High tension Rectification

HIGH TENSION RECTIFICATION

Introducing

PHILIPS

GASFILLED RECTIFYING VALVE

PHILIPS METALIX

PHILIPS LAMPS LIMITED., 145 CHARING CROSS ROAD, LONDON, W.C.2.

PREFACE

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Radiological technique has long since passed the stage where inefficiency can be allowed to exist anywhere in the X-ray Department. Every stage in the production of radiographs—from switching on the mains to removal of the film from the fixing bath—must be performed with optimum efficiency, if consistently good results are to be obtained.

The importance of good mains, high quality transformers, tubes, measuring instruments, films, screens and irreproachable developing technique, is so widely realised that reference to them here is almost superfluous.

The same cannot be said, however, with regard to the Rectifying Valve which in many cases appears to receive scant consideration beyond that of how inexpensively it can be replaced. And yet, the Valve can make or mar the performance of the best equipment. It will, if unsuitable or improperly operated, prevent the production of uniform results. It may cause additional running expenses by wastage of films, and its failure can irremediably damage the X-ray tube and other Valves in the circuit. There may also be untold inconvenience, the cost of which cannot be estimated, when the failure of a Valve throws the whole apparatus out of commission.

It is the object of this publication to explain as fully as possible the general functioning of Rectifying Valves and the relative efficiency of the various types. In so doing, it inevitably follows that PHILIPS latest production—the Gasfilled Valve—will find the appreciation it undoubtedly deserves.

It is hoped too, that the other technical material contained herein may assist towards easier understanding of present day equipment and will be of value to those whose interests lie in the practice of Radiology.

PHILIPS METALIX *September 1935.*

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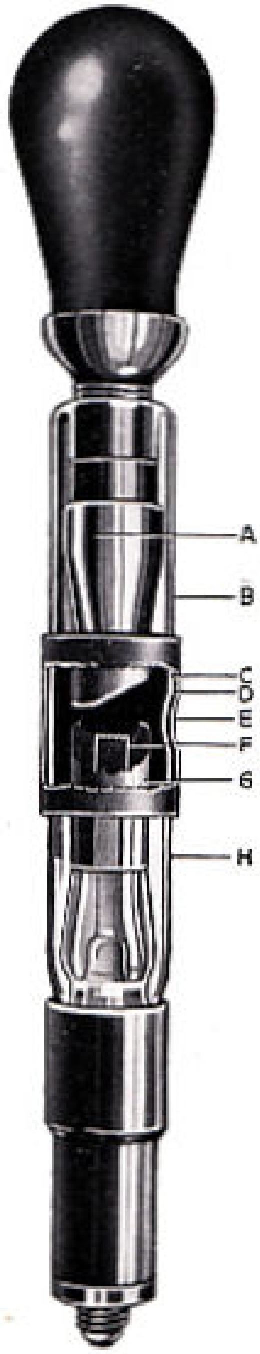

Figure 1.—A heavy Anode insert tube for the "METALIX" Universal Shockproof Shield. Cooling is effected by thermal storage in a solid metal body specially shaped to conform with the electric field, and having a blackened surface from which the heat is continuously dissipated by radiation. In the illustration, part of the centre of the tube is cut away to show its internal arrangement.

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THE X-RAY TUBE

In order to understand completely the principles of the Valve rectifier, it is helpful first to consider the functioning of the X-ray tube.

Fig. 1 illustrates the construction of a Metalix hot cathode tube of modern type for shockproof enclosure. The tube consists essentially of two electrodes—an Anode (A); and a Cathode (G) in which is incorporated a Filament (F)—enclosed within an evacuated container comprising a central metal Discharge Chamber (C) (Philip's Patent) with Glass Extensions (B) and (H) to which the electrodes are sealed. A lead jacket (D) encircles the discharge chamber and provides the required X-ray protection. The rays emerge through a window (E).

When the filament is heated by the application of low tension current, it emits electrons (particles of negative electricity), the quantity of electrons emitted depending on the temperature and nature of the filament material.

The electrons which "evaporate" from the filament have normally a strong tendency to remain in close proximity to their source—they form, so to speak, a cloud around the heated material.[1]

When, however, a high potential is applied between the anode and cathode, so that the anode is positively charged, the electrons, being negative particles, are detached from the filament and after travelling through the vacuum at high speed, impinge upon the anode with considerable force.

The energy dissipated by the electrons at the moment of impact, is converted partly into X-rays and the remainder into heat over the region of bombardment, i.e., the focus.

The ***penetrating power*** of the resultant rays depends on the velocity of the electrons at the moment of impact. When a high kilovoltage is applied to the tube, the electrons travel at high speed and produce short wave length radiation of high penetrating power. When the tension across the tube is lower, the velocity of the electrons is less and the resultant X-rays are of longer wave length with lesser penetrating power.

The ***intensity*** of the radiation varies directly with the current (mA) passing through the tube, i.e., is proportionate to the quantity of electrons transported to the anode. This in turn is governed by the temperature of the filament and may, therefore, be increased or decreased by adjusting the filament heating current.

It will be seen from the above, that a certain difference of potential must exist between the anode and cathode, in order to draw the electrons from the cathode and give them the required velocity. This potential, or in other words, the volt drop across the tube, is, of course, varied in practice according to the density of the object under examination. The denser the object, the greater must be the applied potential in order to obtain rays of the desired penetrating power.

One of the greatest problems in the design of an

1. The term "evaporation," whilst it assists in forming a conception as to what actually occurs, should not be taken too literally. For explanatory purposes, however, it possesses the virtue of being easily followed.

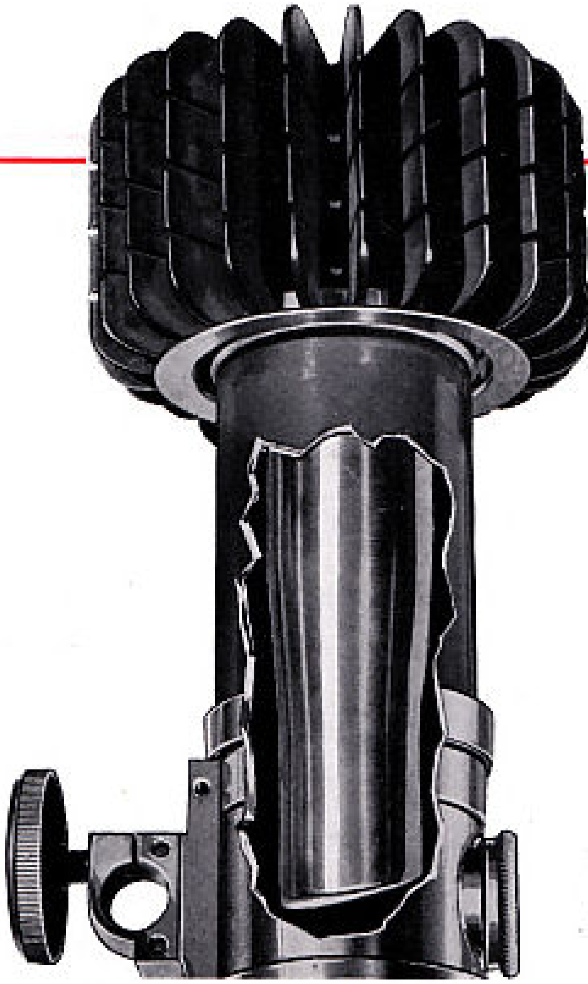

Figure 2.—A section of the " METALIX " SA Tube with exterior partly cut away to show the massive Anode. Note the large radiator for cooling purposes.

X-ray tube is that of dissipating the very large amount of heat generated at the face of the anode by the electronic bombardment.

The target must be composed of material having a high melting point and the heat must be conducted away from the focus and dissipated as quickly and efficiently as possible, in order to avoid fusion of the anode material. All users of X-ray tubes will be familiar with the water cooling system used for the latter purpose, and in the later improved types of " METALIX " tubes, with the massive anode and large radiator cooler. (See fig. 2.)

When rectified tension is applied to the tube, that is to say, when the anode is never other than at positive potential in relation to the cathode, the load capacity

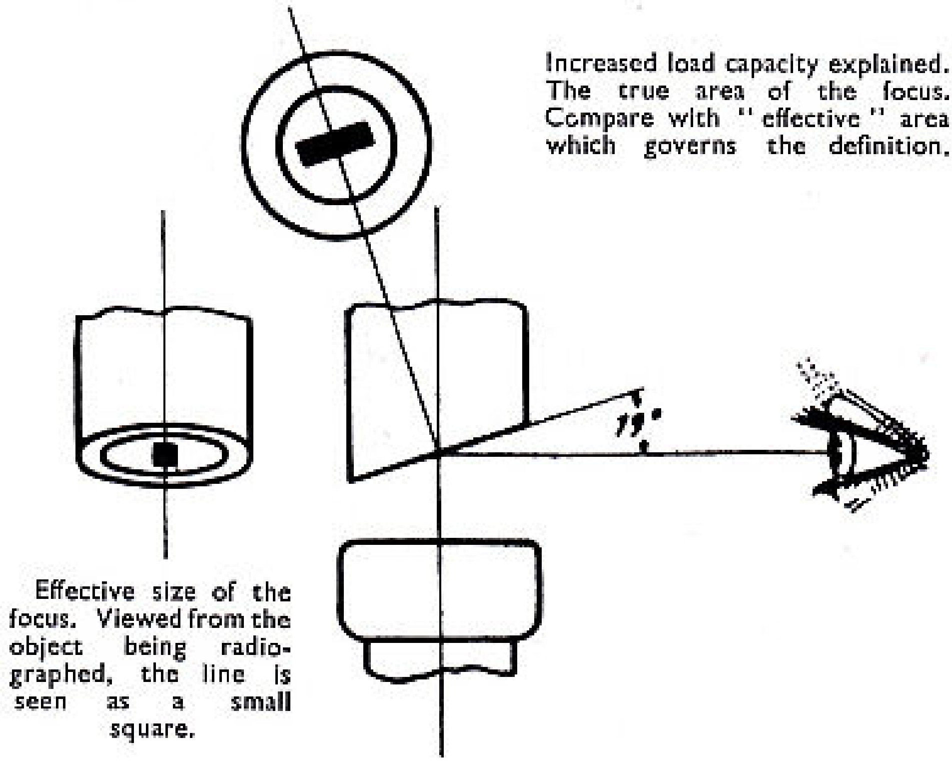

Figure 3.—Showing principle of "Line" focus.

of the tube is limited only by the temperature rise of the target and the efficiency of the method by which the heat is conducted away. With proper design, as for example with a "METALIX" Tube with "line" focus (see Fig. 3), a load of 6 kilowatts may be imposed for one second and even larger loads for shorter periods upon a focal spot having an "effective" area no larger than 3.1 × 3.1 millimetres. Under these conditions, the focal area may normally become incandescent.

When unrectified tension is applied, however, another important factor is introduced. In this case, the anode is alternately positive and negative in relation to the cathode. When it is positive the electrons flow, but when it becomes negative and the cathode positive, no current must pass, otherwise the filament will be bombarded and quickly destroyed (see Fig. 4). When the anode is cold, no electrons

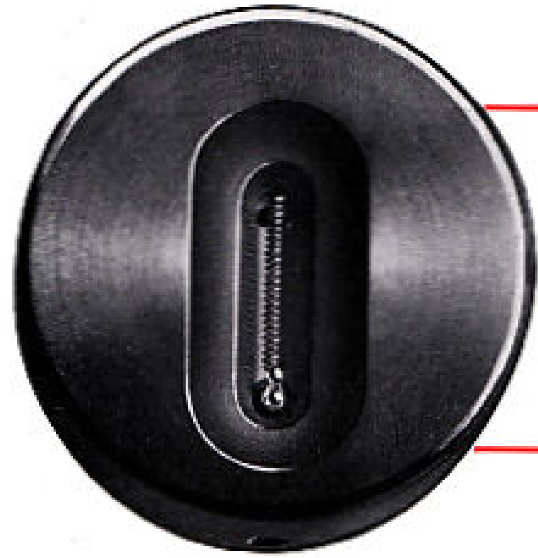

Figure 4.—A striking illustration of destruction of the filament of an X-ray tube by reverse emission. It will be seen that the damage has occurred at the end of the spiral whereas when failure is due to excessive filament current or thinning of the wire by normal usage, the filament fuses at its centre, this being normally the hottest region.

are given off, but when it reaches a certain temperature, the High Tension must be cut off if harm to the tube is to be avoided.

By virtue of this, the load capacity of an X-ray tube on unrectified tension is **not** determined by the maximum temperature which the anode material will withstand. It is in this case, governed by the temperature at which electrons are liberated and current passes in the reverse direction.

For this reason, it is essential when applying unrectified tension to the tube, to exercise rigid control over the applied loads. Separate controls for mA and tension are undesirable under such conditions. By far the best method —and one which was originated by Philips—is the use of controls with a ***fixed*** value of mA for each tension setting. This system has definite advantages, since the Tube can be loaded always at its optimum capacity and, therefore, gives at all times the fullest degree of radiographic definition, without possibility of overloading the Tube.

Nevertheless, there are times when higher loadings are desirable—as for instance, for extra high speed radiography with the "ROTALIX" Tube, etc.—and in these cases and for Therapy above a certain kilovoltage, rectified tension must be applied to the Tube.

TO SUMMARISE

(*a*) The potential applied to an X-ray tube must be sufficiently high to give the required ***velocity*** to the electrons.

(*b*) The filament heating must be adequate to produce the necessary ***quantity*** of electrons.

(*c*) The target material must be capable of withstanding the bombardment and consequent ***heating*** and must be properly dimensioned and in good thermal contact with the body of the anode.

(*d*) The ***cooling*** system must be capable of transporting the heat away from the target and dissipating it into the outer air.

(e) The tube loading must be rigidly controlled when ***unrectified*** tension is used in order that reverse emission due to overheating of the target may be avoided.

(*f*) Rectified tension must be applied if the tube loading is to exceed the value at which reverse emission would occur.

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HIGH TENSION RECTIFICATION

The main object of inserting a rectifier into the H.T. circuit, is, as we have already seen, to eliminate the possibility of reverse emission through the tube and in so doing allow the use of higher loadings. By using a combination of Valves, it is possible to make use of both half waves of single or three phase H.T. supply and by the further application of combining Valves and Condensers, the output tension may be increased to several times that of the H.T. transformer (see circuit arrangements, pages 22-43).

To be of practical use, a Valve must comply with certain essential conditions. It must be capable of withstanding the full pressure of the reverse half wave. It must be adjusted to pass the ***peak*** value of current required by the X-ray tube (this is, in some cases, several times the ***mean*** value indicated by the mA meter in the tube circuit—see pages 44-46), or, where Condensers are used, the peak value of the charging current—and its presence in the circuit should occasion as little loss as possible in the tension applied to the X-ray tube. ***In no circumstances, should the Valve be capable of emitting X-rays.***

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Figure 5.—Philips E.H.T. Rectifying Valve type K.125.

THE GLASS VALVE

Although not the earliest form of Valve, the glass bulb thermionic type, an example of which is illustrated in Fig. 5, was the first to find general application in conjunction with Alternating Current Transformers. This type of Valve is, to a certain extent, similar to a hot cathode X-ray tube, in that it consists of a highly evacuated vessel equipped with two electrodes—an Anode and a Cathode. Its functioning is likewise similar, in that electrons emitted from the filament form a conductive path for the electricity. Whereas in the case of the tube, however, the electrons are purposely made to bridge the gap between the electrodes at high speed and impinge upon the anode with considerable force, they must necessarily travel at minimum speed in the Valve, since X-rays are not required and the temperature of the anode must remain below the figure at which electrons are emitted and reverse emission takes place. In order to overcome, or at least to reduce, the possibility of such an occurrence, Valves of this type are equipped with a large filament and providing this is ***maintained*** at a sufficiently high temperature, a (comparatively) small potential will be sufficient to draw the required quantity of electrons from the filament and thereby provide passage for the energy required for the tube.

Characteristic curves of a Valve of the type illustrated on this page are shown in Fig. 6. It will be seen from the lower curve that with a filament current of 8.0 Amperes about 260 mA. would be passed through the

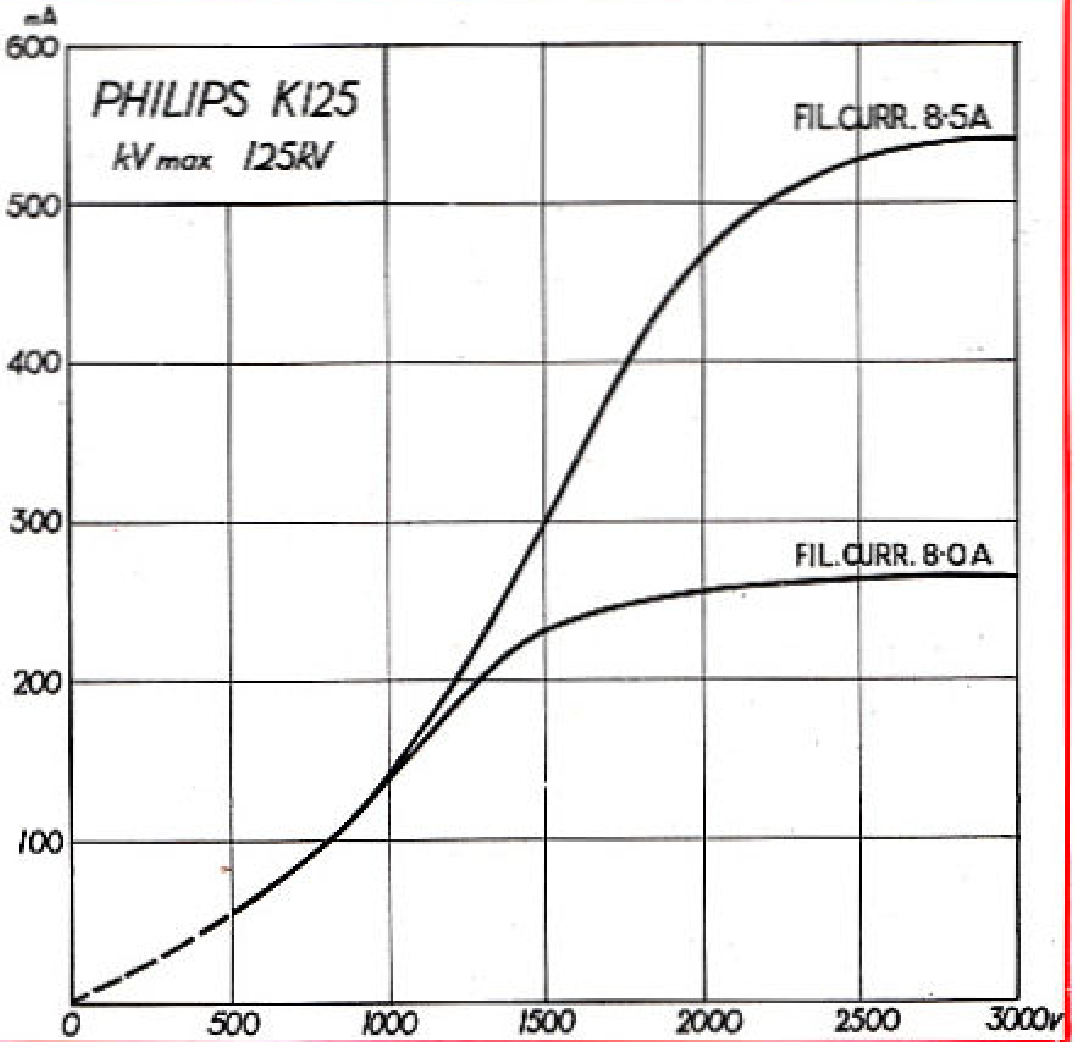

Figure 6.—Curves showing characteristics of a Philips glass Valve type K.125. [1]

Valve by the application of a potential of the order of 2,000 Volts. The curve also shows that an increase in this potential is **not** followed by a similar increase in current, since all electrons are being fully utilised and no more are available. When this point is reached the Valve commences to function as an X-ray tube. However much the tension is increased the current passing through the valve remains unaltered.

[1] The curves shown are not necessarily applicable to all Valves of this type and the rating chart referring to the valve in use, should always be consulted when adjusting filament emission.

This current, having reached a maximum value, would be termed the "saturation" current for the filament current in question, i.e. 8 amperes. If the filament current is increased, however, the "saturation" current is also increased. This can be seen from the upper curve where at 8.5 amperes filament current the "saturation" current is shown as being approximately 540 mA.

Valves must always be operated ***below*** "saturation" current with no greater difference of potential beyond that which is necessary to overcome the "space charge" effect, i.e., for carrying the electrons from the filament to the anode. A higher potential difference serves only to accelerate the speed of the electrons and results, therefore, in excessive heating of the anode and the production of X-rays.

Although popular and in fact still widely used, Valves of this type have certain disadvantages. In the first place, the "saturation value" varies directly with variation of the filament current. If the filament current is set too low, or, as is by no means unusual, a fall occurs owing to drop in the mains voltage when the exposure is made, the volt drop across the Valve will increase. The immediate effect of this is :—

1. The tension delivered to the X-ray tube is lessened, since an increased part of the tension produced by the transformer is lost across the Valve.
2. The velocity of the electrons in the Valve is increased and the anode, therefore, becomes heated to a greater degree.

3. The overheating may cause gassiness of the Valve with consequent premature failure.

4. X-rays may be produced by the Valve.

An additional drawback of the glass bulb Valve is the influence of a strong negative charge which forms on the interior surface of the bulb. This has the effect of increasing the "space charge" effect (mutual repulsion between the electrons) and causes an increase in the volt drop across the Valve. The charge and, therefore, the tension lost across the Valve, is continually varying and the tension which reaches the tube fluctuates in consequence. As the Valve gets older and the interior of the bulb becomes coated with metal thrown off from the electrodes, it takes on a stronger charge and the "space charge" effect is increased.

This characteristic is particularly detrimental where the Valve is used for Therapy, since the tube tension and consequently the X-ray output (the output of radiation from the tube is proportionate to the ***square*** of the kV.) is constantly varying and falls progressively as time goes on. The proportion of depth dose to surface dose also falls with the reduction of tube tension. These losses may pass unnoticed and cause under-dosage if the apparatus is not regularly calibrated and a Dosimeter is not used to measure and integrate the amount of radiation reaching the patient.

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THE METALIX VALVE

Figure 7.—
" METALIX " Valve type M.125.

Many of the drawbacks associated with the glass bulb thermionic Valve, are avoided with the " METALIX " hollow anode type, see fig. 7.

This type, like its predecessor, relies entirely upon electronic emission for the passage of current, but differs from the glass bulb type in that the anode actually forms the discharge chamber (see fig. 8) and encloses the filament in all directions except in that of the insulating stem which supports the filament.

The " METALIX " Valve has several important merits. Firstly, the " space charge " effect is reduced and in consequence the drop in potential across the Valve is small ; secondly, the emission of the Valve is higher (see curves fig. 9) ; thirdly,

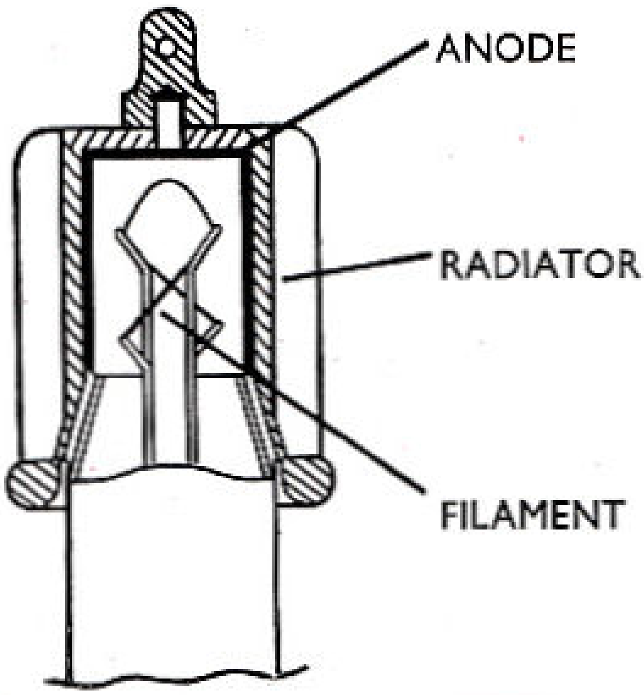

Figure 8.—
" METALIX " Valve
—sectional diagram.

the exterior of the anode is exposed to the outer air and may, therefore, be fitted directly with a radiator for cooling purposes and finally, owing to the metal wall of the discharge chamber being at the same time the anode, a negative charge cannot possibly be formed. The improvement in the latter respect is clearly indicated in fig. 10, which shows the characteristic curve of a " METALIX " Valve as compared with a Valve of the glass bulb type.

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EMISSION CHARACTERISTICS

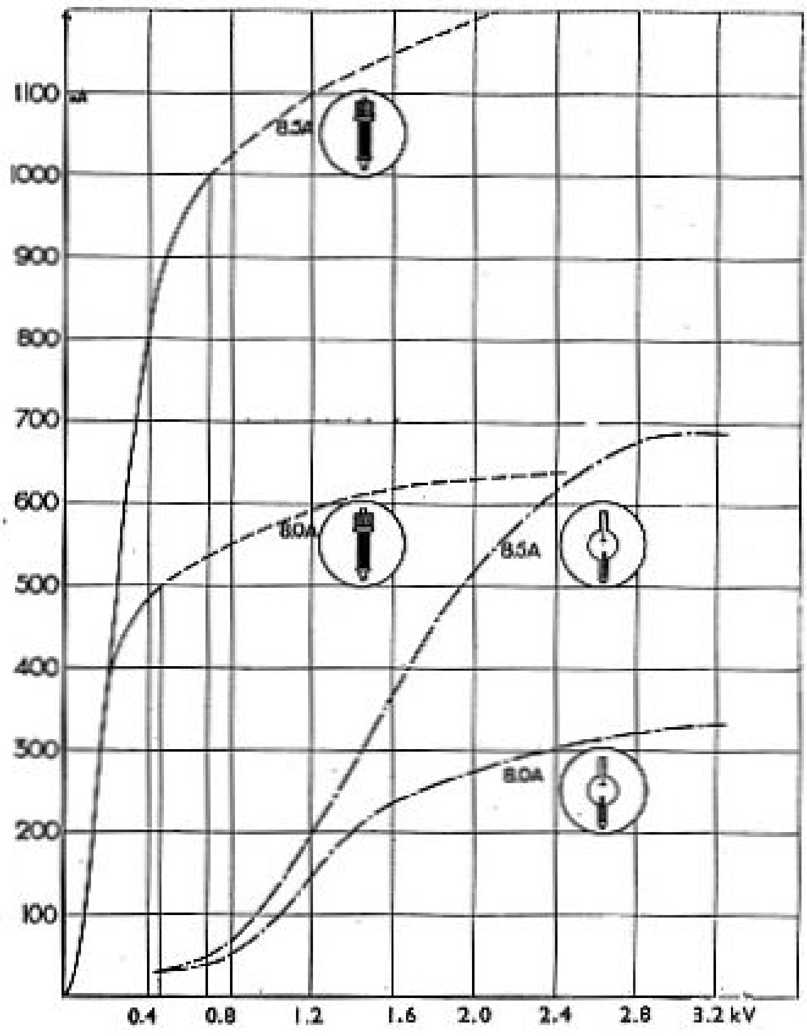

Figure 9.—These curves show the characteristics of "METALIX" Valve type M.125/1000 as compared with a glass valve for the same filament current. The measurements were made on D.C. As a valve must always be operated below "saturation" current, the increase in efficiency which follows the use of the "METALIX" valve will at once be apparent.

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GLASS WALL EFFECT

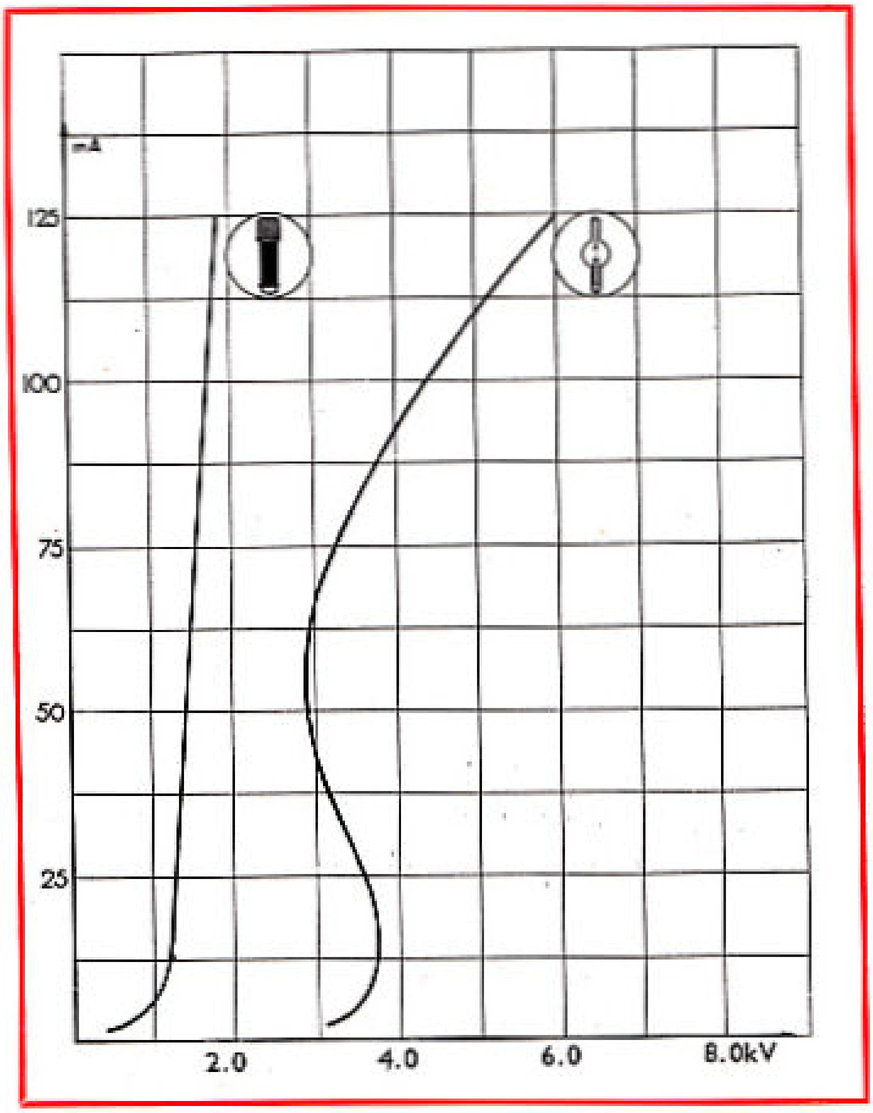

Figure 10. — In the above curves the current-voltage characteristic of "METALIX" Valves equipped with metal discharge chamber and glass valves (diagnostic) are again effectively compared. Note in the case of the glass valve the effect of the negative charge on the interior of the bulb.

The measurements were made under X-ray load conditions and with both valves in series. Each valve was designed to withstand the same tension. It will be seen, that with increasing anode current the volt-drop across the glass valve becomes extremely detrimental.

Figure 11.—Exterior view of the PHILIPS Type G.125 Gasfilled Rectifying Valve showing moulded Philite Condensers which encircle the discharge unit.

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THE PHILIPS GASFILLED VALVE

Despite the improvement effected by the hollow anode construction of the "METALIX" Valve, the purely electronic valve still possesses the drawback of complete dependence of emission upon correct and unvarying filament heating.

This deficiency is completely overcome with PHILIPS' Gasfilled Valves (see figs. 11 - 13). Unlike ordinary (electronic) types, the passage of current is, in these new Valves, brought about by "collision ionisation" of a low pressure gas filling. The ionised condition results from bombardment of the gas molecules by electrons emitted from a small subsidiary dull emitter filament. Bombardment of the gas and, therefore, the passage of current through the Valve occurs during one half cycle only. During the reverse half cycle, the gas is non-conducting since the electrons adhere to the filament and ionisation of the gas does not occur.

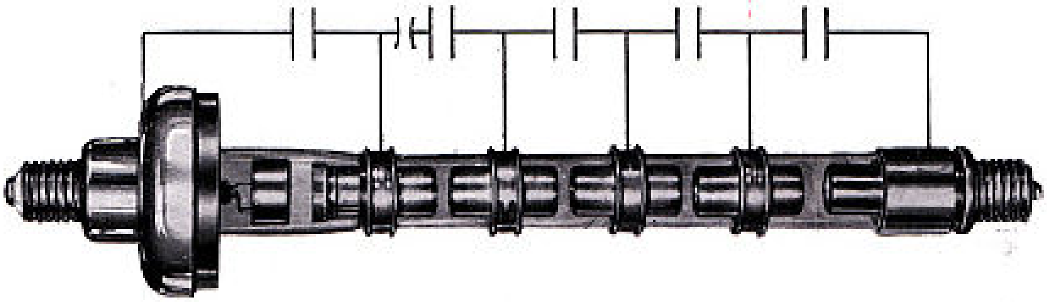

Figure 12.—Interior discharge unit of the PHILIPS G125 Gasfilled Rectifying Valve.

This system has the advantage of making the instantaneous current almost entirely independent of variations in filament heating. Once the gas is sufficiently ionised, any quantity of current will pass. Even when the filament current falls considerably, the current carrying capacity of the Valve is maintained for a sufficient period owing to the construction of the Valve and to high thermal lag in the oxide coated dull emitter filament. The possibility of a sudden increase in the volt drop across the Valve during short heavy current exposures is exceedingly remote.

Hollow intermediate conductors, situated at intervals along the interior of the discharge tube (see fig. 12) are interconnected by condensers which encircle the unit (as shown in figs. 11 and 13) and perform the function of distributing the potential by equal stages along the length of the Valve. The risk of puncture—which in an ordinary Valve is due to excessive tension stress at one point on the glass wall—is thereby reduced to a minimum.

A further advantage of the PHILIPS' Gasfilled Valve is that the volt drop across it remains constant at a figure of the order of 50 volts only, irrespective of the emission

Figure 13.—The Philips type G.160 Gasfilled valve for tensions up to 160 kVp and for therapy.

current. At full emission therefore (the G125 and G160 types are each rated to carry 1,000 mA.) the energy dissipated is in the region of 50 watts—a fraction of that with even a "METALIX" Valve. No provision is necessary, therefore, for cooling the anode.

To summarize, the Gasfilled Valve is the ideal type for any equipment and possesses none of the inherent deficiencies of the electronic type. Although capable of very high emission, the energy dissipated in the Valve is so low that cooling is entirely unnecessary for normal purposes. Its emission is unaffected even by violent mains fluctuations. Filament compensating devices are dispensed with entirely. Tension losses across the Valve are minimized and remain virtually constant at all loadings from Screening to Radiography at maximum emission and for Therapy. The puncture risk is reduced.

The colossal wastage of energy involved in the production of X-rays, is lessened by this important new development. By the simple addition of a Gasfilled Valve, the efficiency of any unit, even if working under the worst conditions, can be materially improved.

Figure 14.— H. T. Transformer-valve unit of the Philips Quatralix Apparatus showing arrangement of the Phillips Gas-filled Valves.

The following pages contain useful diagrams of the circuits more usually employed for X-ray purposes. Theoretical wave forms of tube tension are shown in each case. The additional oscillograms of current wave form with "METALIX" "grid action" therapy tubes will be found of particular interest. The lately developed circuit of the Philips' 400 kV. generator—which has the merit of being easily extended for much higher tensions if desired—is an important example of improved practice made possible by the Philips' Gasfilled Rectifying Valve.

THE SINGLE VALVE RECTIFIER

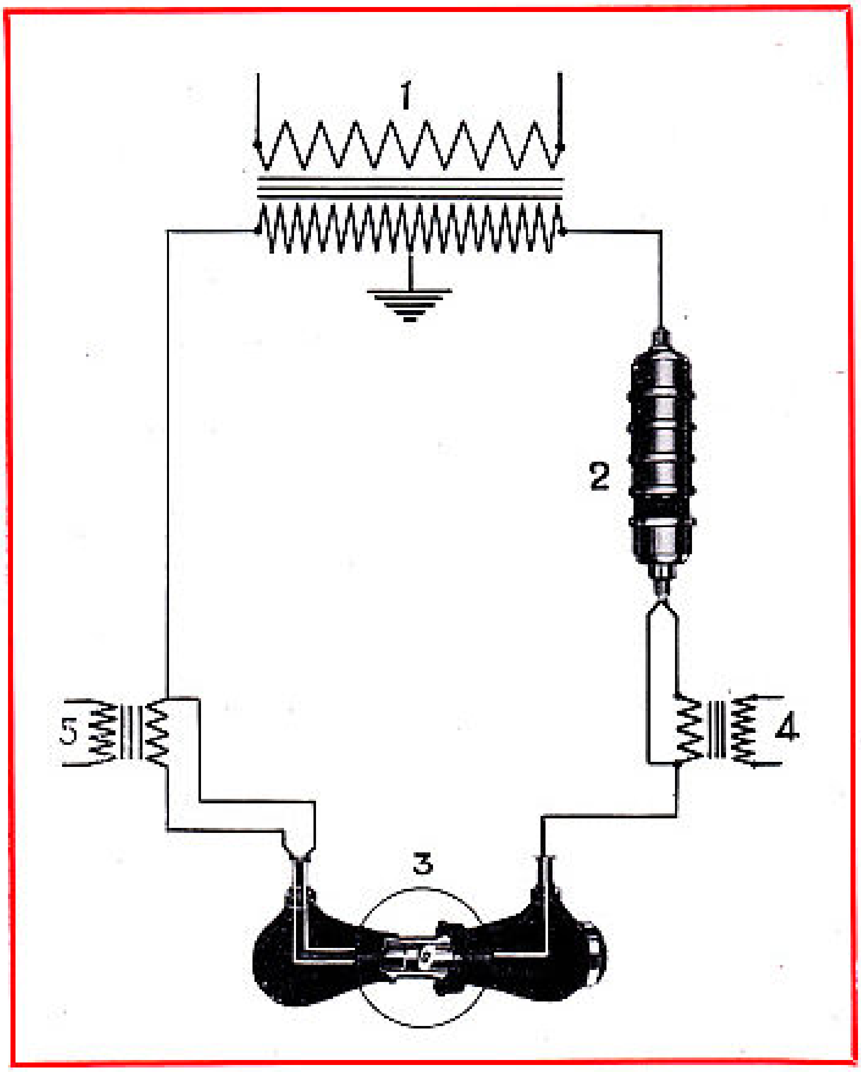

Figure 15.—Half-wave Circuit.

1. High Tension Transformer.
2. Valve.
3. X-ray Tube.
4. Filament transformer for Valve.
5. Filament transformer for X-ray tube.

Half-Wave Rectification.—In this circuit a single valve is connected in series with the X-ray tube and completely suppresses one half-wave of the Alternating Current. Circuit details are shown in fig. 15. Under these conditions, the tube (to which in unrectified transformer units the Alternating tension is directly applied) has no longer to function as its own Valve.

The theoretical wave form of tension is shown in fig. 16. Alternate half-cycles of tension reach the tube whilst the half-cycles of reverse polarity are held back by the Valve. When using Shockproof tubes with apparatus of this type, the Gasfilled Valve should always be specified. Unbalancing of the high tension so far as it is due to the Valve is thereby reduced to a minimum.

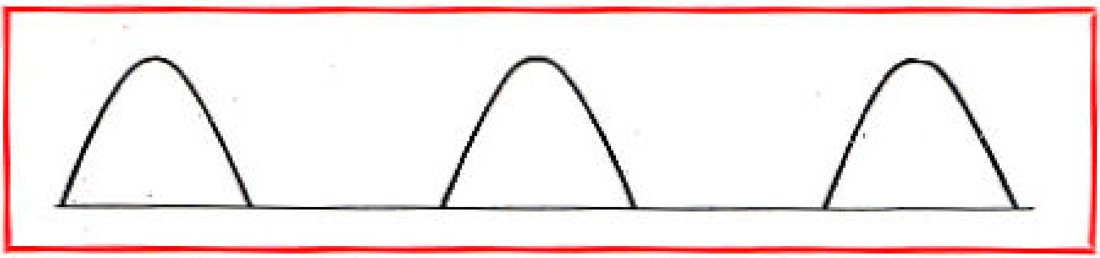

Figure 16.—Theoretical wave form of tension across the tube with 1 Valve apparatus.

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THE FOUR VALVE CIRCUIT

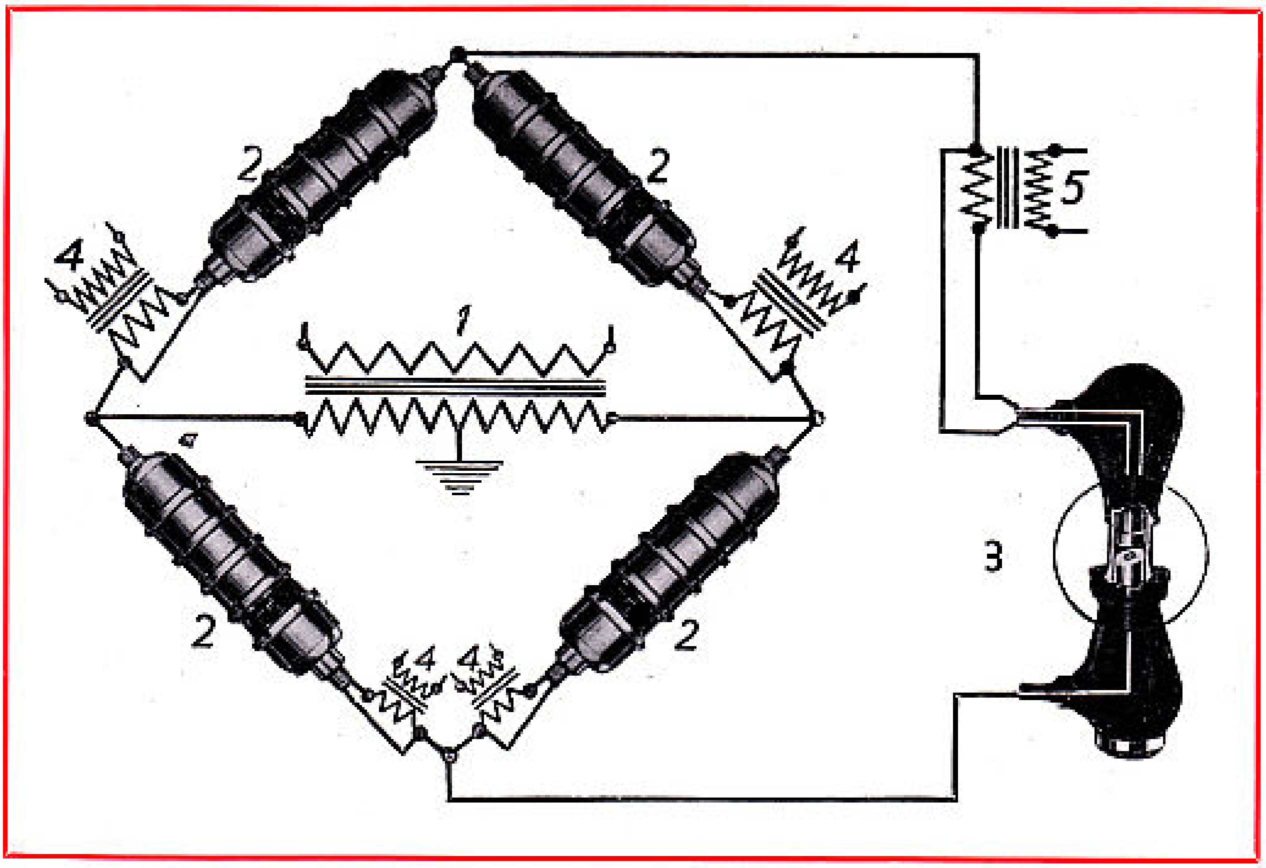

Figure. 17.—Grätz Circuit.

1. High Tension Transformer.
2. Valves.
3. X-ray tube.
4. Filament transformers for Valves.
5. Filament transformer for X-ray tube.

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Full-Wave Rectification.—The four Valve rectifier first described by Grätz, is the most common of all rectification circuits. As may be gathered from fig. 17, each end of the secondary winding of the transformer is connected with two valves arranged in reverse directions, so that both half waves of the Alternating Current and the output of the transformer, are fully utilised. This circuit is generally used for radiographic work.

Since high loads are invariably used with four Valve apparatus, the high emission characteristics and low volt drop of the Gasfilled Valve, make it particularly suitable for inclusion in such equipment.

The theoretical wave form of tension is shown in fig. 18.

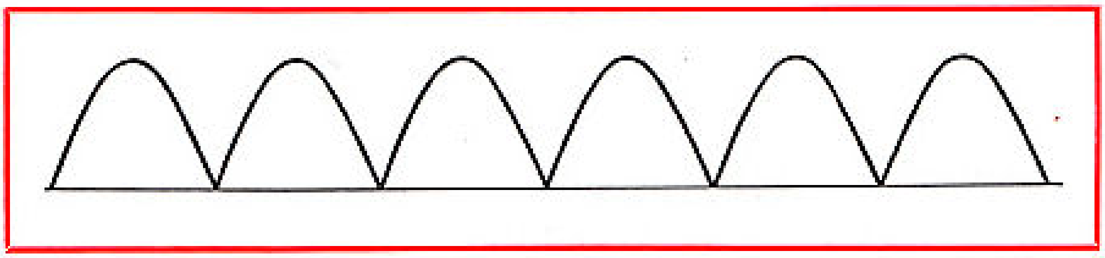

Figure 18.—Theoretical wave form of tension across the tube with 4 Valve apparatus.

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THE SIX VALVE CIRCUIT

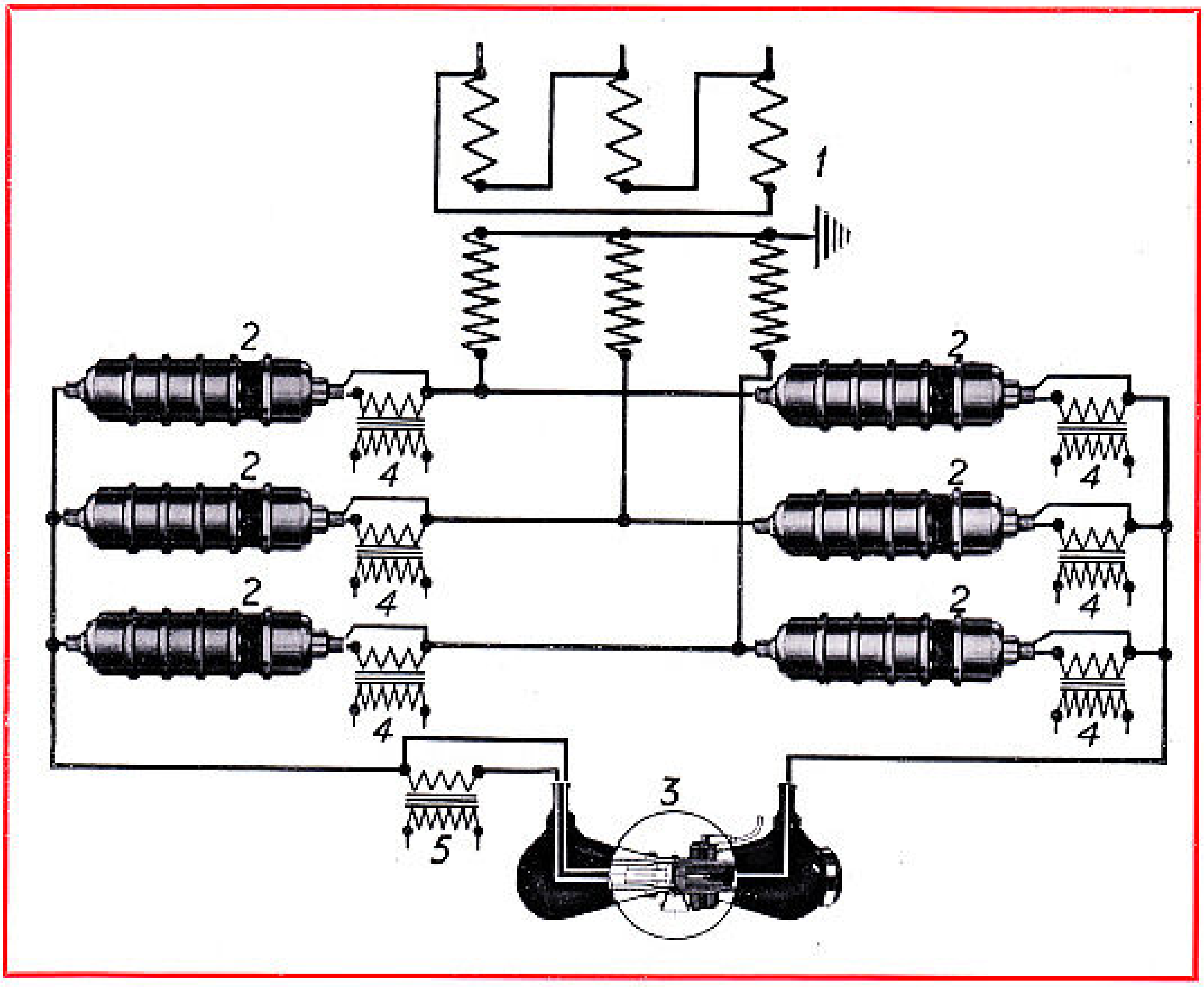

Figure 19.—Three-Phase Rectification.

1. Three-phase high tension transformer.
2. Valves.
3. " ROTALIX " Tube.
4. Filament transformers for Valves.
5. Filament transformer for X-ray tube.

Three-phase Rectification.—For diagnostic work with very heavy outputs. A circuit of this nature gives almost constant potential. The fluctuation under favourable load conditions is not more than a few per cent. of the effective mean value, but requires six Valves for rectification. For energy inputs of 20 to 30 kW. such as are possible with the " ROTALIX " Tubes (rotating anode), this is a highly efficient circuit. Circuit details are given in fig. 19 and tension wave form in fig. 20.

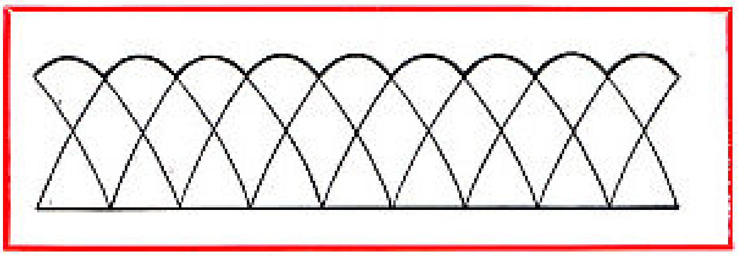

Figure 20.—Theoretical wave form of tension across the tube with 6 Valve apparatus under favourable load conditions.

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THE VILLARD CIRCUIT

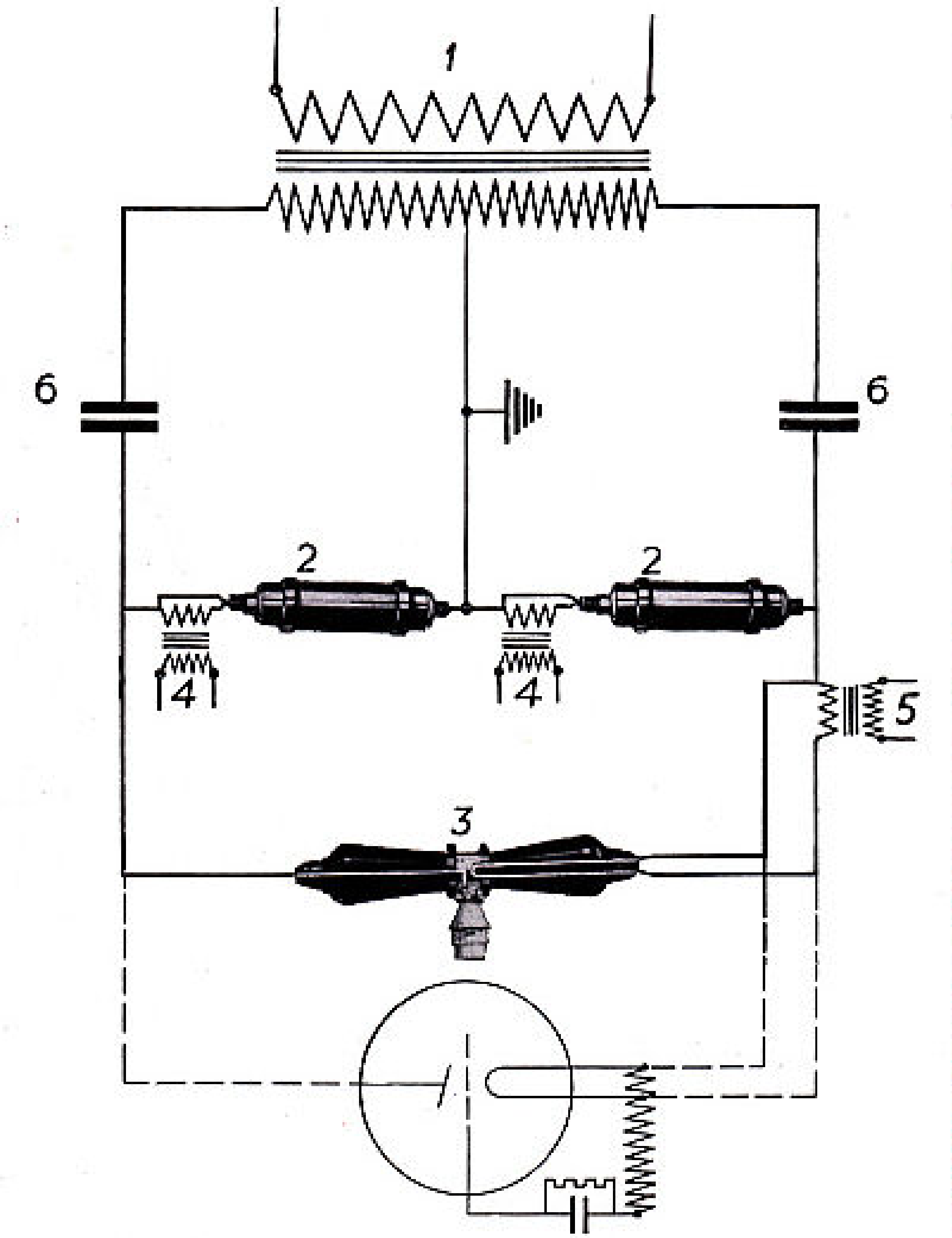

Figure 21.—Villard Circuit.

1. High Tension transformer.
2. Valves (type G160).
3. X-ray tube.
4. Filament transformers for Valves.
5. Filament transformer for X-ray tube.
6. Condensers.

(The lower part of the diagram, joined to the main circuit by dotted lines, illustrates the theoretical arrangement of the three electrodes and biassing system of "METALIX" 'grid action' therapy tubes).

Pulsating Tension.—Widely used for Therapy, a circuit due to Villard also employs Valve rectification. By making use of condensers and two Valves connected in a reverse direction to that of the X-ray tube (see fig. 21), the tube tension becomes double that of the H.T. transformer.

The ends of the secondary winding of the high tension transformer are each connected to one terminal of a condenser, the other terminals of the condensers being connected with the Valves and the X-ray tube. During one half-cycle the current can pass through the valves. Since the two inner terminals of the condensers are connected together via the Valves, the condensers are each charged up to half the potential of the transformer. During

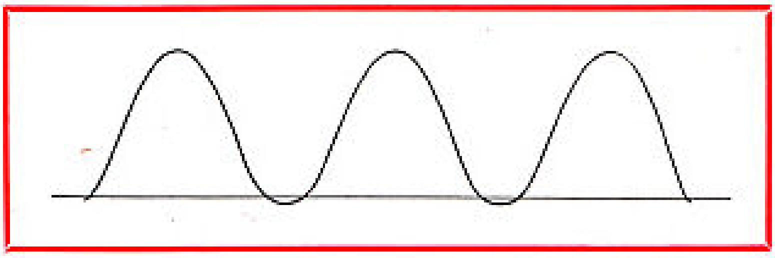

Figure 22.—Theoretical wave form of tension across tube with apparatus in Villard Connection.

the following half-cycle, however, when the transformer tension changes polarity, both the condensers and the transformer are in series and the current, with a voltage reaching approximately twice that of the transformer,

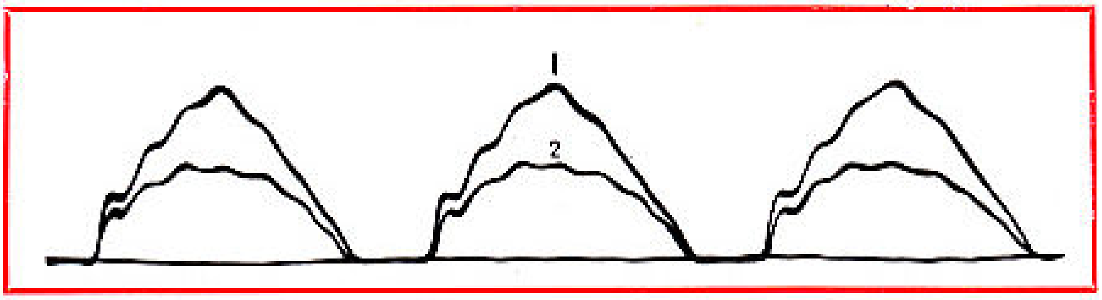

Figure 23.—Oscillograms of wave forms with ordinary " METALIX " Tube.
2. Current passing through tube.
1. Tension across tube.

passes through the X-ray tube. Whilst in this direction it cannot pass through the Valves.

The Villard circuit originally employed only one Valve, but later practice has proved the desirability of connecting two valves in series, with the mid point earthed, as shown in the circuit diagram. This arrangement plus the usual earthing of the centre of the secondary ensures balanced potential and makes the system suitable for use with shock-proof tubes.

The theoretical wave form of tension across the tube is shown in fig. 22; and figs. 23 and 24 are reproductions of actual oscillograms of tension and current waves with two electrode (ordinary type) and three electrode (" METALIX " " grid action ") therapy tubes. Note with the grid tube the much higher peak value of current which passes through the tube coincident with the peak of the tension wave.

This change in current wave form—the mean milliamperage as shown by the mA meter is the same in each case—brings about an increase of almost 100 per cent. in X-ray output.

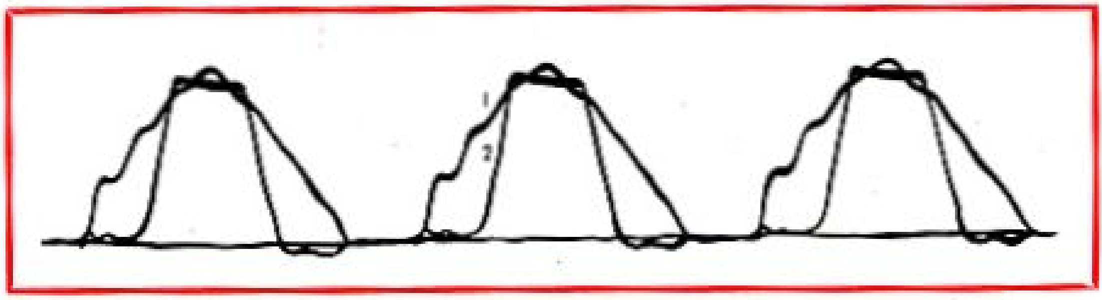

Figure 24.—Oscillograms of wave form with "METALIX" 'grid action' therapy tube, working on apparatus in Villard connection.

1. Tension across tube.
2. Current passing through tube.

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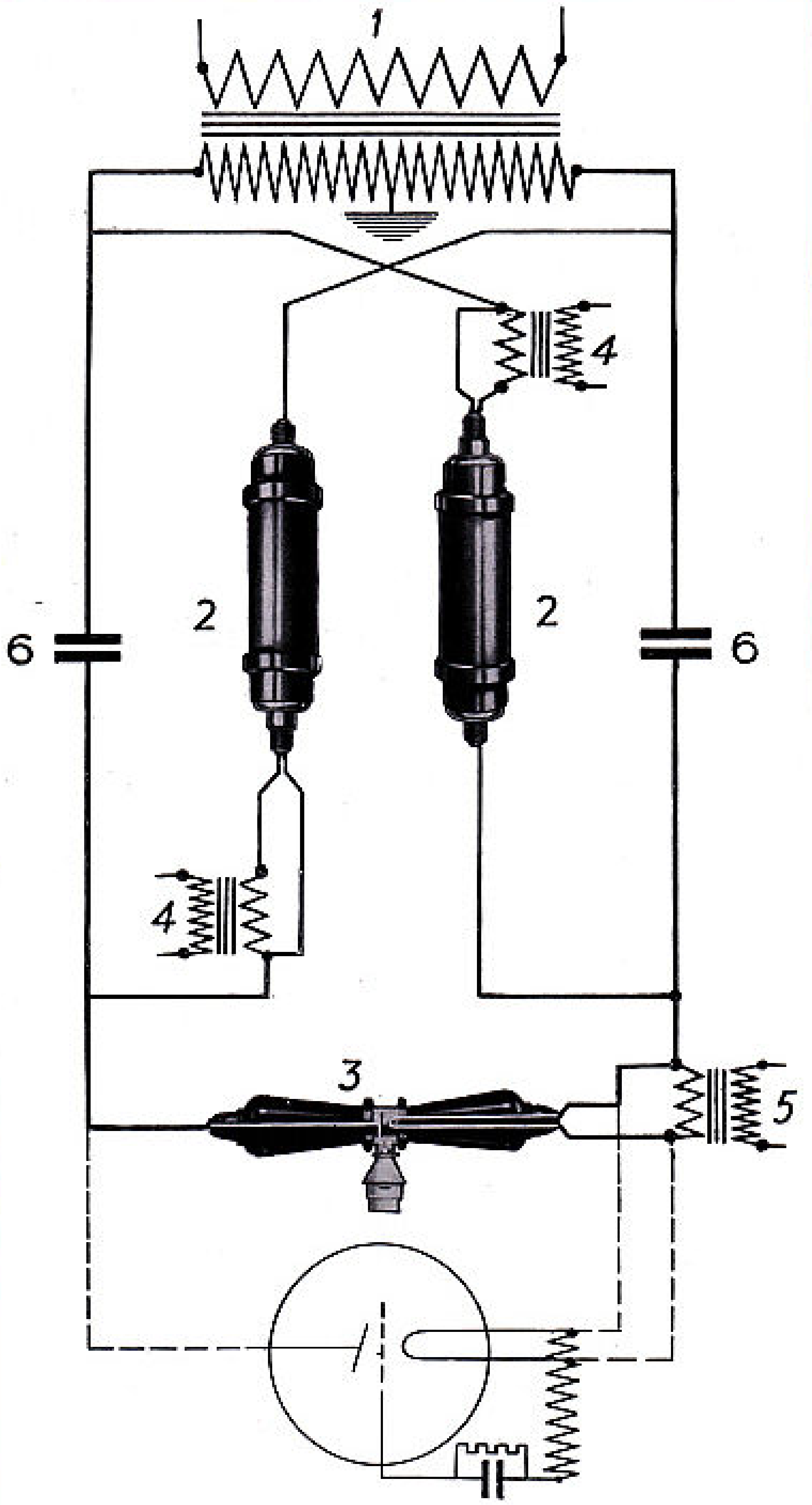

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THE WITKA CIRCUIT

Figure 25.—Witka Circuit.
1. High Tension Transformer.
2. Valves (type G160).
3. X-ray tube.
4. Filament transformers for Valves.
5. Filament transformer for X-ray tube.
6. Condensers.

(The lower part of the circuit diagram again illustrates the arrangement of a "METALIX" three electrode tube).

Pulsating Tension.—Another circuit for therapy, and one with which the tension wave form is particularly favourable for extra high voltage tubes, is that evolved by the Russian engineer, Witka (fig. 25). In a sense this arrangement is a modified form of the Villard circuit, differing in that each pole of the high tension transformer is connected through a valve and condenser to the other pole of the transformer, so that each condenser is charged with the ***full*** transformer tension.

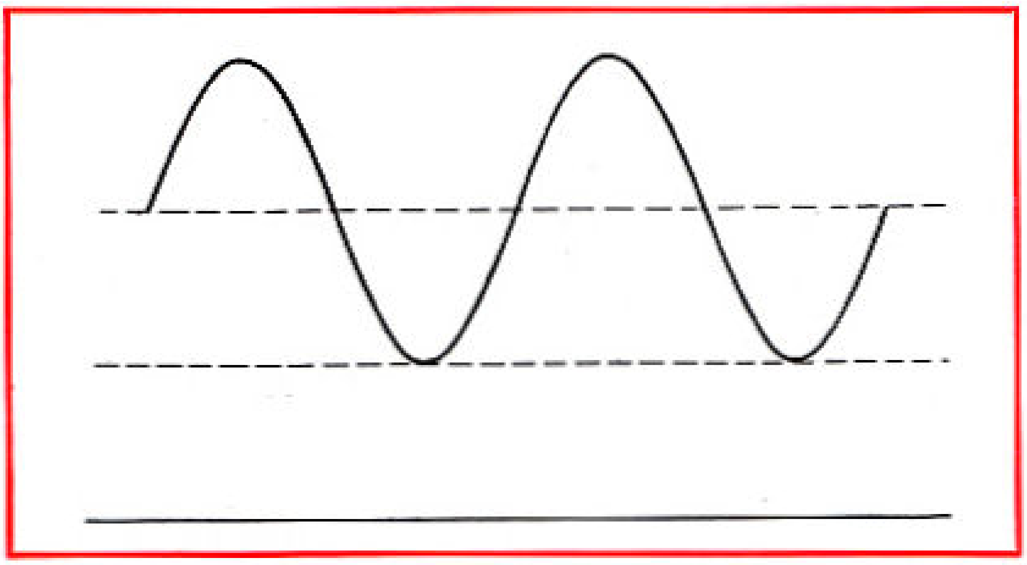

Figure 26.—Theoretical wave form of tube tension with apparatus in Witka connection.

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In the second half period, both condensers, as with the Villard circuit, are in series with the transformer and the tension impressed upon the tube is, therefore, ***three times*** that of the transformer. During operation the tension

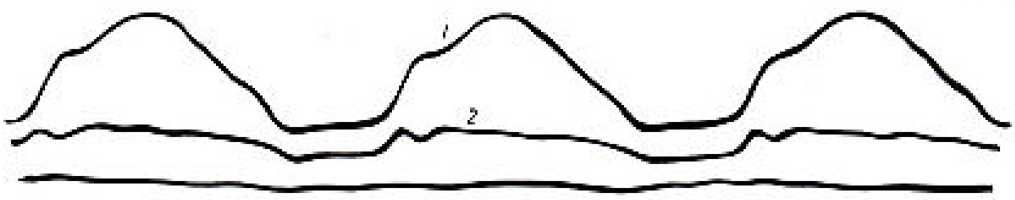

Figure 27.—Oscillograms of wave forms with ordinary tube working on apparatus in Witka connection.

1. Tension across tube.
2. Current passing through tube.

across the tube does not fall to zero but only to the single transformer voltage, as during the charging of the condensers the tube is in parallel with them. (See theoretical wave form, fig. 26.) An important feature of this circuit is the fact that the valves have only to suppress double the transformer tension, whereas the X-ray tube is fed with three times this tension. Oscillograms of tension and

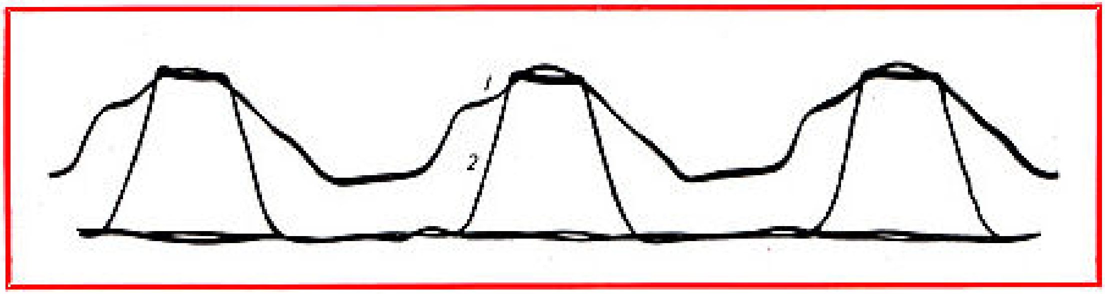

Figure 28.—Oscillograms of wave forms with "METALIX" 'grid action' therapy tube working on apparatus in Witka connection.

1. Tension across tube.
2. Current passing through tube.

current waves with apparatus in Witka connection, using ordinary and "METALIX" "grid action" tubes are reproduced in Figs. 27 and 28.

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THE GREINACHER CIRCUIT

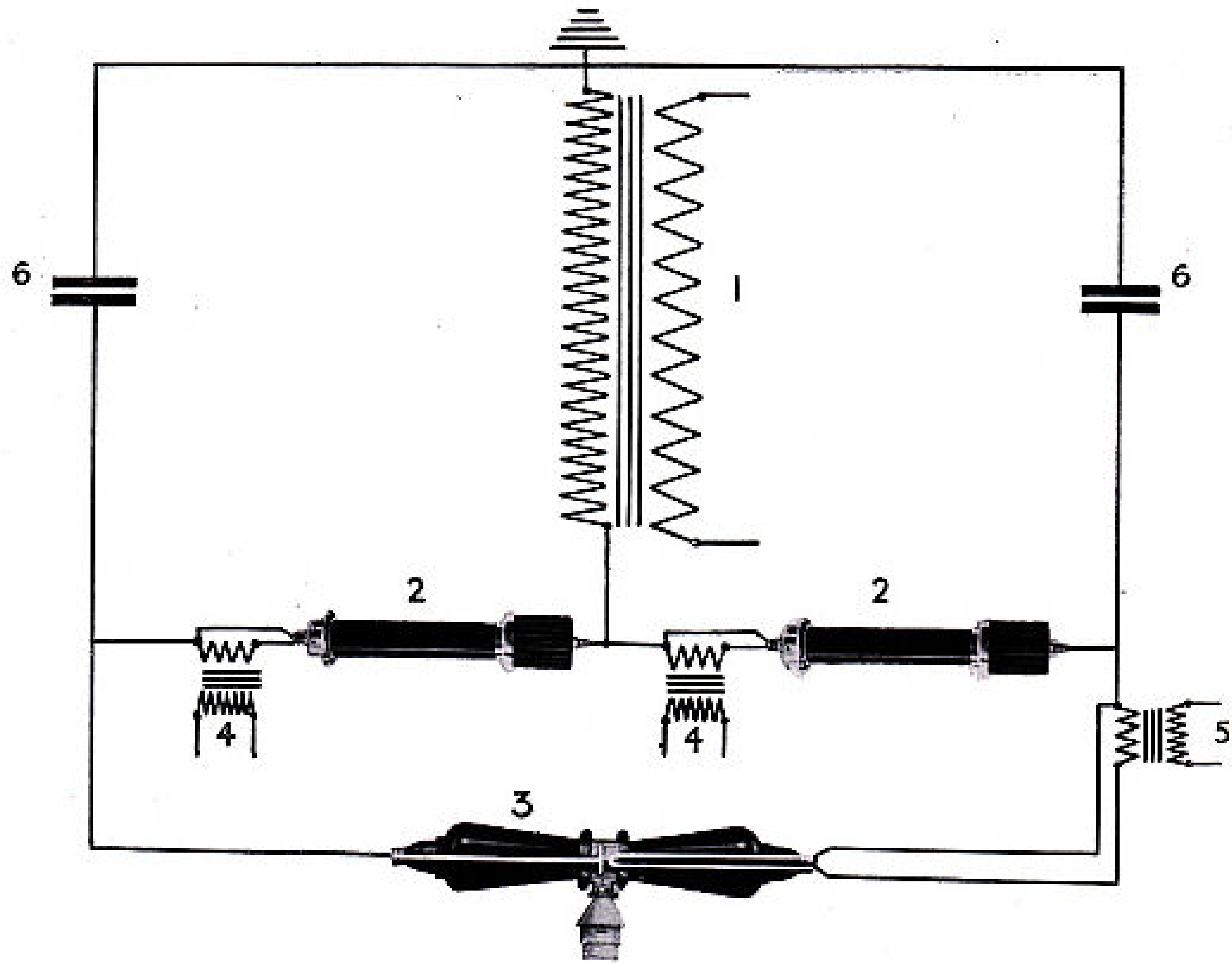

Figure 29.—Greinacher Circuit.

1. High Tension Transformer.
2. Valves.
3. X-ray tube.
4. Filament transformers for valves.
5. Filament transformer for X-ray tube.
6. Condensers.

Constant Tension.—By means of the Greinacher circuit (fig. 29) twice the transformer peak tension is applied to the X-ray tube. The tension wave form is very smooth and the tube is fed with continuous current at almost continuous voltage (fig. 30.) Two condensers are used, each being charged to the full potential of the transformer during alternate half cycles. The two condensers in series discharge through the X-ray tube. The valves in this circuit are called upon to withstand ***twice*** the transformer tension, i.e., the same tension as is applied to the tube.

This circuit has been widely adopted for deep therapy, but is now less popular, owing to the introduction by Philip's of the " METALIX " three electrode tube, which, on the less costly pulsating tension apparatus, gives an X-ray output almost equivalent to that obtained with constant tension equipment.

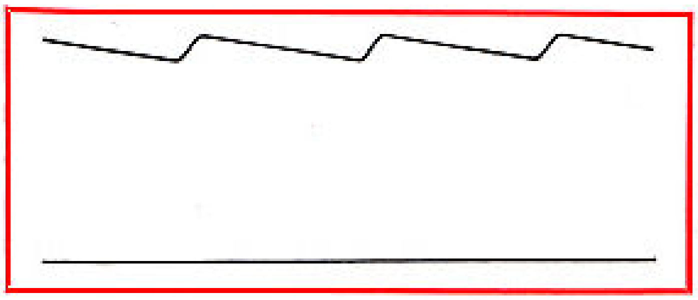

Figure 30.—Theoretical wave form of tension across tube with apparatus in Greinacher connection. The amount of ripple varies with the load.

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CIRCUIT FOR EXTRA HIGH TENSION

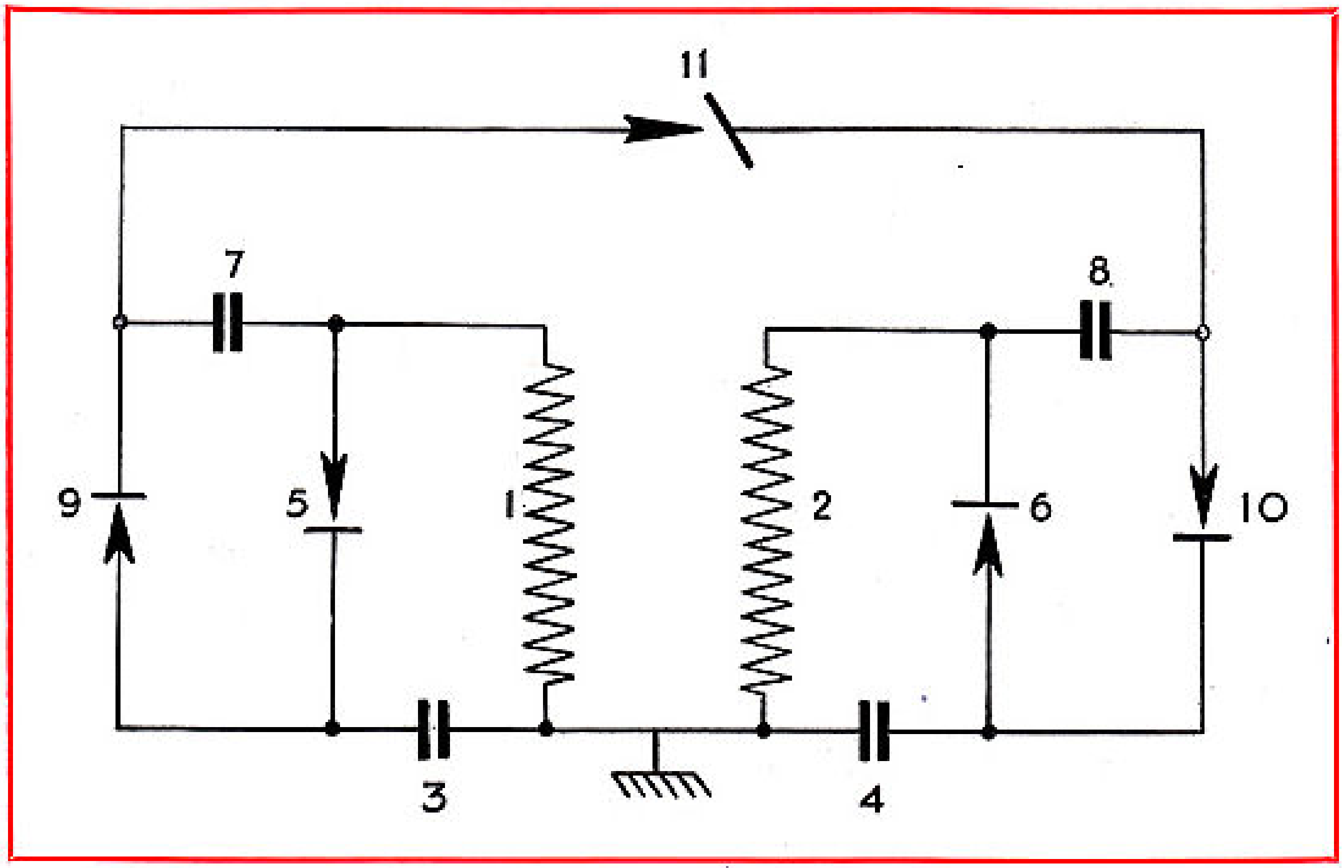

Figure 31.—Circuit of Philips 400 kV apparatus

1 and 2. H.T. Transformers.
3, 4, 7 and 8. Condensers.
5, 6, 9 and 10. Valves.
11. X-ray tube.

Although some of the circuits previously mentioned may be used for the production of extra high tensions, many drawbacks exist in their practical application, not least among which are problems of insulation and the necessity for valves capable of withstanding the high reverse pressures thereby involved. Two or more units may be connected in series—this is often done in practice and obviates the necessity for abnormally large valves—but here again the transformers may require to be cascaded to obtain the required insulation whilst the space necessary to accommodate such apparatus is not inconsiderable.

A circuit which in its practical application may be extended without difficulty to give almost unlimited tension is shown in fig. 31. This circuit—it is the one on which the Philips' 400 kV. Generator is based—necessitates using only two small transformers, each with one pole earthed, the tension from which is multiplied by condensers and impressed upon the X-ray tube in the following manner :—

During the first half-cycle, when the tension at the terminals of the transformers is of suitable polarity, condenser 3 is charged up via valve 5 to the potential of transformer 1, and simultaneously condenser 4 is charged by transformer 2 via valve 6. In the second half-cycle, when the tension of the transformers changes polarity, valves 9 and 10 (which during the previous half-cycle opposed the flow of current) now permit current to pass and condensers 7 and 8 each become charged to a potential twice that of one transformer. (On the one side condenser 7 is charged via valve 9 by transformer 1 in series with condenser 3 : and on the other side, condenser 8 is charged by transformer 2 in series with condenser 4 via valve 10.)

This ends what may be considered as (for explanatory purposes) the initial condenser charging period and when the next half-cycle is reached, i.e., when the polarity of the transformers is again reversed, condensers 7 and 8 in series with the two transformers impress a tension equal to ***six times*** that of one transformer upon the tube. At the same time, the cycle of operations is recommenced, condensers 3 and 4 being recharged via valves 5 and 6 respectively.

During the following half-cycle (while condensers 7 and 8 are being recharged), the tension across the tube falls to approximately one-third of the value it attained during the previous half period. This is due to the change of polarity of the transformers which are now opposed to the tension of condensers 7 and 8 in the output circuit.

The tension delivered to the tube is thus pulsating in character, fluctuating between one-third and full tension as with the Witka circuit (see fig. 26). It is likewise symmetrically distributed in relation to earth, by grounding of the mid point of the H.T. system. When it is desired to extend the apparatus for higher tension this is achieved by simply adding valve and condenser units to each end of the circuit and transferring the tube connections. In actual practice this is done by adding further condensers and valves to the tops of the condenser columns.

The arrangement of the Philips 400 kV. apparatus is shown in fig. 32. The two small transformers can be seen between the condenser columns which also carry the type G160 Gasfilled Valves. The whole unit occupies a floor space only 12 ft. $\times$ 4 ft.

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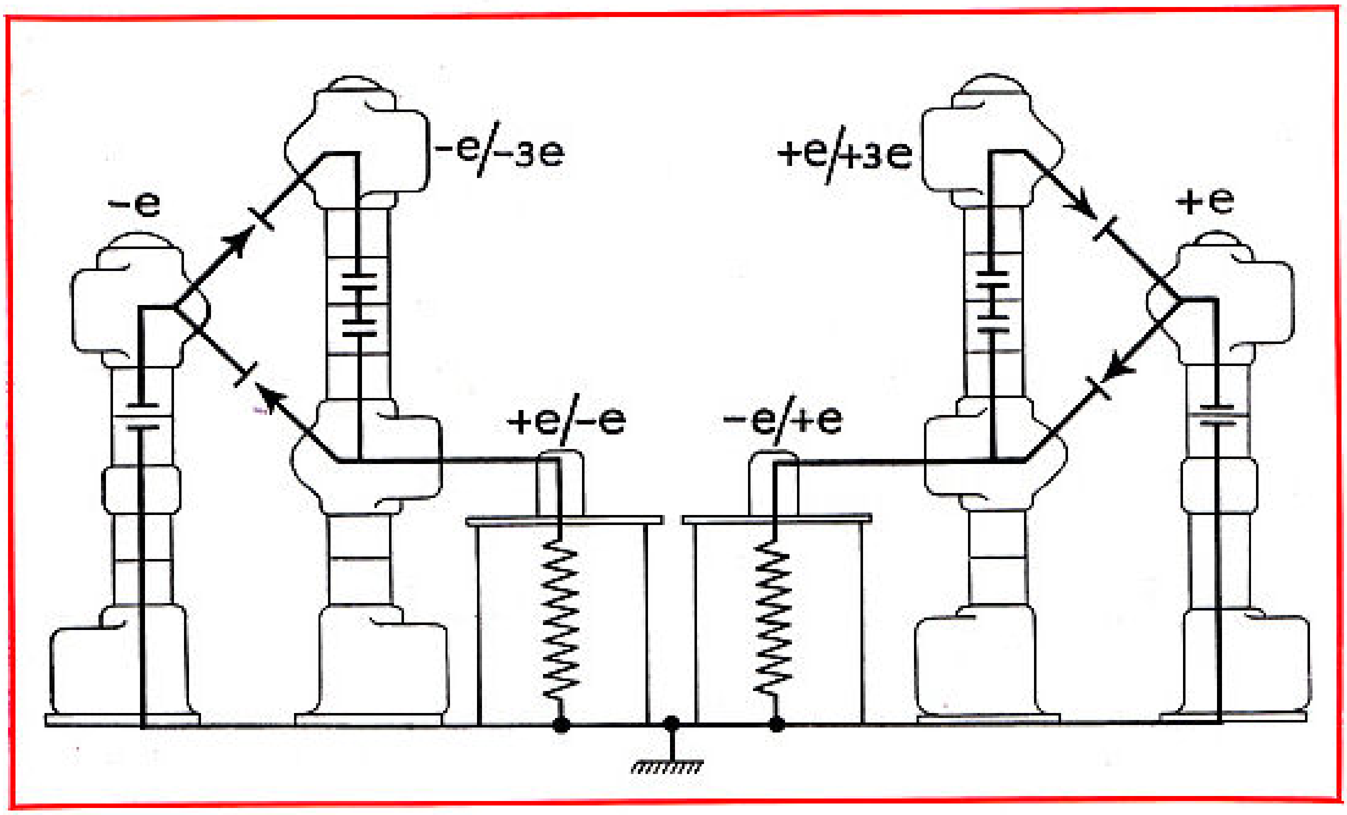

Figure 32.—Theoretical arrangement of the Philips H.T. generator for 400 kV. An increase in output tension is achieved by adding further condensers and valves to the tops of the condenser columns.

"MEAN" AND "PEAK" CURRENT

With the majority of the circuits previously described, the high tension current passing through the X-ray tube is of a pulsating nature, i.e., it fluctuates continuously during the exposure between certain minimum and maximum values, determined by the characteristics of the equipment in use.

To illustrate this, we might perhaps refer back, as an example, to the curve of tension wave form with one valve apparatus (fig. 16). The tension, as has already been explained, reaches the tube during one half cycle only and during the reverse half cycle is suppressed by the valve. It is obvious that the current also will pass during one half cycle only, coincident with the tension and no current at all will be delivered to the tube during the period of reverse tension.

With our example of one-valve apparatus, therefore, the tube current, instead of flowing at a steady rate is actually passing in the form of a series of impulses each separated by an interval corresponding to the period when the transformer tension is reversed. The characteristics of the tube used also have a bearing on the manner in which the current flows, as will be seen to a marked extent in the oscillograms of current with "METALIX" "grid action" tubes.

The pointer of the mA. meter in the tube circuit, however, is incapable of reacting to the fluctuation—which occurs at a very rapid rate—and it assumes instead, a mean position somewhere between the minimum and maximum value. (See fig. 33.)

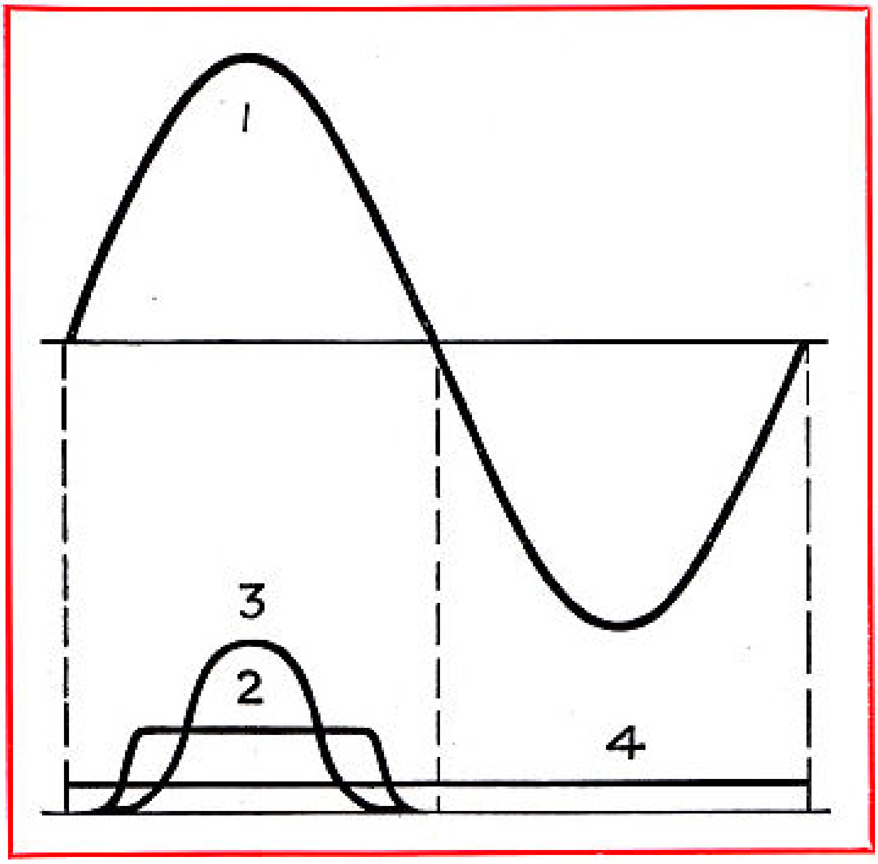

Figure 33.— 1. Potential wave form H.T. transformer.

2. Current wave form— hot cathode X-ray tube.

3. Current wave form— 'grid action' X-ray tube.

4. **Mean** value of curves 2 or 3, as indicated by milliampere meter in tube circuit.

From the radiographic or therapeutic point of view, the ***mean*** reading given by the mA. meter is sufficient as an indication of tube current.[1] When adjusting the emission of an electronic valve, however, it is important to remember that the supply of electrons in the valve must be sufficient to allow passage of the maximum or ***peak*** current.

The following rules should, therefore, be observed when adjusting the filament heating of valves of the ***electronic*** type. (With gasfilled valves any emission from minimum to maximum is obtained with the one filament setting. These rules may, therefore, be disregarded when gasfilled valves are used.)

1. Even this is misleading as an indication of radiographic ***value*** since with a "grid action" tube the X-ray output is much greater than with an ordinary tube for the same mean mA.

RULES FOR ADJUSTING FILAMENT HEATING

Single-Valve Apparatus. For this type of plant (with an ordinary tube) the filament heating must be adjusted so that the saturation current of the valve is at least three times that of the mean current through the X-ray tube as indicated by the milliammeter in the tube circuit.

Four-Valve Apparatus. The saturation current of each Valve must be set to a value at least 1.5 times the X-ray tube current as indicated by the milliammeter.

Six-Valve Apparatus. With 3-phase plants the maximum momentary value of the current is practically the same as that of the X-ray tube as indicated by the milliammeter.

Condenser Apparatus for Therapy. The maximum momentary value of the valve current is not only dependent on the X-ray tube current, but also on two additional factors : (1) The output of the high tension transformer (short circuit characteristics) ; (2) The capacity of the condensers.

With the usual types of deep therapy condenser plant, the valve emission should be adjusted to a figure at least twenty times that of the X-ray tube current.

Should the filament of an electronic valve be heated unnecessarily high, its life and, therefore, that of the valve is shortened to a considerable extent. On the other hand, if the filament is underheated, the valve is made to function as a power limiting device which may result in immediate breakdown. ***This difficulty is completely overcome by using Philips Gasfilled Rectifying Valves.***