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[54] **METHOD FOR INCREASING THE POWER X-RAY TUBES AND APPARATUS FOR CARRYING OUT THE METHOD**

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[58] **Field of Search** 313/60, 330

[56] **References Cited**

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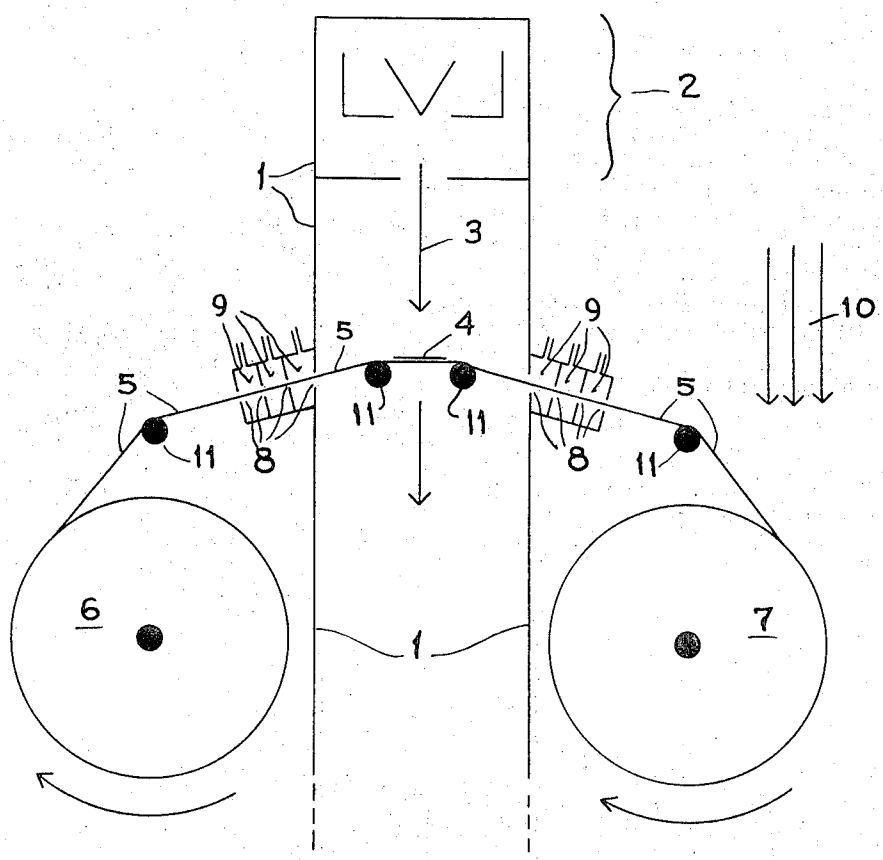
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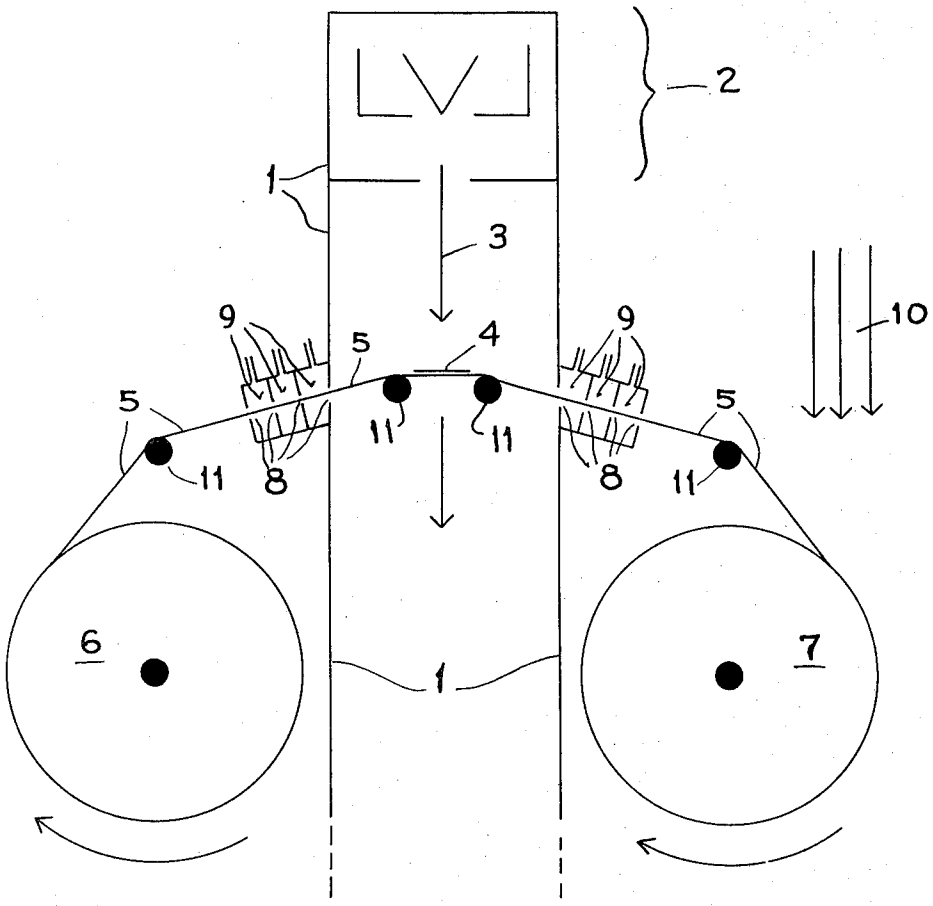
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[57] **ABSTRACT**

A method for increasing the electron beam density and power of X-ray tubes, and a novel X-ray tube construction, wherein the target is in the form of an elongated member of target material, such as a strip, tape or filament, which is mechanically moved across the path of the electron beam to continuously present cold target material to the beam and remove heated target material from the electron beam path for cooling at a location spaced therefrom.

10 Claims, 1 Drawing Figure




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METHOD FOR INCREASING THE POWER X-RAY TUBES AND APPARATUS FOR CARRYING OUT THE METHOD

The invention relates to a method for increasing the power of X-ray tubes and apparatus for carrying out the method.

As is well known, in the generation of X-ray radiation by slowing down electrons (ions) in a target more than 99 percent of the energy of the electrons (ions) impinging on the target is converted to heat. In powerful X-ray tubes the heat must be dissipated by cooling.

The increase of X-ray radiation density (X-ray radiation energy per unit area and unit time) by increasing the electron stream density (beam value) with the aid of known electron-optical steps can only be obtained to a definite limit. This limit is due to the fact that damage to the target should be avoided and said target must not be heated to melting temperature. If cooling is provided the load limit is reached at a correspondingly higher electron beam density than is the case without cooling of the target.

The X-ray radiation density which is technically possible thus depends primarily on the effectiveness of the cooling of the focal spot. It does not however depend on the power of the electron beam producing system with which of course material destruction is possible (for example in electron beam drilling).

The prior art offers the following possibilities for cooling anode targets:

1. Radiation cooling

The heat is irradiated into the (cooled) surroundings. Radiation cooling is used for example in the transmission method wherein the electron beam is directed onto a thin foil. An effective thermal contact to the foil support is hardly possible. Thermal conduction can take place only via the small foil crosssection. Its contribution to the cooling is small compared with the radiation cooling.

A disadvantage is that the load on the target in continuous operation and after setting stationary conditions can only be increased until the maximum amount of heat is dissipated by radiation from a unit area of the target per unit time. This amount of heat depends on the temperature difference between the target and surroundings and the nature of the surface of the target and the surrounding (cooled) walls and may be expressed with the aid of the radiation laws. With optimum cooling the maximum amount of heat is irradiated when in the target the temperature is just below the melting temperature.

2. Cooling with water, oil and other liquids

This is a frequently used cooling method for solid anodes as employed for example in reflection arrangement. In this case the anode — in the case of sealed-off tubes the entire tube as well — is brought into good thermal contact with the coolant liquid. The latter may also be vaporized (boiling cooling).

A disadvantage is that the load of the target in continuous operation and after setting stationary conditions can be increased only until the maximum possible heat flow density by thermal conduction and heat exchange is reached, i.e., until the maximum amount of heat is dissipated by thermal conduction in the target and from the target into the cooling liquid by unit area of the target per unit time. This amount of heat depends on the thickness, geometry and thermal conductivity of the target, the temperature gradient, the thermal contact with the coolant liquid, the speed thereof, etc.. The maximum amount of heat is dispersed when — with optimum cooling — the temperature on the target surface is just below the melting temperature.

The problem underlying the invention is to overcome or avoid the disadvantages of the aforementioned cooling methods and apparatuses and thus obtain more powerful X-ray tubes. According to the invention this problem is solved by a method in which the heat produced at the location of the X-ray focal spot by the bombardment with electrons or ions in the target is removed mechanically.

In a further development of the invention the mechanical removal of the heat from the location of the X-ray focal spot is effected by bringing the heated target area out of the region of the focal spot. The target is preferably moved at such a speed that the temperature of the bombarded target area remains below the melting temperature of the target.

An apparatus suitable for carrying out the method of mechanical heat removal according to the invention resides in that the target is constructed as a long strip or belt which is moved past under the electron or ion beam.

The invention will be explained hereinafter with reference to an example of embodiment with the aid of the associated drawing, which shows schematically an X-ray tube operating by the method according to the invention.

In the drawing **1** denotes a X-ray tube which comprises in its upper portion an electron or ion beam generating system **2.** The electron or ion beam **3** generated by this source impinges on a target at the point **4.**

According to the invention the target has the form of a 20 μm thick tape or strip **5** which is moved at high speed relatively to the electron beam **3.** The target strip **5,** used in this case in transmission arrangement, consists for example of a plastic support which is metallized on the bombarded side. An example of a tape strip which may be satisfactorily used as the target strip **5** is conventional metal coated magnetic recorder tape of the type sold commercially for magnetically storing information in computers. For a reflexion arrangement a thin metal tape may also be used as target.

The heat is dissipated by conveying practically all the heat produced at the location of the focal spot **4** directly from said location by moving the target strip **5,** the heated target material itself thus being removed from the location of the focal spot **4** so that the entrained heat quantity is not dissipated in the focal spot itself or the immediate vicinity thereof but relatively remote therefrom, mostly outside the actual X-ray tube, where it is given up to the surroundings by conventional cooling. The speed of the target material is approximately equal to the speed of the heat removal. In one example, a satisfactory target tape speed was 6 meters per second, although it will be appreciated that faster speeds may be employed where greater heat removal rates are desired without mechanical injury to the tape strip. According to the invention, in continuous operation of the X-ray tube the removed heated target material is continuously replaced by cold material.

Consequently, no real cooling of the target takes place at the location of the X-ray focal spot **4**; the cooling is displaced some distance from the location of the

heating, making it possible to cool the target outside the X-ray tube **1** after removal of by far the greater part of the produced heat with the target strip **5** out of the range of the focal spot **4.** The "cooling" of the focal spot is effected by replenishment with cold target material.

The tape **5** may be very long, for example 1,000 meters, and wound from and onto spools **6** and **7** respectively. The spool **7,** which receives the heated strip **5,** is cooled in a relatively straightforward manner. If, as illustrated here, the strip **5** is removed from the evacuated tube **1** through slots **8** via differential pressure chambers **9,** the spool **7** can be cooled by air **10** directed toward the spool from a fan type blower of conventional construction (not shown). The two guide pins **11** may be constructed of metal having good thermal conduction properties so that they serve simultaneously to carry away the heat as well as providing stationary guide surfaces and to hold the strip **5** in constant position. When the entire strip length has been unwound in one direction the strip movement maybe reversed.

According to the invention the strip **5** may be made in the form of an endless loop guided in any suitable manner through a desired path externally of the X-ray tube, for example by training the strip over guide rollers externally of the tube. The length is chosen as far as possible so that the residence time of a given point of the strip (between two passages through the focal point) in the cooled surroundings is sufficient for complete cooling. Alternatively, the endless loop maybe crossed once by rotating the strip through 180° about its longitudinal axis to form a mobius loop, thus doubling the interval between two passages through the focal point for the same strip length. According to the invention, instead of the strip a metal wire or a metallized quartz filament maybe used in which case the long metal wire or filament is unwould from the spool **6** and wound on the spool **7,** after passing over the guide surfaces provided by the guide pins **11** and passing through suitably shaped slots or recesses in the differential pressure chambers **9.**

Following the focal spot **4,** seen in the direction of movement of the strip, a temperature sensing device may be provided which controls the speed of the target strip in dependence upon the heating thereof. According to the invention the guide pins **11** may also be constructed as temperature sensing devices.

In particular, the invention obviates the disadvantages of known cooling methods enumerated under (1) and (2):

1. Radiation cooling

In the method according to the invention the maximum heat flow density explained in detail under point (1) for radiation cooling depends only insignificantly, if at all, on the radiation laws, i.e., on the temperature difference between the target and surroundings and the nature of the surfaces, being determined almost exclusively by the speed of the target. The latter can be easily increased enough to enable a considerably higher loading of the X-ray focal spot than with conventional radiation cooling. The load limit and thus (for a given spot size) the maximum X-ray radiation density is reached when at maximum target speed the temperature is just below that which would damage the target.

2. Cooling with water, oil and other liquids

In the method according to the invention the maximum heat flow density as explained in detail under point (2) for thermal conduction and liquid cooling depends only insignificantly, if at all, on quantities such as thickness, geometry and thermal conductivity of the target, temperature gradient, thermal contact with the cooling liquid, speed thereof, etc., once again being determined almost exclusively by the speed of the target. The speed maybe easily made large enough to permit a considerably greater loading of the X-ray focal spot than is the case with conventional conduction and liquid cooling. The maximum X-ray radiation density is obtained at maximum target temperature and target speed.

The advantages of the invention are summarized again under the following three points.

1. X-ray tubes having the mechanical heat removal according to the invention permit substantially higher maximum X-ray densities than X-ray tubes with conventional cooling. In the case of focal spots of small extent in the direction of movement of the strip, wire or filament, for example a microfocus in line form of 50 μm width, the radiation densities obtainable are several powers of 10 times greater than with conventional tubes.

2. X-ray tubes having the mechanical heat removal according to the invention permit substantially higher radiation powers than tubes with conventional cooling and comparable focal spot sizes.

3. In X-ray tubes having the mechanical heat removal according to the invention the ratio of X-ray radiation density to thermal radiation density, or the ratio of the corresponding radiation powers in the vicinity of the focal spot, is substantially higher, i.e., more favorable as regards protecting the irradiated object from heat than with tubes having conventional cooling. The method according to the invention thus provides relatively cold X-ray sources.

What is claimed is:

1. A method of increasing the X-ray radiation density capacity of X-ray tubes having a moving anode, comprising passing an elongated target tape having a continuous metallic portion along its length through the X-ray focal zone of an X-ray tube to serve as a moving anode target for the bombarding beam of electrons or ions in the X-ray tube, and mechanically carrying away the heat generated at the X-ray focal zone by bombardment of the moving anode target tape by transferring the portions of the target tape being bombarded away from the region of the focal zone at such velocity that the heating of the bombarded target tape material remains below a temperature critical for the target material.

2. Apparatus for increasing the X-ray radiation density capacity of X-ray tubes comprising an X-ray tube envelope having a subatmospheric pressure therein and means for generating and directing a beam of electrons or ions to a target zone within the envelope, a moving anode target for the X-ray tube in the form of an elongated thin web of material having a large longitudinal dimension relative to its transverse dimension and including a metallic portion for producing X-rays responsive to bombardment by the beam, means for continuously feeding the elongated target web along a feed path located in part externally of the X-ray tube and passing through the target zone to continuously present cool target web portions in the path of the beam and

withdraw beam-heated-portions of the web from the beam path during bombardment thereof, the X-ray tube enevelope having inlet and outlet openings therein for passage of the target web from externally of the envelope to the target zone and return to locations externally of the tube, and inlet and outlet pressure locks along the web feed path at said openings to preserve the subatmospheric pressure conditions within the envelope.

3. Apparatus according to claim **2,** wherein the target is constructed as tape or strip.

4. Apparatus according to claim **2,** wherein the target is constructed as filament.

5. Apparatus according to claim **2,** wherein the target is a metal wire.

6. Apparatus according to claim **2,** including metallic guide pins in the tube over which the target web is trained to position the web in the target zone.

7. Apparatus according to claim **2,** wherein the target is constructed as endless loop.

8. Apparatus according to claim **7,** wherein the target forms an endless loop turned through 180° to define a Mobius strip.

9. Apparatus according to claim **2,** including a supply reel and a take-up reel supported externally of the X-ray tube, the target web being trained about said reels, and means for driving at least one of the reels to withdraw web material from the supply reel and wind web material on the take-up reel.

10. Apparatus according to claim **9,** including forced air propelling means for blowing cool air on the web portions withdrawn along the feed path externally of said outlet pressure lock.

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