Abstract: The present invention relates to a test object for X-ray imaging, an X-ray imaging system, a method for testing an X-ray imaging system, the use of a test object, a computer program element, and a computer-readable medium. In order to provide a test object for quality assurance in X-ray imaging with a facilitated handling and improved evaluation process, a test object (30) for X-ray imaging is provided, comprising a plate structure (32) with at least a first layer (34) with a first material (36) with a first X-ray attenuation. The plate structure is provided at least on one side with a boundary profile (38), which boundary profile is arranged between the first layer with the first X-ray attenuation and an adjoining second layer (40) with a second X-ray attenuation, wherein the second X-ray attenuation is lower than the first X-ray attenuation. The boundary profile comprises a plurality of minima (44) and maxima points (48), which are arranged periodically. On the boundary profile, at least one intermediate value point (50) is provided between each adjacent minima and maxima point.
FIELD OF THE INVENTION

The present invention relates to a test object for X-ray imaging, an X-ray imaging system, a method for testing an X-ray imaging system, a use of a test object, a computer program element, and a computer-readable medium.

BACKGROUND OF THE INVENTION

Test objects are used in order to achieve actual information about the current status of an X-ray imaging system, for example as used in medical imaging. In US 2004/0156480 Al, an image quality test for X-ray is described allowing a field engineer to effectively maintain and troubleshoot vascular imaging systems. A specific test stand is described utilizing a number of calibration phantoms. However, it has been shown that test objects are usually difficult to handle and require complex attention.

SUMMARY OF THE INVENTION

There may be a need to provide a test object for quality assurance in X-ray imaging with a facilitated handling and improved evaluation process.

The object of the present invention is solved by the subject-matter of the independent claims, wherein further embodiments are incorporated in the dependent claims.

It should be noted that the following described aspects of the invention apply also for the test object, the X-ray imaging system, the method for testing an X-ray imaging system, the use of a test object, the computer program element and the computer-readable medium.

According to an embodiment of the invention, a test object for X-ray imaging comprises a plate structure with at least a first layer with a first material with a first X-ray attenuation. The plate structure is provided at least on one side with a boundary profile, which boundary profile is arranged between the first layer with the first X-ray attenuation and an adjoining second layer with a second X-ray attenuation. The second X-ray attenuation is lower than the first X-ray attenuation. The boundary profile comprises a plurality of minima and
maxima points, which are arranged periodically. On the boundary profile, at least one intermediate value point is provided between each adjacent minima and maxima point.

According to an exemplary embodiment, the boundary profile is a graph with a continuous function.

According to an exemplary embodiment of the invention, the boundary profile comprises a sinusoidal cross section.

According to an exemplary embodiment of the invention, the boundary profile comprises a plurality of grooves formed by the minima and maxima points, wherein the plurality of grooves is arranged on a plate structure in a circular manner as concentric rings.

According to an exemplary embodiment, a test object for X-ray imaging is provided, comprising a plate structure with at least a first layer with a first material with a first X-ray attenuation. The plate structure is provided at least on one side with a boundary profile, which boundary profile is arranged between the first layer with the first X-ray attenuation and an adjoining second layer with a second X-ray attenuation. The second X-ray attenuation is lower than the first X-ray attenuation. The boundary profile is a step function comprising only a plurality of minima and maxima segments, which are arranged periodically. The boundary profile comprises a plurality of slits formed by the minima segments between adjacent maxima segments. The slits are arranged on the plate structure in a circular manner as concentric rings.

According to an exemplary embodiment, adjacent to the first layer, a second layer is provided with a second material with the second X-ray attenuation.

According to an exemplary embodiment, an X-ray imaging system is provided, comprising an X-ray source, a detector, and a test object according to one of the above described embodiments. The X-ray source generates X-ray radiation and the test object is arranged between the X-ray source and the detector, wherein the detector is adapted to record raw image data.

According to an exemplary embodiment, a method for testing an X-ray imaging system is provided, comprising the steps of:

a) placing a test object between an X-ray source and a detector, wherein the test object is a test object according to one of the above described exemplary embodiments.

b) acquiring at least one 2D X-ray test image.

c) selecting a sub-frame of the X-ray image which is within the profiled part of the test object.

d) performing a transformation from spatial domain to spectral domain for the
sub-frame image data.

e) determining a peak position in the frequency domain.
f) determining average peak signal and background noise signal.

According to an exemplary embodiment, the use of a test object according to
one of the above described exemplary embodiments in an X-ray imaging system is provided.

It can be seen as the gist of the invention to provide a test object with a plate
structure which is easy to handle and that can be positioned between the X-ray source and the
detector due to the boundary profile according to the invention. An X-ray image can be
acquired in which the signal of the boundary profile structure and the image noise can be
measured and provided as average peak signal and background noise signal to the user. The
test object is easily manufactured and the necessary experiments or steps, respectively, are
simple, so that the evaluation can be done, for example, also by hospital stuff.

For example, a sinusoidal shaped test object generates a sinusoidal modulation
in the image data in case of a logarithmically scaled X-ray image, wherein the sinusoidal
modulation is superimposed to the quantum noise. Only a sinusoidal modulation converts to a
sharp peak in the Fourier domain. Preferably, the modulation is of the same order of
magnitude as the noise. When using other boundary profiles, according to the embodiments
described herein, different peak structures are shown in the Fourier domain, for example two
or more sub-peaks are also provided. However, by applying more complicated algorithms, it is
also possible to extract the respective information, however, a sinusoidal modulation leads to
easier achievable and better results. For example, the sinusoidal profile can be described by a
single spatial frequency. Circles with sub-profiles will provide information about the MTF in
all directions, X, Y, and in between. This is explained further below. The noise depends on the
exposure level, but the signal will be constant (LOG-data). By performing two or more
exposures, it is possible to calculate the dose level leading to a predefined value of $SPsNRO(v)$,
for example 1.0. This figure can then be checked for constancy within a system, but it is also
possible to compare it between different systems.

These and other aspects of the present invention will become apparent from
and elucidated with reference to the embodiments described hereinafter.
BRIEF DESCRIPTION OF THE DRAWINGS

Exemplary embodiments of the invention will be described in the following with reference to the following drawings.

Figs. 1a to 1f schematically illustrate X-ray imaging systems according to exemplary embodiments of the invention.

Fig. 2 schematically illustrates a perspective view of a test object according to the invention.

Figs. 3 to 5 show further exemplary embodiments of a test object according to the invention.

Figs. 6 and 7 show further aspects of exemplary embodiments according to the invention.

Figs. 8 to 12 show plan views of exemplary embodiments of the invention.

Figs. 13 and 14 show perspective views of further exemplary embodiments of a test object according to the invention.

Fig. 15 shows a further exemplary embodiment of a test object according to the invention in a plan view and a cross section.

Figs. 16 to 19 show further exemplary embodiments of a test object according to the invention.

Figs. 20 to 25 show further exemplary embodiments of test objects according to the invention.

Figs. 26 show a further exemplary embodiment of a test object according to the invention in a perspective view.

Figs. 27 and 28 show exemplary embodiments of methods for testing an X-ray imaging system according to the invention.

Figs. 29 and 30 show further aspects of exemplary embodiments according to the invention.

Figs. 31 to 36 show further aspects in relation with exemplary embodiments of methods according to the invention.

Fig. 37 shows a further exemplary embodiment of a method according to the invention.
DETAILED DESCRIPTION OF EMBODIMENTS

Fig. 1a schematically shows an X-ray imaging system 10 with an X-ray source 12, and a detector 14. The X-ray source 12 and the detector 14 are arranged on opposite ends of a C-arm structure 16 which is only schematically shown. The C-arm structure may be mounted rotatably such that the detector and the X-ray source can be freely moved around an object of interest. Further, a table 18 is shown which is provided to receive an object of interest, for example a patient. The table 18 is movably mounted to a support 20, wherein, for example, a horizontal sliding movement in the longitudinal direction of the table 18 and also an adjustment in the height of the table can be provided. Further, a display device 22 is shown. Further, the X-ray imaging system 10 also comprises a processing unit 24 and an interface 26 which can be located, for example, in the base structure 20 and are thus not further shown in Fig. 1a. In the vicinity of the display 22, a secondary interface device 28 is shown, for example for controlling the X-ray imaging system.

In order to provide quality testing and quality assurance of the system, a test object 30 is arranged between the X-ray source 12 and the detector 14.

During examination procedure, as well as during testing procedure, the X-ray source 12 generates X-ray radiation towards the detector 14, which is recording raw image data. The raw image data is then further processed to the processing unit 24 via the interface 26.

The processing unit 24 is adapted to receive raw image data from the detector via the interface, to select a sub-frame of the X-ray image which is within the profiled part of the test object (described further below), to perform a transformation from spatial domain to spectral domain for the sub-frame image data, to determine a peak position in the frequency domain, and to determine average peak signal and background noise signal. The interface 26 is further adapted to provide the determined information to the user, for example via the display 22.

It is further noted that the example shown is of a so-called C-type image acquisition device, however, also other X-ray image acquisition devices can be provided, for example CT systems and stationary systems with fixed X-ray source and detector arrangements.

Fig. 1b shows an example for a mammography system 10, comprising an X-ray source 12 and a detector 14 which are mounted to a base 20. Further, in the vicinity, a display 22 and a secondary interface 28 and a processing unit 24 as well as an interface 26. As can be seen, a test object 30 according to the invention is placed on the detector.

The detector may be adapted with a flat surface to receive a breast of a patient. To hold the breast in place and for compression, a paddle 19 may be provided, which can be
adjusted in height and inclination. For protection of the user operating the system, a protection shield 27 is shown.

The source 12 and the detector 14 are arranged on a supporting device which can be swivelled around a central axis as shown on Fig. 1c. Figure 1d shows an example in which the paddle 19 can be adapted vertically, indicated by a double arrow on the right side of the arrangement. Fig. 1e shows an example in which the height of the detector 14 is also adaptable (indicated by a double arrow on the right side of the arrangement), in combination with the source 12.

In Fig. 1f, a section of a further mammography system 10 is shown. As can be seen, a test object 30 according to the invention is arranged on the detector for test purposes according to the invention.

Fig. 2 shows the test object 30 for X-ray imaging, comprising a plate structure 32 with at least a first layer 34 with a first material 36 with a first X-ray attenuation. The plate structure is provided at least on one side with a boundary profile 38, which boundary profile is arranged between the first layer 34 with the first X-ray attenuation and an adjoining second layer 40 with a second X-ray attenuation, wherein the second X-ray attenuation is lower than the first X-ray attenuation.

The boundary profile 38 comprises a first plurality 42 of minima points 44 and a second plurality 46 of maxima points 48. The minima and maxima points 44, 48 are arranged periodically. On the boundary profile 38, at least one intermediate value point 50 is provided between each adjacent minima and maxima point.

The boundary profile 38 may be a graph with a plurality of minima and maxima points, which are arranged periodically, wherein at least one intermediate point is provided between each minima and maxima point on the graph.

The periodicity is indicated with the letter $P$, also indicated with reference numeral 52.

According to an aspect of the invention, the boundary profile 38 may be a graph with a continuous function 54.

For example, the graph is a triangular function 56, as schematically shown in Fig. 3.

According to a further aspect of the invention, the boundary profile may comprise a sinusoidal cross section 58 as schematically shown in Fig. 2.

The boundary profile 38 may also be provided with a parabolic cross section
60, as shown in Fig. 4.

The boundary profile 38 may also be provided with an approximation of a sinusoidal cross section (not further shown).

The boundary profile may also be provided with a stepped or discretized shape 62 of a sinusoidal or parabolic or triangular cross section, an example for which is shown in Fig. 5.

The plate structure 32 is adapted to be arranged essentially perpendicular to an X-ray beam, wherein the X-ray beam is indicated with a number of arrows 64 in Fig. 2.

Of course, the X-ray beam can also hit the plate structure 32 in an inclined manner, differing from an exact perpendicular direction. For example, the boundary profile 38 may be a projection of perspective cross section, wherein the projection is adapted to a radiation direction of the X-ray beam, for example according to a preferred arrangement with respect to the particular X-ray imaging system.

The boundary layer profile is a continuous contact surface between the adjacent layers. As can be seen from Fig. 2, for example, the boundary profile or contact surface profile may be arranged perpendicular, or essentially perpendicular to the X-ray beam 64.

The boundary profile 38, for example the sinusoidal profile 58, is provided between two areas with different X-ray absorption or attenuation values, wherein the area or side with the lower attenuation may be provided facing towards the X-ray radiation, as shown in Fig. 2.

According to another aspect, the area or side with the lower attenuation may be provided facing away from the X-ray radiation, i.e. the profile on the plate structure is facing away from the source.

For example, the second X-ray attenuation differs from the first X-ray attenuation at least by a factor of 2.

According to an exemplary embodiment of the invention, the second layer is air, i.e. the surrounding air, or a surrounding gaseous atmosphere, according to the particular use of the test object 30.

As shown in Fig. 6, the sinusoidal profile 58, as an example for the boundary profile 38, comprises upper peaks 64 and lower peaks or lower points 66. The lower peaks 66 form groove-like recesses 68 between projections formed by the upper peaks 64.

For example, the lower peaks form concave profile sections and the upper peaks form convex profile sections of the first layer 34.
According to a general aspect of the invention, the boundary profile 38 comprises a plurality of grooves formed by the minima and maxima points, when referring to the cross section of the boundary profile.

The first layer 34 has an average thickness $Z_0$, indicated with reference numeral 70. The boundary profile 38, for example the sinusoidal cross section 58, has a Z-modulation, or peak-to-peak modulation $\Delta Z$, also referred to by reference numeral 72. The peak-to-peak modulation is so-to-speak the amplitude of the boundary profile 38.

Due to the periodic repetition of the boundary profile segments, the boundary profile 38 is arranged with a spatial frequency $v$, which may be referred to as the number of periods with respect to a certain length unit. For example, the unit LP/mm is used for a pair of lines per millimetre, wherein the term "pair of lines" or "line pair" refers to one period of a boundary profile according to the invention. For example, a spatial frequency $v = 2$ LP/mm refers to a spatial frequency of two periods of the respective boundary profile pattern along a distance or length of 1 mm.

It must be noted that the profiles shown are only schematically shown as examples. Of course, the sinusoidal profile 58 of Fig. 6 could also be arranged with a steeper profile, i.e. with a higher Z-modulation, and also with a higher spatial frequency, an example for which is shown in Fig. 7.

According to a further aspect of the invention, the boundary profile 38 comprises a plurality of grooves 68 formed by the minima and maxima points, wherein the grooves 68 are arranged in a parallel pattern 74 parallel to each other in a linear manner 76 across the plate structure. An example is shown in Fig. 8, where the test object 30 is shown in a plan view, i.e. from the top or from the direction from which the X-ray radiation is coming.

According to a further aspect of the invention, the boundary profile comprises a plurality of grooves 68 formed by the minima and maxima points, wherein the plurality of grooves are arranged on the plate structure in a circular manner 78 as concentric rings 80, as shown in Fig. 9.

A respective cross section along the indicated lines A-A is schematically shown in Fig. 8 as well as in Fig. 9.

According to a further aspect of the invention, the boundary profile 38 comprises at least one groove 68 arranged as at least one spiral 82, which is forming the boundary profile. An example for a boundary profile 38 with one spiral is shown in Fig. 10. Here again, a cross section along the section line A-A is shown beneath the view plan in Fig. 10.
It must be noted that the cross sections shown for Figs. 8 to 10 are schematically indicating a sinusoidal cross section as an example. Of course, other profiles, as for example mentioned above, are also possible.

The boundary profile may also comprise a plurality of grooves 68 formed by the minima and maxima points, wherein the grooves are arranged on the plate structure as concentric circular arc segments 84, as schematically shown in a plan view in Fig. 11.

For example, the grooves can be arranged as semicircles or quadrants, the latter are shown in Fig. 11. Of course, other angles of the arc segments are also possible. Further, it is also possible to provide arc segments with a decreasing or increasing or varying angle.

The boundary profile 38 may also comprise two spirals 86, 88 provided in an interwoven manner as shown in Fig. 12.

According to Figs. 13 and 14, a first structure 90 and a second structure 92 may be overlaid forming a boundary profile.

For example, a plate structure is provided with the first structure 90 as a profile structure according to one of the above described embodiments on one side, and the second structure 92 provided as a profile structure according to one of the above described exemplary embodiments on the other side, as schematically shown in Fig. 13.

According to Fig. 14, the first structure 90 and the second structure 92 are arranged on the same side of the plate structure 32.

It may be provided that one of the structures is finer than the other structure, not further shown. For example, the first structure can be provided with an integer of the second structure, or vice versa.

According to a further aspect of the invention, a test object 30 for X-ray imaging is provided, comprising a plate structure 32 with at least a first layer 34 with a first material 36 with a first X-ray attenuation. The plate structure 32 is provided at least on one side with a boundary profile 138, which boundary profile is arranged between the first layer with the first X-ray attenuation and an adjoining second layer 40 with a second X-ray attenuation, wherein the second X-ray attenuation is lower than the first X-ray attenuation. As can be seen from Fig. 15, lower part, the boundary profile is a step function 94 comprising only a plurality of minima segments 96 and maxima segments 98, which are arranged periodically, which is indicated with reference numeral 100 and letter P. The boundary profile 138 comprises a plurality of slits 102 formed by the minima segments between adjacent maxima segments. The slits are arranged on the plate structure in a circular manner 104 as
concentric rings 106, which is shown in the upper part of Fig. 15 in a plan view.

For example, the boundary profile is a rectangular function.

The grooves or slits 102 can also be arranged as semicircles or quadrants, in a manner similar to the aspect described in relation with Fig. 11, expect for the difference that the profile is a rectangular profile and not a continuous function or a function with intermediate value points.

A plan view of a test object 30 according to the invention is shown in Fig. 16, wherein a circular structure 78 with concentric rings 80 is provided together with a further information field 108 on one side of the concentric ring structure 80. This field can be used for indicating the respective information, for example the respective Z-modulation and spatial frequency.

Fig. 17 shows an enlarged part of Fig. 16. Fig. 18 shows a set 110 of different test objects, wherein a first test object, shown in the upper right half or part, also indicated with reference numeral 112, has a wider boundary profile, a second test object 114 shown in the upper right half has a medium boundary profile, and a third test object 116 has a finer boundary profile, wherein the terms are related to a comparison of the three respective test objects, and wherein a fourth test object 118 is provided in the lower right corner, next to the finer boundary profile of the third test object 116 shown in the lower left corner, which test object 118 has no boundary profile, but the same average thickness Z₀ for comparison test runs.

In case of a concentric ring structure, i.e. in case of a circular arrangement 78, 104, the plate structure 32 of the test object 30 can be square when regarded in the plan view, such that the largest one of the concentric rings 80, 106 is an inscribed circle, which is fitting inside the edges of the ground plate. Of course, an additional field 108 for providing information, as mentioned in relation with Fig. 16, can also be provided additionally.

However, it is also possible to provide the concentric rings 80, 106 such that in case of a square field of the plate structure 32, the boundary profile 38 completely covers a square field, i.e. the ground plate is an inscribed circle with respect to the largest of the concentric rings just hitting the corners of the ground plate. This is indicated in Fig. 19 with a first dotted square 120 for the latter case and a second dotted square 122 for the first case.

According to a further aspect of the invention, the boundary profile comprises a number of subareas 124, which subareas are each provided with a different boundary profile.

For example, Fig. 20 shows a boundary profile 38 with three subareas 124, namely a first inner circle 126a, a following first concentric ring stripe 126b, and a further
concentric ring stripe 126c. The inner subarea, i.e. the inner circle 126a, comprises a first boundary profile, the first concentric ring stripe 126b comprise a second boundary profile, and the further concentric ring stripe 126c comprises a third boundary profile.

Of course it is also possible to provide subareas in which different subareas may have the same boundary profile, for example, the inner circle 126a and the outer concentric ring stripe 126c can be provided with the same boundary profile, whereas the intermediate or second subarea, i.e. the first ring stripe 126b, has a different boundary profile.

For example, the inner circle 126a comprises a boundary profile with one line pair/mm, the first concentric ring stripe 126b, a boundary profile with three LP/mm, and the second concentric ring stripe a boundary profile 5 LP/mm.

According to a further example, the test object shown in Fig. 20 may be provided with outer dimensions of 11 cm by 12 cm, wherein the diameter of the circumferential line of the second concentric ring stripe 126c may be 10 cm.

Fig. 21 shows a test object 30 with five subareas 124, for example an inner circle 126a, a first concentric ring stripe 126b, a further, i.e. second ring stripe 126c, a third concentric ring stripe 126d has a fourth subarea and a fourth concentric ring stripe 126e as a further, i.e. outer subarea.

As an example, the different subareas 126a - 126e may be provided with boundary profiles of 1 LP/mm, 2 LP/mm, 2 LP/mm, 4 LP/mm, and 4 LP/mm.

For example, the test object may have outer dimensions of 16 cm by 17 cm, wherein the outer circumferential line of the fourth concentric ring stripe 126e may have a diameter of 15 cm.

For example, the rings, i.e. the concentric stripes, may have the same area, i.e. the same width across a section line through the common centre of the concentric circles.

According to a further aspect, the ring, i.e. the concentric ring stripes may have the same surface area.

It is also possible to provide a number of subareas 124 as parallel stripes 130a, 130b, etc. with different boundary profiles, as indicated in Fig. 22.

The subareas 124 can have similar sizes or widths, as shown in Figs. 20 to 22, but they can also be provided with different area sizes or different widths, i.e., for example with different radii for circular arrangements, or with different widths of stripes as schematically shown in Fig. 23.

It is also possible to provide the subareas 124 in a chess-board pattern 132, as
schematically indicated in Figs. 24 and 25. For example, Fig. 24 shows a chess-board pattern with a first boundary profile 134a and a second boundary profile 134b, arranged in an alternating manner. Fig. 24 shows the boundary profiles for as parallel linear arrangements, wherein the arrangements are arranged parallel to each other also. However, it is also possible to provide the alternating boundary profiles with varying orientations, for example the second boundary profile 134b with an arrangement perpendicular to the linear arrangements of the first boundary profile 134a, which is not further shown. Of course, it is also possible to provide a chess-board pattern 135 with a first boundary profile 136a, a second boundary profile 136b, and a third boundary profile 136c, arranged periodically in both directions of the chess-board pattern 135, as shown in Fig. 25.

Of course, other variations of arrangements of subareas are also possible.

According to a further aspect of the invention, the boundary profile is provided as a diffraction structure adapted to change phase and/or amplitude of an X-ray beam passing the boundary profile.

For example, the boundary profile is a sinusoidal profile, as mentioned above, which is adapted to provide a sinusoidal modulation in an image data superimposed to quantum noise.

Preferably, the modulation is provided in the same order of magnitude, or at least in a similar order of magnitude as the noise.

For example, the boundary profile comprises a frequency range of 0.1 to 10 periods/mm, preferably 0.25, 1, 5, or 7 periods/mm.

It is noted that the term "period" in the unit periods/mm is also referred to as "a pair of lines", as already mentioned above.

For example, the peak-to-peak modulation of the boundary profile is in a range from 50 to 500 micrometer, preferably 100 to 300 micrometer.

The term "average thickness" is measured for the centerline of the boundary profile cross section, as mentioned before.

According to a further aspect of the invention, as shown in Fig. 26, adjacent to the first layer 34, a second layer 140 is provided with a second material 142 with a second X-ray attenuation.

As can be seen, the grooves arranged in the first layer 34, indicated in Fig. 26 with reference numeral 144, are filled with the second material. Thus, a common surface or surface profile between the first layer 34 and the second layer 140 is provided as the boundary
profile 38.

It is explicitly noted that the above described embodiments concerning the
different surface embodiments of the boundary profile 38 are also applicable for the test object
30 of Fig. 26 with a first and second layer attached to each other.

For example, the first layer 34 is provided as a plate made from plastic material,
for example PMMA or to be defined.

The test object 30 may be provided for mammography X-ray examination testing.

According to a further aspect, the first layer 34 is provided as a metal plate, for
example an aluminium plate comprising the boundary profile 38 at least one side.

For example, the test object 30 may be provided for normal medical X-ray
examination.

The second layer 140 may be provided as protective layer made from a visually
transparent second material. The grooves are then filled with a second material such that a
surface is provided of the test object, i.e. an outer surface, which can easily be cleaned.

In the following, a method 200 for testing X-ray imaging system shall be
explained with reference to Fig. 27. The method 200 comprises the following steps. In placing
step 210, a test object is placed between an X-ray source and a detector, wherein the test
object is a test object according to one of the above described exemplary embodiments and
aspects and examples. In an acquisition step 212, at least one 2D X-ray test image 214 is
acquired. In a first selection step 216, a sub-frame 218 of the X-ray image 214 is selected
which sub-frame is within the profiled part of the test object. Further, in a performance step
220, a transformation 222 from spatial domain to spectral domain is performed for the sub-
frame image data. In a determination step 224, a peak position 226 in the frequency domain is
determined. Next, in a second determination step 228, average peak signal 230 and
background noise signal 232 are determined.

For example, the placing step 210 is also referred to as step a), the acquisition
step 212 as step b), the selection step 216 as step c), the first performing step 220 as step d),
the first determination step 224 as step e), and the second determination step 228, or further
determination step, as step f).

For example, in step a), the test object is placed on the detector or on the cover
of the detector as accessible during normal X-ray procedure.

The test object may also be placed closer to the detector by providing a
reception opening for inserting the test object into the housing of the detector, in order to arrange the test object next to the detector as close as possible.

For example, the sub-frame 218 in step c) comprises at least 1024 x 1024 pixels.

As a further example, the profile, i.e. the boundary profile 38, comprises concentric circles, and in step c), the sub-frame 218 is selected to be within the circles.

As another example, in step c), in case of a detector area larger than the test object, the edge portions of the test object are removed from the image data, or cut off, and replaced by a mean value. For example, the mean value is determined on behalf of the surrounding upside the edges of the test object.

For example, in step d), the sub-frame data is transformed from the spatial domain into a frequency domain.

In step d), a 2D Fast Fourier Transformation may be performed.

In step e), a Fast Fourier Transformation peak position may be determined.

In step f), a radial average of the amplitude spectra may be performed.

As a further example, in step f), an average is calculated for all areas of a peak line representing the peak signal.

In step f), the average may be calculated for selected areas of the peak line.

In step f), the peak line may also be a peak circle, wherein an average is calculated for a plurality of selected circular arc segments.

Further, in step f), the average may be calculated for a first and a second pair of angle sections arranged opposite to each other, wherein the first and a second pair are arranged perpendicular (see also Fig. 36).

Further, a third pair may be provided, which is arranged diagonally to the first and/or second pair.

According to a further example, following step f), a signal-to-noise-ratio is determined.

For example, in step f), the peak line is a peak ellipse, wherein the average peak signal is an elliptical average.

According to a further aspect, shown in Fig. 28, following step f), a step g) is provided in which a sinus-peak-to-spectral-noise ratio 234 is determined in a determination step 236.

According to a further aspect (not shown), the test object according to the
invention is also used for tomosynthesis. As data, a series of 2D images is acquired from which 3D data is computed. It is noted that the aspects and features described above are also provided for tomosynthesis purposes, where applicable.

Further, the present invention is also related to the use of a test object according to one of the above described exemplary embodiments, aspects or examples of the invention, in an X-ray imaging system. For example, the X-ray imaging system is a medical X-ray imaging system.

In the following, further aspects of the invention shall be described.

For example, a test object and evaluation procedure according to the invention is provided for quality assurance in mammography and radiography systems. For example, a thin foil or plate with concentric rings, for example with a sinusoidal surface profile, of a given spatial frequency \( v \) is provided, wherein the term "thin" may comprise an average thickness of approximately 1 mm, the surface modulation may be small, for example with a Z-modulation \( \Delta Z \) of approximately 200 micrometers, to keep the signal in the same order of magnitude as the image noise of the system. In an X-ray image of such a test object, the signal of the rings and the image noise can be measured, for example, in the Fourier domain. The signal-to-noise ratio (SNR) is the quotient of these figures.

Fig. 29 shows an X-ray image 146 which is added by sinus rings, for example with 2 LP/mm in low contrast, wherein the simulated sinus rings are indicated with reference numeral 148. The X-ray image 146 so-to-speak represents the image noise which is added by the image added by quantum noise into the image of the test object represented by the sinus rings. As a result, i.e. the measured X-ray image, an X-ray image data 150 is shown. The structure of the test object can hardly be seen, and is indicated in Fig. 29 for illustrative purposes in an enhanced way. If in a next step, the line 152 is drawn through the X-ray image 150, which processing or image handling step is indicated with an arrow 154, the result through the profile would be a curve 154 shown in a graph below in the right half of Fig. 29. As can be seen, the line profile shows different lower and higher peaks. However, a frequency cannot be determined by the user, since it is covered or hidden by the noise.

For example, after taking the test image, for example the X-ray image 150, a 2D Fast Fourier Transformation can be performed, and the radial average in the spatial domain can then be determined. Next, signal peak signal and noise signal can be identified.

Fig. 30a) shows a photographic image of a test object according to the invention in a plan view, Fig. 30b shows an X-ray image acquired with the test object of Fig.
30a), and Fig. 30c) shows the result in form of a noise peak signal \( NPS \) (spectrum).

Fig. 31 schematically illustrates further examples of a method. A first box 156 indicates the performance of a 2D Fast Fourier Transformation which leads to a spectrum u-v-domain 158, however in a so-called unified version. A square 160 indicates a portion of the image which is shown in a magnified manner as box 162, which magnification is indicated with an arrow 164. The spectrum shown in box 162 is shown in full resolution, such that the circle 156 visible in the spectrum domain is shown as an arc segment 168 in box 162.

Further, a box 170 is shown with the Fast Fourier Transformation of test object showing a circle 172 indicating a peak location. For example, using the test object, the 2D Fast Fourier Transformation spectrum will have a peak line, as shown, with a shape of a circle or a slightly distorted ellipse.

As a next step, the radial average of the amplitude spectra is performed.

Fig. 32 shows spatial frequency \( v \) 174 in relation with spectrum 176 on the upright scale. A first curve 178a indicates noise and ring amplitude, a second curve 178b indicates a ring amplitude, and a third curve 178c indicates noise amplitude. It is noted that Fig. 32 shows a full spectrum, normalized to the NYQUEST.

Fig. 33 shows an enlargement of a peak of Fig. 32.

For example, a test object with sinusoidal thickness modulation \( h(r) = h_0 \times \sin(r \times 2n \times v) \) at a specific spatial frequency is provided. The method with such an object, and also with objects with different boundary profiles 38 as described above, can be referred to as "circle test" and the measured value can be named the "sinus-peak-to-spectral-noise ratio" \( SPsNR \).

The ring structures, i.e. the circle structures, make a test independent from the orientation of the object during the exposure.

For example, the signal of the rings is very low, approximately 1 %, and in the order of the image noise, as mentioned above. The ratio of sinus peak signal and noise is used as the measure according to the present invention: \( SPsNR^2 = PEAK/NOISE \).

One of the advantages is that an easy to use test procedure for quality assurance is provided, for example within the mammography diagnostic systems. Since the test includes an automatic quantification according to one example, it is easy to use and any visual assessment is not necessary.

As a further advantage, the test object according to the invention can be used in existing X-ray imaging systems provided with the possibility for the above described
performance of method steps according to the invention.

According to a further example, the measurement and calculation of the

\[ SPsNR^2 \] shall be explained in the following. First, images are made at the various exposures. Next, noise power spectra \( NPS \) is calculated and the circular integrated \( NPS \) is calculated to receive the \( ciNPS \). Then, the peak frequency \( v \) and the PEAK signal are determined, for example by the following equation:

\[
PEAK = \sum_{i=v-2}^{v+2} (ciNPS(i) - NOISE)
\]

Further, also the noise \( (v) \) at the same spatial frequency is determined. By calculating \( PEAK/NOISE \), the \( SPsNR^2 \) is received. The noise may be received with the following equation:

\[
NOISE = \frac{1}{10} \left[ \sum_{i=v-9}^{v-5} ciNPSii + \sum_{i=v+5}^{v+9} ciNPS(i) \right]
\]

An example for the calculated circular integrated \( NPS \) (ciNPS) is shown in Fig. 34 for a 2 LP/mm test object.

The horizontal axis in Fig. 34, indicated with reference numeral 180, shows the LP/mm and the vertical axis 182 shows the \( ciNPS \). A first graph 184a shows the measurements for 16 mAs, a second graph 184b for 32 mAs, a third graph 184c for 63 mAs, a fourth graph 184d for 125 mAs, a fifth graph 184e for 150 mAs, and a sixth graph 184f for 500 mAs.

Fig. 35 shows a number of measured points 186 for 28 kV at 125 mAs for a 2 LP/mm test object using \( 1024^2 \) pixels. A horizontal line segment 188 indicates the noise level, which level is also indicated by arrow 190. From the noise level, the measured points above are referenced with a number of peak calculation arrows 192a, 192b, 192c, 192d, as well as 192e. The peak calculation arrow segments 192a et seq. are then added onto each other which results in the peak level 194, indicated by a bracket enclosing the addition of the peak segment values.

Fig. 36 shows a further example, which also relates to the result shown in Fig. 31. Fig. 36a) shows a circular peak location 196 for an average of 0 to 360 degrees. In Fig. 36b), an average is shown in a range of -15 degrees to 15 degrees, indicated with reference numeral 198, for an average at 0 degrees, indicated with a dotted horizontal line 199. In Fig. 36c), an average is calculated at 90 degrees, which is indicated with a vertical line 197, for an average of -75 degrees to 105 degrees, indicated with reference numeral 195. Fig.
36d) shows an average for a horizontal line 199, as shown above, and two inclined lines 193a and 193b, which are both arranged in 60 and 120 degrees, respectively to the horizontal line 199. As indicated, for the respective positions, a respective arc segment of approximately 30 degrees, i.e. -15 degrees and +15 degrees from the respective line 199, 193a, 193b is shown, which arc segments are indicated with reference numeral 191.

According to Fig. 36e), an average is calculated for the horizontal, shown with horizontal line 199, and the vertical line 197 with the respective arc segments and also for a diagonal direction, indicated with a dotted line 189, thus providing also information about the quality of the detector with respect to a diagonal direction.

In other words, it is possible to split the result of the peak location circle into different line orientations, for example by applying the following equation:

\[ SPsNR(v) \rightarrow SPsNR_{x=0}, SPsNR_{y=90}, SPsNR_{45} \ldots \text{ etc.} \]

In case the X-ray radiation is not applied exactly in a perpendicular manner to the centre of the circles of the test object, in case of a circular arrangement, the circles will be projected to the detector in the shape of an ellipse with minimal distortion in respect to a circle. As a consequence, the shape of the peak line in the FFT spectrum (Fast Fourier Transformation spectrum) will also be an ellipse. Therefore, when referring to a radial average, in case of an ellipse correction, this is implemented as an elliptical average.

In case of using a linear test pattern, more than one exposure is advisable to cover a range of possible directions.

Fig. 37 shows a further example for a method according to the invention. In a method 300, in a first step 310, a test exposure 312 is made using, for example, a ring object v with a dose d. This results in an image 314 (LOG). In a next step 316, a 1024 x 1024 sub-frame 318 is selected that lies completely within the circles. This results in an image 320 with 1024² pixels. In a further step 322, a 2D Fast Fourier Transformation 324 is performed which leads to FFT(w,v) 326 in an amplitude data. In a further step 328, an ellipse 330 is identified that contains the peak data in the spectrum. The deviation to a circle may be very small.

This leads to an FFT(u,v) peak position 332. In a further step 334, an average peak signal PS 336 and a noise background signal NN 33% is obtained. In a further step 340, the SPsNR(v) value 342 is calculated by SNR(v) = SP/NN.

According to a further aspect, for X-ray tomosynthesis, a number of plates with different v-values can be stacked. If the plates, i.e. the multiple-element test object, comprises structures themselves, the rings will be shown before the background of these structures.
Within one tomosynthesis layer, these structures can then be reduced. As an example, this could then be measured with the circle-ring method. The signal would then not be a signal in form of the quantum noise alone, but also a signal in front of the structure noise of the plates. For example, as a side aspect, it would also be possible to evaluate the Z resolution of the system.

According to the invention, a test object with a continuous material, and thus a continuous X-ray absorption characteristic, is provided, wherein the boundary profile applied to the plate structure results in a modulation as described above. So-to-speak, the test object according to the invention, leads to a modulation of the integral absorption characteristics.

For example, the Z-modulation is of importance, contrary to the relation of the Z-modulation to the average thickness, which is not of importance for the modulation.

In another exemplary embodiment of the present invention (not shown), a computer program or a computer program element is provided i.e. characterized by being adapted to execute the method steps of the method according to one of the preceding embodiments, on an appropriate system.

The computer program element might therefore be stored on a computer unit, which might also be part of an embodiment of the present invention. This computing unit may be adapted to perform or induce a performing of the steps of the method described above. Moreover, it may be adapted to operate the components of the above described apparatus. The computing unit can be adapted to operate automatically and/or to execute the orders of a user. A computer program may be loaded into a working memory of a data processor. The data processor may thus be equipped to carry out the method of the invention.

This exemplary embodiment of the invention covers both, a computer program that right from the beginning uses the invention and a computer program that by means of an up-date turns an existing program into a program that uses the invention.

Further on, the computer program element might be able to provide all necessary steps to fulfil the procedure of an exemplary embodiment of the method as described above.

According to a further exemplary embodiment of the present invention (not shown), a computer readable medium, such as a CD-ROM, is presented wherein the computer readable medium has a computer program element stored on it which computer program element is described by the preceding section.

A computer program may be stored and/or distributed on a suitable medium,
such as an optical storage medium or a solid state medium supplied together with or as part of other hardware, but may also be distributed in other forms, such as via the internet or other wired or wireless telecommunication systems.

However, the computer program may also be presented over a network like the World Wide Web and can be downloaded into the working memory of a data processor from such a network. According to a further exemplary embodiment of the present invention, a medium for making a computer program element available for downloading is provided, which computer program element is arranged to perform a method according to one of the previously described embodiments of the invention.

It has to be noted that embodiments of the invention are described with reference to different subject matters. In particular, some embodiments are described with reference to method type claims whereas other embodiments are described with reference to the device type claims. However, a person skilled in the art will gather from the above and the following description that, unless otherwise notified, in addition to any combination of features belonging to one type of subject matter also any combination between features relating to different subject matters is considered to be disclosed with this application. However, all features can be combined providing synergetic effects that are more than the simple summation of the features.

In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. A single processor or other unit may fulfil the functions of several items re-cited in the claims. The mere fact that certain measures are re-cited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.
CLAIMS:

1. A test object (30) for X-ray imaging, comprising:
   - a plate structure (32) with:
     at least a first layer (34) with a first material (36) with a first X-ray attenuation;
     wherein the plate structure is provided at least on one side with a boundary
     profile (38), which boundary profile is arranged between the first layer with the first X-ray
     attenuation and an adjoining second layer (40) with a second X-ray attenuation; wherein the
     second X-ray attenuation is lower than the first X-ray attenuation; and
     wherein the boundary profile comprises a plurality of minima (44) and maxima
     points (48), which are arranged periodically; wherein on the boundary profile, at least one
     intermediate value point (50) is provided between each adjacent minima and maxima point.

2. Test object according to claim 1, wherein the boundary profile is a graph with a
   continuous function (54).

3. Test object according to claim 1 or 2, wherein the boundary profile comprises a
   sinusoidal cross section (58).

4. Test object according to one of the preceding claims, wherein the boundary
   profile comprises a plurality of grooves formed by the minima and maxima points; wherein the
   grooves are arranged parallel (74) to each other in a linear manner (76) across the plate
   structure.

5. Test object according to one of the claims 1 to 3, wherein the boundary profile
   comprises a plurality of grooves formed by the minima and maxima points; wherein the
   plurality of grooves are arranged on the plate structure in a circular manner (78) as concentric
   rings (80).
6. Test object according to one of the claims 1 to 3, wherein the boundary profile comprises at least one groove arranged as at least one spiral (82); which spiral is forming the boundary profile.

7. A test object (30) for X-ray imaging, comprising:
   - a plate structure (32) with;
     at least a first layer (34) with a first material (36) with a first X-ray attenuation;
     wherein the plate structure is provided at least on one side with a boundary profile (138), which boundary profile is arranged between the first layer with the first X-ray attenuation and an adjoining second layer (40) with a second X-ray attenuation; wherein the second X-ray attenuation is lower than the first X-ray attenuation; and
     wherein the boundary profile is a step function (94) comprising only a plurality of minima (96) and maxima segments (98), which are arranged periodically;
     wherein the boundary profile comprises a plurality of slits (102) formed by the minima segments between adjacent maxima segments; wherein the slits are arranged on the plate structure in a circular manner (104) as concentric rings (106).

8. Test object according to one of the preceding claims, wherein the boundary profile comprises a number of subareas (124); which subareas are each provided with a different boundary profile.

9. Test object according to one of the preceding claims, wherein, adjacent to the first layer, a second layer (140) is provided with a second material (142) with the second X-ray attenuation.

10. An X-ray imaging system (10) comprising:
   - an X-ray source (12);
   - a detector (14); and
   - a test object (30) according to one of the preceding claims; wherein the X-ray source generates X-ray radiation;
   wherein the test object is arranged between the X-ray source and the detector; and
   wherein the detector is adapted to record raw image data.
11. A method (200) for testing an X-ray imaging system, comprising the steps of:
   a) placing (210) a test object between an X-ray source and a detector; wherein
      the test object is a test object according to one of the claims 1 to 9;
   b) acquiring (212) at least one 2D X-ray test image (214);
   c) selecting (216) a sub-frame (218) of the X-ray image which is within the
      profiled part of the test object;
   d) performing (220) a transformation (222) from spatial domain to spectral
      domain for the sub-frame image data;
   e) determining (224) a peak position (226) in the frequency domain; and
   f) determining (228) average peak signal (230) and background noise signal
      (232).

12. Method according to claim 11, wherein following step f), a step g) is provided
    in which a sinus-peak-to-spectral-noise ratio (234) is determined (236).

13. Use of a test object according to one of the claims 1 to 9 in an X-ray imaging
    system.

14. Computer program element for controlling an apparatus according to claim 10,
    which, when being executed by a processing unit, is adapted to perform the method
    steps of claims 11 or 12.

15. Computer readable medium having stored the program element of claim 14.
Fig. 34

Fig. 35
Fig. 37
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

INV. A61B 6/00  G01T 7/00

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  G01T

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, COMPENDEX, EMBASE, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
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<th>Relevant to claim No.</th>
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<td>Y</td>
<td>abstract paragraphs [0039] - [0041], [0043], [0045], [0058] - [0060], [0063], [0066] - [0069], [0073] - [0082], [0087], [0089]; claims 1-27; figures 3,5,7,8,10, -----</td>
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[√] Further documents are listed in the continuation of Box C.  [X] See patent family annex.

* Special categories of cited documents:

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Date of the actual completion of the international search: 24 April 2012

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Fax: (+31-70) 340-3016

Authorized officer: Daoukou, El eni
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