to approx. 18.

The flip-flop circuit

The monostable flip-flop circuits of V_4 and V_{10} are identical and operate under similar conditions. The tubes employed are double triodes ECC 40. The grid of the conductive section has about the same potential as the cathode, whilst the grid of the non-conductive section is highly negative with respect to the cathode. The grid resistors have such values that the potential of the grid of the first section is about + 56 V and that of the second section about + 20 V with respect to the chassis. The potential of the cathodes with respect to chassis is about + 56 V. When the conductive section of the double triode is cut off by a negative pulse on the grid, the anode voltage increases suddenly by approximately 130 V. A large positive pulse is therefore applied to the grid of the other section so that this becomes conductive. This results in a considerable voltage drop in its corresponding anode circuit, so that via C_{14} a negative pulse reaches a common tap on the anode load resistors of both

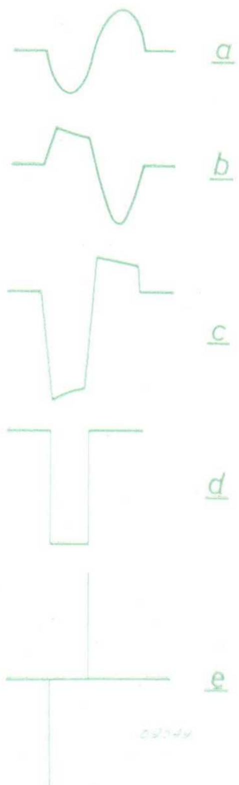


Fig. 64. Oscillograms of the magnetic pick-up signal.

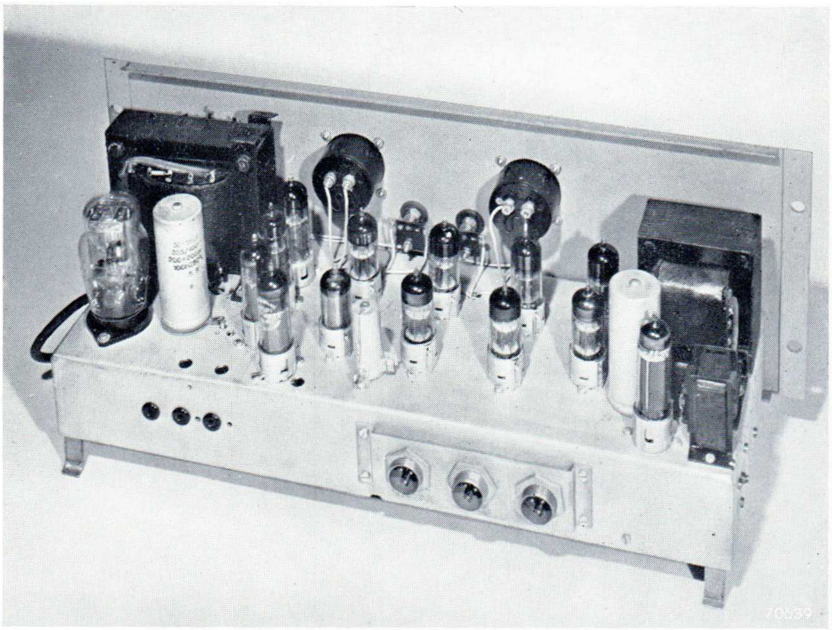


Fig. 65. Back view of the electronic control apparatus.

sections of the following bistable Eccles-Jordan circuit. This negative pulse is passed on, via the coupling resistors and capacitors, to the grids. Since the grid of the non-conductive section is already negative, a negative pulse is of no influence. In the conductive section, however, a negative pulse results in the tube being suddenly cut off, the anode voltage increases and the grid of the non-conductive section receives a positive pulse. The double triode reverses and, since the positive peak of the incoming pulse (see fig. 63*h*) is of no influence on such a circuit, it remains reversed until the grid of the non-conductive section becomes positive by the closing of switch *S*. When this switch closes, a positive voltage from the supply unit reaches the grid of the non-conductive section via R_{42}, R_{34} and R_{32}. The double triode V_5 is returned to its original state and remains so until the switch opens again and the commanding signal from the phototube or the magnetic pick-up reaches the grid of the conductive section of V_5 or V_{11}.

The sections of V_5 and V_{11}, which are non-conductive in the inital position, are shunted by a neon pilot lamp of the type Z10 in series with a 0.5 MΩ resistor. When the switch *S* is closed, the signal lamps light up and show that the double triodes V_5 and V_{11} are in the initial position. Even the opening of the switch may not cause a reversal of V_5 and V_{11}; so the lamps remain burning. However, if a pulse passes through the circuit, V_5 and V_{11} are reversed and the pilot lamps are extinguished.

The cathodes of V_5 and V_{11} and of the double triodes V_6 and V_{12} of the bridge circuit are interconnected and have one common cathode resistor P_5. This resistor may be of the semi-adjustable type and is set at about 6 kΩ.

The bridge circuit

The grids of the double triodes of the bridge circuit are connected to the grids of V_5 and V_{11} in the manner already described in the General Description. In the initial condition and when the double triodes V_5 and V_{11} are both reversed, each of the double triodes V_6 and V_{12} has one conductive and one non-conductive section. The anode voltages are then 90 V. If only V_5 or V_{11} are reversed, both sections of one of the double triodes are in the cut-off condition and the other double triode has two conductive sections. The anode voltages of the tube of which both sections are non-conductive rise to 270 V and the voltage on the conductive tube decreases to 75 V. The voltage drop of 15 V is not

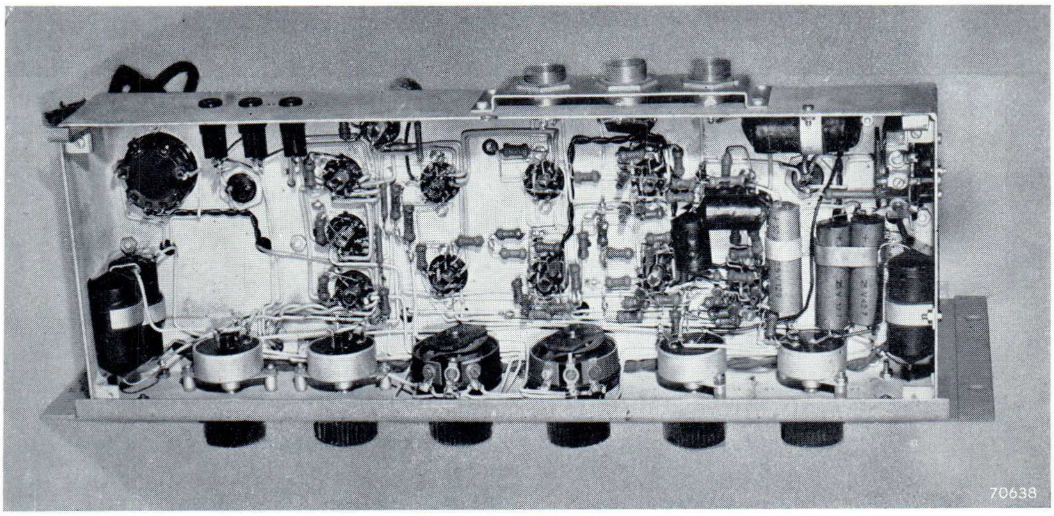


Fig. 66. Under-chassis view of the electronic control apparatus

important, but the increase in anode voltage of the cut-off double triode results in a pulse of max. 180 V peak value across the potentiometer in the corresponding anode circuit. The duration of the pulse is determined by the time interval between the arrival of the phototube and magnetic pick-up signals.

The diode circuit and the power stage

Fig. 67 is a schematic diagram of one half of the bridge circuit, one half of the double diode EB 41 and a power tube with one of the field coils of the auxiliary motor in its anode circuit. The voltage on the capacitor between the bridge circuit and the diode depends on the pulse duration. The shape of the pulses is shown in fig. 68*a*, *b* and *c*, for a long, a medium and a short pulse, thus for a large, a medium and a small error in the material. Fig. 68*a'*, *b'* and *c'* show the pulse form on the anode of the diode, and the charge of C_{19}, hence the grid-voltage variation of the final stage, is demonstrated by the shape of *a''*, *b''* and *c''*.

As long as the charge of the capacitors is increasing, the diode is conductive, but as soon as the balance in the bridge circuit is restored, the charge on C_{17} leaks away rapidly, while the charge on C_{19} leaks away slowly via R_{37}. This has the effect that the pulses of the double triodes V_5 and V_{11}, if they are "translated" to positive grid voltages on the power tubes, are already considerably smoothed. This smoothing is, not sufficient, however.

The fault in materials is as a rule uniform over large parts of the material; so when the correcting signal is applied to the power tubes, the auxiliary motor driven by the pulse does not run smoothly, but every time a pulse passes to the power stage, the armature is jerked, which causes heavy wear of the differential. Therefore additional smoothing is required and this can be obtained by shunting the field coils by electrolytic capacitors of values between 4 μF and 50 μF. This smoothing results in accumulation of a number of corrections, which saves maintenance costs. In the experimental apparatus described here adjustable grid resistors were used, but in various tests made with this outfit it proved that maximum value for these resistors always gave the best results. So in the definite form the apparatus can be provided with fixed grid resistors in the final stage. Adjustments can be made with the potentiometers of the bridge circuit, this varying the amplitude of the pulse but leaving the smoothing undisturbed. The output stage employs four power pentodes

EL 41 connected as triodes. To obtain a high slope and large anode current, two tubes are connected in parallel in each half of the circuit. In order to prevent parasitic oscillations, stopper resistors of 1 kΩ are connected in series with the control grids, and of 100 Ω in series with the screen grids. These resistors must be connected close to the tube sockets.

If there is a considerable error to correct, the power tubes dissipate about 9 W each, and this must be taken into account when considering the location of the tubes on the chassis. The power tubes may not be placed too close to each other or in the immediate vicinity of the power transformers, rectifier tubes or the electrolytic capacitors. In order to reduce the space required, however, two tubes of different halves of the final stage can be placed close to each other, so tube V_7 near to tube V_{14} and tube V_8 near to tube V_{15}.

In the anode circuits milliammeters of 100 mA are connected to facilitate the adjustment of the apparatus and to obtain information about the error in the material.

Fig. 69 shows the grid voltage delivered by the diodes V_D and the anode current I_a of the power tubes as a function of the error. Curves are given for triode connection and for pentode connection of the output tubes. It can be seen that the triode connection is to be preferred, because the slope in the vicinity of the origin of the curve is greater than for pentode connection. Small errors are therefore better corrected when triode connection is used. Another advantage of the triode connection consists in the fact that if a connecting wire to the field coil should be interrupted the tube will not be damaged, the screen grid and anode circuits being interrupted simultaneously. In the case of pentode connection such an interruption would result in overloading of the screen grids.

From the insert of fig. 69 it can be seen that for the correction of small errors it is advantageous not to operate the power tubes in the cut-off position, the slope of the characteristic being rather small at this point. A bias somewhere at the lower bend of the tube characteristics is much more favourable in this respect.

The supply units

Two supply units are built together on the same chassis carrying the apparatus just described. One of them, using a rectifier tube AZ 41 in

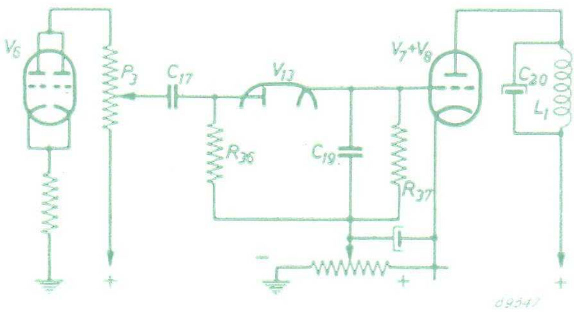


Fig. 67. Diagram of one half of the bridge circuit.

a full-wave circuit, supplies the anode voltage for the magnetic pick-up amplifier, the flip-flop circuits and the bridge circuit. The grid bias for the power tubes is also delivered by this unit. The grid bias can be adjusted, by means of the potentiometers P_6 and P_7, to values between 0

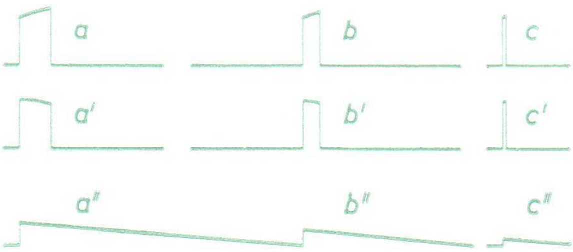


Fig. 68. Oscillogram of the pulses in the bridge circuit.

and —20 V. and is smoothed by the electrolytic capacitors C_{36} and C_{37} of 50 μF. The heater supply for 5 of the double triodes is delivered by the mains transformer T_3.

The other supply unit is not grounded and is only used for the anode supply of the power stage. A rectifier tube AZ 1 is employed as a full-wave rectifier and, sufficient smoothing is obtained by only one electrolytic capacitor of 50 μF. The double triodes of the bridge circuit, the double diode and the power tubes obtain their heater supply from the transformer of this unit T_4.

The D.C. supply for the incandescent lamp

In order to avoid ripple in the light source, the incandescent lamp is fed with D.C. Therefore a supply transformer, a selenium rectifier in a bridge circuit, a current stabilizing tube 1910 and two electrolytic capacitors of 2 × 500 μF, 25 V are employed. This supply unit is built on one chassis with the phototube amplifier. With this circuit the current through the lamp is sufficiently smoothed and stabilized to make the intensity of the light beam independent of variations in the mains supply.

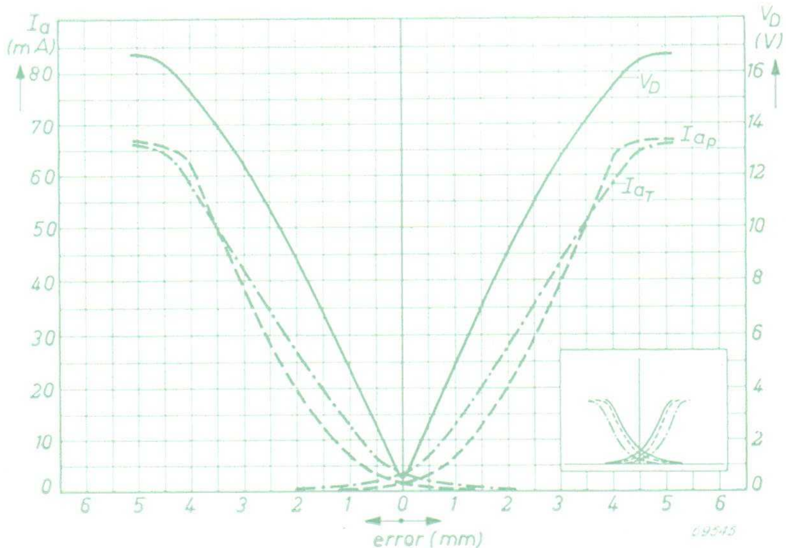


Fig. 69. Voltage on the diodes (V_D) and the anode current (I_a) of the power stage, as a function of the error. The curves marked I_{ap} are for pentode connection, those marked I_{at} for triode connection of the power tubes.

Voltages and currents (with respect to chassis)

1. PHOTOTUBE AMPLIFIER

	Supply voltage	V_b = 370 V
Phototube	Anode voltage	V_a = 65 V
EF 40 (V_1)	Anode voltage Screen-grid voltage Cathode voltage Anode current Screen-grid current	V_a = 63 V V_{g2} = 100 V V_k = 1.5 V I_a = 0.65 mA I_{g2} = 0.17 mA
EF 40 (V_2)	Anode voltage Screen-grid voltage Cathode voltage Anode current Screen-grid current	V_a = 20 V V_{g2} = 53 V V_k = 0 V I_a = 1 mA I_{g2} = 0.23 mA
ECC 40(V_3)I	Anode voltage Cathode voltage Anode current	V_a = 370 V V_k = 35-90 V I_a = 0 mA
ECC 40(V_3) II	Anode voltage Cathode voltage Grid voltage Anode current	V_a = 370 V V_k = 144 V V_g = 139 V I_a = 6.5 mA

2. MAGNETIC PICK-UP AMPLIFIER

	Supply voltage	V_b = 270 V
ECC 40 (V_9)I	Anode voltage Cathode voltage Anode current	V_a = 220 V V_k = 6.7 V I_a = 1.4 mA
ECC 40(V_9)II	Anode voltage Cathode voltage Anode current	V_a = 165 V V_k = 5 V I_a = 1 mA

3. FLIP-FLOP CIRCUITS

ECC 40 (V_4) and ECC 40 (V_{10})I	Anode voltage Grid voltage Cathode voltage Cathode current	V_a = 100 V V_g = 56.8 V V_k = 56 V I_a = 8.2 mA
ECC 40 (V_4) and ECC 40(V_{10})II	Anode voltage Grid voltage Cathode voltage Anode current	V_a = 230 V V_g = 20 V V_k = 56 V I_a = 0
ECC 40 (V_5) and ECC 40(V_{11})I	Anode voltage Grid voltage Cathode voltage Anode current	V_a = 90 V V_g = 56 V V_k = 56 V I_a = 3.6 mA

ECC 40(V_5) and ECC 40(V_{11})II	Anode voltage Grid voltage Cathode voltage Anode current	V_a = 170 V V_g = 35 V V_k = 56 V I_a = 0

4. BRIDGE CIRCUIT

ECC 40(V_6) and ECC 40(V_{12}) (conductive condition)	Anode voltage Grid voltage Cathode voltage Anode current	V_a = 90 V V_g = 56 V V_k = 56 V I_a = 3.6 mA
ECC 40 (V_6) and ECC 40 (V_{12}) (blocked condition)	Anode voltage Grid voltage Cathode voltage Anode current	V_a = 270 V V_g = 35 V V_k = 56 V I_a = 0

5. FINAL STAGE

EL 41 (V_0) EL 41 (V_0) EL 41 (V_{14}) EL 41 (V_{15})	Anode voltage Screen-grid-coltage Grid voltage Anode current + Screen-grid current	V_a = 240 380 V V_{g2} = 240 380 V V_{g1} = -6—20 V $I_a + I_{g2}$ = 50+2 mA

Parts list

RESISTORS

Circuit ref.	Type	Value	Power rating (W)
R_1	wire-wound	0.1 MΩ	3
R_2	,, ,,	40 kΩ	3
R_3	,, ,,	0.1 MΩ	1
R_4	carbon	1.8 kΩ	0.5
R_5	,,	0.27 MΩ	0.5
R_6	,,	0.82 MΩ	0.5
R_7	,,	27 kΩ	0.5
R_8	,,	0.82 MΩ	0.5
R_9	,,	0.22 MΩ	0.5
R_{10}	,,	0.82 MΩ	0.5
R_{11}	,,	29 kΩ	5
R_{12}	,,	0.82 MΩ	0.5
R_{13}	,,	4.7 kΩ	0.5
R_{14}	,,	0,1 MΩ	0.5
R_{15}	wire-wound	22 kΩ	5
R_{16}	carbon	0.82 MΩ	0.5

Circuit ref.	Type	Value	Power rating (W)
R_{17}	carbon	0.18 MΩ	1
R_{18}	,,	0.1 MΩ	0.5
R_{19}	,,	0.1 MΩ	0.25
R_{20}	,,	47 kΩ	0.25
R_{21}	,,	22 kΩ	0.25
R_{22}	,,	22 kΩ	0.25
R_{23}	,,	6.8 kΩ	0.25
R_{24}	,,	0.1 MΩ	0.25
R_{25}	,,	22 kΩ	0.25
R_{26}	,,	0.1 MΩ	0.25
R_{27}	,,	47 kΩ	0.25
R_{28}	,,	10 kΩ	0.25
R_{29}	,,	22 kΩ	0.25
R_{30}	,,	22 kΩ	0.25
R_{31}	,,	0.1 MΩ	0.25
R_{32}	,,	33 kΩ	0.25
R_{33}	,,	12 kΩ	0.25
R_{34}	,,	0.1 MΩ	0.25
R_{35}	,,	0.5 MΩ	0.25
R_{36}	,,	2 MΩ	0.5
R_{37}	,,	1 MΩ	0.5
R_{38}	,,	100 Ω	0.25
R_{39}	,,	1 kΩ	0.25
R_{40}	,,	1 kΩ	0.25
R_{41}	,,	100 Ω	0.25
R_{42}	,,	3.9 KΩ	1
R_{43}	,,	33 kΩ	0.25
R_{44}	,,	0.1 MΩ	0.25
R_{45}	,,	4.7 kΩ	0.25
R_{46}	,,	4.7 kΩ	0.25
R_{47}	,,	0.1 MΩ	0.25
R_{48}	,,	0.1 MΩ	0.25
R_{49}	,,	47 kΩ	0.25
R_{50}	,,	22 kΩ	0.25
R_{51}	,,	22 kΩ	0.25
R_{52}	,,	6.8 kΩ	0.25
R_{53}	,,	0.1 MΩ	0.25
R_{54}	,,	22 kΩ	0.25
R_{55}	,,	0.1 MΩ	0.25
R_{56}	,,	47 kΩ	0.25
R_{57}	,,	10 kΩ	0.25
R_{58}	,,	22 kΩ	0.25
R_{59}	,,	22 kΩ	0.25
R_{60}	,,	0.1 MΩ	0.25
R_{61}	,,	33 kΩ	0.25
R_{62}	,,	12 kΩ	0.25
R_{63}	,,	0.1 MΩ	0.25
R_{64}	,,	0.5 MΩ	0.25
R_{65}	,,	2 MΩ	0.5
R_{66}	,,	1 MΩ	0.5
R_{67}	,,	100 Ω	0.25
R_{68}	,,	1 kΩ	0.25
R_{69}	,,	1 kΩ	0.25
R_{70}	,,	100 Ω	0.52
R_{71}	,,	0.1 MΩ	1

POTENTIOMETERS

Circuit ref.	Type	Value	Power rating (W)
P_1	carbon	0.5 MΩ	
P_2	wire-wound	10 kΩ	2.5
P_3	carbon	50 kΩ	
P_4	,,	50 kΩ	
P_5	wire-wound	10 kΩ	2.5
P_6	,, ,,	16 kΩ	2.5
F_7	,, ,,	16 kΩ	2.5

CAPACITORS

Circuit ref.	Type	Value	Working voltage (V)
C_1	paper	0.47 μF	500
C_2	,,	400 pF	500
C_3	electrolytic	50 μF	12.5
C_4	paper	0.47 μF	500
C_5	electrolytic	25 μF	350
C_6	paper	0.1 μF	500
C_0	,,	0.47 μF	500
C_0	,,	0.1 μF	500
C_0	electrolite	50 μF	100
C_{10}	paper	0.1 μF	500
C_{11}	,,	0.1 μF	500
C_{12}	ceramic	220 pF	
C_{13}	,,	220 pF	
C_{14}	,,	220 pF	
C_{15}	,,	220 pF	
C_{16}	,,	220 pF	
C_{17}	paper	0.47 ΩF	500
C_{18}	,,	0.47 μF	500
C_{19}	,,	0.47 μF	500
C_{20}	electrolytic	4 to 50 μF	350
C_{21}	,,	4 to 50 μF	350
C_{22}	,,	50 μF	12.5
C_{23}	paper	0.1 μF	500
C_{24}	,,	0.1 μF	500
C_{25}	,,	0.16 pF	
C_{26}	ceramic	220 pF	
C_{27}	,,	220 pF	
C_{28}	,,	220 pF	

Circuit ref.	Type	Value	Power rating (W)
C_{29}	,,	220 pF	
C_{30}	,,	220 pF	
C_{31}	paper	0.47 μF	500
C_{32}	electrolytic	500+500 μF	25
C_{33}	,,	500+500 μF	25
C_{34}	electrolytic	50 μF	450
C_{35}	,,	50 μF	450
C_{36}	,,	50 μF	25
C_{37}	,,	50 μF	25
C_{38}	,,	50 μF	350
C_{39}	,,	50 μF	350
C_{40}	,,	50 μF	450

TRANSFORMERS AND COILS

L_1, L_2	field coils of auxiliary motor
L_3	magnetic pick-up
L_4	16 V, 2 A
L_5	220 V, 50 ~
L_6	choke coil 60 mA, 8 H, 300 Ω
L_7, L_8	2 × 275 V, 35 mA
L_9	4 V, 1 A
L_{10}	6.3 V, 1 A
L_{11}	primary 220 V, 50 ~
L_{12}	choke coil 8H, 60 mA, 300 Ω
L_{13}, L_{14}	2 × 275 V, 50 mA
L_{15}	4 V, 1 A
L_{16}	6.3 V, 3 A
L_{17}	primary 220 V, 50 ~
L_{18}, L_{19}	2 × 275 V, 100 mA
L_{20}	4 V, 1.1 A
L_{21}	6.3 V, 4.2 A
L_{22}	primary 220 V, 50 ~
T_1	mains transformer for exciter lamp
T_2	mains transformer H.T. unit phototube amplifier (T_1 and T_2 can be combined)
T_3	mains transformer
T_4	mains transformer

TUBES

V_1	FF 40	V_7	EL 41	V_{13}	EB 41
V_2	EF 40	V_8	EL 41	V_{14}	EL 41
V_3	ECC 40	V_9	ECC 40	V_{15}	EL 41
V_4	ECC 40	V_{10}	ECC 40	V_{16}	AZ 41
V_5	ECC 40	V_{11}	ECC 40	V_{17}	AZ 41
V_6	ECC 40	V_{12}	ECC 40	V_{18}	AZ 1

For detailed circuit diagram see fig. 70.

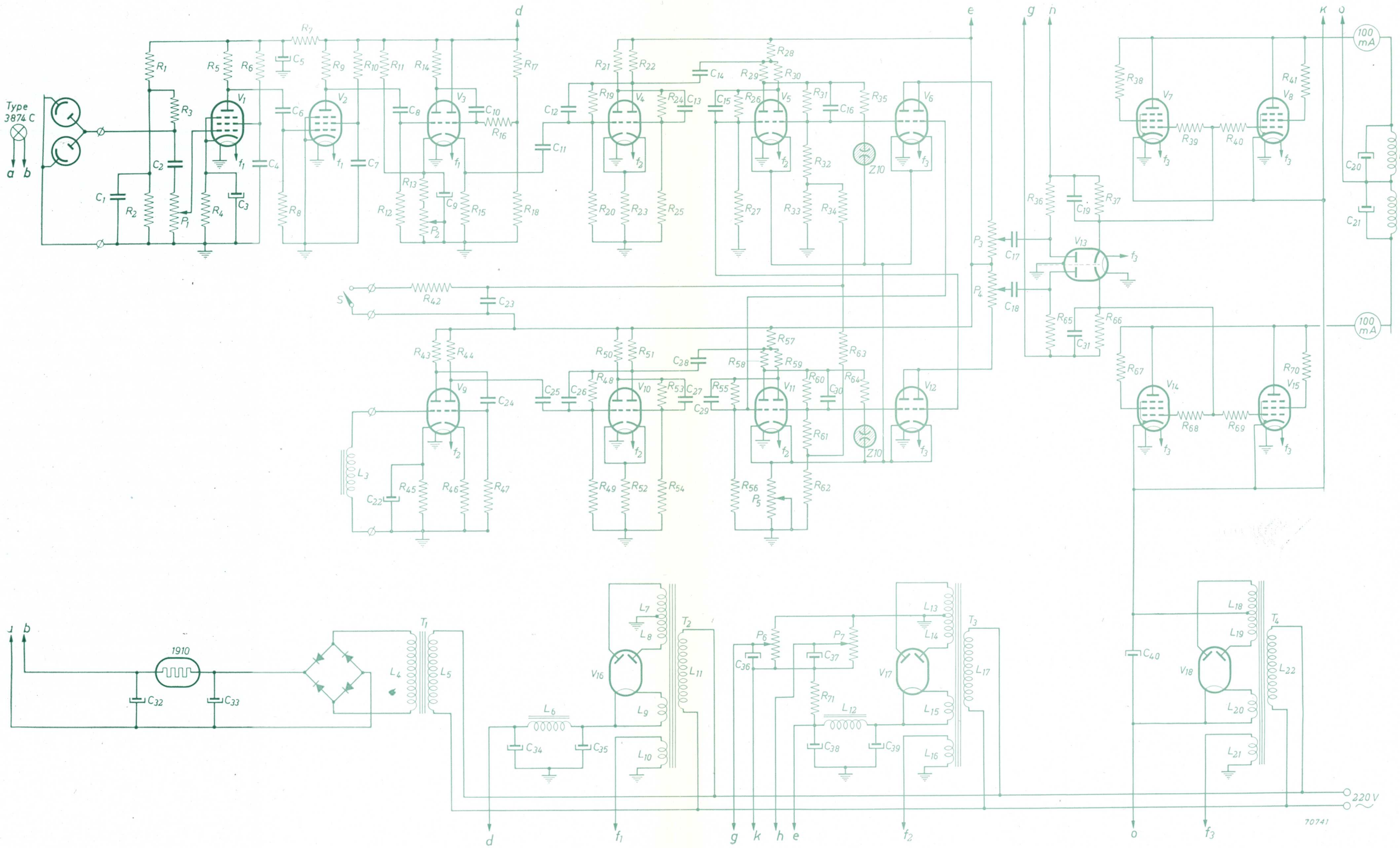


Fig. 70. Circuit diagram of the electronic register control apparatus.

Spectral oscillograms obtained with phototubes

During the development of the register control apparatus the question arose as to what colour contrasts are sufficiently indicated by phototubes and which type of photocathode was to be preferred. To answer this question the following test was carried out.

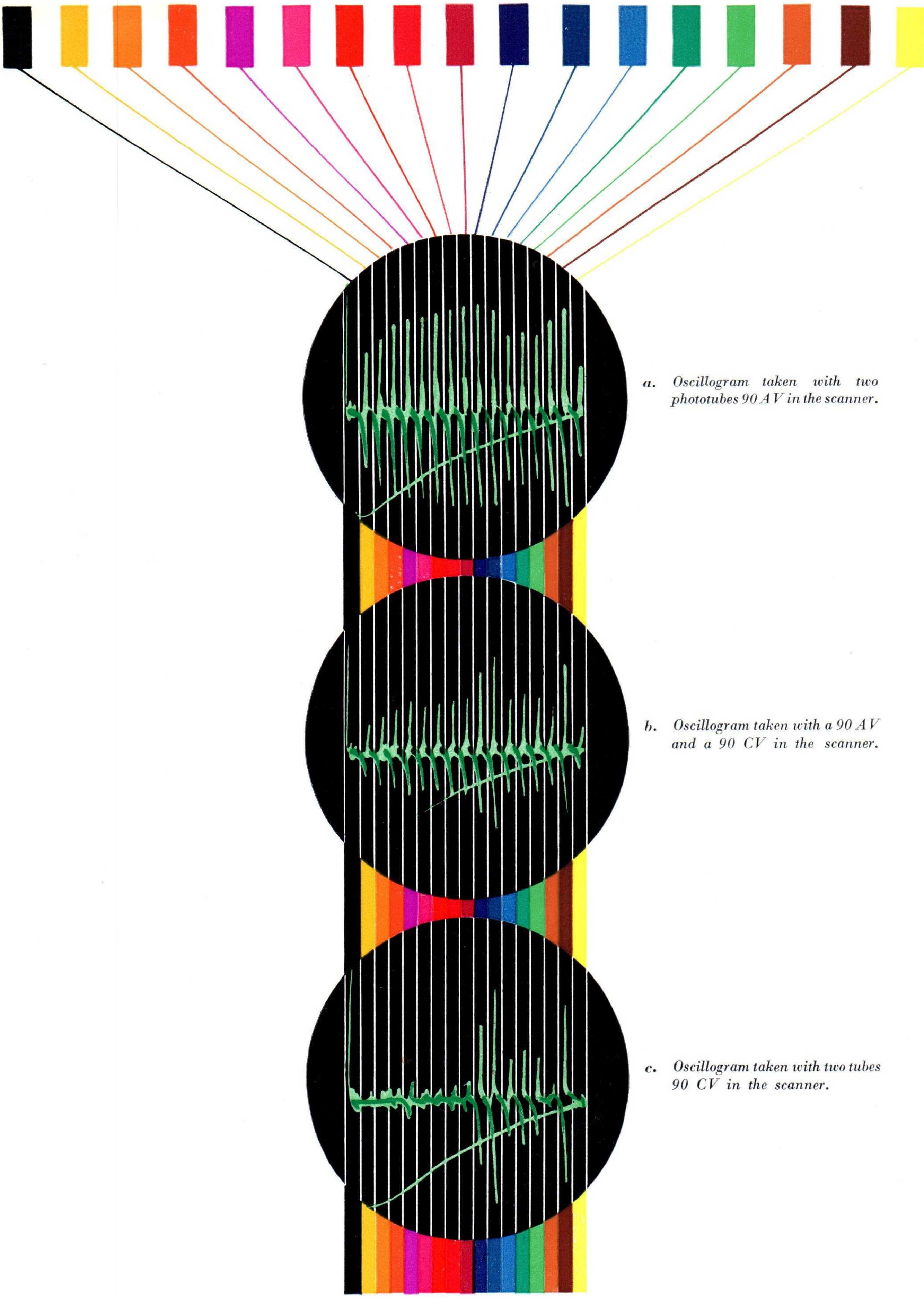
Sixteen colour strips, representing different colours and shades, are glued onto a strip of white paper attached to the circumference of a metal drum, the spacing of the colour strips on the paper being such that they are distributed uniformly around the circumference.

The drum can be rotated by a motor, and a scanner as used by the register control apparatus is placed in front of the drum. The voltage across the load resistor is registered by means of an oscilloscope. In order to obtain a reference line on the oscillogram and to provide a synchronizing pulse, a hole is cut in the drum and in the paper strip. This hole represents "black", that is to say there is no reflection of incident light. It should be borne in mind that when working with reflected light even a black surface will show some reflection. With this installation, the oscillograms on page 59 were made (Fig. 71*a*, *b* and *c*.

The different colours are apparently not in chromatic sequence. It is impossible to place black between dark red and violet, because these colours are too near to black to obtain good synchronization. Therefore black is placed in the yellow part of the spectrum. Furthermore, the mixed colours are placed near one of the components; brown near yellow, crimson near red. This explains the somewhat haphazard sequence of the different colours.

When interpreting the oscillograms it must be understood that the colours are on a white background reflecting a maximum of light. Therefore the current through the load resistance is maximum at white, and minimum at black and at the colours for which the phototube is not sensitive. A large amplitude therefore indicates either a colour for which the phototube is less sensitive or a colour which is less dominant in the emissive spectrum of the exciter lamp. The difference between the "A" type of cathode (oscillogram *a*) and the "C" type (oscillogram c) is clearly visible. The "A" type of cathode, being sensitive to daylight and near blue radiation, "sees" all the colours in the light of an exciter lamp as a contrast from white. The contrast is smallest for yellow and light blue (see fig. 71*a*). The "C" type of cathode, which is most sensitive to incandescent light and red radiation, "sees" the red, orange and yellow colours as white; so for these colours there is little contrast in the oscillogram (see fig. 71*c*). From the information furnished by the oscillograms it may be concluded that register control apparatus, for instance, should be equipped with phototubes having an "A" cathode. The "C" type of cathode is to be preferred only if blue marking spots on a red background are used.

From the oscillogram given in fig. 71*b* it can be seen that the combination of two phototubes with different cathodes gives good overall spectral response; only three colours, viz. dark-brown, dark-blue and violet give a response near to black. This is of importance for the design of spectrophotometers. The insensitivity for dark blue and violet is due to the small energy emitted by an incandescent lamp in this part of the spectrum, whilst dark-brown reflects very little light.



a. Oscillogram taken with two phototubes 90 A V in the scanner.

b. Oscillogram taken with a 90 A V and a 90 CV in the scanner.

c. Oscillogram taken with two tubes 90 CV in the scanner.

Fig. 71. Oscillograms made with the scanner of the register control apparatus. The entire spectrum is divided in two parts and to obtain good synchronization black is placed between the yellow shades. The first line in the oscillogram is obtained with black and can be used as a reference line to compare the response for the different colours.

SUGGESTIONS FOR A SIMPLE SPECTRO-PHOTOMETER

In a laundry experiments were made with diverse machines and washing powders to ascertain the cheapest and most efficient method of washing. Several pieces of fabric were soiled to the same degree and washed in different machines with different washing powders. In the course of the experiment it proved to be difficult to distinguish by eye between the results obtained, and to obtain comparative measurements a kind of photometer had to be developed. A diagram of this photometer is shown in fig. 72.

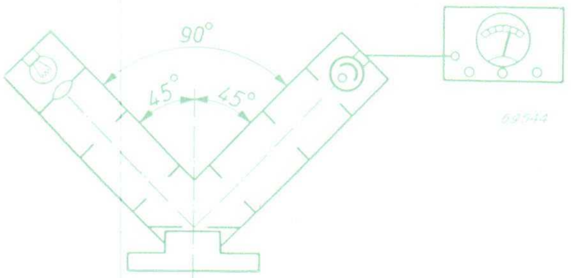


Fig. 72. Photometer for comparative measurement of washings.

Two metal tubes are welded to each other at an angle of 90°. One of these tubes comprises the exciter lamp, while the other contains the phototube. Baffles are provided inside the tubes to intercept stray light. The fabric under inspection is stretched over a small steel table with rounded edges and the tubes are placed above it. A suitable meter connected in the phototube circuit gives an indication of the whiteness of the washing. A tablet of magnesium carbonate is used as standard white. This instrument gives very good results. The meter is set to full deflection with the magnesium carbonate block on the exposure table, and the results of the washing experiments are expressed in percentages of this maximum deflection.

Starting from this photometer for comparative measurements it seems only one step further to make a spectro-photometer for comparing the colours of inks, paints or dyes. Suppose a slide with suitable filters is inserted in the tube containing the exciter lamp, then the material under test on the exposure table reflects a certain amount of light in every colour transmitted by the filters. Actually, however, a spectrophotometer is somewhat more complicated than the photometer previously described. First of all, if the angle of reflection is equal to the angle of incidence, gloss of the material under inspection can upset the measurement. Therefore another form must be given to the new instrument. Furthermore, if only one phototube is used, this is either sensitive in the blue or in the red region of the spectrum. A combination of a blue-sensitive and a red-sensitive phototube is necessary, which can be obtained by connecting two phototubes with different cathodes in parallel (see fig. 73). For colour measurement only the visible part of the spectrum has to be covered, say between 4000 Å and 7000 Å. Therefore a number of selective filters for the different colours of the

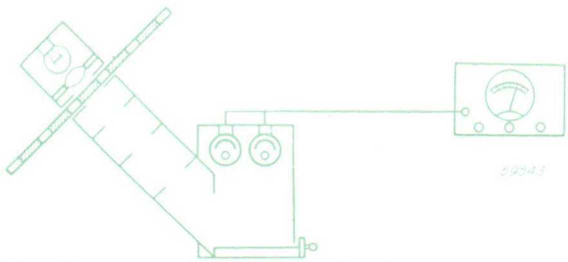


Fig. 73. A simple spectro-photometer for comparative measurements.

spectrum must be used. Furthermore, it should be possible to use commercial filters that are easy to obtain. There are several optical industries making good filters for this purpose. The curves for the filters described below were taken from an article by R. Donaldson [1]). The filters have transmission curves as shown in fig. 77 and are of the following composition:

[1]) R. Donaldson, Proceedings of the Physical Society, p. 554/1947.

Filter No.	Colour	Make	Type	Thickness
1	blue	Chance Bros.	OB1	2.5 mm
2	blue-green	Wratten	gelatine filter No. 75	
3	green	Chance Bros Zeiss	OY 4 plus BG 7	2.1 mm 4.2 mm
4	yellow-green	Chance Bros. „ „	OG1 plus cadmium yellow plus cadmium yellow	2.8 mm 1.7 mm 1.4 mm
5	orange	Chance Bros. Corning Chance Bros.	OR 2 plus 978 plus cadmium yellow	2.5 mm 2.9 mm 0.9 mm
6	red	Chance Bros. „	OR 1 plus Calorex	1.8 mm 3.3 mm

In fig. 77 the relative sensitivity of a phototube with the "A" type of cathode (blue-sensitive) and the relative sensitivity of the "C" type of cathode (red-sensitive) are drawn, a curve showing the relative spectral energy distribution of an exciter lamp being also given. From these curves it can be seen that, as a result of the shape of the curve for the exciter lamp, the sensitivity will be low in the blue region and high in the red region of the spectrum. There is a considerable infra-red radiation which can spoil gelatine filters, so a heat absorbing filter must be provided. The Zeiss filter Schott No. BG 19 of 1 mm thickness (the transmission curve of which is drawn in the figure), however, reduces the heat considerably. Other heat absorbing filters are, for instance, the Calorex filters of Chance Bros. With the data obtained from fig. 77 the sensitivity of the spectro-photometer for the six filter wavelengths can be calculated, the result of such a calculation being given in fig. 74. This graph is calculated for the use of two phototubes in parallel, viz. the blue-sensitive vacuum phototube 90 AV and the red-sensitive vacuum phototube 90 CV. The first has a sensitivity of 45

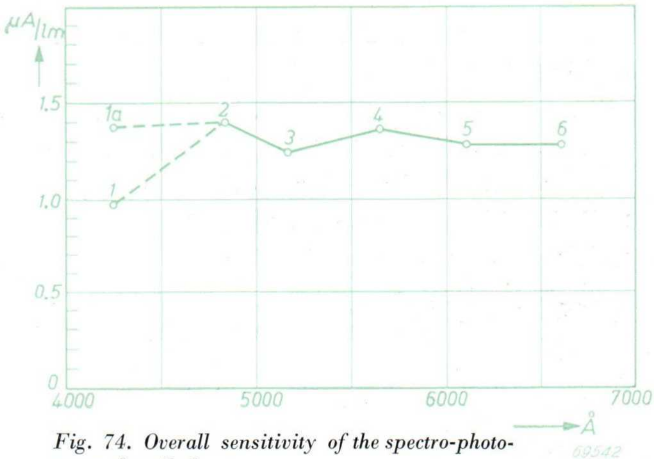


Fig. 74. Overall sensitivity of the spectro-photometer described.

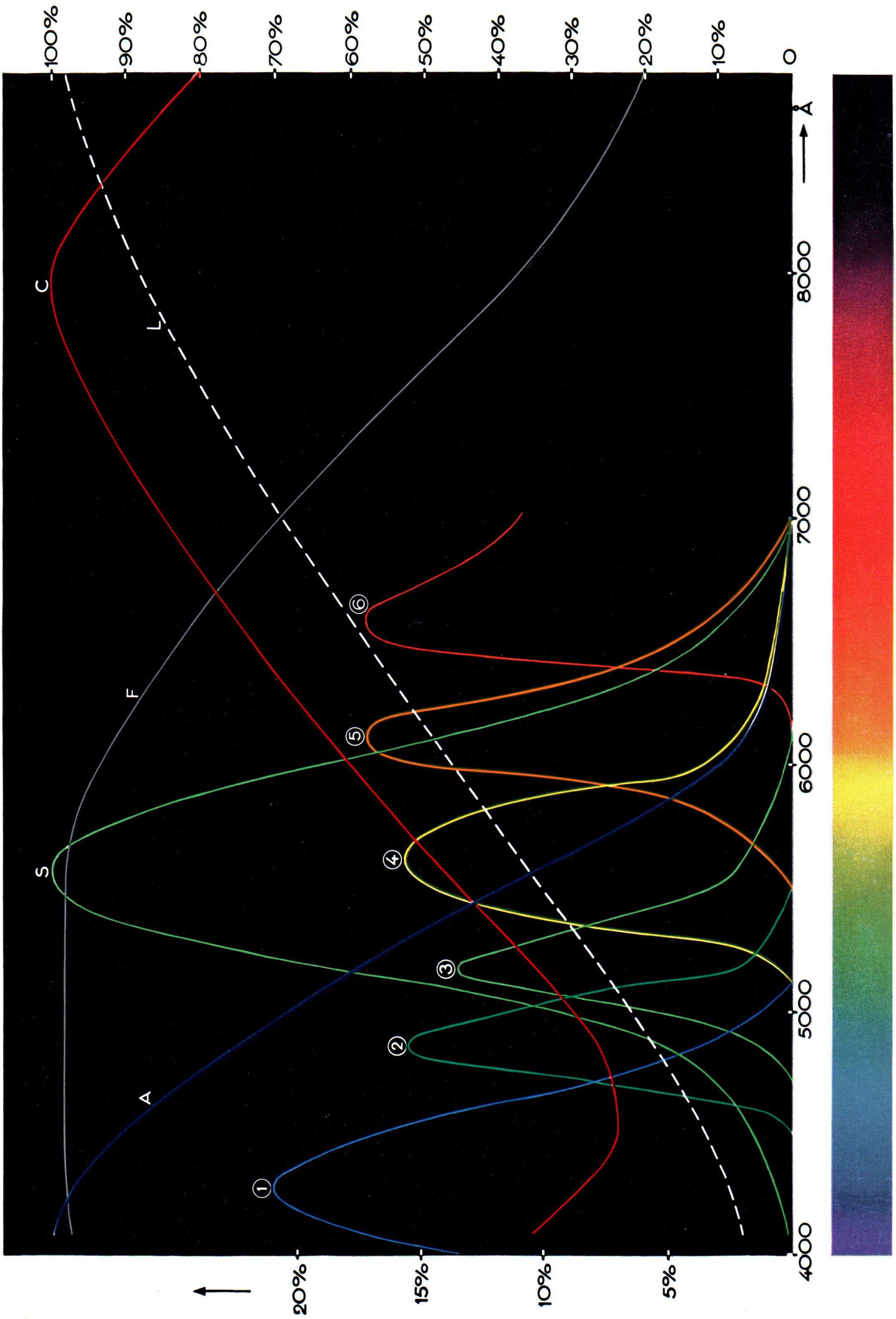
μA/lm, whilst the sensitivity of the latter is 20 μA/lm, measured with an incandescent lamp with a colour temperature of 2700 °K. The part of the spectral response curve of the 90 CV between 4000 Å and 4800 Å is not always the same for all phototubes of this type. Therefore point No. 1 of the curve may lie on the line between 1 and 1a.

From this graph it can be seen that the sensitivity is sufficiently uniform for comparative colour measurements.

A possible arrangement for the part of the apparatus so far discussed is shown in fig. 75. The exciter lamp (E) is in the top of a well ventilated compartment. The light passes through a heat absorbing filter (F) and is focused on the object under inspection by a lens (L). A revolving wheel (W) contains the six filters that can be placed in the light beam. The lower compartment contains the phototubes (A and C) and a slide (S) on which the material under inspection can be placed. All the innerparts of this compartment have to be made dull black. It is also possible

→

Fig. 77. Relative sensitivity of phototubes with A and C cathode: Relative spectral energy distribution of an incandescent lamp; Relative transmission curves of the selective filters 1-6; Relative transmission curve of the heat absorbing filter; Schott BG 19 and relative eye sensibility curve.



100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0
Å
8000
7000
6000
5000
4000
20%
15%
10%
5%
C
L
F
S
A
①
②
③
④
⑤
⑥

Fig. 77

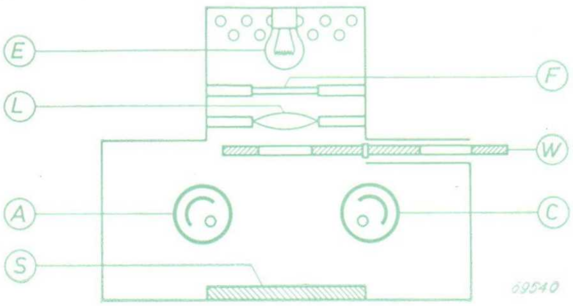


Fig. 75. Arrangement of a simple spectro-photometer, for comparative colour measurements.

to provide a hole in the bottom of the apparatus and place it over the material under inspection. To prevent stray light from entering the phototube compartment, a rubber ring can be applied to the bottom.

The V.T. voltmeter for use with the apparatus can be made according to the circuit diagram of fig. 76. This circuit has the advantage that the balance of the triode voltmeter is practically independent of variations in the supply voltage. The sensitivity can be adjusted by means of the potentiometer P_2, whilst zero adjustment is made with the potentiometer P_1. Adjustments can be carried out as follows: With an extinguished exciter lamp zero adjustment is made with P_1. Then a block of magnesium carbonate is exposed to the light, and with filter No. 2 inserted, because with this filter the sensitivity is maximum, the pointer of the milliammeter is brought to full deflection with P_2. After this adjustment the zero adjustment must be corrected again. If the initial adjustment was very bad the process must be repeated a few times. Colour measurements can now be made with the different filters and the results can be plotted in a graph similar to the one of fig. 76.

The phototubes are fed from a voltage reference tube 85A1. The load resistance is rather high. In the test model of this V.T. voltmeter this value was used, but measurements made with this instrument have shown that sufficient sensitivity can be obtained with a lower value of R_1. A lower value for R_1 reduces the influence of grid current, and a better stability is obtained. Another improvement of the circuit is to include shunt resistance across the milliammeter. This resistor can be interrupted by a press-button switch for obtaining greater sensitivity if meter readings at the lower end of the scale have to be taken. The resistor may have the same value as the meter resistance to obtain double sensitivity. In this case it may be necessary to use a meter of 250 or 500 μA full scale deflection.

The anode supply is conventional for this type of instrument. A heater type rectifier tube EZ 40 is used, which can be connected to the same heater supply as the double triode.

There are no objections against A.C. supply for the exciter lamp, but it is advisable to use a current stabilizer in series with this circuit. The light source will then be sufficiently constant during the test.

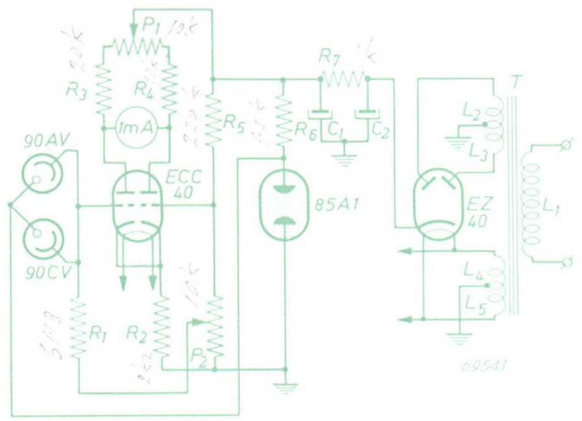


Fig. 76. Circuit of the V.T. voltmeter to be used with the spectro photometer.

Voltages with respect to chassis measured in test model V.T. voltmeter.

Supply voltage	**C_2** **C_1**	**280 V** **265 V**
85 A1	**Anode voltage**	**84 V**
ECC 40 (I)	**Anode voltage** **Cathode voltage**	**150 V** **16 V**
ECC 40 (II)	**Anode voltage** **Grid voltage** **Cathode voltage**	**150 V** **14 V** **16 V**

Parts list

Circuit ref.	Type	Value	Power rating (W)
R_1	carbon	6.8 MΩ	1
R_2	carbon	2.2 kΩ	1
R_3	wire-wound	20 kΩ	2.5
R_4	wire-wound	20 kΩ	2,5
R_5	carbon	0.22 MΩ	1
R_6	wire-wound	45 kΩ	2.5
R_7	carbon	1 kΩ	1
P_1	wire-wound	10 kΩ	2.5
P_2	wire-wound	10 kΩ	2.5
C_1, C_2	double electrolitic 2×50 μF, 350 V		

Transformer *T*

L_1	220 V	
L_2, L_3	2×250 V	20 mA
L_4, L_5	2×3.15 V	2 A.

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