

Sept. 9, 1952

H. GUTTON

2,610,309

MAGNETRON TUBE FOR THE TRANSMISSION OF ULTRASHORT WAVES

Filed April 14, 1948

2 SHEETS—SHEET 1

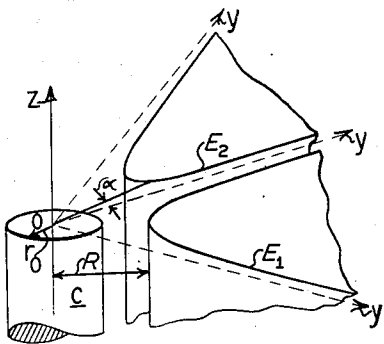


Fig. 1

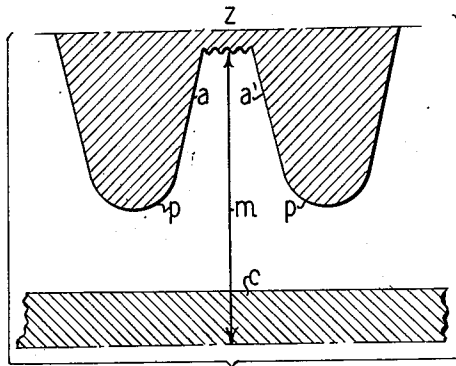


Fig. 2

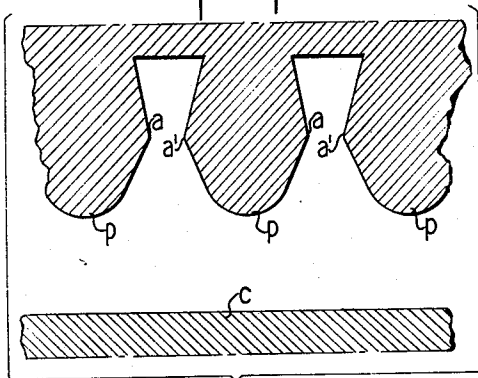


Fig. 4

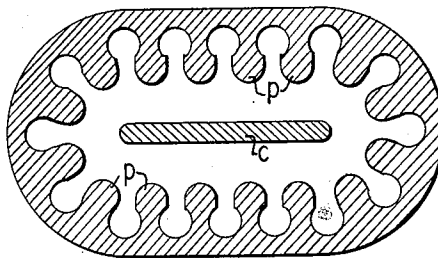


Fig. 6

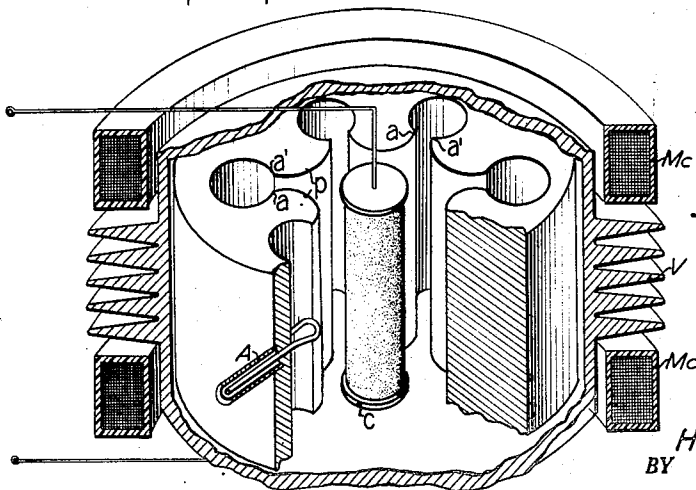


Fig. 3

INVENTOR.

HENRI GUTTON

BY

Haseltine Lake and Co.,

AGENTS

Sept. 9, 1952

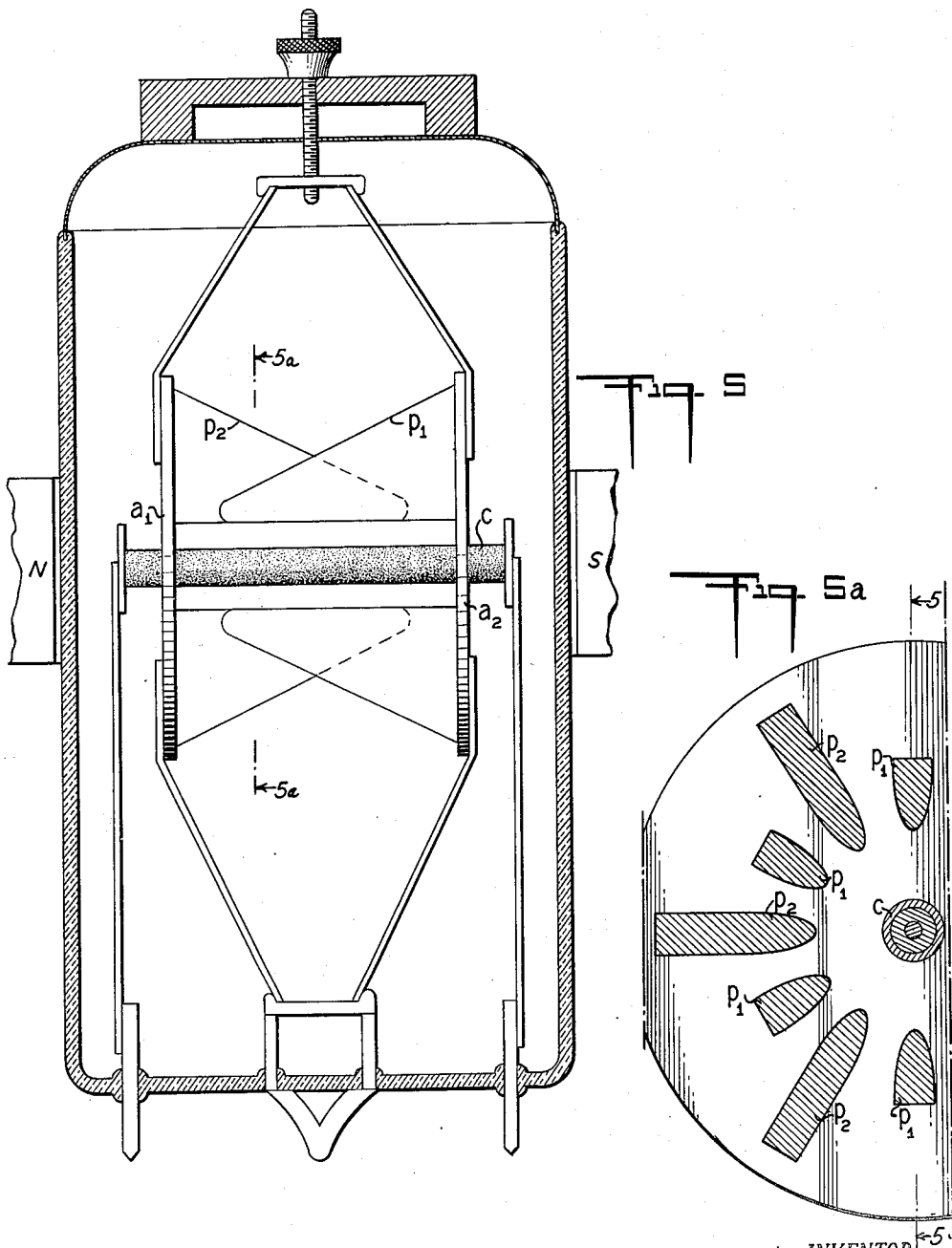
H. GUTTON

2,610,309

MAGNETRON TUBE FOR THE TRANSMISSION OF ULTRASHORT WAVES

Filed April 14, 1948

2 SHEETS--SHEET 2



INVENTOR.

HENRI GUTTON

BY

Hoseltine Lake and Co.,

AGENTS

UNITED STATES PATENT OFFICE

2,610,309

MAGNETRON TUBE FOR THE TRANSMISSION OF ULTRASHORT WAVES

Henri Gutton, Paris, France, assignor to Compagnie Generale de Telegraphie Sans Fil, a corporation of France

Application April 14, 1948, Serial No. 21,067
In France April 18, 1947

5 Claims. (Cl. 315-40)

1

This invention relates to tubes serving for the generation or the amplification of electric oscillations of a ultrahigh frequency, in which it is desired, for the purpose of increasing the output, to favor an electromagnetic oscillation of a particular order in comparison with the others, or even to completely eliminate the latter.

The invention relates more particularly to tubes of the type called magnetrons having a cylindrical anode slit parallel to the longitudinal axis or generatrices of the cylinder, and divided into a certain number of segments disposed about the cathode.

Heretofore, for the purpose of obtaining the desired effect, segments have been arranged two-by-two in short-circuited relation by means of conductor tabs, but these means introduce considerable losses due to high frequency circulation currents in the said connections; moreover, they complicate manufacture and production due to the fact that they have to be clamped or welded, which is difficult to carry out under the conditions of the smallness of the elements concerned.

The subject of the present invention consists in a process of manufacture and in the construction of such tubes enabling elimination in an associated circuit of all the oscillation, except practically one, without resorting to the hereinbefore mentioned short-circuiting arrangements, and thereby avoiding the losses and the complication in manufacture in connection with their employment. The invention insures this result by giving the anodic segments of magnetrons a section approaching the form of equipotential lines of the electromagnetic oscillation of a particular order which is the only one to be selectively maintained in practice. In order to obtain such an equipotential surface, the anodic segment is constructed in a very characteristic rounded form which clearly distinguishes it from the sharp-edge segments of the anode of classical magnetrons, having edges formed by the notches along the generatrices of the cylinder provided in the body of the anode.

The invention is also directed to a process which, for a certain number of given parameters, such as the order of the oscillation to be favored, the number of segments, the diameter of the cathode and that of the anode, enables the tracing of the desired equipotential lines, and thereby the determination of the patterns for the cutting of the anodic segments. The latter will have a section resembling the form of a hairpin whose apex is directed toward the cathode, and whose

2

branches diverge along the path of the rays issuing from the axis of the cathode.

My invention will be more fully understood from the following specification by reference to the accompanying drawings, which illustrate, by way of non-limiting examples, preferred forms of my invention and wherein:

Figure 1 is a diagram showing the manner of laying out the desired equipotential surfaces; Fig. 2 represents a fragmentary view of a magnetron whose segments have been prepared according to my invention, and in which for the sake of simplicity the anodic crown and the cathode which normally have a circular form have been shown in a straight line; Figs. 3 and 4 show modified forms of elements of a magnetron constructed in accordance with my invention and in which there is shown the connection between the sectioned notches of resonant cavities of various forms; Fig. 5 represents the application of the invention to magnetrons with overlapping anodic segments; Figure 5a represents a partial section of this magnetron along the line 5a-5a in Figure 5; and, Fig. 6 represents the application of the invention to magnetrons.

There will first be considered a classical magnetron operating at an ultrahigh frequency and having a cylindrical anode slit parallelly with the generatrices of the cylinder. Assume that the number of the said slots is n .

The energy produced by the work of the electrons radiates, through the intermediary of the said slots, to the interior of a connected cavity. The presence of slots produces, in the interval separating the cathode from the anode, a stationary electromagnetic field, which can be divided into two fields of waves, the one travelling in the one direction and the other in the other direction. The electric field in this space has two components, the one radial and the other tangential. The radial component is maximum when the tangential component is zero, and conversely.

The continuous current of the anode, and the presence of a magnetic field, create a movement of rotation of the electrons, whose velocity depends on the potential of the anode, and the size of the magnetic field. When the velocity of displacement of the electrons is substantially equal to the velocity of rotation of one of the traveling electro-magnetic fields, there occurs a loss of kinetic energy of the electronic charge which increases the electromagnetic field. The electromagnetic field increases in amplitude until the moment at which the energy produced

equals the sum of the energies radiated by the oscillator and lost by the Joule effect in the walls of the circuits.

In general, circuits which are all disposed in series on the path of the electromagnetic wave constitute an indefinite chain capable of transmitting an indefinite number of electromagnetic waves circulating at speeds of rotation, as follows:

$$\omega = \frac{\pi}{nT}, \frac{2\pi}{3nT}, \frac{2\pi}{4nT}, \frac{2\pi}{5nT}, \text{ etc.}$$

in which T is the period of oscillation.

These different modes of propagation of the electromagnetic wave furnish between the lips of a same slot differences in phase equal to

$$\pi, \frac{2\pi}{3}, \frac{2\pi}{4}, \frac{2\pi}{5}, \text{ etc.}$$

It is of the greatest interest to retain only one of these modes of propagation of the electromagnetic field in such a way that all the actions of the field are in phase with the movements of the electrons. There is usually retained only the mode for which the electromagnetic output of the tube is the best. For the purpose of avoiding the other modes of propagation there is a known method for arranging the electrodes into short-circuit two-by-two by means of strap connections.

It will now be demonstrated that it is possible, by giving, according to the invention, the anodic segments a suitable form, to retain only the mode of oscillation of the order p_i , without resorting to the short-circuit connections, thereby avoiding high frequency losses, and complications in manufacture.

Consider in effect the equation of the electromagnetic field in cylindrical coordinates r, α, Z (Fig. 1) and assume, as is usually the case, that the electric and magnetic vectors are independent of the coordinate along the axis of the cylinder. Assume, further, the period wave of pulsation kc . The cathode may be assumed to be a perfect conductor and, under this assumption, the electric field has no tangential components on the surface of radius r_0 of the cathode.

The general solution for electric and magnetic vectors is of the following form:

$$\begin{aligned} rE_r &= \sum_{p=\frac{n}{2}}^{p=0} ApZp(kr) \cos p_\alpha e^{ikct} \\ E_\alpha &= \sum_{p=\frac{n}{2}}^{p=0} ApZ'p(kr) \sin p_\alpha e^{ikct} \\ H_z &= ik \sum_{p=\frac{n}{2}}^{p=0} \frac{A}{p} Zp(kr) \sin p_\alpha e^{ikct} \end{aligned}$$

in which E_r is the radial component of the electric vector; E_α is the tangential of the electric vector; H_z is the axial component of the magnetic field, the other components being zero.

K is a constant of integration; $Z'p(kr)$ is a derivative of this function in relation to kr ; Ap is a coefficient of amplitude; p represents the order of the mode propagation, which varies from

$$p = \frac{n}{2}$$

for the p_i to $p=0$ for the mode corresponding to a cylindrical magnetron without slots. The sequence of the numbers p is

$$\frac{n}{2}, \frac{n}{3}, \frac{n}{4}, \dots$$

Each solution of the order P must satisfy the condition $E=0$ on the cathode, from which it results that $Z'p(kr_0)=0$ for all the values of p . This condition determines the value of K .

The amplitudes Ap of each of the waves can be selected in such a way that one of the equipotential lines of the electric field coincides with the form of the anodic surface. With a given form of the anodic surface, these amplitudes will be a series of values more or less great. If the form of the surface of the anode is selected in such a way that the amplitudes Ap are all zero except the amplitude of the wave corresponding to

$$p = \frac{n}{2}$$

(mode p_i), then there can only exist the electromagnetic wave of order

$$\frac{n}{2}$$

corresponding to the mode p_i , and the other waves will not be able to propagate themselves. Thus, by calculating the equipotential lines of the field corresponding to the order p_i , and employing one of these equipotential lines as the surface of the anode, there is only retained the mode p_i , to the exclusion of all the other modes. It is this which constitutes the principle of my invention.

$$kr = \frac{2\pi r}{\lambda}$$

is usually a number sufficiently smaller than 1 that there is only retained the first term of the development in series of the function $Zp(kr)$. The components of the electromagnetic field of order

$$p = \frac{n}{2}$$

then became as follows:

$$\begin{aligned} rE_r &= \left\{ \left(\frac{r}{r_0} \right)^p + \left(\frac{r_0}{r} \right)^p \right\} \cos p_\alpha e^{ikct} \\ rE_\alpha &= - \left\{ \left(\frac{r}{r_0} \right)^p - \left(\frac{r_0}{r} \right)^p \right\} \sin p_\alpha e^{ikct} \\ H_z &= \frac{ik}{p} \left\{ \left(\frac{r}{r_0} \right)^p + \left(\frac{r_0}{r} \right)^p \right\} \sin p_\alpha e^{ikct} \end{aligned}$$

These equations show that, if kr always remains sufficiently smaller than 1, that is, if the perimeter of the anodic circumference is small enough for the wave length, then the form and amplitude of the electromagnetic field are independent of the frequency.

The equipotential lines of the electric field are represented by the equation:

$$\left(\frac{r}{r_0} \right)^p - \left(\frac{r_0}{r} \right)^p = \frac{A}{\cos p_\alpha}$$

and their forms are independent of the frequency.

Fig. 1 represents the application of this equation to the tracing of the equipotential in the case of a magnetron with ten slots

$$(n=10 \text{ and } p=\frac{n}{2}=5)$$

The cathode is designated by C ; the reference E_i designates a point on the equipotential line defined by the coordinates a and r ; for the angle α equals zero $\cos p_\alpha$ becomes equal to 1; and r denotes the inside diameter R of the anode. This enables determination of the constant A . When

5

p is sufficiently great, and the diameter of the anode is sufficiently great compared with the diameter of the cathode, then the term

$$\left(\frac{r_0}{r}\right)^p$$

becomes negligible. The equipotential lines become

$$r = \frac{B}{(\cos p\alpha)^{1/p}}$$

and are practically independent of the diameter of the cathode.

The foregoing equation enables the tracing of the equipotential lines E_1, E_2 , etc., for any magnetron with slots whose parameters are given, and for any single mode of propagation which it is desired to maintain. With the help of these lines as patterns it is easily possible to trace and cut out the segments in the crown of the anodic crown. While in the classical magnetrons the faces of the segments turned toward the cathode present a form of circonvolution bounded by sharp edges, the magnetron according to this invention presents rounded edges and the section of segments resembling the form of a hairpin whose rounded summit is turned toward the cathode and whose branches are directed toward the exterior along the asymptotes $Y-Y$ of the equipotential lines as shown in Fig. 1.

Moreover, the magnetron according to my invention is characterized by the absence of short-circuiting connections between the anodic segments. If it is desired for the purpose of eliminating all the waves except one, particularly the wave p_1 , to give the anode a section identical to the equipotential line, there are thereby already obtained satisfactory results, enabling the short-circuiting tabs to be dispensed with, and giving the said section a rounded form similar to that of the equipotential lines. Magnetrons constructed in this way retain a high output, and do not require the employment of short-circuiting connections.

In the case of the above calculation the radial wave which penetrates through the slot was assumed to be stationary. It may be regarded as the sum of two traveling waves. If the slot is terminated at aa' by a purely reactive impedance Z , Fig. 2, it is possible to avoid disturbing the wave in the zone which separates aa' from the cathode, and, for this purpose, it is sufficient for the impedance to have such a value that the current and the voltage between aa' are identical with those prevailing in the electromagnetic field in this place. This impedance may be zero, in which case aa' is a short-circuit; in this case aa' must be disposed at such a distance M that the electric field E_a is zero, that is, if the following condition, between the above determined Bessel functions, is realized.

$$\frac{J'p(kM)}{Y'p(kM)} = \frac{J'p(kr_0)}{Y'p(kr_0)}$$

When kr_0 is small $J'p(kr_0)$ is practically zero, in which case M is calculated by the equation:

$$Jp - l(kM) = Jp + l(kr_0)$$

This relation determines the depth M of the radial slits which terminate where the field becomes zero.

For the purpose of simplifying the anode it is desirable to terminate the form of the slot at aa' with a purely reactive self-impedance by cutting in the body of the anode a cylindrical cavity

6

such as is represented in Fig. 3, in which M_c indicates the magnetic coils and V the containing vessel.

Starting at aa' it would be possible to connect at the end of the slot any other form of cavity serving to give a suitable self-impedance at aa' , Fig. 4.

The invention is also applicable to magnetrons with resonant segments, in which there are employed two groups of overlapping segments, the one inside the other, and all of them radiating into a single cavity surrounding the assembly. Such tubes have been particularly described in French Patent No. 835,305, filed March 16, 1938, 1937, to the present applicant. In the case of these magnetrons the slot terminates in the form of an opening at aa' and radiates toward the exterior. The impedance occurring between aa' is complex, and has a real part. The wave which circulates in the slot is not stationary. The incident wave transports a greater energy than the reflected wave. The movement of the wave can be represented by a system consisting of a stationary wave plus a fraction of a traveling wave circulating from the interior toward the exterior. This fraction of a progressive wave represents the useful energy. This energy is furnished by the work of the electronic charges in the interval between the cathode and the anode. Fig. 5 shows such a magnetron, which is particularly described in my patent application Serial No. 759,663, filed July 8, 1947. The segments P_1 belonging to the one group overlap in the segments P_2 of the opposite group presenting an imbricated appearance, and they surround the cathode C . Experience shows that it is desirable to give the segments a bevel in the direction of the cathode. The section of these segments is represented in Fig. 5a giving a partial view in section along $5a-5a$. It has been carried out according to this invention, but instead of being solid these segments may also be hollow, and at the same time be given the rounded form. The invention is of the greatest importance in this case, because with this type of magnetron the expedient of short-circuiting by means of tabs is entirely dispensed with, and the modification of the section of the segments is all that is necessary to reach a high output through the elimination of all the oscillations except one.

Fig. 6 represents another type of magnetron, the so-called flat type, in which the cathode C is flattened instead of rounded, and is surrounded by the anodic segments $P-P$ disposed along a contour which is also flattened. The latter are given a section according to my invention. The results obtained are highly important in that the ordinary method of short-circuiting by means of tabs becomes superfluous when the dimensions of the anodic plane are of the same order of magnitude of or greater than the wave length. The anodic slots may terminate either in a series of cavities connected as with the cylindrical magnetron, or, in the case of the magnetron with resonant segments, in the interior of a single cavity into which all of the slots radiate.

I desire that it be understood that the invention is not limited to the types of magnetrons herein described but that it is applicable to any magnetron or any tube, regardless of its function, in which it is desired to eliminate all the modes of propagation of the electromagnetic wave except one, in such a way that all the actions of the field are in phase with the movements

of the electrons. The invention covers any tube serving for the transmission of short waves, and, more particularly, ultrashort waves, in which this result is obtained by giving a suitable form to particular elements, particularly the anodic segments in the case of the magnetron, which form is similar to or identical with the trace of the equipotential lines at the place of the said elements, in which the said lines correspond to the single wave which it is desired to maintain.

What I claim as new and desire to secure by Letters Patent of the United States is as follows:

1. Magnetron of the type having cavity resonators comprising in the interior of an air-tight envelope, a single cathode, an anode surrounding said cathode and comprising a plurality of segments extending towards the cathode, and whose section in the plane perpendicular to the cathode axis is bounded by a curve in the form of a hairpin whose apex is directed toward said cathode, and means adjacent said magnetron for producing a magnetic field parallel to the axis of the cathode.

2. Magnetron comprising in the interior of an air-tight envelope, a single cathode, an anode surrounding said cathode and comprising a plurality of segments extending towards the cathode, having a section determined substantially by the equation in polar coordinates r and α :

$$\left(\frac{r}{r_0}\right)^p - \left(\frac{r_0}{r}\right)^p = \frac{A}{\cos p\alpha}$$

in which r_0 and A are parameters, and p the mode of propagation of the wave produced by said magnetron, and means adjacent said magnetron for producing a magnetic field parallel to the axis of the cathode.

3. Magnetron of the type having cavity resonators comprising, in the interior of a gas-tight envelope, a cathode, a single cylindrical anode coaxial with and surrounding said cathode, a plurality of slits formed in the said anode, terminating on the one hand in said cavity resonators and opening on the other hand on to the cathode-anode space, said slits defining anodic segments whose section in a plane perpendicular to the cathode axis is substantially in the form of a hairpin whose apex is directed toward the cathode, and means adjacent said magnetron for producing a magnetic field parallel to the axis of the cathode.

4. Magnetron of the type having interleaved

segments comprising, in the interior of a gas-tight envelope, a single cylindrical cathode, two plane parallel supports perpendicular to the axis of said cathode, each support carrying a certain number of anodic elements extending parallel with the cathode and symmetrically arranged around it, the segments of the two supports being interlaced among themselves and having a section in a plane perpendicular to the cathode axis in the form of a hairpin whose apex is directed toward the cathode, and means adjacent said magnetron for producing a magnetic field parallel to the axis of the cathode.

5. Method of making a magnetron tube with split anodes, said magnetron comprising a plurality of anodic segments arranged symmetrically around a single cylindrical cathode of radius r_0 , the said magnetron being designed to oscillate in accordance with the mode p , said method comprising placing a smooth curve of the section of said segment around a point in the axis of said anode taken as a pole, in accordance with the equation in polar coordinates r and α , r being the distance of a point of the curve to said pole and α the polar angle of said point with respect to the axis of symmetry of said sections:

$$\left(\frac{r}{r_0}\right)^p - \left(\frac{r_0}{r}\right)^p = \frac{A}{\sin p\alpha}$$

in which A is a parameter, embodying the anodic sections substantially in accordance with said smooth curve, and arranging the cathode within the anode thus formed in section so as to make its axis coincide with that of the anode.

HENRI GUTTON.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,084,867	Prinz et al.	June 22, 1937
2,233,261	Hollmann	Feb. 25, 1941
2,419,172	Smith	Apr. 15, 1947
2,454,337	Okress	Nov. 23, 1948
2,473,567	Brown	June 21, 1949

FOREIGN PATENTS

Number	Country	Date
103,231	Australia	Feb. 9, 1938
104,874	Australia	Aug. 19, 1938