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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : G01N 23/04, G06T 11/00	A2	(11) International Publication Number: **WO 00/46592** (43) International Publication Date: 10 August 2000 (10.08.00)

(21) International Application Number: PCT/NL00/00076

(22) International Filing Date: 7 February 2000 (07.02.00)

(30) Priority Data:
1011222 5 February 1999 (05.02.99) NL

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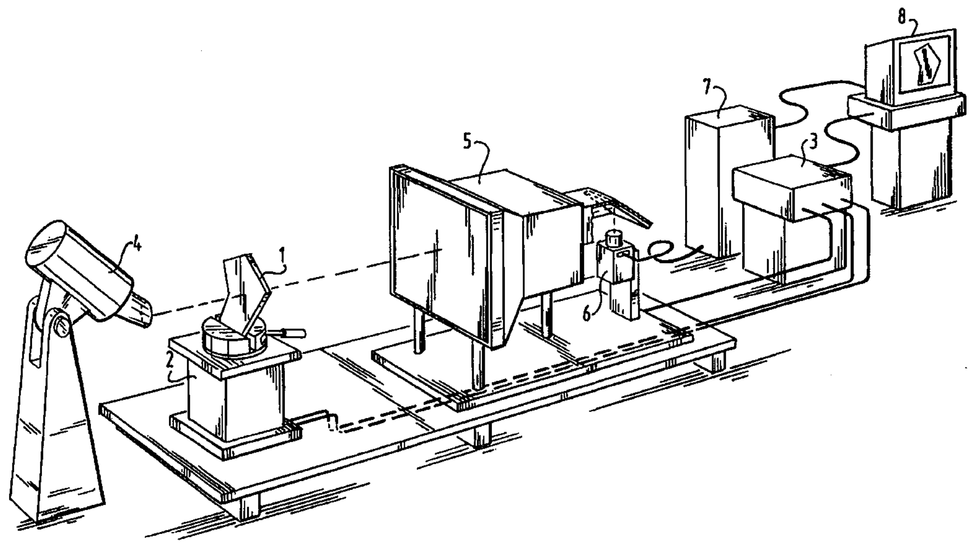
(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
In English translation (filed in Dutch).
Without international search report and to be republished upon receipt of that report.

(54) Title: METHOD AND APPARATUS FOR EXAMINATION OF BODIES BY PENETRATING RADIATION



(57) Abstract

The invention relates to a method and an apparatus for examining bodies by means of penetrating radiation, wherein the body is irradiated with a beam of rays which is emitted by a radiation source and which is detected by a radiation detector and converted into electrical signals, wherein the signals are processed in a digital computer in order to produce a three-dimensional reconstruction of the density distribution of the examined body, and wherein the source and the detector carry out a substantially helical movement relative to the body, wherein: the source and the detector are both stationary; the body is moved; the source emits a conical radiation beam; and the detector extends in two directions of the same dimension. The method is particularly suitable for examining bodies of material with a density greater than 2000 kg/m^3, for instance a turbine blade.

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METHOD AND APPARATUS FOR EXAMINATION OF BODIES BY PENETRATING RADIATION

The present invention relates to a method for examining bodies by means of penetrating radiation, wherein the body is irradiated with a beam of rays which is emitted by a radiation source and which is detected by a radiation detector and converted into electrical signals, wherein the signals are processed in a digital computer in order to produce a three-dimensional reconstruction of the density distribution of the examined body, and wherein the source and the detector carry out a substantially helical movement relative to the body.

Computer tomography is generally known.

In the classical forms of method associated with this medical-diagnostic technique two different movement configurations are applied.

There are thus machines of the "rotate only" type, wherein source and detector perform a circular movement around the body. It will be apparent that herein only a narrow part of the body, i.e. only a "slice", is examined. For this purpose the radiation source is equipped to generate a beam of rays which is very narrow in one direction and which widens in fan shape in the other direction. The detector is of course adapted hereto.

In order to examine a part larger than a "slice" of the body, the body is shifted after an examination in a first "slice" is completed, whereafter a subsequent "adjacent" slice is examined. This process is continued until a complete reconstruction of the density distribution within the examined area is obtained. The attempt is made here to have the examination of each of the "slices" take place separately, so that no mutual influencing occurs.

Machines are further known of the "translate and rotate" type. In these machines source and detector perform in the first instance a linear movement in a plane, whereafter a part of a rotating movement is carried out within the same plane. Such a movement configuration leads to similar results as the first mentioned. Owing to the mechanical problems involved in this latter type of configuration, this type has fallen into disuse.

It is pointed out here that in this type of movement configuration the movements in the direction perpendicular to the examined plane usually take place by shifting the support on which the body to be examined is placed instead of shifting the source and the detector. This results in any case in a structurally simpler solution.

Apparatus for performing such a method nevertheless continue to be structurally complicated installations. In such apparatus only a part of a body for examining is usually examined, wherein usually only a part of the human body, for instance only a head or for instance only the thorax, is examined.

The present invention has for its object to provide such an apparatus, wherein a body can be examined in its entirety. The field of application here does not lie in the first instance in medical examinations, but in materials testing. It is usually wished to be able to examine a whole body, for instance a turbine blade, for cracks and other defects. The prior art apparatus is less suitable for this purpose; the examination, "slice" for "slice", takes a relatively long time.

The object of the present invention is to provide such a method which can be performed more quickly, particularly in the case of elongate objects.

This objective is achieved in that the source and the detector are both stationary, the body is moved, the source emits a conical radiation beam and the detector extends in two directions of the same dimension.

These measures have the result that a large amount of data is converted simultaneously into electrical signals in the detector. This is caused by the cone shape of the radiation beam and the two-dimensional structure of the detector. A fact of further importance is that the mutual movement between the source and the detectors on the one hand and the object to be examined on the other is helical. The helical movement is regularly interrupted for taking of a "photo". It is herein necessary to make use of quite a long exposure time. This is associated with the great density of the material for examination and the limited power of the X-ray source.

It is surprising here that these two measures can be combined. Both measures after all make use of complicated coordinate systems, whereby the number of conversion computations to an unequivocal coordinate system is large.

According to another preferred embodiment a body with a specific density greater than 2000 kg/m^3 is examined, for instance a turbine blade manufactured from metal.

The examination of material with such a great density causes some problems; on the one hand the great density results in a stronger attenuation of the radiation, such that either a larger radiation dose must be applied, or detectors must be applied which are adapted to detect smaller quantities of radiation.

Another problem, which occurs particularly in bodies with a high density, is the so-called "hardening" of the radiation. This means that when a radiation is emitted within a determined band width the distribution of the radiation within this band width changes during the passage through the body; radiation components of a greater wavelength are adsorbed better than radiation components of a smaller wavelength. This also results in a disruption of the usually assumed linearity of the attenuation. According to a preferred embodiment this is taken into account during the computations.

Another problem which occurs in the examination of bodies with a great density is the greater scattering. In order to eliminate the effects of scattering as far as possible, it is important to apply collimators with a small incident angle, preferably at least a factor of two smaller than usual.

According to another preferred embodiment an image amplifier is used. This image amplifier increases the intensity of the radiation, so that even when there is a great attenuation by the body to be examined the radiation can be detected more easily.

According to yet another preferred embodiment the digital computer computes the rotation axis and the rotation movement of the source and the detector relative to the body.

This measure makes it possible to correct possible alignment errors.

According to yet another preferred embodiment the computer divides the volume in which the body is situated into areas with a density above and below a predetermined density, and the computer performs independent computations within each segment.

According to a specific embodiment use is made in the discrete Fourier analysis of a discrete filter with fixed parameters.

The accuracy of the reconstruction is hereby greatly improved.

According to a further preferred embodiment, "back projection" is performed initially and the filtering performed subsequently.

This sequence makes it possible to arrive at a reconstruction with an acceptable accuracy even in the case of large cone angles. It is pointed out here that, in accordance with the so-called "Feldkamp"-algorithm, it is known to initially perform the filtering and then the "back projection". This already results however in great variations at small top angles.

The method according to the embodiment avoids these problems.

The segmentation enables considerable simplification of the computations. The large differences in density between areas where material is present and where no material is present make it possible to carry out such a separation. This separation brings about a significant simplification of the computations, since the areas without material are ignored.

According to a final preferred embodiment, the computer carries out measurements and calculations of a differing precision within different volume segments. Due to this configuration there is the possibility of more accurate examination of particular, important segments, for instance critically loaded components of for instance turbine blades. It is in any case of the greatest importance to obtain as much information as possible about these specific parts.

The present invention will be elucidated hereinbelow with reference to the annexed figure, which shows a cross-sectional view of an apparatus according to the present invention, which is adapted to perform a method according to the present invention.

The figure shows a turbine blade 1 to be examined which is fixed in a clamping device 2. Clamping device 2 comprises means for causing the turbine blade 1 for examination to displace in a helical movement. For this purpose use is made of a control computer 3. For generating X-radiation use is made of an X-ray source 4. On the other side of turbine blade 1 is arranged a radiation amplifier 5 which is particularly suitable for amplifying radiation within the wavelength emitted by X-ray source 4.

Although use is made here of a source for emitting X-radiation, it is possible to apply radiation sources with a wavelength outside the range of X-radiation, for instance gamma radiation. In that case the radiation amplifier 5 will of course also have to be adapted for the relevant radiation.

A video camera 6 is mounted connecting onto radiation amplifier 5. It is assumed herein that the radiation amplifier converts the radiation to visible light which can be recorded by the video camera. The signal from the video camera is fed to a computer 7 which is coupled to a screen 8. Computer 7 performs the relevant calculations. It is also possible to use another computer for this purpose. As already stated in the preamble, use is herein made of algorithms which are based on the Fourier thesis; herein a matrix of exceptionally large dimensions is, as it were, solved. This computation method seems more satisfactory and to result in faster and more accurate results than the method known from the prior art for determining the matrix by means of an iterative distribution process. When the density distribution is known, it is brought into model form and made visible on screen 8 by means of a 3D-visualisation program. Such programs are per se known. It is possible herein to observe the body from the empty spaces in the examined body.

It is also possible to cut away determined parts of the body, so that a better image of the forms of the body can be obtained. This measure is particularly applicable here to turbine blades; these are in any case provided with internal channels, wherein a small wall thickness is present between the channels and the outside of the blade. It will be apparent that with the high loads on these turbine blades this wall thickness must exceed a minimal dimension. These aspects can be well detected by means of the method according to the present invention.

In addition, a correct geometry of the interior of a blade is of crucial importance for cooling of the blade.

CLAIMS

1. Method for examining bodies by means of penetrating radiation, wherein the body is irradiated with a beam of rays which is emitted by a radiation source and which is detected by a radiation detector and converted into electrical signals, wherein the signals are processed in a digital computer in order to produce a three-dimensional reconstruction of the density distribution of the examined body, and wherein the source and the detector carry out a substantially helical movement relative to the body, **characterized in that**

- the source and the detector are both stationary,
- the body is moved,
- the source emits a conical radiation beam, and
- the detector extends in two directions of the same dimension.

2. Method as claimed in claim 1, **characterized in that** a body with a specific density greater than 2000 kg/m^3 is examined, for instance a turbine blade manufactured from metal.

3. Method as claimed in claim 2, **characterized in that** use is made of an image amplifier placed between the object and the detector.

4. Method as claimed in any of the foregoing claims, **characterized in that** the digital computer computes the rotation axis of the rotation movement of the source and the detector relative to the body.

5. Method as claimed in any of the foregoing claims, **characterized in that** the computer divides the volume in which the body is situated into areas with a density above and below a predetermined density limit, and performs independent computations within each segment.

6. Method as claimed in claim 5, **characterized in that**

- the examined body comprises areas with a geometry substantially differing from each other,

- the segments are chosen to substantially coincide with the areas,

- measurements of differing accuracy are performed within the segments, and

- the computer performs computations of a differing accuracy within different volume segments.

7. Method as claimed in any of the foregoing claims, **characterized in that** use is made of Fourier analysis along line integrals during making of the reconstruction.

8. Method as claimed in claim 7, **characterized in that** use is made in the discrete Fourier analysis of a discrete filter with fixed parameters.

9. Method as claimed in any of the foregoing claims 6, 7 or 8, wherein the algorithm is adapted to perform "back projection" and filtering, **characterized in that** back projection is performed initially and the filtering performed subsequently.

10. Method as claimed in any of the claims 2-8, **characterized in that** reconstruction of the body is presented as a 3D image.

11. Method as claimed in claim 10, **characterized in that** parts of the 3D image of the examined body are removable.

12. Method as claimed in any of the foregoing claims, **characterized in that**

- a radiation source is used which emits a radiation susceptible to hardening, and

- the effects of hardening are at least partially compensated during reconstruction by a correction computation, wherein use is made of a correction model obtained during previous measurements.

13. Apparatus for examining a body by means of penetrating radiation, comprising:

- a support for a body for examining;
- a radiation source for emitting a conical beam of penetrating radiation through the body for examining;
- a detector extending in at least two dimensions for detecting the radiation which has passed through the body;

characterized in that the support is adapted to cause the body to pass through a helical movement relative to the stationary source and detector.

14. Apparatus as claimed in claim 13, **characterized in that** the source and the detector are dimensioned to examine bodies of material with a density greater than 2000 kg/m^3, for instance a turbine blade.

15. Apparatus as claimed in claim 13 or 14, **characterized in that** an image amplifier is placed between the source and the detector.

16. Apparatus as claimed in claim 14 or 15, **characterized in that** between the detector and the body for examination or between the image amplifier and the body for examination is placed a collimator, the incident angle of which is at least a factor of two smaller than the incident angle of collimators applied in accordance with normal dimensioning for examining living bodies.

17. Apparatus as claimed in claims 13-16, **characterized in that** the detector comprises a video camera.

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