The Limits and Achievements of Modern X-Ray Tube Constructions

By H. B. G. Casimir and W. J. Oosterkamp, Eindhoven

§ 1. *Introduction*

Looking back over the development of X-rays from the moment of Roentgen's fundamental discovery to the present, one fact is immediately obvious:

The generation of X-rays still bases on the same physical mechanism i. e. the bombardment of solid matter by high speed electrons. In the field of light sources we have, during these years experienced the change from gas lights to the electric incandescent lamp and to gas discharge tubes. With X-rays on the other hand it has been more a development of technical details than a change in principals. It is highly improbable that X-rays will ever be generated by an entirely different mechanism. As a source of hard X-rays, radio active substances must also be considered. Radium is now used for therapeutical purposes as well as for examining materials. One may assume that the preparation of new radioactive elements will give a wide scope of new possibilities.

If for the moment we do not consider the possibility of successive acceleration of electrons, which will be briefly discussed at the end of this paper, we see that for the generation of X-rays we need a source of electrons, an anode (anticathode) as well as a high tension generator for the accelerating voltage. The use of high vacuum tubes with a heated cathode as source of electrons was a considerable progress over the gas discharge tube, where the electrons were generated by ions striking the cathode. The high vacuum tube also allows changes of current and voltage within wide limits independently of each other. The complicated and not always very reliable devices to maintain the necessary gas pressure were no more needed. At the same time Ruhmkorff's inductor was replaced by the transformer with or without rectifier and condensers. Lately, electrostatic generators have been used for extremely high tensions. However for the normal operation of X-ray tubes, they will probably not be of any importance.

The prototype of an X-ray tube based on the principles outlined above, is shown in fig. 1. All further developments can be considered as an improvement of this tube. Further progress was made to satisfy the demands for higher outputs and to ensure simpler and safer operation of the tubes and equipments. We do not intend to discuss the development of X-ray equipment here in detail, although the peculiar connection of high and low power technics is a very interesting subject for the electrician. Neither shall we try to give an even halfways complete list of the tubes developed until now, as this would only lead to quite a tedious enumeration of technical details. Instead we should like to discuss two problems in greater detail which are of vital importance for the construction of X-ray tubes i. e. heat dissipation at the anode and the insulation problem inside as well as outside of the tube. The different types of tubes discussed here serve only to illustrate the general aspects, and the choice of these types should in no way be considered as an opinion of their technical value.

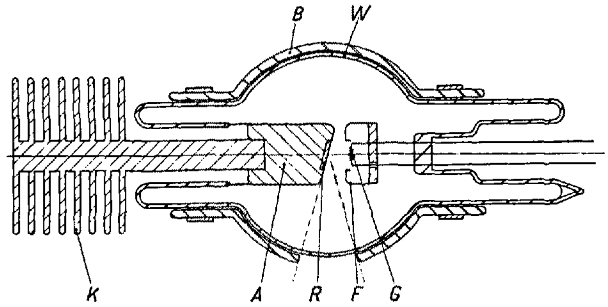

Fig. 1. The Prototype of Modern X-Ray Tubes.
G = filament with focussing device F.
A = anode with tungsten disc R.
W = glasswall of the tube.
K = radiator for dissipating heat into the surroundings.
B = lead glass casing for ray proofing.

§ 2. *The Problem of Heat Development in the Anode*

The generation of X-rays is necessarily connected with a considerable development of heat. As already mentioned in the introduction, high speed electrons i. e. high powered electrons are used to generate X-rays. Unfortunately the yield of X-rays is very low, for electrons of 100 kV (i. e. for electrons that have passed through a potential difference of 100000 V, such electrons have a velocity of 165000 km/sec) and a tungsten anode, about 0·5 per cent. The yield expressed in per cent increases approximately proportionally with the accelerating tension and is also about proportional to the atomic number of the anode material. Apart from these two factors the yield cannot be influenced in any way. Two facts can immediately be deduced from these rules: firstly one should construct the anode of a material with a high atomic number, unless a definite spectral composition is specified as it is the case for structure analysis of crystals. Later on we shall see why amongst different substances, tungsten is often preferred. Secondly one would be inclined to rise the tube tension as high as possible within technical limits. However the hardness, or in other words, the penetrating power of the emitted rays is a function of the operating tension and increases rapidly with the tension. X-ray photography is based on the varying absorption within the object, therefore too hard rays would lead to too small differences of absorption by the different parts of the object and so to too small a contrast. This means that the nature of the object which is to be examined, determines within certain limits the most favorable operating tension. For example dental photography requires about 50 kV, radiology of the lungs 60 kV, although here different specialists advise varying tensions. For radiology of the stomach a tension of 90 kV is usually employed.

In deep therapy an intense radiation of deeper lying parts of the body is the objective, while the surface layers should be spared as far as this is possible. Therefore rays with a high penetrating power are very advantageous and tensions up to 200 kV are used. Higher tensions are not commonly employed, as the equipment for these high tensions is considerably more expensive and difficult to handle. Nevertheless higher tensions are often used today. In surface therapy one wants to avoid an effect on the deeper lying tissues and must therefore employ a lower voltage (approx. 50 to 100 kV). For soft ray therapy after BUCKY, tensions as low as 7 kV are used.

High tensions must also sometimes be employed for testing materials according to the thickness and composition of the workpiece. For metal parts, as they are used in modern heavy industry, one has had to apply the highest tensions available. But even in this case the yield hardly exceeds 10 per cent. The yield of X-rays is always low and the rest of the energy, which for a 100 kV amounts to 99·5 per cent, is simply converted into heat.

This heat development in the anode is a limiting factor and to discuss its influence, it is advisable to distinguish between two different cases: firstly the momentary load as if we have it in medical radiology and secondly the continuous load as applied for testing materials and X-ray therapy[1]. X-ray screening lies more or less in between these two extremes and as this case brings no new sides into the discussion, we shall not consider it.

Medical Radiology

We have already seen that the operating tension should be adapted to the object under examination. There are also certain other conditions which must be fulfilled, if one demands as high radiographic definition as possible. Moving of the radiographed part during the exposure causes blurring (blurring due to movement). The finite area of the focus, that is the area of the anode bombarded by electrons also causes a loss of detail (geometrical blurring). To reduce the blurring due to movement of the patient to a minimum, one tends to shorten the time of exposure. The time of exposure can be shortened by increasing the intensity of the X-rays or by combining the film with a fluorescent amplification foil. Such foils however also cause a certain blurring (foil blurr) which as a rule increases with the effectiveness of the foil. Geometrical blurring can be reduced by increasing the distance of the X-ray tube from the film. This however immediately causes a loss of intensity of the X-rays, proportional to the square of the distance. Reducing the area of the focus also reduces geometrical blurring, but the area of the actual focus is also inversely proportional to the intensity and this because the load capacity per mm^2 of the focus is limited.

The energy produced in the anode causes the temperature to rise the higher, the smaller the area of the focus is. This heat is distributed through a layer of definite thickness. The dimensions can be calculated from the specific heat, the heat conductivity and the time of exposure. For short exposures they are almost independent of the area of the focus[1]. In no case must the temperature rise so high that the anode melts or vaporizes. We now see that not only should the anode material have a high atomic weight but also a high melting point, low vapor pressure and be a good heat conductor. Besides, the material must satisfy certain mechanical conditions. Of all metals in question, tungsten has proved itself the most favorable. At a greater distance from the focus, a high melting point is not of such vital importance and it is of advantage to replace the tungsten by copper which conducts the heat three times better than tungsten. Through this, one arrives at the rather standardized construction of a tungsten disc of about 2 mm thickness, slightly bigger than the actual focus, imbedded in a copper bar. This bar is calculated so that it can absorbe the energy applied during the heaviest exposures without a damaging rise in temperature. The highest load capacity of a tube of this construction is about 300 W/mm^2 for 0·1 sec. At 60 kV this gives a tube current of 5 mA/mm^2.

By making use of the line focus principle, it is possible to improve the load capacity per mm^2 of the effective focus area. The radiation of a *visible*, luminous area is expressed by LAMBERT'S cosine law. In this case, an inclination of the luminous area to the direction of the central ray would not increase the intensity. A luminous area always shows the same brightness independently of the angle of view. The emission of X-rays however is mainly isotrope, at least at not too high tensions and not too small glancing angles.

Through this it is possible to obtain a three times higher intensity per mm^2 of the effective focus. This is the limit of the physically possible.

A great improvement can however be achieved by using a rotating anode in place of a stationary anode. If a disc is rotated about an axis vertical to the plain of the disc and the electrons strike the disc close to the

1 W. J. OOSTERKAMP, Diss. Delft (1939).

1 A. BOUWERS, Z. techn. Phys. *8*, 271 (1927).

circumference, every point of the anode that passes through the stream of electrons will only be bombarded by electrons for a split second of the total time of exposure, provided the velocity of rotation is so great that such a point passes through a distance greater than the width of the focus. Through this the bombardment of electrons is distributed of a larger area, although the X-rays are emitted from the same area as they would be if the anode were stationary. Therefore the geometrical proportions determining radiographic definition, are not changed.

One would assume that the load capacity would increase in proportion to the velocity, as the area bombarded by electrons increases in proportion to the velocity. However by shortening the time the load is applied to the different points of the target, the heat generated penetrates less deeply, so that the effective thickness of the layer absorbing the heat is reduced. An exact calculation shows that the load can be increased in proportion to the square root[1] of the velocity. Most of the commercial tubes today employ velocities up to 3000 revolutions per minute and a diameter of 70 mm for the anode. The first tube working on these principles as shown in fig. 2, was constructed by Bouwers[1] in 1929. The load capacity for an exposure of 0·1 sec reaches about 2–4 kW per mm², more than a ten fold increase as compared to a stationary anode.

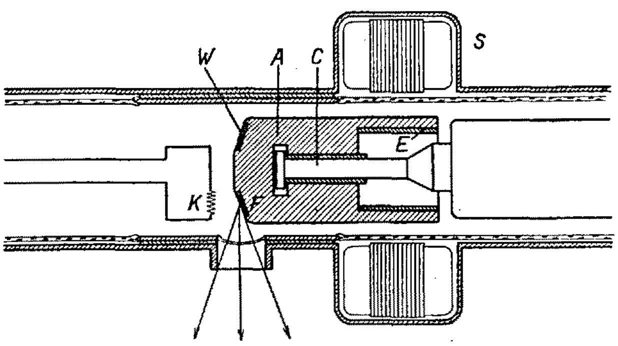

Fig. 2. The first "Rotalix Tube" (schematically). The discharge chamber between the cathode K and the anode A is entirely surrounded by metal. The cathode is placed excentrically in the tube and shaped, so that a line focus forms along a line of the curved surface of the cone, which is coated with a layer of tungsten W. The anode rotates about axis C and is driven by a threephase current in the stator coils S, similar to the rotor of an induction motor. The iron field ring E serves to concentrate as many lines of force as possible in the interior of the copper of the anode. (After Philips' techn. Rev. *3*, 299 [1938]).

A further increase in load capacity would be physically possible by increasing the diameter and the number of revolutions per min of the anode. However the technical difficulties increase incommensurately with the speed of the anode, till finally the tensile strength of the anode puts an end to such endeavours. One can therefore say that the present load capacities cannot be greatly surpassed[2].

[1] A. Bouwers, Kongreßheft Fortschr. Röntgenstr. *20*, 103 (1929).
[2] A. Bouwers, Erg. Techn. Röntgenkunde IV, 144 (1934).

What effect has this ten times higher load capacity on diagnostic radiology? To reach an optimum, one must consider all previously mentioned causes of blurring i. e. blurring due to movement of the patient, geometrical blurring, and blurring caused by foils. Closer consideration shows that these three factors must be adjusted to each other, so that the blurring due to each factor is of about the same amplitude[1]. All technical progress must be evenly distributed amongst these three factors. For instance, there is no sense only to reduce the area of the focus and with it geometrical blurring. From this we see that with optimal adjustment the higher specific load capacity of the rotating anode tube reduces blurring in proportion to the cube root of the improvement factor. Applying this to the above mentioned large increase in load capacity, one sees that blurring is only 2–2·5 times less. Nevertheless this improvement is of fundamental importance, because now blurring is so far reduced that it lies below the dimensions of many details of interest for the diagnostician, which can now be examined.

Therapy

During short exposures the total energy developed can be absorbed in the anode, and only after the radiograph, a slow exchange of temperature with the surroundings will take place. For longer exposures as usually needed in therapeutical applications, one arrives at an equilibrium, the heat developed per unit of time is equal to the heat transmitted to the surroundings per unit of time. The fact that the dimensions of the focus are not of such great importance simplifies matters. As a rule, a focus diameter of 15 mm is readily admissible. The loads employed are considerable, usually up to 4 kW. In this case, radiator cooling is not adequate, and unless one purposely restricts oneself to smaller loads[2], one is forced to effect cooling by means of water or insulating oil. Insulating oil is often used for its electrical properties, although as a heat conductor it is considerably less advantageous. A load of 4 kW can be handled with oil without too great complications. The temperature of the area bombarded by electrons remains far below the admissible value. An increase in load leads mainly to cooling difficulties, as the temperature of the cooled area rises too high, which causes the oil to decompose. However there are still further possibilities in this direction. There are two reasons why one has restricted oneself to the above mentioned load. Firstly higher loads require complicated and costly high tension equipment for feeding the tubes, and secondly there has been no special demand from the medical profession in this direction.

[1] A. Bouwers and W. J. Oosterkamp, Fortschr. Röntgenstr. *54*, 87 (1936).
[2] J. H. v. d. Tuuk, Philips' techn. Rev. *6*, 314 (1941).

Testing of Material

The testing of material usually demands long exposure times. This is obviously the case in radiographing series of castings, etc., as it is often done industrially. Radiographs of large workpieces with high absorptive power require a considerable amount of rays and the exposure time therefore often reaches several hours. There can be no question of short time – high load exposures. Structure analyses of crystals also requires longer exposures.

Contrary to the therapy tubes a small focus is demanded as in diagnostic work to obtain good definition. One must not fear blurring due to movement, but nevertheless high intensities are necessary, as otherwise exposure times become prohibitive. The time of exposure could be shortened by rising the tension, but only at a loss of the so essential contrast which is needed to detect small flaws. As for diagnostic purposes, one must strive to obtain a high specific load capacity of the focus. To achieve this, the heat generated at the anode must be removed effectively. This can be done by employing a thin anode, intensely cooled from the back side.

Cooling is here the governing principle. If the heat dissipated per mm² of the backside of the anode is increased, the capacity of the tube is also increased correspondingly, provided the focus area is kept constant. The anode can always be made so thin, that the temperature of the focus does not rise higher than permissible. For this reason it is very advantageous to ground the anode, so that the cooling system can be directly attached to the water mains. A tube for structure analysis of crystals constructed after full consideration of all these facts is shown in fig. 3[1].

A great improvement in testing materials can be achieved by applying the principle of the rotating anode, where the heat generated is distributed over a larger area. This also increases the area available for cooling. The combination of rotating anode and circulating cooling medium requests rotating vacuum joints, which are never entirely tight, so that the tube must constantly be evacuated during operation. Tubes of this kind have actually been constructed in different research institutes[1]. Presumably they will only be used in laboratories, at least for the time being.

For certain questions in the field of testing of materials, a tube with rotating anode without enforced cooling offers considerable advantages, especially if an extremely small focus at a low total load is demanded[2].

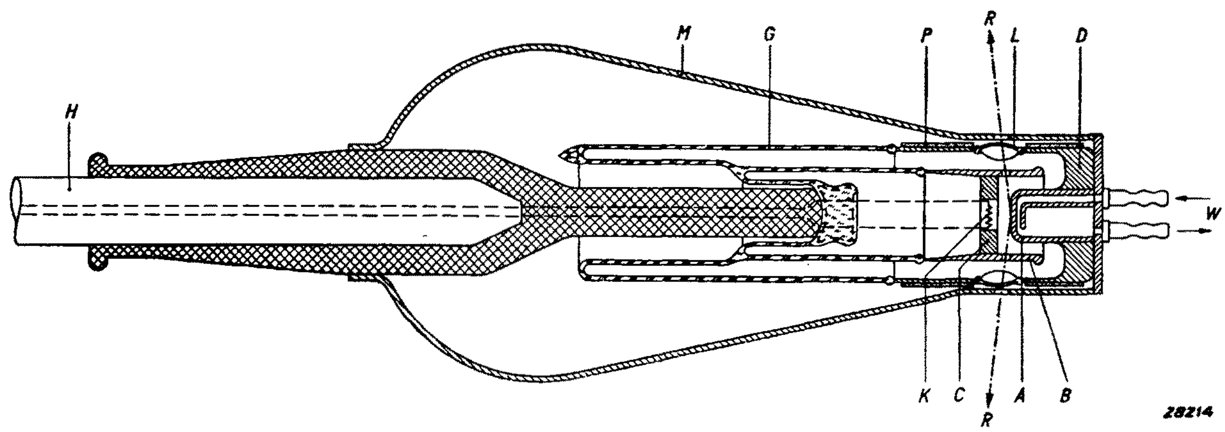

Fig. 3. X-Ray Tube for Structure Analysis of Crystals. The anode *A* forms part of the chrome-iron container *D* with welded on glass extension *G*, carrying the shielding cylinder *B* with plate *C* and the cathode *K*. The X-rays emerge in direction of the arrows *R* through the aperture *L*. The cooling water flows in and out at *W*. The tube is placed in a metal shield *M* which like the anode and the metal shields of the high tension cables *H* is earthed. The anode container is surrounded by a lead jacket *P*. (After Philips' techn. Rev. *3*, 263 [1938].)

§ 3. *Insulation Problems*

At the beginning of § 2 we mentioned the tensions required for different applications. We shall now discuss the factors controlling the insulation of the tubes. One distinguishes between inner and outer insulation.

The Problem of Insulation Inside the Tube

In the first place high tension requires a very good vacuum. Amongst high vacuum electronic tubes, X-ray tubes are an exception, not only because of the high tensions employed, but also because they contain large metal masses under heavy thermic stress in vacuum. We have similar conditions only in large transmitting tubes. This requires an extremely careful degassing of the tube as well as greatest prudence in the choice of constructing material. Considerable progress was achieved by using absorbing substances (getters), not only because they allowed a simplification of the

[1] J. E. DE GRAAF and W. J. OOSTERKAMP, J. Sci. Instr. XV, 293 (1938); Philips' techn. Rev. *3*, 263 (1938).

[1] A. MÜLLER, Nature *124*, 128 (1929). W. T. ASTBURY and R. D. PRESTON, Nature *133*, 460 (1934). FOURNIER, GONDET and MATHIEU, J. de Physique *7*, 160 (1937). J. W. M. DU MOND, B. B. WATSON and B. HICKS, Rev. Sci. Instr. *6*, 183 (1935).

[2] J. H. v. d. TUUK, Philips' techn. Rev., to be published shortly.

fabrication process and ensured an excellent vacuum for the total life of the tube, but also because they allowed constructions which would hardly have been possible without them[1]. In this laboratory a special barium-getter was developed for these purposes[2]. To give you an impression of its effectiveness it may be mentioned that 80 mg of this substance can completely absorbe 4 ml of nitrogen, hydrogen or oxygen at atmospheric pressure.

Secondly the emission of electrons caused by strong electric fields, the so-called cold emission, should be avoided as far as possible. These electrons lead to currents at undesired points of the tube. If for instance they strike the glass wall, they can easily destroy the glass and even if they strike metal parts, this is not always harmless, as they can cause gas eruptions and lead to overheating. To avoid this emission of electrons, the tube should firstly be so dimensioned that not too strong electrical fields can be formed. One cannot however go too far in this direction, as a short distance between cathode and anode is very advantageous to avoid ionisation by collision. Secondly the surface of the electrodes should be as smooth as possible, because every roughness leads to a local increase in field intensity. Thirdly every impurity must be excluded, as impurities tend to reduce the energy needed to release electrons and so lead to an increased cold emission. Usually for a difference of potential of 1 kV, a distance of 0·1 mm between the electrodes is chosen. For a tube for diagnostic purposes operating on a tension of 100 kV this gives a distance of 1 cm. Due to the special construction of the cathode, field intensities of 300 kV/cm can arise.

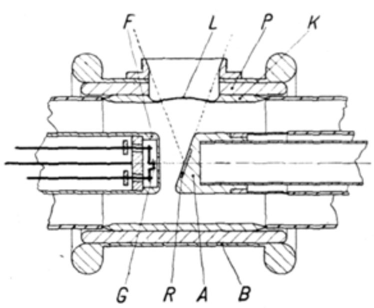

Fig. 4. The Center Part of the "Metalix"-Tube. *A* anode with tungsten disc *R*, *G* filament with focussing device *F*, *K* chrome-iron container with opening for emerging rays *L*. *P* lead jacket for X-ray protection surrounded by aperture collar for holding tube.

For commercial tubes until now glass has been used for the insulating part of the wall. This part must also satisfy several conditions. Field intensities, not only the transversal, but also the tangential components, must not be too high. It is clear that high transversal field intensities can lead to sparking and high tangential intensities, to electric discharges along the inner surface of the glass, and eventually to electrolysis near glass-metal joints, especially if they are at a high temperature. To avoid high field intensities it is necessary to give the electrodes an appropriate form and to arrange them correspondingly. Besides, all influences leading to an irregular distribution of tension must be avoided, such are: charges on the wall caused by secondary electrons originating from the focus or by cold emission and metal deposits, which can come from the cathode as well as from the focus. These difficulties were solved satisfactorily in the "Metalix Tube" of BOUWERS[1], fig. 4. Here the most exposed part of the wall is made of metal. The insulating glass-parts are in a considerable distance from the actual discharge chamber[2]. The modern hard glasses with a low alkali-content are much more resistant, so that for not too high tensions, constructions without metal walls can be employed. In some respects this is a simplification.

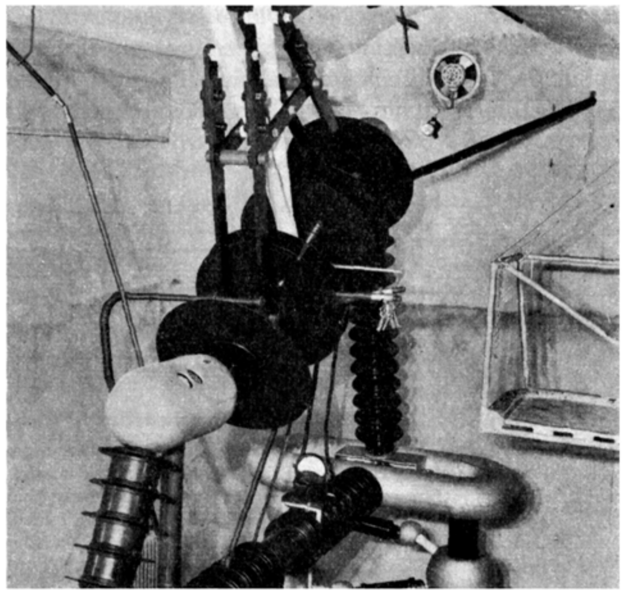

Fig. 5a. X-Ray Tube for Deep Therapy, Operating on a Tension of 1 Million V at the Cancer Institute in Amsterdam (ANTONI VAN LEEUWENHOEKHUIS). For irradiations, tensions of 825 kV are applied, for measurements up to 1000 kV have been used.

(a) X-ray Tube Support. The center of the tube is earthed and directly suspended from the ceiling. The first and third units are supported by bars of insulating material.

As soon as the operating tension exeeds 200 kV, it is very difficult to satisfy all the above mentioned conditions in a one stage tube construction, and it is advisible to subdivide the tension. A tube for 1000 kV, subdivided in 6 stages is shown in fig. 5[3].

[1] A. BOUWERS and J. H. v. d. TUUK, Brit. J. Rod. IX, 431 (1936). J. H. v. d. TUUK, Philips' techn. Rev. *4*, 161 (1939).
[2] J. E. DE GRAAF, N.O.S. 48111.

[1] A. BOUWERS, Physica *4*, 173 (1924).
[2] The "Metalix"-Tube was the first tube which was made ray- and shockproof. Two features which today are considered as natural for all tubes.
[3] A. BOUWERS and J. H. v. d. TUUK, Brit. J. Rod. XII, 658 (1939). J. H. v. d. TUUK, Philips' techn. R. *4*, 161 (1939).

The Problem of Insulation Outside the Tube

To treat all questions on this subject exhaustively would lead to a discussion of almost the entire field of high-tension technics, especially for equipment with for tubes, operating on extremely high tensions, exceptions are often made by placing all parts under tension in a room separated from the room used for exposures (fig. 6).

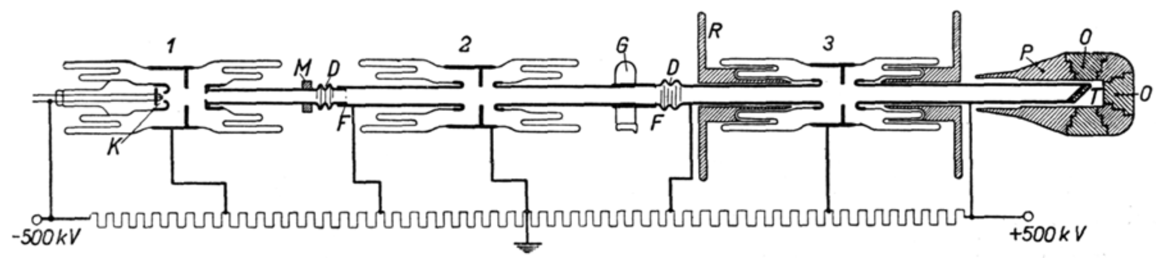

Fig. 5b.

(b) Diagram of the Tube. The three units *1*, *2*, *3* are manufactured separately, evacuated and then put together. At *F* foils for closing tube provisionally. *K* cathode, *T* anode, *M* focussing magnet, *D* flexible connecting parts, *G* metal container with reserve getters, *P* lead jacket for X-ray protection beyond the useful cone of rays emerging from the three apertures. The circular grooves *R* in the doubly folded glass wall of each unit are filled with "Philite" (drawn only in the third unit). The voltage is subdivided in six stages taken from a potentiometer clearly visible at the lower side of fig. 5. (After J. H. v. D. TUUK, Philips techn. Rev. *4*, 161 [1939]).

tube and high tension generator built in one container. However we shall limit the discussion here to the immediate surroundings of the tube. The insulation problem has changed since the beginning of X-ray tube construction. For practical applications one now demands that each tube should be surrounded by the smallest possible earthed shield, so that all danger of touching parts under high tension is excluded. Only

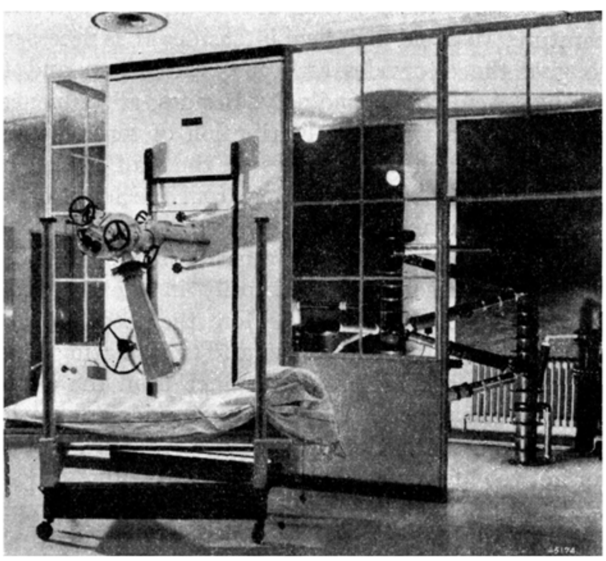

Fig. 6a. Specially constructed Unit for X-Ray Therapy, Operating on a Tension of 400 kV and 10 mA at the University Hospital at Groningen (Holland). The tube contains a 1·8 m long earthed hollow anode, carrying the focus on one end and projecting from the instrument room into the operating room. The tube has two apertures, by shifting and turning the tube as well as by adjusting the apertures, the beam of X-rays can be directed in every direction desired.

(a) Survey of the Installation. On the left hand side one sees the part of the X-ray tube which projects into the operating room. A localising cone is attached to one of the apertures. In the instrument room behind the glass wall, one can see the cascade generator, producing a tension of 400 kV.

By employing solid insulation materials one arrives at the smallest dimensions, as they have the highest disruptive strength and can be used as construction elements[1]. They have however the disadvantage that unhomogeneousness and flaws in the material, which greatly weaken the dielectric strength, are very difficult to avoid. One also must consider, that through a single breakdown the insulator becomes entirely useless. Besides, organic insulating materials are very sensitive to heat and are such poor conductors of heat, that transportation of heat through the insulating material should be strictly avoided. These disadvantages can be removed by combining the solid insulator with other insulating materials, such as oil or air. For those points under greatest stress the solid insulator is employed, and for cooling at less exposed points, oil or air. This allows a simpler construction of the insulator, which is more easily obtained flawless. This principle has been applied to the tube shown in fig. 7 for short distance irradiation.

Of the liquid insulating materials, insulating oil is used exclusively. They do have a lower disruptive strength, but have the advantage of being homogeneous, if such easily separated impurities as water or dust particles are removed. A single breakdown is no catastrophe and only repeated breakdowns reduce the dielectric strength of the insulator. Convection currents allow a considerable exchange of heat without a great difference in temperature[2]. Certain disadvantages must however be mentioned. The oil is easily decomposed by high field intensities, oxidation and high temperatures. This can lead to a development of gas, which reduces the dielectric strength. The heavy decomposition products on the other hand form a layer, which

[1] A. BOUWERS and W. J. OOSTERKAMP, Amer. J. Roentg. *41*, 444 (1939).

[2] J. H. v. d. TUUK, Philips' techn. Rev. *6*, 314 (1941).

is very unfavorable for the exchange of heat. Besides, the constructor must also solve the problem of making the container oil-tight and yet leave a possibility for the thermic expansion of the oil. A modern tube with oil insulation is shown in fig. 8[1].

We therefore like to refer shortly to the so-called betatron, where electrons can be accelerated to velocities equivalent to several million volts without employing high tensions. Energies up to 20 million V have been reported by American workers[1]. The basic principle is easily understood, if one compares the betatron to a normal high tension transformer. There the changing magnetic flux through the iron core induces a tension in every turn and by connecting very many turns in series, one obtains a high tension. Now if it were possible to conduct an electron in vacuum around an iron core without employing actual wire turns, the electron would have an energy equivalent to the previously mentioned high tension without applying this tension at any point. At normal tensions, the output of X-rays is always low. At 2·5 million V however the yield already exceeds 10 per cent[2] and at 20 million V, the greatest part of the energy is emitted as X-rays. Besides the radiation is highly concentrated in the direction of the electron beam which again means a further considerable increase in

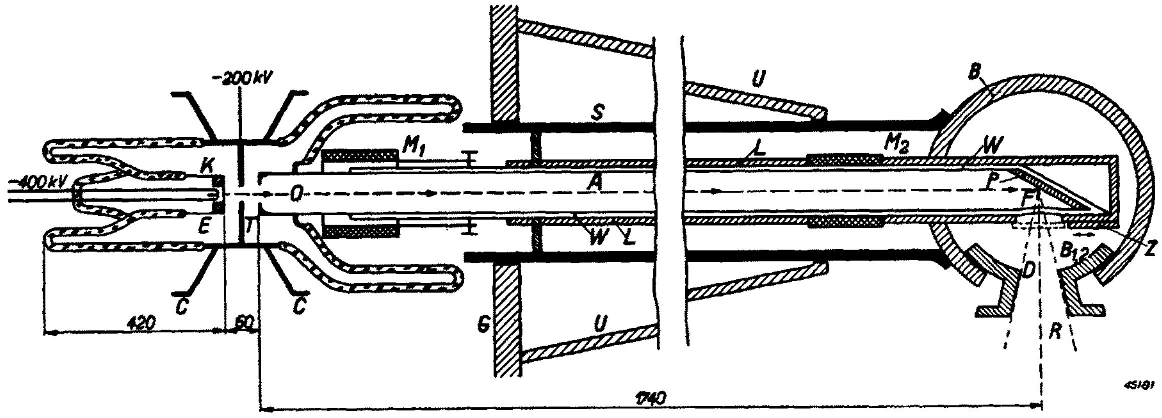

Fig. 6b.
(b) Schematic Diagram of the entire X-Ray Tube. K filament with focussing device E, T container with aperture, O opening of earthed anode tube, M_1 and M_2 magnetic focussing coils, P tungsten disc with focus F, the source of the X-rays R, W cooling tube for running tap water, L layer of lead surrounding anode tube, B lead sphere, $B_{1,2}$ lead caps with apertures D, Z lead shutter for dimming rays, S steel tube carrying the anode tube, C discharge caps. To simplify the diagram, only one aperture is drawn in. (After W. HONDIUS BOLDINGH and W. J. OOSTERKAMP, Philips' techn. Rev., to be published shortly.)

Dry air is still the simplest and cheapest insulation material, although the breakdown tension compared to solid or liquid insulating materials is rather low and therefore requires larger dimensions. Even though an air insulated tube plus shield weighs more than an oil tube, there are many other advantages, such as ensured homogeneity, insensitiveness towards breakdowns and rises in temperature as well as the possibility of equalizing local inhomogeneities of field intensities by sparking. We should not like to discuss the application of compressed air and gases of high dielectric strength such as freon[2], which are increasingly employed for extremely high tensions.

As we have seen one cannot talk of a general superiority of any particular insulating material. It must be left to the constructor to choose the most appropriate insulator in each case.

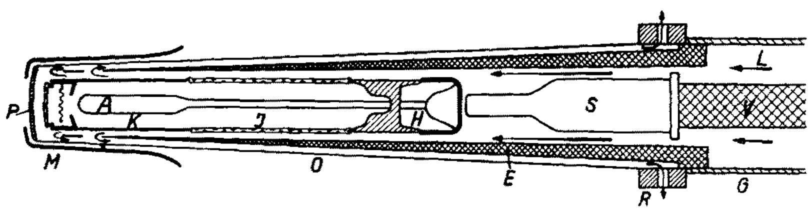

Fig. 7. X-ray Tube for Short Distance Treatment. The anode support H carries high tension and is insulated from the earthed hood O by an ebonite insulator E. A gap is left between the two metal parts and the insulator, through which air L is blown to cool the cathode can K. The heat generated at the anode A is transmitted through radiation to the cathode can K. J connecting glass tube, P cover of weakly absorbing material to protect aperture. V high tension cable, S plug, G rubber tube, R ring with outlets for air, M metal cone to adjust tube on the skin. (After J. H. v. D. TUUK, Philips' techn. Rev., to be published shortly.)

§ 4. *Final Remarks*

The possibilities in normal X-ray tube constructions are limited much more by the problem of heat dissipation than by insulation problems, which usually can be solved satisfactorily in several ways. This is entirely different for tubes operating on extremely high tensions. The main problem here lies in finding constructions capable of withstanding these high tensions.

[1] J. H. v. d. TUUK, Philips' tech. Rev. *6*, 314 (1941).
[2] E. E. CHARLTON, W. F. WESTENDORP, L. E. DEMPSTER and G. HAFTALING, Radiology *35*, 585 (1940).

[1] D. W. KERST, Phys. Rev. *61*, 93 (1942).
[2] A. A. PETROUSKAS, L. C. VAN ATTA and F. E. MYERS, Phys. Rev. *63*, 389 (1943).

intensity. Furthermore experience has shown that ionisation in an object irradiated by these hard rays reaches its maximum only at a certain depth from the surface[1]. For deep therapy this means intense radiation

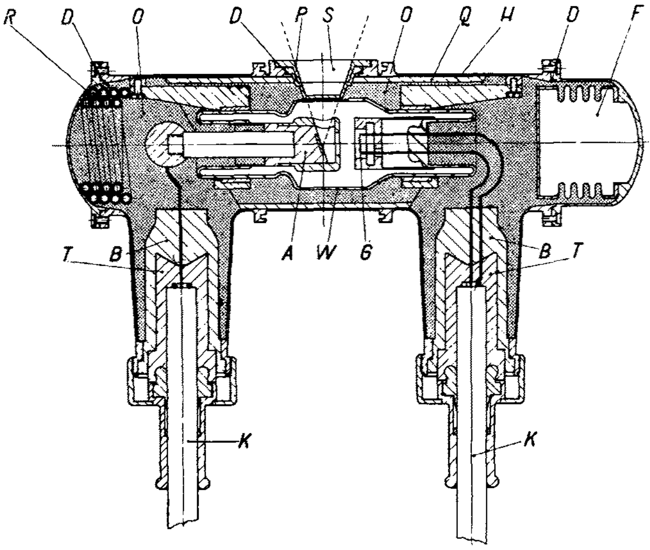

Fig. 8. Oil Insulated Diagnostic Tube. *A* anode, *G* cathode, *W* glass-wall of tube, *H* metal hood with protecting layer of lead *Q*, *S* aperture, *P* "Philite" cone to lessen absorption of oil layer. *O* insulating oil, *D* packings, *R* spiral for cooling with running water (usually unnecessary), *K* high tension cable with male and female plug *T* and *B*, *F* elastic container to compensate expansion of oil. (After J.H.v.D.TUUK, Philips' techn. Rev. *6*, 314 [1941].)

of deeper lying parts, while the surface remains almost unaffected. The betatron also opens new perspectives for the examination of very large workpieces.

We have now come to the end of our review. It is a long way from the simple tube Roentgen discovered all the properties of the X-rays with, to the modern tubes and the betatron. We hope that this article could convey an idea of the incessant attempts at further development of ROENTGEN's discovery under consideration of the physical aspects to obtain a more and more useful instrument for research and praxis.

Zusammenfassung

In vorstehender Arbeit wird kurz die Entwicklung der Röntgenröhre geschildert, wobei erwähnt wird, daß die Erzeugung der Röntgenstrahlen nach wie vor auf dem gleichen physikalischen Mechanismus beruht. Als wesentlicher Fortschritt seit der Entdeckung RÖNTGENS ist der Übergang von der Gasentladungsröhre zur Hochvakuumröhre und dadurch die unabhängige Regulierung von Röhrenstrom und Spannung zu bezeichnen. Gleichzeitig damit wurde der Funkeninduktor durch den Transformator ersetzt.

Im wesentlichen wird die Wärmeentwicklung in der Anode und die Isolationsprobleme der Röntgenröhre beschrieben.

Die Ausbeute der Röntgenstrahlen ist eine Funktion der Elektronengeschwindigkeit respektive Anodenspannung und der Atomnummer des Anodenmaterials. Sie beträgt bei 100 kV Anodenspannung und Wolfram als Anodenmaterial *nur* 0,5%; der ganze Rest der Energie wird in der Anode in Wärme umgesetzt.

Betrachtungen dieser Verhältnisse für Moment- und Dauerbelastung.

Die Anwendung des GOETZE-Strichfokus und der Drehanode für Momentbelastungen zwecks größerer Belastungsmöglichkeit bei kleinstem optisch wirksamem Brennfleck wird beschrieben. Hierbei genügt allgemein eine schwere Kupferanode mit eingelegter Wolframronde und ein Rippenkühler zur Ableitung der erzeugten Wärme. Anders liegen die Verhältnisse für die Dauerbelastung im Therapiebetriebe, wo mit zusätzlicher Wasser- und Ölkühlung gearbeitet wird.

Die Verhältnisse betreffend Kühlung an Materialuntersuchungsröhren mit deren Forderung von großer, dauernder Belastbarkeit und kleinstem Brennfleck werden beschrieben.

Als erstes Gebot für eine einwandfreie interne Isolation der Röntgenröhre ist das hohe Vakuum zu bezeichnen. Es werden die Fortschritte durch Verwendung eines Getters (Barium-Getter) erwähnt. Der Verhinderung von Kaltemissionen von Elektronen durch besondere Elektrodengestaltung ist besonderes Augenmerk zu schenken. Ebenfalls ist für nicht allzu hohe Feldstärken sowohl an den internen Konstruktionsteilen wie auch an der äußeren Glashülle zu sorgen (Formgebung). Die äußere Isolation, an welche ebenfalls hohe Ansprüche sowohl an die Isolationsfestigkeit als auch an die Wärmeleitung gestellt wird (Berührungsschutz und Kühlung) ist beschrieben.

Als Isolation kommt eine Kombination von festen Isolierkörpern, welche gleichzeitig als Konstruktionsteile dienen, mit Öl oder Luft in Frage.

In der Schlußbemerkung wird auf die Beschleunigung von Elektronen entsprechend Energien von bis zu 20 Millionen V ohne Hochspannungsquelle, durch das sogenannte Betatron, hingewiesen. Durch diese Methode eröffnen sich neue Perspektiven für die Röntgentechnik.

[1] H.W. KOCH, D.W. KERST and P. MORRISON, Radiology XI, 120 (1943).

Quelques exemples de l'utilisation des rayons de Rœntgen pour des recherches biologiques ultramicroscopiques

Par A. LACASSAGNE, Paris

La découverte des rayons X par RŒNTGEN, il y a 50 ans, a permis d'étendre les moyens de perception de l'homme, bien au delà des limites que son œil semblait devoir lui imposer. A côté de la vision à travers les corps opaques, deux autres applications ont contribué à la connaissance de la constitution ultramicroscopique de la matière: dans le domaine des substances inanimées, l'analyse des structures molé-