United States Patent [19]

Magendans et al.

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[45] **May 29, 1973**

[54] **METHOD OF MANUFACTURING ROTARY ANODES FOR USE IN X-RAY TUBE AND ROTARY ANODES MANUFACTURED BY SAID METHOD**

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[30] **Foreign Application Priority Data**

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[51] **Int. Cl.** **H01j 9/16,** H01j 9/44

[58] **Field of Search**.................29/25.1, 25.11, 25.13, 29/25.14, 25.17, 25.18, 420, 504

[56] **References Cited**

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Primary Examiner—John F. Campbell
Assistant Examiner—Richard Bernard Lazarus
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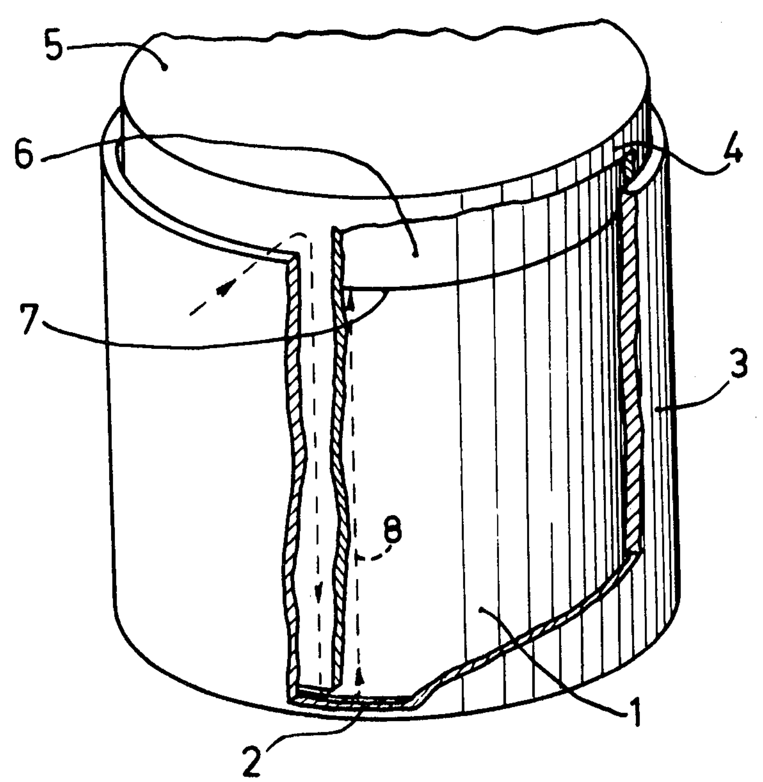
[57] **ABSTRACT**

A novel method of manufacturing a double-layer rotary anode for use in X-ray tubes, in which by means of a "high energy rate forming process" an anode portion mainly made of tungsten and a supporting portion mainly made of molybdenum are secured to each other by one stroke. The composition and the pretreatment of each of these portions may be chosen to the optimum with respect to the required properties such as mechanical strength and heat resistance, which properties are not adversely affected by this process of adhesion in contrast to the effect of known adhering techniques.

6 Claims, 4 Drawing Figures



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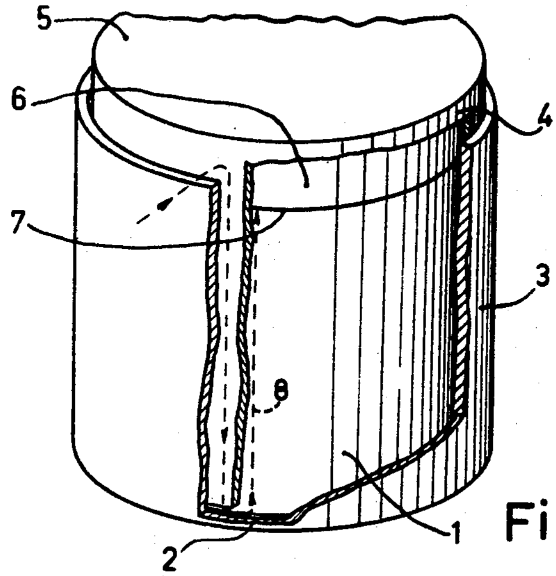

Fig.1

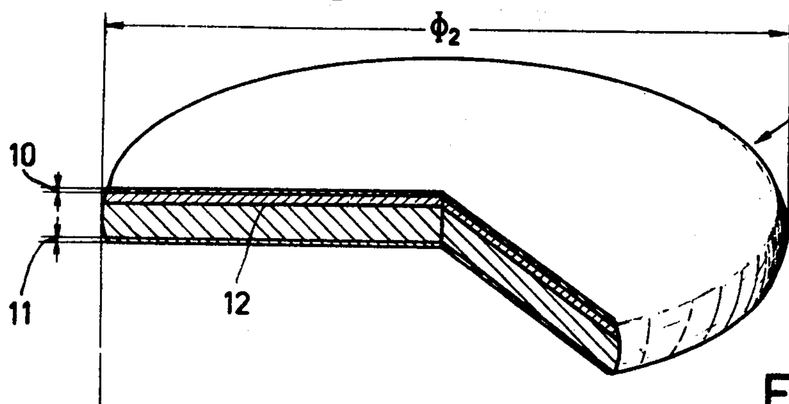

Fig.2

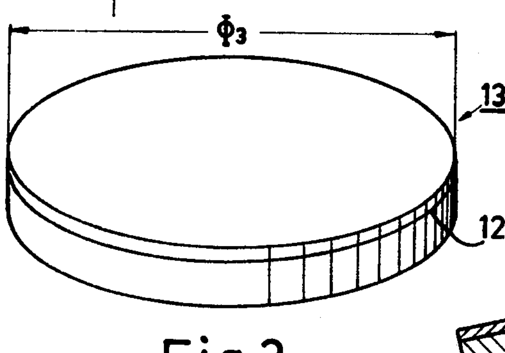

Fig.3

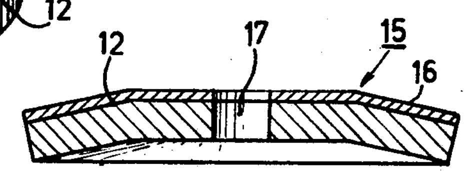

Fig.4

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AGENT

METHOD OF MANUFACTURING ROTARY ANODES FOR USE IN X-RAY TUBE AND ROTARY ANODES MANUFACTURED BY SAID METHOD

The invention relates to a method of manufacturing rotary anodes for use in X-ray tubes, in which a disc-shaped anode portion mainly consisting of tungsten and a disc-shaped support mainly consisting of molybdenum are joined at increased temperature by pressure to form a disc-shaped assembly and to a rotary anode manufactured by carrying out said method.

It is known that with respect to stationary anodes rotary anodes used in X-ray tubes have the advantage of a considerably higher X-ray output, since the latter depends upon the loadability of the anode, that is to say upon the absorption of energy from the electron beam striking the anode and upon the capacity of conducting away this energy converted into heat without giving rise to inadmissibly high temperatures or temperature gradients in the material.

The height of the permissible temperature is limited, for example, by the required mechanical rigidity, which usually decreases with an increase in temperature, whilst the values of the permissible temperature gradients are determined by the mechanical stresses produced by discrepancies in thermal expansions and being likely to give rise to cracks, when exceeding said mechanical rigidity, particularly in the target area of the anode for the electron beam.

Since in operation of a rotary anode the electron beam impacts on all consecutive points of an annular path on the surface the energy provided by the electrons and converted into heat is absorbed per unit time by a considerably larger anode volume so that with the same energy absorption or the same load the mechanical stress involved is lower and the temperatures at the impact area are lower, or transgressions, if any, of permissible temperatures or temperature gradients will occur only at a markedly higher load of the anode, so that higher radiation intensities can be attained than with stationary anodes.

An important improvement in loadability of rotary anodes was expected from a known proposal to form a rotary anode in which the thin disc forming the anode portion proper of a metal of high X-ray output, particularly tungsten is joined with good thermal contact with a disc forming the support of the anode portion and made of a material of high thermal conductibility and, as compared with the material of the anode disc, a low specific weight, for example, molybdenum, so as to form a double layer, so that with the same overall weight a higher thermal capacity and a higher mechanical rigidity are obtained, which permits of using higher speeds of rotation.

The methods hitherto known for the manufacture of double-layer rotary anodes provide results fairly satisfying the aforesaid requirements. Owing to the recent progress, for example in the domain of X-ray tomography, the requirements to be satisfied by rotary anodes have become considerably severer.

The rotary anode is then loaded repeatedly for a short time, it being required to obtain radiation pulses of very high intensity and an accurately defined, reproducible sense.

Owing to this quite different kind of anode load extremely high temperatures may be produced locally on the annular path of electron impact on the anode portion of the rotary anode. As a result the gas mixtures

enclosed in the pores of the usually porous material, particularly of the anode portion, sooner exhibit their harmful effect on the lifetime of an X-ray tube, whilst the higher temperature gradients involved, particularly at the boundary between anode and the support impose severer requirements on the quality of the thermal contact and the durability of the joint between the layers. The requirements for the supporting portion are considerably higher with respect to stability in shape at temperatures considerably higher than usual, at least locally, so that at these temperatures the requirements of mechanical rigidity are higher. The latter requirements can be satisfied with even greater difficulty because in operation recrystallization or an increase rate of recrystallization may occur so that the material is mechanically weakened and less higher speeds of rotation of the anode are permitted.

The inventor has found that the methods hitherto known are not suitable for obtaining rotary anodes, at least not in a simple and cheap manner, so as to meet all requirements imposed on rotary anodes by modern X-ray technology.

From German Patent specification No. 316,554, for example, a double-layer rotary anode is known, which is assembled from separately manufactured anode and supporting portions, the tungsten anode portion being intimately clamped in a recess of the molybdenum supporting portion.

The present requirements relating to a durable, thermally good conducting joint between the layers are found not to be satisfied by this anode.

A further method of joining is proposed in German Utility Model No. 1,622,218, in which a ring punched from tungsten sheet is connected with a molybdenum supporting portion by annealing the two superimposed portions in an inert gas atmosphere, for example, hydrogen and, if required, by exerting pressure. The advantage of this method is that the required ovens are expensive and the process takes much time, whilst, in addition, in this essentially diffusive adhesion, since material is diffused mutually at the interface of the portions, the high annealing temperature may give rise to recrystallization, which weakens the supporting portion mechanically, whereas the annealing period will be uneconomically long with a low annealing temperature.

Inconveniences of the same kind in joining the portions by an annealing process also apply to known methods in which the joint is obtained by a sintering process.

Such a method is known from Dutch Patent specification No. 85,468, in which a separately manufactured tungsten disc having at least 98 percent of the specific weight fixed for pure tungsten is connected in a durable and thermally good conducting manner with a supporting layer of molybdenum powder by sintering the molybdenum powder on the surface of the tungsten disc.

This anode is indeed capable of satisfying the aforesaid requirement of a very low porosity, but the high sintering temperature required also brings about the aforesaid disadvantages of recrystallization or the long duration and expenditure of the method as stated for the annealing process.

These disadvantages also apply to a further method known from Austrian Patent specification No. 218,640, in which a compressed piece having a top layer of powdery tungsten and a bottom layer of molybdenum powder is presintered, the layers being jointed by mould forging.

According to the invention it has been found to be a particular disadvantage in this case that the recrystallization of the sintered supporting portion, which is thus rendered mechanically weaker, seriously hinders stiffening of the supporting portion by mould forging due to the presence of the anode portion sticking thereto by the sintering process, said anode portion having a porous structure and being densified during forging, it is true, but being at the same time hardened so that the risk of rupture during forging is increased.

The invention has for its object to provide a simple, little expensive method taking only a short time and avoiding the aforesaid disadvantages, said method permitting of obtaining a rotary anode comprising an anode portion and a supporting portion and satisfying all the aforesaid requirements.

According to the invention this method is characterized in that in a non-oxidizing, preferably reduced atmosphere the said two portions are heated and subsequently joined by pre-processed faces and subjected to a quick-forming impact process, the thickness of the portions, the temperature at which the portions are joined and the deformabilities determined by the nature and quality of the materials of the portions being chosen so that during the impact the diameters of the two portions increase and their thicknesses decrease, the portions being at the same time rigidly secured to each other, the resultant assembly of the portions being subsequently annealed to remove stress in a non-oxidizing, preferably reducing atmosphere, after which the assembly is subjected in known manner to shaping processes to obtain the final shape of the rotary anode.

The invention provides, more particularly, a method in which a rotary anode is obtained, at least the anode portion of which has a density of material of at least 98 percent, also in the case in which the starting material of the anode portion does not yet exhibit said density of 98 percent.

In a preferred embodiment of the method the oxidation of the portion faces to be joined, which may be harmful in this method of adhesion of the portions, is avoided by joining the discs and arranging them in a fitting, thin-walled envelope of a material not melting during the impact process and being indifferent to the discs, in which envelope the portions are heated and subjected to the impact.

The method according to the invention provides furthermore the advantage of a great freedom in choosing the starting materials for the anode and supporting portions so that the requirements for the rotary anode can be more fully satisfied.

According to the invention a rotary anode having a supporting portion of high mechanical strength can be obtained from materials commercially available, already having the desired high mechanical rigidity, which is not reduced by the method according to the invention.

This method is characterized in that the supporting material comprises at least one constituent capable of reducing the recrystallization rate or of increasing the recrystallization temperature.

The invention will be described more fully with reference to a few embodiments to be described hereinafter, a few details becoming illustrated in the drawing.

In the drawing:

FIG. 1 shows the two portions of the rotary anode in a perspective view, the portions being joined one on the other in a protective envelope.

For the sake of clarity parts of the envelope have been omitted.

FIG. 2 shows the assembly resulting from the impact process in a perspective view, one sector being omitted.

FIG. 3 shows the assembly after removal of a peripheral part.

FIG. 4 shows the assembly having a peripheral part bent over through a small angle, a hole being provided for a shaft, the final shape of the rotary anode being thus achieved.

EXAMPLE I

Method of manufacturing a double-layer rotary anode from a tungsten anode portion and a supporting portion of a cast molybdenum alloy. The staring material of the anode portion is a rod of sintered tungsten having a rectangular section of about 34 × 23 mms, the porosity corresponding to a material density of 60 to 80 percent. From this material wafers are sawed, which wafer is flattened by repeated rolling to a solid sheet of a density of more than 90 percent, the thickness being 5 to 7 mms. From this sheet a circular disc of a diameter of about 49 mms is cut, this disc being smoothed to the optimum at least on one side by grinding and/or polishing so that at the same time a clean surface free of an oxide skin is obtained.

In this example the starting material of the supporting portion is normally available on the marked, that is to say a molybdenum alloy known under the tradename "TZM" containing 0.55 to 40 (0.5) percent of titanium, 0.12 to 0.06 (0.08) percent of zirconium and 0.03 to 0.02 (0.015) percent of carbon, having an adequate density of at least 98 percent and being satisfactorily workable by temperature and deformation treatments already carried out in the factory. The adjuvants of titanium and zirconium in the molybdenum have lowered the melting point so that this material can be cast and the recrystallization temperature is raised to 1,800°C. Thus the increase in mechanical strength achieve in this manufacture of the rotary anode is maintained even under very heavy operational conditions provided in the temperature of the supporting portion remains below 1,800° C.

From a rod of this material a disc is formed having a thickness of, for example, 25 mms and a diameter of 49 mms, smoothed on at least one side by conventional cutting processes.

The anode and supporting discs are then joined by their smooth sides and heated in an oven at a temperature of about 1,650° C. In order to prevent oxidation of the joined smooth surfaces from interfering with the quality of the adhesion during the subsequent impact process the increase in temperature to 1,650° C is carried out in the oven in a non-oxidizing (e.g., nitrogen) or reducing (e.g., hydrogen) atmosphere. According to the invention a further protection against oxidation is obtained by arranging the discs in a box-shaped envelope of the kind shown in FIG. 1 of the drawing. The supporting disc 1 is arranged on the bottom 2 of a cylindrical box 3 having a wall thickness of about 0.4 mm. This box is made of a material, which does not melt during the process and which is inert relative to the anode and supporting materials, for example molybdenum shaped in the form shown by deep-drawing. For the sake of clarity parts of the cylindrical walls of this box 3 and of a second box 4 intimately surrounding the discs 1 and 6 and having a diameter of about 50 mms and made in the same manner as the former, are omitted from the drawing. FIG. 1 shows the thinner anode disc 6. The two discs 1 and 6 join each other in the plane 7 by their clean, smooth surfaces. The narrow gaps between the discs and the inner wall of the box 4 and between the wall of the box 3 and the wall of the box 4 form a very narrow communication channel, which has a maximum length by arranging the thicker supporting disc 1 on the bottom of the box 4 between the ambient atmosphere and the interface 7 of the portions 1 and 6. The supply of oxygen from the ambience causing the harmful oxidation of the adhering faces of the portions 1 and 6 at 7 is impeded and as soon as the portions are arranged in a non-oxidizing atmosphere the oxygen still present in the envelope will be soon exhausted, owing to the small volume of said channel, also because the oxidation of the material of the envelope and of the further faces of the portions, where the oxidation is not harmful, consumes oxygen. A stretched wire, for example, of molybdenum (not shown in FIG. 1) around the outer surface of the box 3 for holding the filled box 3 and the box 4 together when displaced, may improve the seal against the ambience to 100 percent.

After heating at a temperature of 1,650° in an oven (not shown) the joined portions are conveyed as quickly as possible, in order to restrict any oxidation and to minimize cooling, to a quick-action impact forming device.

Such devices, known in the trade under various names, permit of deforming a work piece very rapidly by a high-energy impact. In the method according to the invention such a device known under the name of "USI High-Energy Rate Machine" was used.

The basic construction of such a machine and the possibilities of use thereof are known from an article in the review "Machine Design," September 1965, page 144, under the title of "High-Energy Rate Forming."

Basically the machine comprises a hammer and an anvil (each weighing about 350 kgs), which are moved towards to each other with high speed by means of the expansion of a strongly compressed gas.

To a work piece disposed on the anvil, in this case the joined discs 1 and 6 of the aforesaid dimensions and kinds of material, can be transferred in one stroke within a deformation period of the order of 1 μsec, a deformation energy of about 7,000 kgs/m, which value corresponds to about 80 percent of the maximum capacity of the machine, the gas having to be compressed to about 125 kgs/cm^2.

FIG. 2 illustrates the assembly resulting from the method according to the invention in this example after the quick-forming impact process by means of the above-mentioned press, when the discs 1 and 6 are arranged in the box shown in FIG. 1. The overall height of the joined discs is reduced by the impact to about one fifth, that is to say to about 6 mms.

The diameter of the resultant assembly 9 has then increased to $\Phi 2$ of about 10.5 mms, whilst the edges exhibit slight rounding-off. The molybdenum envelope is also flattened and forms cover layers 10 and 11 on the top and bottom sides of slight thickness, which layers have to be removed afterwards by grinding or polishing.

In order to fully employ the available deformation energy of about 7,000 kgs/m, it has been found to be advantageous to cover the proximal impact surfaces of the hammer and the anvil on the side of the work piece with a layer of graphite. The friction between these faces and the work piece, the diameter of which strongly increases during the stroke, is thus minimized. A very strong adhesion is obtained between the anode portion and the supporting portion by the enlargement of the surfaces, i.e., the contact faces 7 of FIG. 1, into the resultant surface of adhesion 12 of FIG. 2, which is approximately five times larger, together with the enormous pressure at a temperature found to be not more than about 300° C lower than the temperature of about 1,650° C at which the portions leave the oven owing to the short deformation time and hence to slight heat conduction to the machine parts at the termination of the stroke. The high-quality adhesion may be due to the fact that the diameters of the two discs increase so that in the contact face the available structure and any troublesome oxide layers are broken up so to say fresh material not yet having been in contact with the ambience in the two layers forms an intimate bond at a very high pressure. Since the deformation may be considered to have taken place below the recrystallization temperature of 1,800° C of the supporting portion, so that a cold-state deformation is concerned here, the high deformation produced by the impact will provide in addition a high stiffening of the supporting portion.

Apart from the required strength and satisfactory adhesion the method can also provide any desired density of 98 percent of the anode portion and, if desired, also of the supporting portion; this is achieved in this example by starting from anode and support material having already a high density prior to the impact, which density is increased by the density obtained by the impact to at least 98 percent. This example and the following examples clearly show the surprising effect of the invention, that is to say, the great freedom in the choice of starting materials, which may be individually chosen so as to match to the optimum the desired properties of the rotary anode, whilst the rotary anodes can be manufactured in a simple and economic manner. The starting materials, as well as the tungsten already densified to 98 percent, may be obtained on the market. Since the adhesion may be considered to have been achieved by a cold-state operation, which will be explained more fully hereinafter, no expensive ovens are required, which are required for an adhesion by a sintering or annealing process. It is thus possible to obtain a satisfactory adaptation of the deformabilities of the materials of the anode and supporting portions during the impact process. Further possibilities of choosing the nature and properties of anode and support materials will be dealt with hereinafter.

A further advantageous feature of the method according to the invention resides in the fact that the material, particularly that of the electron-beam target plate formed by the surface of the anode portion, does not exhibit a texture. This is conducive to the radiation properties of the anode portion in operation for known special uses in which the direction of the resultant X-ray beam is important, for example, in X-ray tomography as stated above.

Immediately after the impact process the mechanical stress produced in the material is obviated by an annealing process in a non-oxidizing atmosphere of nitrogen and/or hydrogen at a temperature sufficiently low for maintaining any resultant stiffening and thus lying below the recrystallization temperature of the supporting portion, carried out for about one and a half hours. However, this temperature has to exceed a value at which the yield limit of the material disappears, which value is sometimes termed the critical temperature, which is about a few hundred degrees centigrade dependent upon prior deformation for molybdenum. By carrying out the annealing process at about 1,000° C, this phase of the method may be shortened to about 1.5 hours.

FIG. 3 shows the assembly obtained by grinding the disc shown in FIG. 2 into a suitable portion 13 of a diameter 3 of about 80 mms, whilst any remaining parts of the envelope, if used, as shown in FIG. 1 are removed.

The final shape of the rotary anode is frequently desired to be dished. A disc 15 of this shape shown in FIG. 4 can be obtained by cold deformation of a peripheral part 16 at about 1,000 °C.

A hole 17 is drilled in the disc 15 for fastening the resultant rotary anode to a rotary shaft.

If during the impact process the portions 1 and 6 are enlarged to unequal extends, for example, because of the fact that at the working temperature the tungsten anode layer is scarcely or not at all deformed as compared with the molybdenum alloy layer, so that particularly towards the edge of the resultant assembly the thickness of the tungsten layer is too small, or the adhesion is of a less high quality, this may be improved, for example, by adjusting the thickness ratio between the anode and supporting discs, but the inventor has found that this ratio is not critical within a range between at least 1 : 3 and 1 : 6 in this case with the aforesaid choice of material.

EXAMPLE II

Method of manufacturing a rotary anode from a solid tungsten anode disc and a supporting portion of molybdenum with the admixture of potassium silicate reducing the recrystallization rate of the supporting portion.

In this method the process is substantially similar to that of the above Example I, the difference being as follows. The anode portion is similar to that of Example I. The starting material for the supporting portion is molybdenum containing potassium silicate of (10 to 50) 10^{-4} percent, which is obtained by sintering a mixture of powdery molybdenum and potassium silicate.

The resultant material, however, is porous, its density being 50 to 60 percent, so that its deformability is higher than the "TZM" material of the support of Example I. For adapting the deformability to that of the solid tungsten anode disc the supporting portion must have a smaller thickness in order to avoid that the whole deformation energy gets into the supporting portion, since this might lead to an excessively thin, hence probably weak supporting layer for the final anode.

Although in principle the starting material may be sintered and porous, it is preferred in this example to use a sheet of sintered molybdenum with an admixture of potassium silicate pre-densified by forging or flattening, for example, with the aid of the aforesaid "USI High Energy Rate Machine" as a solid starting material for the support, the thickness corresponding with that of Example I.

Within the scope of the invention other adjuvants may be used with the molybdenum, which also raise the recrystallization temperature or reduce the recrystallization rate. The first-mentioned effect is mentioned in the first Example, the second effect is obtained in the present case.

Since the recrystallization takes some time and the process according to the invention may take a very short time, for example, 10^{-3} sec, in contrast to the known method, in which the adhesion is achieved by sintering or annealing, which takes the considerable time of several hours, the short period during which the supporting material may heat up above the recrystallization temperature in the method according to the invention little affects the increase in strength obtained by the impact on the supporting portion. With the high energy supply during the transient deformation the temperature may rise markedly, but the duration is too short for causing significant recrystallization, because of which, as stated above, the adhesion may be considered to having been achieved by a cold-deformation process.

Molybdenum adjuvants reducing the recrystallization rate, for example, potassium silicate, provide the desired maintenance of the strength of the supporting portion at least for a longer period of operation, when the anode is operating at a temperature of the supporting portion above the recrystallization temperature of its material, in this case, molybdenum.

The two preceding Examples relate to a method in which the anode portion is made of solid tungsten, which is obtained from porous, sintered tungsten by rolling or other flattening operations.

Although in the second Example this solid anode portion has stuck to it a preferably solid supporting portion of flattened, sintered material, this does not involve that the porosity of the supporting material in itself is inadmissible for carrying out the method according to the invention. If the anode portion consists of solid tungsten sheet, the porous supporting material may, however, be too thin for obtaining a satisfactory adaptation of deformabilities. However, matching may be achieved, as an alternative, by using for the anode portion porous, sintered tungsten, instead of starting with solid material.

It is known that the porosity of sintered materials may be slightly affected by the manner of sintering, so that the adhesion of two sintered layers, for example, for a sintered tungsten sheet for the anode portion and a sintered molybdenum sheet for the supporting portion, may be obtained by the method according to the invention.

It should be noted that in order to obtain by the method according to the invention rotary anodes of particular strength and stability in shape, the supporting portion may be stiffened by known expedients, for example, the incorporation of silicon carbide needles or of a tungsten wire grid.

What is claimed is:

1. A method of manufacturing rotary anodes for use in X-ray tubes wherein a sintered disc-shaped anode portion mainly of tungsten and having a material density of from about 60 to 90 percent is provided and a disc-shaped supporting portion mainly of molybdenum are joined into a disc-shaped assembly, characterized by machining at least one face of said anode and supporting portions, heating said anode and said support-

ing portions in a non-oxidizing atmosphere, joining the machined faces of said anode and supporting portions together and subjecting said joined anode and supporting portions to a quick-deforming impact process while in said atmosphere so that during the impact process step the diameters of said anode and supporting portions increase and the thicknesses decrease, while said joined anode and supporting portions are firmly secured to each other, and annealing the resultant assembly of said joined anode and supporting portions in a non-oxidizing, atmosphere, whereby said joined anode and supporting portions are joined intimately together and stress relieved.

2. A method as claimed in claim **1,** which includes increasing the density of the material comprising said anode portion and said supporting portion prior to the impact process step, whereby at least said anode portion exhibits a density of at least 98 percent after the impact process step.

3. A method as claimed in claim **2,** which includes increasing the density of said anode and said supporting portions prior to the impact process step by flattening said anode and said supporting portions.

4. A method as claimed in claim **1,** which includes arranging said anode and said supporting portions with their machined faces one on the other within a close fitting thin-walled envelope prior to the heating step.

5. A method as claimed in claim **1,** wherein said heating step is carried out in a reducing atmosphere.

6. A method as claimed in claim **1,** wherein said annealing step is carried out in a reducing atmosphere.

* * * * *

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,735,458 Dated May 9, 1973

Inventor(s) FREDERIK MAGENDANS and BERNHARD JOSEF PIETER VAN RHEEHEN

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

IN THE TITLE PAGE

The last name of the second inventor should be --Rheenen--

Signed and sealed this 18th day of June 1974.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

PO-1050
(5/69)

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