Title: X-RAY EQUIPMENT FOR TOMOSYNTHESIS

Abstract: X-ray equipment for tomosynthesis has two pilot bearings in the form of opposite vertical pillars having common vertical symmetry plane; carriage placed on said pillars with possibility of adjustable reciprocal movement; arcwise rails, which are oppositely fixed onto said carriages and circumscribe an area of placement of examined patients, a controllable collimated X-ray emitter and a digital X-ray receiver, which are oppositely positioned onto said arcwise rails with possibility of controllable unidirectional synchronous angular movement and equipped with facilities for positional checking of theirs; a control unit; a data processing unit; and a tomosynthesis unit. This equipment characterized in that an optical axis of exit aperture of said X-ray emitter (and, in operative position, geometrical axis of X-ray beam) is always perpendicular to the said X-ray receiver surface.
Published:

— with international search report (Art. 21(3))
X-RAY EQUIPMENT FOR TOMOSYNTHESIS

Field of the Invention

This invention relates to such X-ray equipments for tomosynthesis, which are meant for differential diagnostics of a state and diseases of human internals (especially of adnexa within a chest or an abdominal cavity and blood vessels of legs) at vertical position of patients.

Background Art

At present X-ray equipments for tomosynthesis are well known. They must:

Move an X-ray emitter relative to a patient's body (and/or a patient's body relative to such emitter) along a desired path,

Treat with X-rays any tested slice of a patient's body at each predetermined position at the desired path,

Receive X-ray radiation passed through any examined slice,

Generate a digital radiographic image of the slice of a patient's body corresponding with each alternate predetermined position, and

Synthesize at least one tomogram on basis of said digital radiographic images.

Software for tomosynthesis is, as a rule, publicly available (see, for example, US 2008/0219567 A1).

Moreover, it is no problem to program control over mechanisms, which can be used in X-Ray equipments for tomosynthesis.

And, finally, now great number of low-dose digital X-ray receivers is available. In comparison with conventional radiophotography, such receivers allow considerable decrease radiation exposure of patients during each examination (generally no less than 20 times). Typical structure of these receivers is well known at present (see, e.g., patents based on WO 98/11722 and WO 2006/049589; US 6,002,743; US 6,370,225; RU 105553 U and many others). Each such receiver has serially arranged a flat converter of X-radiation into the visible light and a set of optoelectronic transducers, whose fields of view are partly overlapped and which generate a set of fragmentary analog video signals. These transducers are connected via ADCs to a data-processing unit that generates integral digital video signal.

Against this background, designers of X-ray equipments for tomosynthesis compete generally in development of bearings and drivers of X-ray units and in their spatial arrangement with a glance of placement of a patient's body, to wit in the lying (horizontal), or in the sitting, or in the standing (vertical) position.

Note. It is clear for each person skilled in the art that aforesaid word combination «X-ray units» refers hereinafter to an X-ray emitter and an X-ray receiver in the aggregate.

Many known X-Ray equipments for tomosynthesis permit examination of patients only in the lying position (see, for example, US 6,940,943 B2). They have:

A practically flat horizontal roentgenoparent table for placement of a patient;

An arcwise rail having angular size up to 180°, which has located above said table so
that said rail and said table have common vertical symmetry plane;

A carriage, which has placed on said arcwise rail and is equipped with a controllable reversible drive of non-interruptible or stepwise angular movement along this rail;

A controllable X-ray emitter, which has fixed onto said carriage and is equipped with an output collimator for desirable shaping of X-ray beam;

Optionally, an adjuster of distance between said X-ray emitter exit aperture and said table;

A digital X-ray receiver arranged under said table;

A controllable drive for reciprocating movement of said X-ray receiver along said table;

At least one facility for positional checking of said X-ray emitter and said X-ray receiver relative to a patient's body;

A control unit, to which said controllable drives; said facility and a starter of said X-ray emitter are connected;

A data processing unit generating integrated digital radiographic images, and

A tomosynthesis unit connected to the said data processing unit.

Horizontal table allows examining any patients including seriously ill. However, above described equipments have unavoidable disadvantages, namely -

(1) They are unsuitable in principle for diagnostics of certain diseases, such as pulmonary edema, deficient vascular permeability of legs and some other, which require to examine patients only in vertical position;

(2) They are massive, cumbersome and, correspondingly, labor-intensive during their making and maintenance,

(3) They require external protectors of patient's genitals for over-radiation, and

(4) They do not ensure stability of tilt angle of geometrical axis of X-ray beam to the digital X-ray receiver surface owing to oncoming movement of the X-ray emitter along a circular arc and said receiver along a straight line. Hereupon an X-ray beam path length within a patient's body during each diagnostic session varies the more appreciably, the more deviation of geometrical axis of X-ray beam from perpendicular to the said X-ray receiver surface. This causes irregular scale distortion of consecutive oblique radiographic images and superposition of organs and tissues images similar to conventional X-radiography.

First disadvantage is eliminated only partly in X-ray equipment for tomosynthesis according to the EP 2308376 B1. This equipment has a drive for rotational displacement of the table (together with the digital X-ray receiver) around one horizontal axle. The controllable X-ray emitter of said equipment is arranged on the end of a U-shaped lever-carrier that can execute a swinging movement around another horizontal axle. This allows examining patients in horizontal and vertical positions.

Unfortunately, second disadvantage is not eliminated, but even intensified. Really, equipment according to the EP 2308376 differs from the foregoing analog by inclusion of the drivers for rotational displacement of the table and the lever-carrier of the X-ray emitter and by use of a drive for reciprocating movement of the table. Therefore, this equipment is more
massive, cumbersome and labor-intensive during its making and maintenance,

Third disadvantage is not eliminated altogether.

Finally, fourth above-mentioned disadvantage cannot eliminate in principle because swinging movement of X-ray emitter in the equipment according to the EP 2308376 is equivalent to its movement along arcwise rail in the equipment according to the US 6,940,943.

This forces to limit the range of options of divergence of X-ray beam geometrical axis from perpendicular to the said X-ray receiver surface only up to ±20° (see Table 1 in the article of Tsutomu Gomi, Hiroshi Hirano, Masahiro Nakajima, Tokuo Umeda "X-ray digital linear tomosynthesis imaging" // J. Biomedical Science and Engineering, 201 1, 4, 443-453).


Illustrations in these articles show that such X-ray equipments including NewTom 5G Cone Beam 3G Imaging (see Dental Market 2012; 2, p.75-77) are characterized by vertical disposition of the X-ray units’ symmetry plane and, correspondingly, by possibility of their unidirectional and synchronous movement along arc trajectories disposed in this plane.

This is comfortable for examination of aforesaid small parts of patients' bodies in the sitting or lying position. It is clear that patients' genitals are placed beyond radiation area in overwhelming majority of diagnostic sessions.

However, as it was stated above, sure diagnostics of many diseases is possible only when patient is allocated just vertically.

Unfortunately, X-ray equipments for tomosynthesis similar to the NewTom 5G Cone Beam 3G are unsuitable thereto. In fact, all such equipments provide unidirectional and synchronous movement of said X-ray units along such identical arcs, which belong to the same circumference disposed in vertical symmetry plane. As soon as the diameter of said circumference will have grown for vertical placement of tall patients, problem of their genitals protection springs up anew.

Two straight vertical pillars, which are rigidly connected with a joint basement, oppositely located at a distance that is sufficient for free entry/exit of patients and have common vertical symmetry plane;

Two carriages, which are positioned on said pillars and able to rectilinear adjustable movement upward/downwards and to independent rotation in vertical symmetry plane of said pillars within the angular limits ±35°; and

An X-ray emitter and a digital X-ray receiver positioned on said carriages oppositely.

It is obvious that such structure -

Firstly, cannot ensure perpendicularity of geometrical axis of X-ray beam to the digital X-ray receiver surface during each diagnostic session,

Secondly, forces, in the majority of cases, to use external security facilities for protection of patients’ genitals for over-radiation.

The US 2008/0219567 discloses a prototype of a proposed below X-ray equipment for tomosynthesis. This prototype has:

1) First and second straight vertical pillars, which are rigidly connected with a joint basement and oppositely located at a distance that is sufficient for placement of a patient in the vertical position;

2) A controllable X-ray emitter that is placed on said first vertical pillar and can be embodied in two variants, namely:

   2.1 in the form of a row of identical X-ray emitters, which are placed in horizontal plane and coordinates each of which are predetermined, or

   2.2 in the form of one X-ray tube, which is equipped with a controllable drive of its rotation in horizontal plane around vertical axis and, optionally, with a controllable drive of its adjustable movement upward/downwards along said first vertical pillar;

3) A collimator that placed at the said X-ray emitter outlet in order to form X-ray beam;

4) A flat digital X-ray receiver that is motionlessly fixed on said second vertical pillar opposite to the said controllable X-ray emitter;

5) Facilities for positional checking of said X-ray emitter relative to the said X-ray receiver;

6) A control unit, to which said controllable drives; said facilities for positional checking and a starter of the X-ray emitter are connected;

7) A data processing unit that has connected to the said X-ray receiver and is meant for generation of integrated digital radiographic images, and

8) A tomosynthesis unit connected to the said data processing unit.

This equipment not requires practically external protectors of patients’ genitals for
over-radiation. In fact, both X-ray units have common horizontal symmetry plane. Therefore, X-ray beam can pass past genitals of vertically standing patients in the majority of examination cases.

However, neither great number of identical X-ray emitters, which are placed in horizontal plane and have predetermined coordinates, nor one X-ray tube equipped with a controllable drive of its rotation in horizontal plane, cannot ensure perpendicularity of geometrical axis of X-ray beam to the digital X-ray receiver surface during each diagnostic session. Correspondingly, instability of tilt angle of geometrical axis of X-ray beam to the said receiver surface will cause all above-mentioned fallouts.

**Summary of the Invention**

The invention is based on the problem to create - by improvement of spatial arrangement and interconnection of mechanical and X-ray units - such X-ray equipment for tomosynthesis that can ensure perpendicularity of X-ray beam geometrical axis to the digital X-ray receiver surface during each diagnostic study of vertically standing patients.

Said problem has solved in that an X-ray equipments for tomosynthesis according to the invention comprises -

First and second straight vertical pillars, which are rigidly connected with a joint basement, oppositely located at a distance that is sufficient for placement of any vertically standing patient, have common vertical symmetry plane, and serve as pilot bearings;

First and second carriages, which are placed on said vertical pillars with possibility of adjustable reciprocal movement upward/downwards and fixation in predetermined positions;

First and second arcwise rails, which are oppositely fixed onto said carriages and circumscribe an area of placement of examined patients,

A controllable X-ray emitter and a digital X-ray receiver, which are oppositely positioned respectively onto first and second arcwise rails with possibility of controllable unidirectional synchronous angular movement so that optical axis of exit aperture of said X-ray emitter (and, in operative position, geometrical axis of X-ray beam) is always perpendicular to the said X-ray receiver surface;

A collimator placed at the controllable X-ray emitter outlet in order to form X-ray beam;

Facilities for positional checking of said X-ray emitter and said X-ray receiver based on at least one circular scale that is rigidly connected with one of two arcwise rails, and at least one position detector of one of two X-ray units relative to the said circular scale;

A control unit, to which said controllable drives; said facilities for positional checking and a starter of the X-ray emitter are connected;

A data processing unit that has connected to the said X-ray receiver and is meant for generation of integrated digital radiographic images, and

A tomosynthesis unit connected to the said data processing unit.

Such configuration and such interconnection of mechanical and X-ray units allow ensuring perpendicularity of X-ray beam geometrical axis to the digital X-ray receiver surface during each diagnostic session of each vertically standing patient. Accordingly,
tomosynthesis is substantially simpler because scale of consecutive radiographic images is practically identical. And, finally, dimension of diagnostic study area is circumscribed only by overall dimensions of the used digital X-ray receiver.

First additional feature consists in that said controllable X-ray emitter and said digital X-ray receiver are connected by such I-shaped mechanical synchronizer of their unidirectional and synchronous angular movement, which has vertical pushing stems those are kinematically connected with said carriages using sliding fit and a horizontal traverse having a vertical projection meant for connection with a motor. This allows using only one motor for angular movement of said X-ray units, one circular scale and one position detector of one of two said X-ray units relative to said circular scale. It is clear for each person skilled in the art that each output signal of said detector corresponds to an ascertained angle of declination of symmetry axis of the said X-ray emitter exit aperture away from the common vertical symmetry plane of aforesaid vertical pillars.

Second additional feature consists in that said controllable X-ray emitter and said digital X-ray receiver have proper electrically synchronized motors of controllable unidirectional synchronous angular movement of theirs along respective arcwise rails, each such rail is equipped with a circular scale, and each said X-ray unit has a proper position detector. This allows creating such X-ray equipment for tomosynthesis that will be free from cumbersome parts.

Third additional feature consists in that said control unit is equipped with an adjustable setter of angular pitch of controllable unidirectional synchronous angular movement of said controllable X-ray emitter and said digital X-ray receiver, and an adjustable setter of vertical rectilinear movement of said carriages. This simplifies automation of control of the X-ray equipment in whole.

Fourth additional feature consists in that said position detector of any X-ray unit is an high-precision optron pair.

**Brief Description of the Drawings**

The invention will now be explained by detailed description of improved X-ray equipment for tomosynthesis with references to the accompanying drawings, in which:

Fig.1 shows a general top view of the proposed equipment together with control unit, data processing unit and tomosynthesis unit;

Fig.2 shows a general side view of the proposed equipment.

**Best Embodiments of the Invention**

Any embodiment of the X-ray equipment for tomosynthesis has (see Fig.1) -

First and second straight vertical pillars 1 and 2, which are rigidly connected with a joint basement that will be showed further, oppositely located at a distance that is sufficient for placement of any vertically positioned patient, have common vertical symmetry plane, and serve as pilot bearings;

First and second carriages 3 and 4, which are placed on said vertical pillars 1 and 2 with possibility of preferably synchronous adjustable reciprocal vertical movement by means
of not showed here drives and with possibility of fixation of theirs in predetermined positions;
First and second arcwise rails 5 and 6, which are oppositely fixed onto said carriages 3 and 4 and, circumscribe an area of placement of examined patients, and can have identical or different operative radiuses,

A controllable X-ray emitter 7 and a digital X-ray receiver 8, which are oppositely positioned respectively onto first and second arcwise rails 5 and 6 with possibility of controllable unidirectional synchronous angular movement by means of not showed here drive(s), so that optical axis 9 of exit aperture of said X-ray emitter 7 (and, in operative position, geometrical axis of X-ray beam) is always perpendicular to the said X-ray receiver 8 surface;

A collimator 10 placed at the controllable X-ray emitter 7 outlet in order to form X-ray beam;
Facilities for positional checking of said X-ray emitter 7 and said X-ray receiver 8 based on at least one circular scale 11 that is rigidly connected with one of two arcwise rails 5 or 6, and at least one position detector 12 of one of two X-ray units 7 or 8 relative to the said circular scale (or scales) 11;
Such (preferable programmed) control unit 13 that is equipped with a not showed especially adjustable setter of angular pitch of controllable unidirectional synchronous angular movement of said X-ray units 7 and 8, and, optionally, may be equipped with a not showed especially adjustable setter of vertical rectilinear movement of said carriages 3 and 4; this unit 13 has control outputs, to which above-mentioned controllable drives of angular and rectilinear movement are connected, and which is connected to a not showed especially starter of the controllable X-ray emitter 7 and to such data entries of back-coupling those belong to the position detector(s) 12, which must give signals of actual positions of X-ray units 7 and 8 relative to the circular scale (or scales) 11;
A data processing unit 14 that has connected to the said X-ray receiver 8 and is meant for generation of integrated digital radiographic images, and
A tomosynthesis unit 15 connected to the said data processing unit 14.

Fig.2 shows clearly that vertical pillars 1 and 2 are rigidly fixed in joint basement, which is denoted by oblique lines and on which a patient stands vertically during examination.

It is clear for each person skilled in the art that said X-ray units 7 and 8 can be connected by a II-shaped mechanical synchronizer showed symbolically on Fig.2 by thick dashed line.
This synchronizer has not designated especially vertical pushing stems, which are kinematically connected with carriages 3 and 4 using sliding fit, and a horizontal traverse having a vertical projection meant for connection by means of suitable clutch with an output shaft of a suitable (in particular, electric or hydraulic) motor. Rotational moment of this motor showed symbolically on Fig.2 by counter arcwise arrows. Such mechanical synchronizer allows using one motor for angular movement of said X-ray units 7 and 8 and one circular scale 11 and one position detector 12 one of two said units 7 or 8 relative to this scale 11.
It is clear also for each person skilled in the art that in case, if said arcwise rails 5 and 6 have different operative radiuses, geometrical axis of above-mentioned vertical projection of horizontal traverse of II-shaped mechanical synchronizer must be located asymmetrically and must include junction point of radiuses of respective arcs.

However, maximal usability of the proposed X-ray equipment for tomosynthesis may be assured (see anew Fig.1), if-

Both X-ray units 7 and 8 have not shown especially proper electrically synchronized motors those connected to above-mentioned control outputs of the control unit 13;

Each arcwise rail 5 and 6 has a proper circular scale 11, and

Said X-ray emitter 7 and said X-ray receiver 8 have proper sensors 12 of their position relative to the applicable circular scale 11.

It is preferably, if the position detector 12 of any X-ray unit is an optron pair.

Radiographic examination with the view of following tomosynthesis can realize using the proposed X-ray equipment as follows.

The carriages 3 and 4 (together with X-ray units 7 and 8) must be in good time shifted along the pillars 1 and 2 with a glance of a patient's stature and fixed preliminarily on determined level. Then X-ray units 7 and 8 must be simultaneously and synchronously turned along the arcwise rails 5 and 6 in one of two extreme positions, and angular pitch of controllable unidirectional synchronous angular movement of theirs during diagnostic examination can be adjusted, if it is necessary.

When a patient stands vertically face to the digital X-ray receiver 8, an attendant can correct, if it is necessary, the level of said X-ray units 7 and 8 in respect of said pillars 1 and 2. Then the patient presses oneself to the surface of the X-ray receiver 8.

Desirable form of X-ray beam at the outlet of said controllable X-ray emitter 8 may be adjusted using said collimator 10.

Further the attendant switches on control unit 13, which forms triggering commands for stepwise unidirectional synchronous angular movement of said X-ray units 7 and 8 along the arcwise rails 5 and 6. Position detector(s) 12 detect actual position of said X-ray units 7 and 8 in respect of the circular scale (or scales) 11. If divergence between specified and actual position of theirs will be unallowable, the control unit 13 makes provision for automatic correction. When the control unit 13 detects right regular position of the X-ray units 7 and 8, it switches on X-ray emitter 7 that examines a selected slice of the patient's body.

The digital receiver 8 forms such fragmentary digital radiographic images of each regular slice of the patient's body, which correspond with actual position of the X-ray units 7 and 8, and transmits these images into the data processing unit 14. This unit 14 integrated digital radiographic images and transmits of theirs into the tomosynthesis unit 15 that synthesizes at least one tomogram.

If it is necessary, such study can be executed in respect of whole patient's body including lumbar region and cervical spine. It is clear that collimation of X-ray beam at this rate must be very careful.
Industrial Applicability

The proposed X-ray equipment for tomosynthesis can serially produce using available components. So, serial pieces **Unimat DR** of the firm Josef Betschart AG and **BS-20** of the firm Listem can be used as pillars (1) and (2), and the Ukrainian firm «TELEOPTIC» can serve as credible supplier of suitable large digital X-ray (8) receivers.

This X-ray equipment simplifies appreciably early differential diagnostics of dangerous human internals' diseases (especially pulmonary tuberculosis or carcinomas of lung, any cancer within an abdominal cavity, and obliterating endarteritis of legs) at vertical position of patients.

In addition, peculiar spatial arrangement and interconnection of mechanical parts and X-ray units in the proposed X-ray equipment allow considerable increasing dimensions of tomosynthesis area and, as needed, permit to scan a whole patient's body.
CLAIMS

1. An X-Ray equipment for tomosynthesis comprising -
   First and second straight vertical pillars, which are rigidly connected with a joint
   basement, oppositely located at a distance that is sufficient for placement of any vertically
   positioned patient, have common vertical symmetry plane, and serve as pilot bearings;

   First and second carriages, which are placed on said vertical pillars with possibility of
   adjustable reciprocal movement upward/downwards and fixation in predetermined positions;

   First and second arcwise rails, which are oppositely fixed onto said carriages and
   circumscribe an area of placement of examined patients,

   A controllable X-ray emitter and a digital X-ray receiver, which are oppositely
   positioned respectively onto first and second arcwise rails with possibility of controllable
   unidirectional synchronous angular movement so that optical axis of exit aperture of said X-
   ray emitter (and, in operative position, geometrical axis of X-ray beam) is always
   perpendicular to the said X-ray receiver surface;

   A collimator placed at the controllable X-ray emitter outlet in order to form X-ray beam;

   Facilities for positional checking of said X-ray emitter and said X-ray receiver based on
   at least one circular scale that is rigidly connected with one of two arcwise rails, and at least
   one position detector of one of two X-ray units relative to the said circular scale;

   A control unit, to which said controllable drives; said facilities for positional checking
   and a starter of the X-ray emitter are connected;

   A data processing unit that has connected to the said X-ray receiver and is meant for
   generation of integrated digital radiographic images, and

   A tomosynthesis unit connected to the said data processing unit.

2. The X-Ray equipment according to the claim 1, in which said controllable X-ray
   emitter and said digital X-ray receiver are connected by such Π-shaped mechanical
   synchronizer of their unidirectional and synchronous angular movement, which has vertical
   pushing stems those are kinematically connected with said carriages using sliding fit and a
   horizontal traverse having a vertical projection meant for connection with a motor.

3. The X-Ray equipment according to the claim 1, in which said controllable X-ray
   emitter and said digital X-ray receiver have proper electrically synchronized motors of
   controllable unidirectional synchronous angular movement of theirs along respective arcwise
   rails, each such rail is equipped with a circular scale, and each said X-ray unit has a proper
   position detector.

4. The X-Ray equipment according to the claim 2 or claim 3, in which said control unit
   is equipped with an adjustable setter of angular pitch of controllable unidirectional
   synchronous angular movement of said controllable X-ray emitter and said digital X-ray
   receiver, and an adjustable setter of vertical rectilinear movement of said carriages.

5. The X-Ray equipment according to the claim 1, in which said position detector of
   any X-ray unit is an optron pair.
commands for lifting/sinking of the carriages 3, 4

to a starter of the X-ray emitter 7
feedback signals from the position detector(s) 12 about tilt angles of X-ray units 7, 8

13 control unit

adjustable setters of angular pitch of controllable unidirectional synchronous angular movement of the X-ray units 7, 8 and vertical rectilinear movement of the carriages 3, 4

signals from the digital X-ray receiver 8

14 the data processing unit that generates integrated digital radiographic images

15 tomosynthesis unit

Fig.1
A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B6/02 A61B6/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal , WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents:

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Date of the actual completion of the international search
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Koci an, Anne

Form PCT/ISA/210 (second sheet) (April 2005)
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