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YAMAMOTO

(54) **ULTRASONIC INSPECTION APPARATUS**

(71) Applicant: **FUJIFILM CORPORATION**, Tokyo (JP)

(72) Inventor: **Hiroaki YAMAMOTO**, Ashigara-kami-gun (JP)

(73) Assignee: **FUJIFILM CORPORATION**, Tokyo (JP)

(21) Appl. No.: **14/594,889**

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(30) **Foreign Application Priority Data**

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Jul. 10, 2013 (JP) 2013-144809

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A61B 8/00 (2006.01)

(52) **U.S. Cl.**

CPC ***A61B 8/14*** (2013.01); ***A61B 8/4488*** (2013.01); ***A61B 8/54*** (2013.01); ***A61B 8/5207*** (2013.01)

(57) **ABSTRACT**

An ultrasonic inspection apparatus includes: a probe; a transmission unit configured to cause the probe to transmit a ultrasonic beam; a reception unit configured to receive analog element signals output by the probe; an A/D conversion unit configured to perform A/D conversion on the analog element signal to obtain first element data; and a data processing unit configured to generate second element data from a plurality of the pieces of first element data, wherein the data processing unit changes conditions of acquisition of two or more of the pieces of first element data for generating the second element data depending on a depth of a position in which the second element data is obtained.

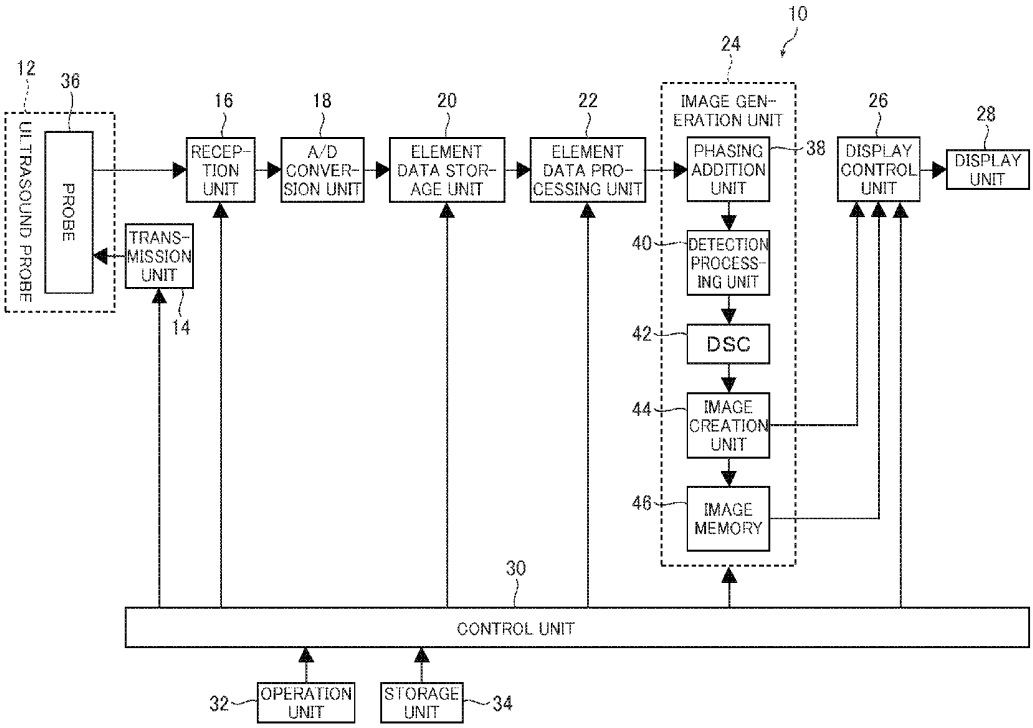


FIG. 1

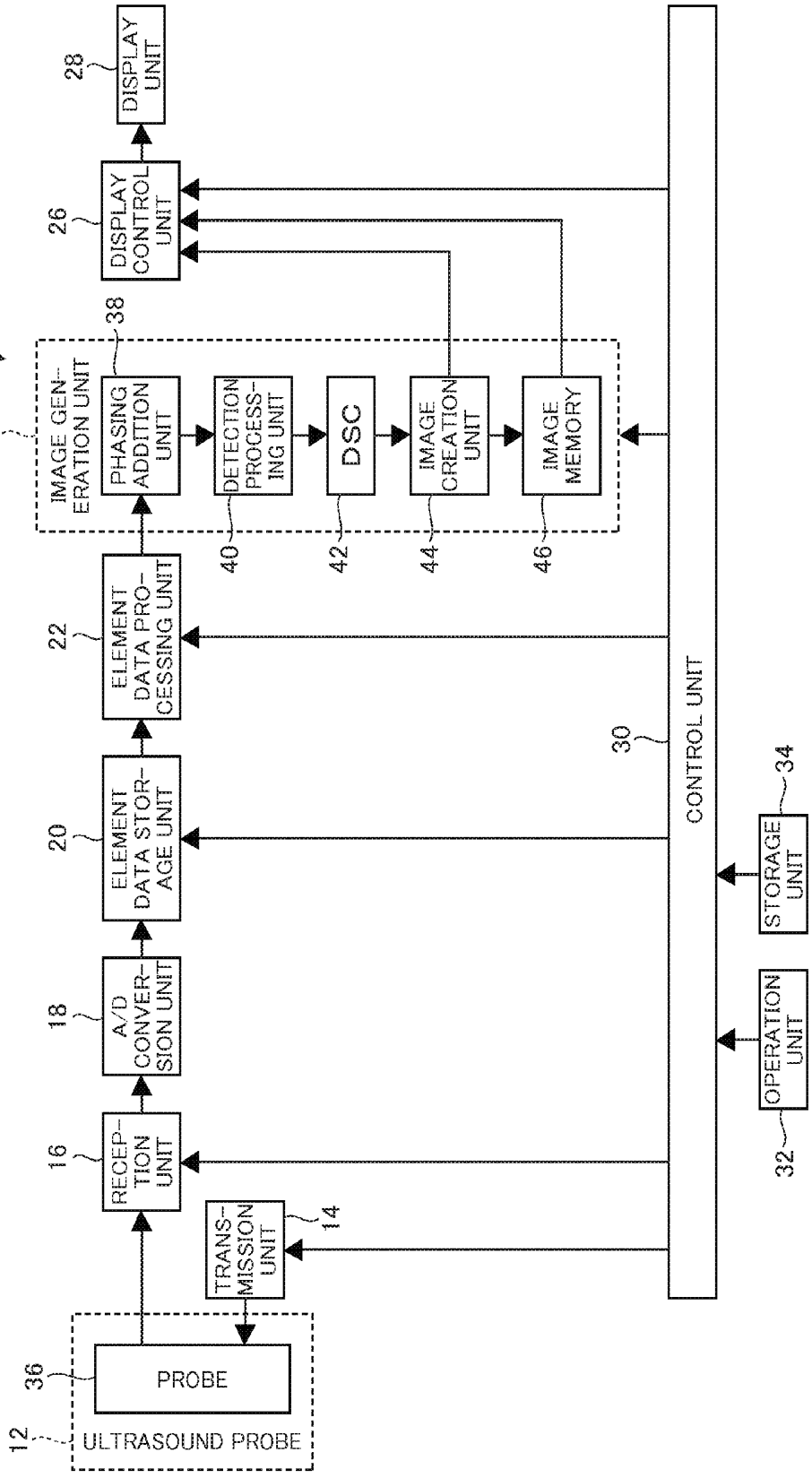
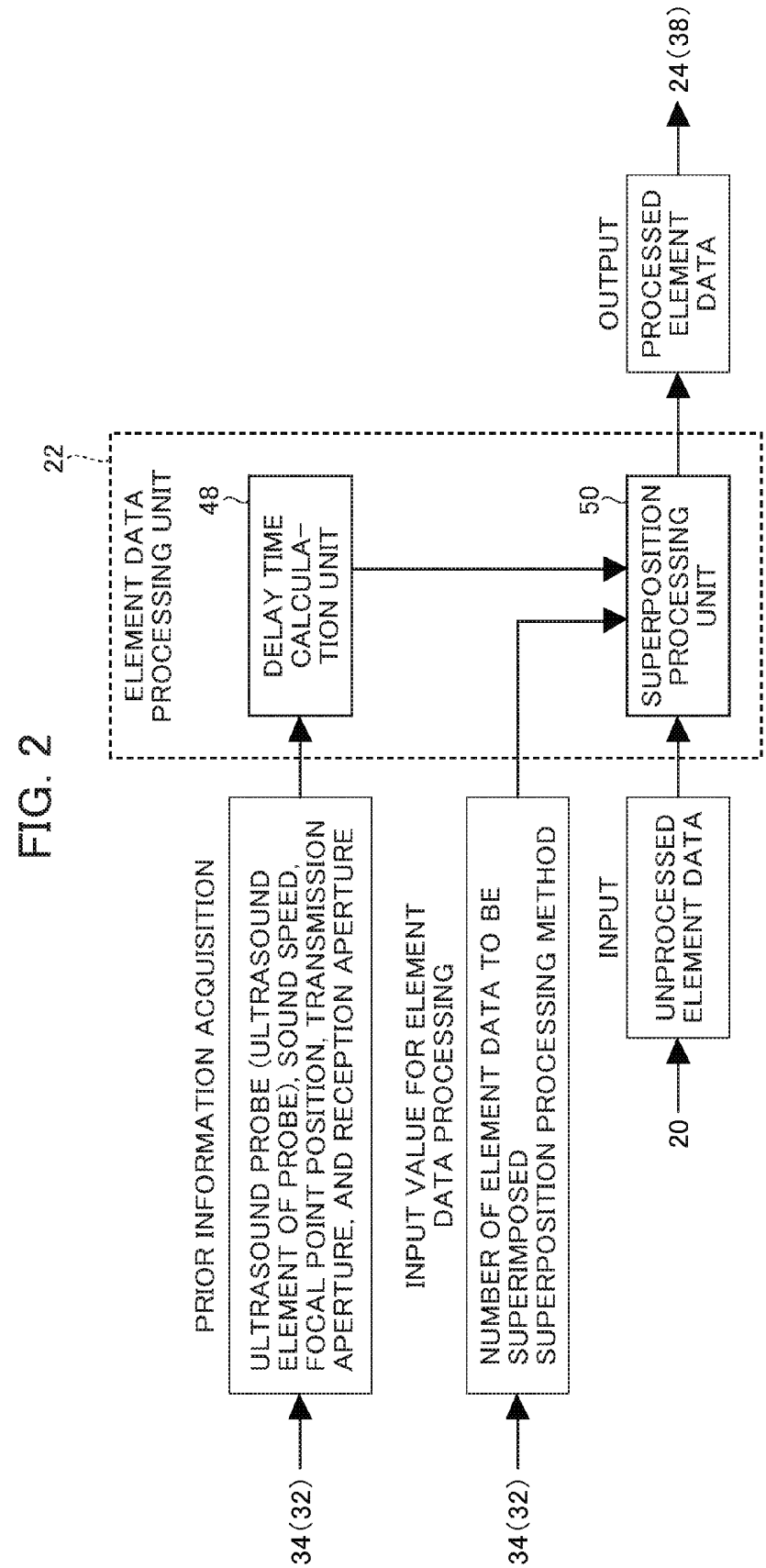

10
12
ULTRASOUND PROBE
36
PROBE
TRANS-MISSION UNIT
14
RECEP-TION UNIT
16
A/D CONVER-SION UNIT
18
ELEMENT DATA STOR-AGE UNIT
20
ELEMENT DATA PRO-CESSING UNIT
22
IMAGE GEN-ERATION UNIT
24
PHASING ADDITION UNIT
38
DETECTION PROCESS-ING UNIT
40
DSC
42
IMAGE CREATION UNIT
44
IMAGE MEMORY
46
DISPLAY CONTROL UNIT
26
DISPLAY UNIT
28
CONTROL UNIT
30
OPERATION UNIT
32
STORAGE UNIT
34

FIG. 2


22
ELEMENT DATA PROCESSING UNIT
48
DELAY TIME CALCULATION UNIT
50
SUPERPOSITION PROCESSING UNIT
OUTPUT
PROCESSED ELEMENT DATA
24 (38)
PRIOR INFORMATION ACQUISITION
ULTRASOUND PROBE (ULTRASOUND ELEMENT OF PROBE), SOUND SPEED, FOCAL POINT POSITION, TRANSMISSION APERTURE, AND RECEPTION APERTURE
34 (32)
INPUT VALUE FOR ELEMENT DATA PROCESSING
NUMBER OF ELEMENT DATA TO BE SUPERIMPOSED
SUPERPOSITION PROCESSING METHOD
34 (32)
INPUT
UNPROCESSED ELEMENT DATA
20

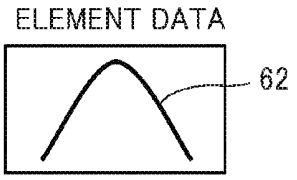


FIG. 3B

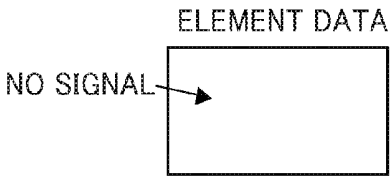


FIG. 3D

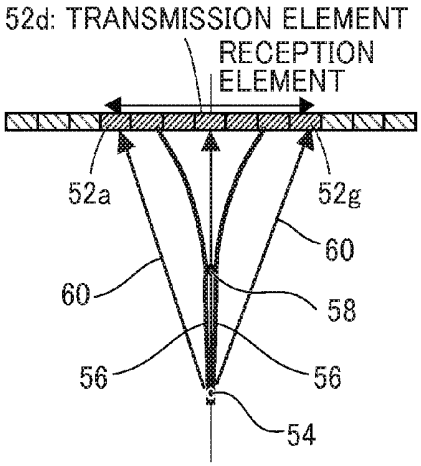


FIG. 3A

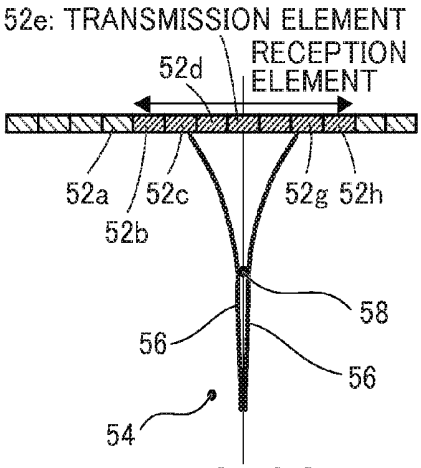


FIG. 3C

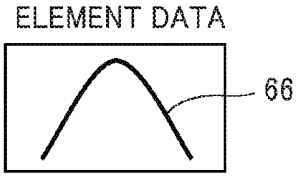


FIG. 4B

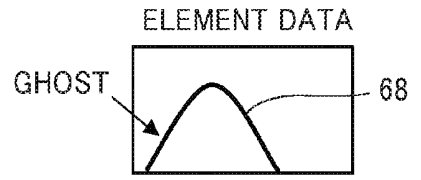


FIG. 4D

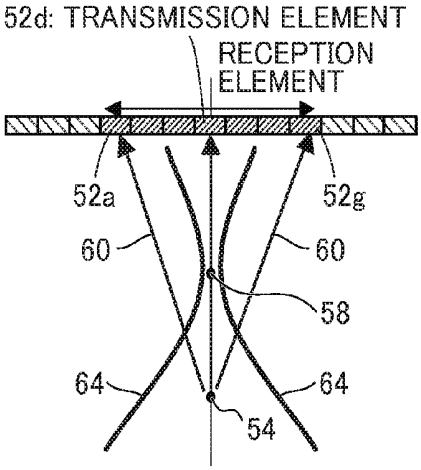


FIG. 4A

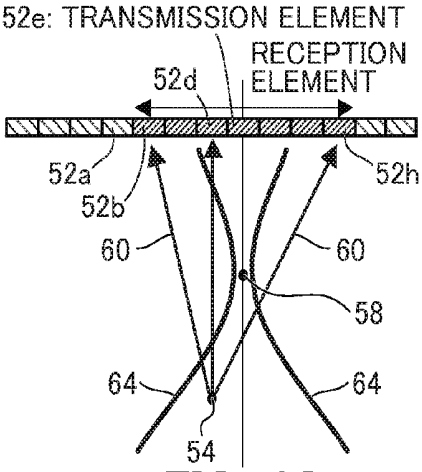


FIG. 4C

FIG. 5A

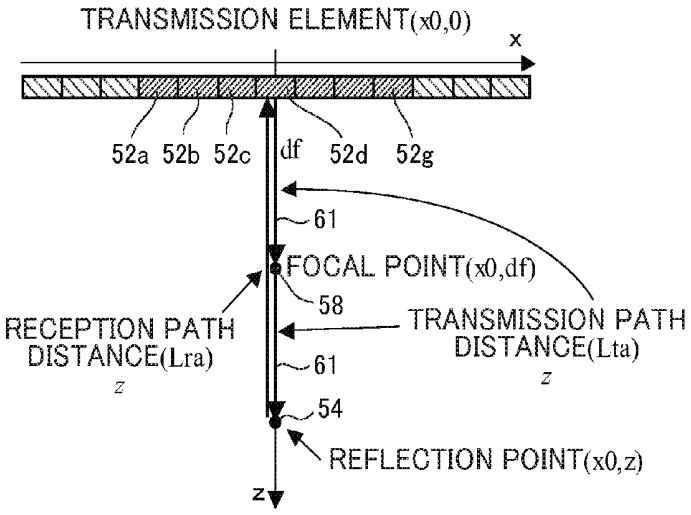


FIG. 5B

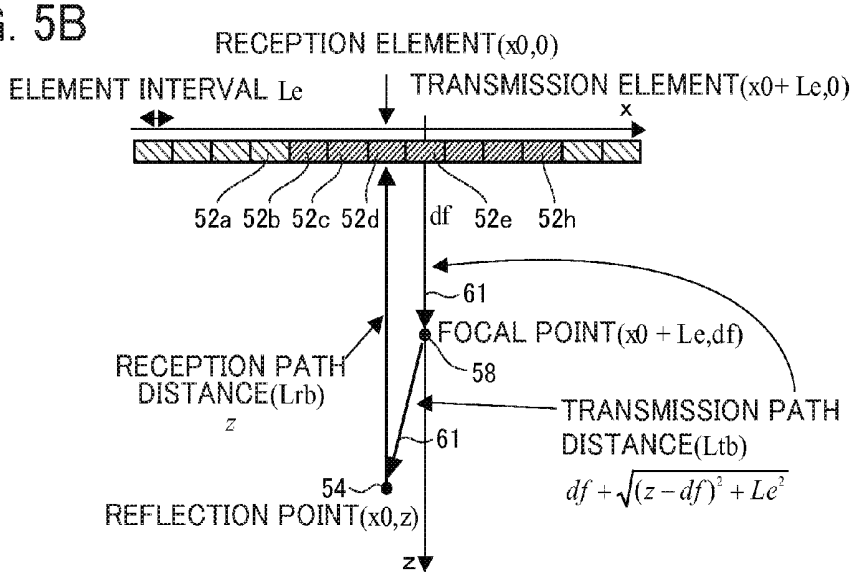


FIG. 5C

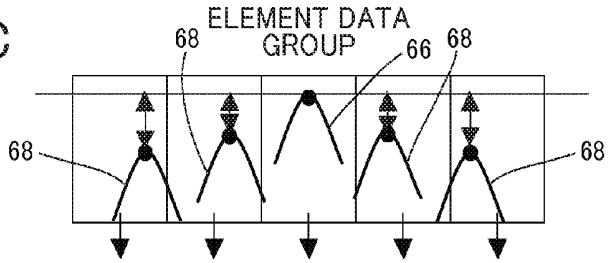
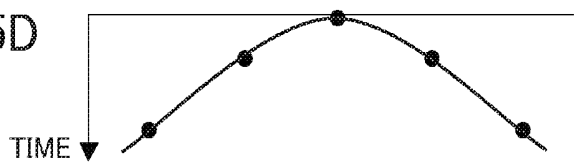


FIG. 5D



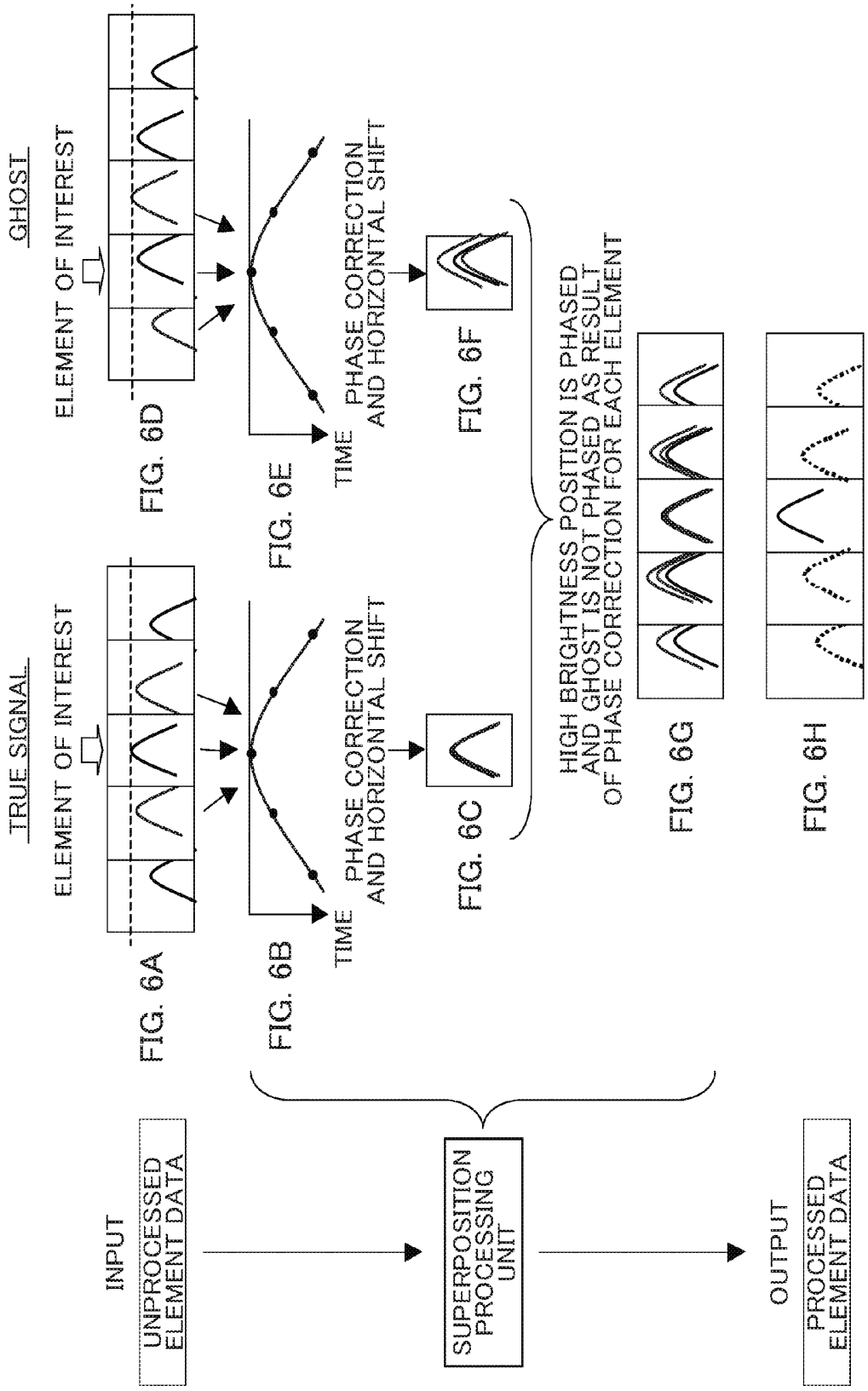

INPUT
UNPROCESSED ELEMENT DATA
SUPERPOSITION PROCESSING UNIT
OUTPUT
PROCESSED ELEMENT DATA
TRUE SIGNAL
ELEMENT OF INTEREST
FIG. 6A
TIME
PHASE CORRECTION AND HORIZONTAL SHIFT
FIG. 6B
FIG. 6C
GHOST
ELEMENT OF INTEREST
FIG. 6D
TIME
PHASE CORRECTION AND HORIZONTAL SHIFT
FIG. 6E
FIG. 6F
HIGH BRIGHTNESS POSITION IS PHASED AND GHOST IS NOT PHASED AS RESULT OF PHASE CORRECTION FOR EACH ELEMENT
FIG. 6G
FIG. 6H

FIG. 7

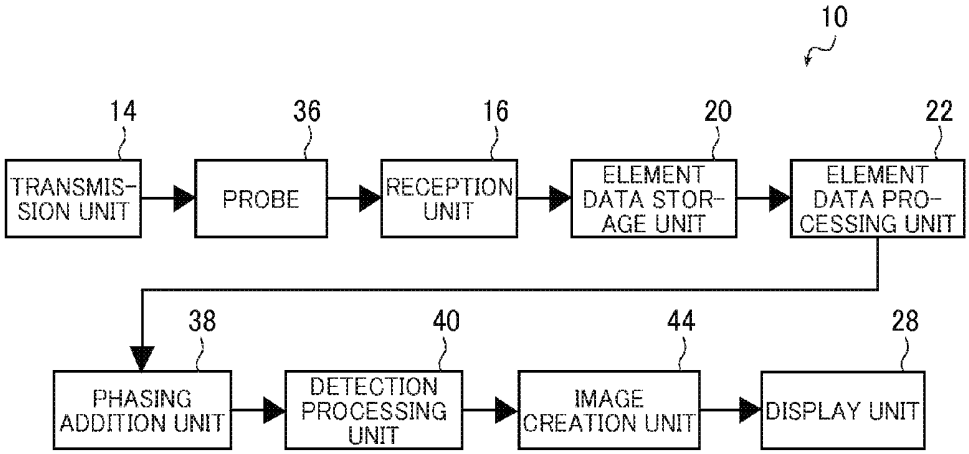

10
14
TRANSMIS-
SION UNIT
36
PROBE
16
RECEPTION
UNIT
20
ELEMENT
DATA STOR-
AGE UNIT
22
ELEMENT
DATA PRO-
CESSING UNIT
38
PHASING
ADDITION UNIT
40
DETECTION
PROCESSING
UNIT
44
IMAGE
CREATION UNIT
28
DISPLAY UNIT

FIG. 8A

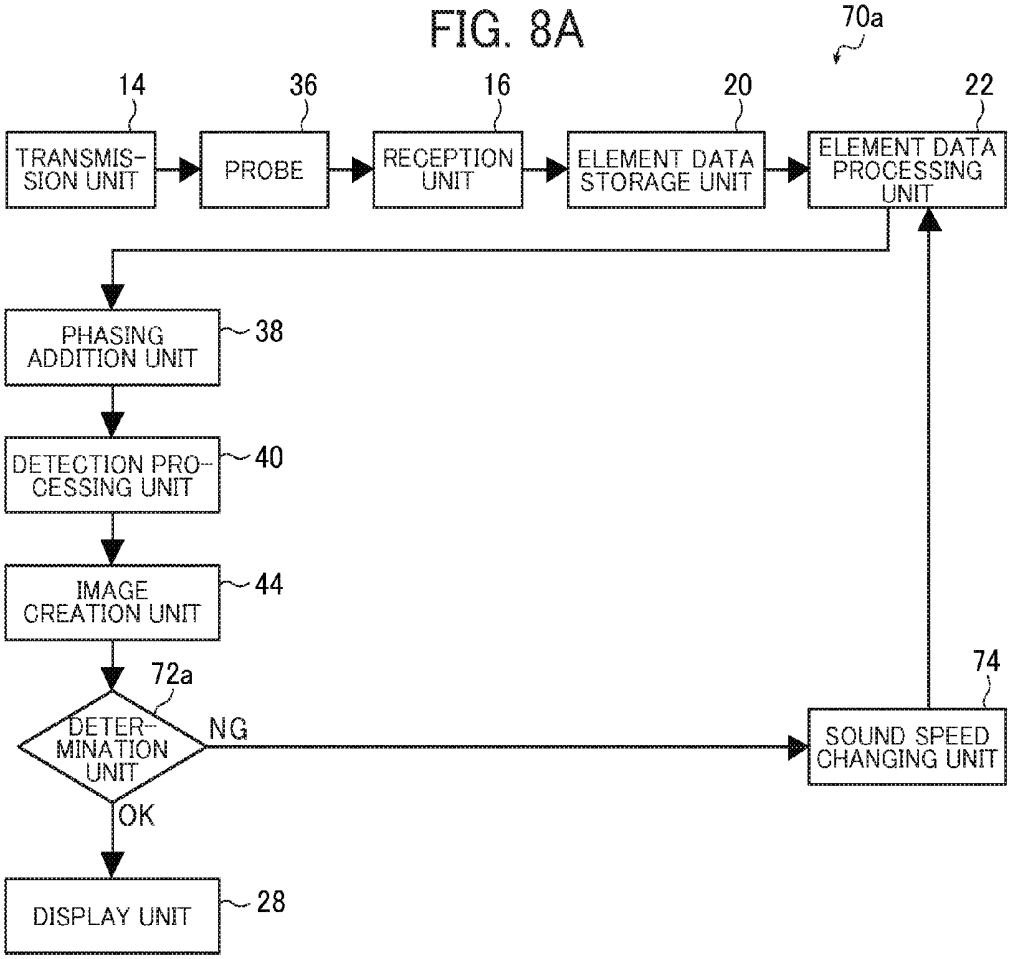

70a
14
TRANSMIS-SION UNIT
36
PROBE
16
RECEPTION UNIT
20
ELEMENT DATA STORAGE UNIT
22
ELEMENT DATA PROCESSING UNIT
PHASING ADDITION UNIT
38
DETECTION PRO-CESSING UNIT
40
IMAGE CREATION UNIT
44
72a
DETER-MINATION UNIT
NG
OK
74
SOUND SPEED CHANGING UNIT
DISPLAY UNIT
28

FIG. 8B

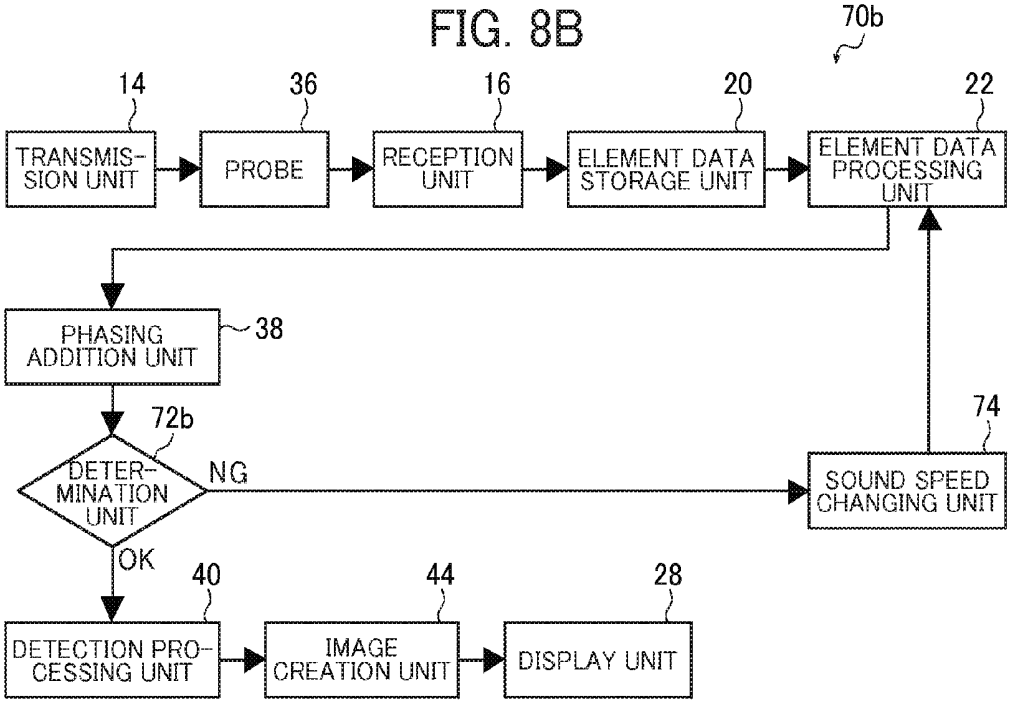

70b
14
TRANSMIS-SION UNIT
36
PROBE
16
RECEPTION UNIT
20
ELEMENT DATA STORAGE UNIT
22
ELEMENT DATA PROCESSING UNIT
PHASING ADDITION UNIT
38
72b
DETER-MINATION UNIT
NG
OK
74
SOUND SPEED CHANGING UNIT
40
DETECTION PRO-CESSING UNIT
44
IMAGE CREATION UNIT
28
DISPLAY UNIT

FIG. 9

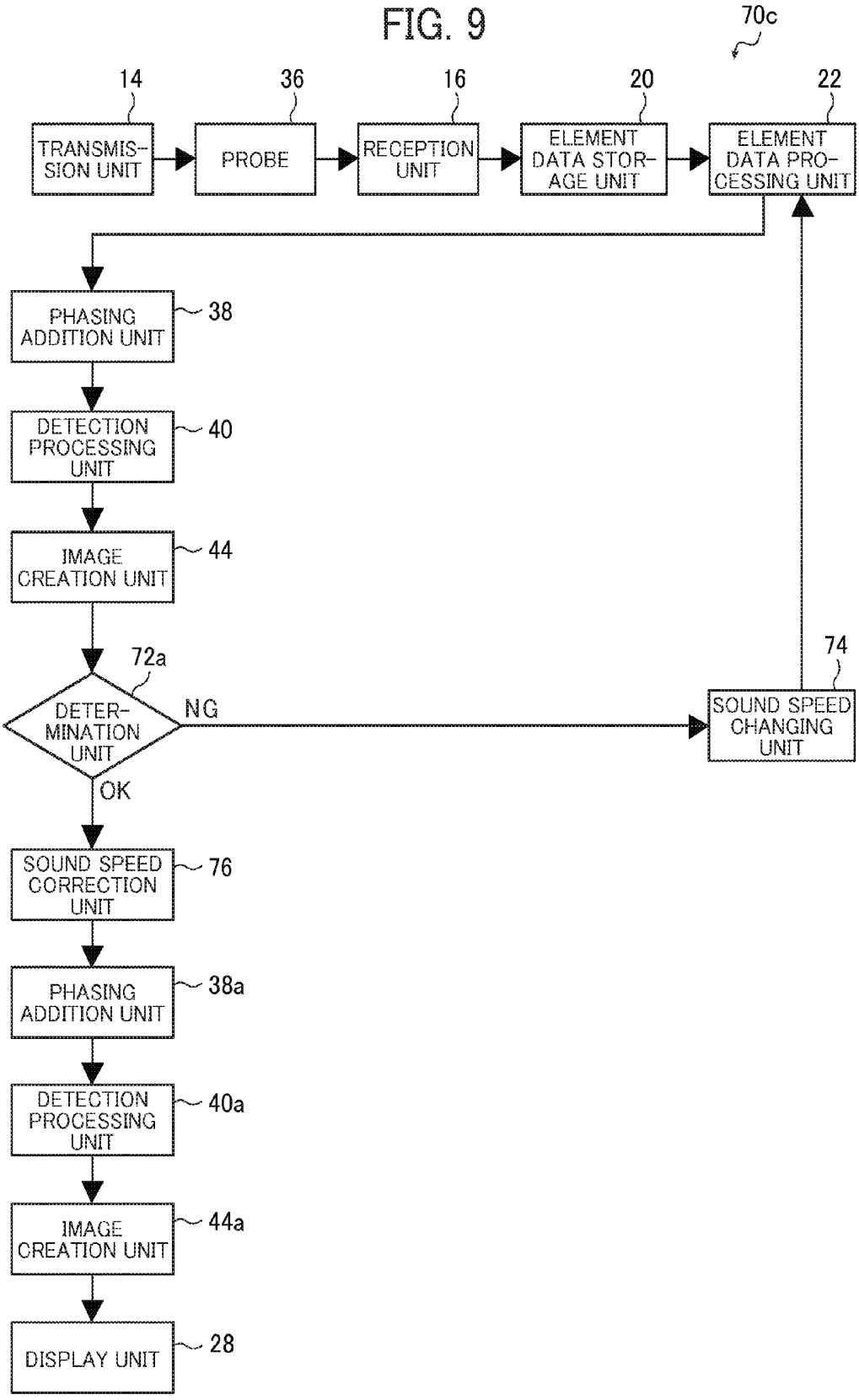

70c
14
TRANSMIS-SION UNIT
36
PROBE
16
RECEPTION UNIT
20
ELEMENT DATA STOR-AGE UNIT
22
ELEMENT DATA PRO-CESSING UNIT
PHASING ADDITION UNIT
38
DETECTION PROCESSING UNIT
40
IMAGE CREATION UNIT
44
72a
DETER-MINATION UNIT
NG
OK
74
SOUND SPEED CHANGING UNIT
SOUND SPEED CORRECTION UNIT
76
PHASING ADDITION UNIT
38a
DETECTION PROCESSING UNIT
40a
IMAGE CREATION UNIT
44a
DISPLAY UNIT
28

FIG. 10A

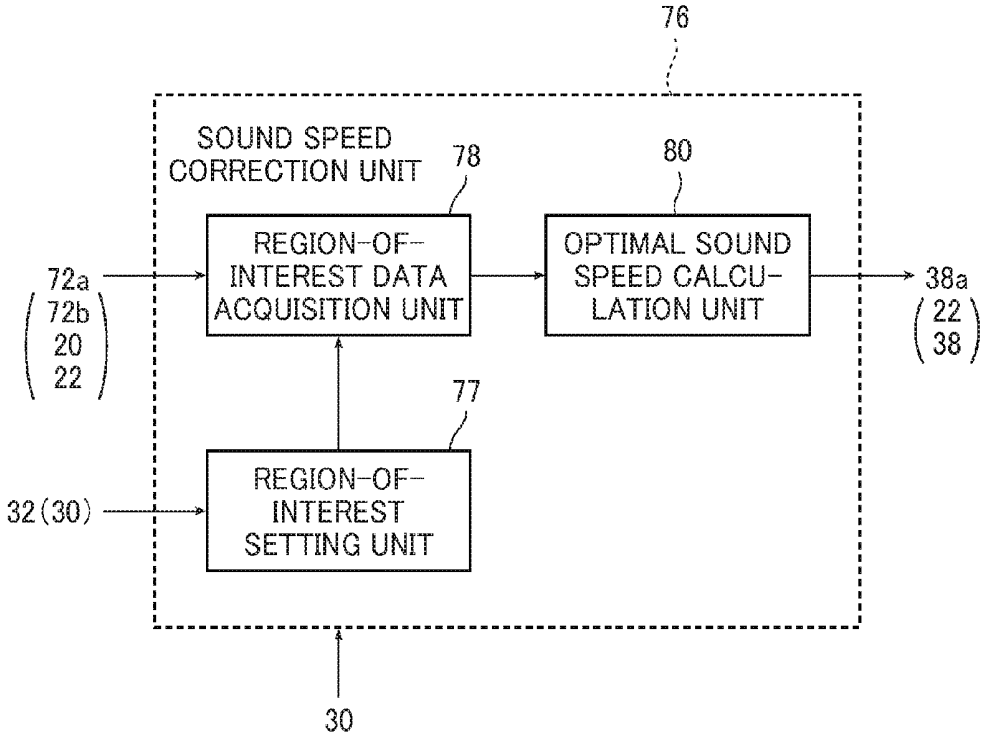


FIG. 10B

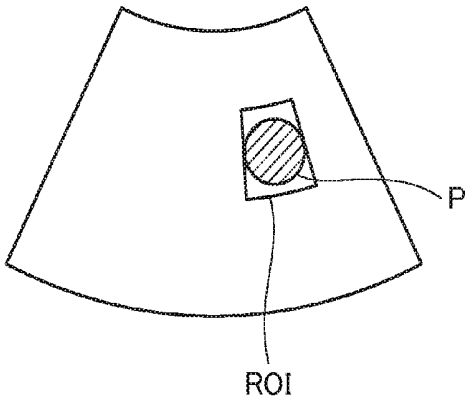


FIG. 11

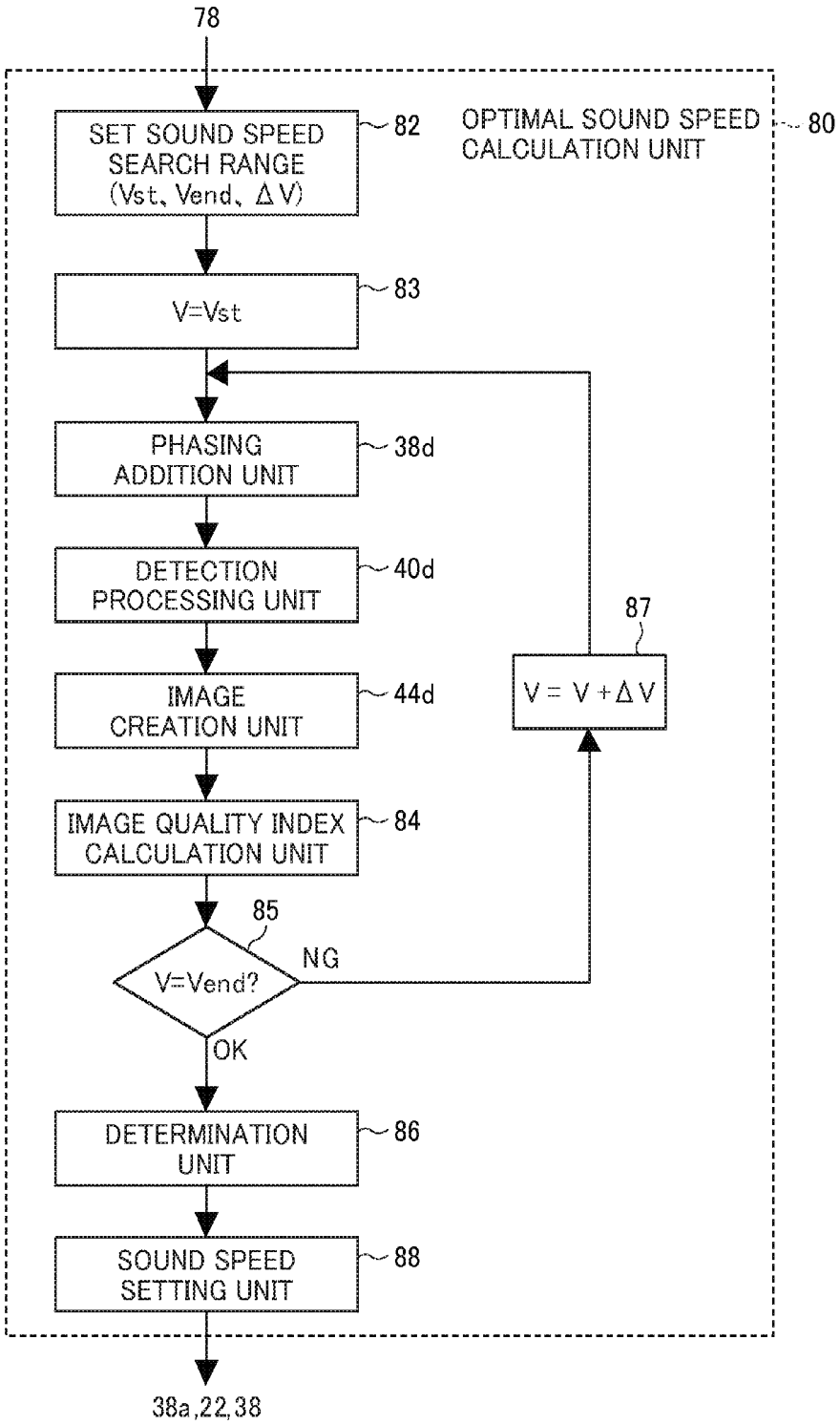

78
SET SOUND SPEED SEARCH RANGE (Vst, Vend, ΔV)
82
OPTIMAL SOUND SPEED CALCULATION UNIT
80
V=Vst
83
PHASING ADDITION UNIT
38d
DETECTION PROCESSING UNIT
40d
IMAGE CREATION UNIT
44d
IMAGE QUALITY INDEX CALCULATION UNIT
84
85
V=Vend?
NG
OK
87
V = V + ΔV
DETERMINATION UNIT
86
SOUND SPEED SETTING UNIT
88
38a,22,38

FIG. 12

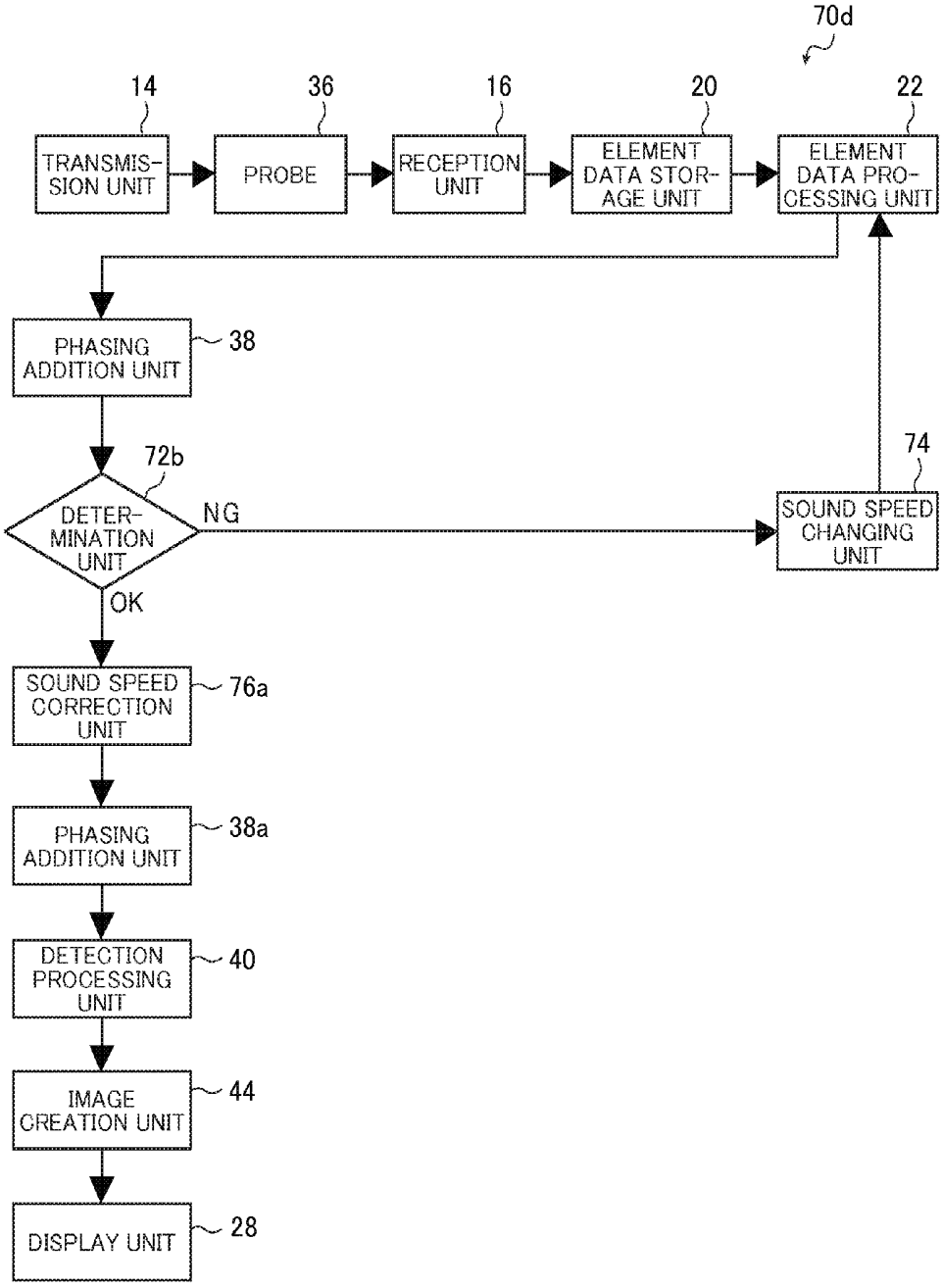

70d
14
36
16
20
22
TRANSMIS-SION UNIT
PROBE
RECEPTION UNIT
ELEMENT DATA STOR-AGE UNIT
ELEMENT DATA PRO-CESSING UNIT
PHASING ADDITION UNIT
38
72b
DETER-MINATION UNIT
NG
74
SOUND SPEED CHANGING UNIT
OK
SOUND SPEED CORRECTION UNIT
76a
PHASING ADDITION UNIT
38a
DETECTION PROCESSING UNIT
40
IMAGE CREATION UNIT
44
DISPLAY UNIT
28

FIG. 13

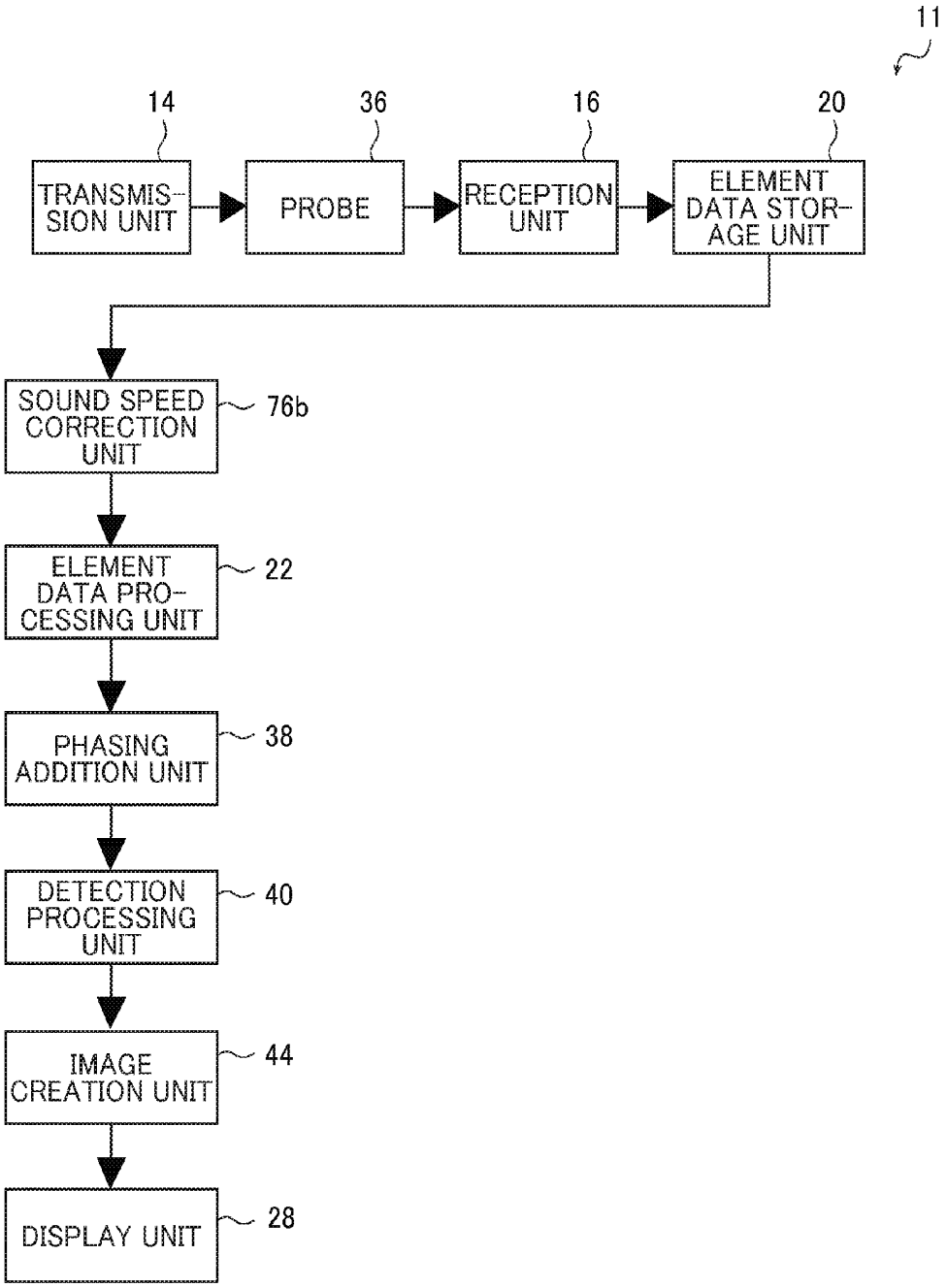

11
14
36
16
20
TRANSMIS-SION UNIT
PROBE
RECEPTION UNIT
ELEMENT DATA STOR-AGE UNIT
SOUND SPEED CORRECTION UNIT
76b
ELEMENT DATA PRO-CESSING UNIT
22
PHASING ADDITION UNIT
38
DETECTION PROCESSING UNIT
40
IMAGE CREATION UNIT
44
DISPLAY UNIT
28

FIG. 14

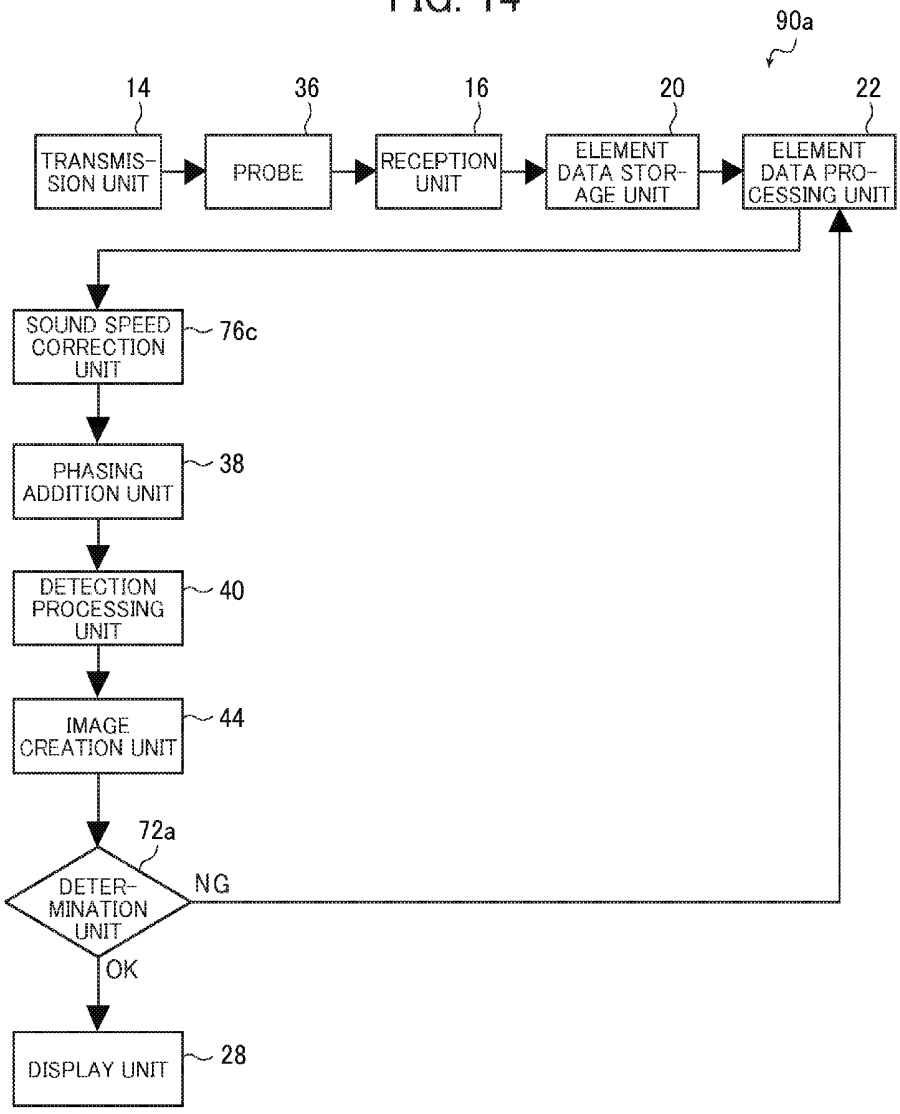

90a
14
36
16
20
22
TRANSMIS-SION UNIT
PROBE
RECEPTION UNIT
ELEMENT DATA STOR-AGE UNIT
ELEMENT DATA PRO-CESSING UNIT
SOUND SPEED CORRECTION UNIT
76c
PHASING ADDITION UNIT
38
DETECTION PROCESSING UNIT
40
IMAGE CREATION UNIT
44
72a
DETER-MINATION UNIT
NG
OK
DISPLAY UNIT
28

FIG. 15

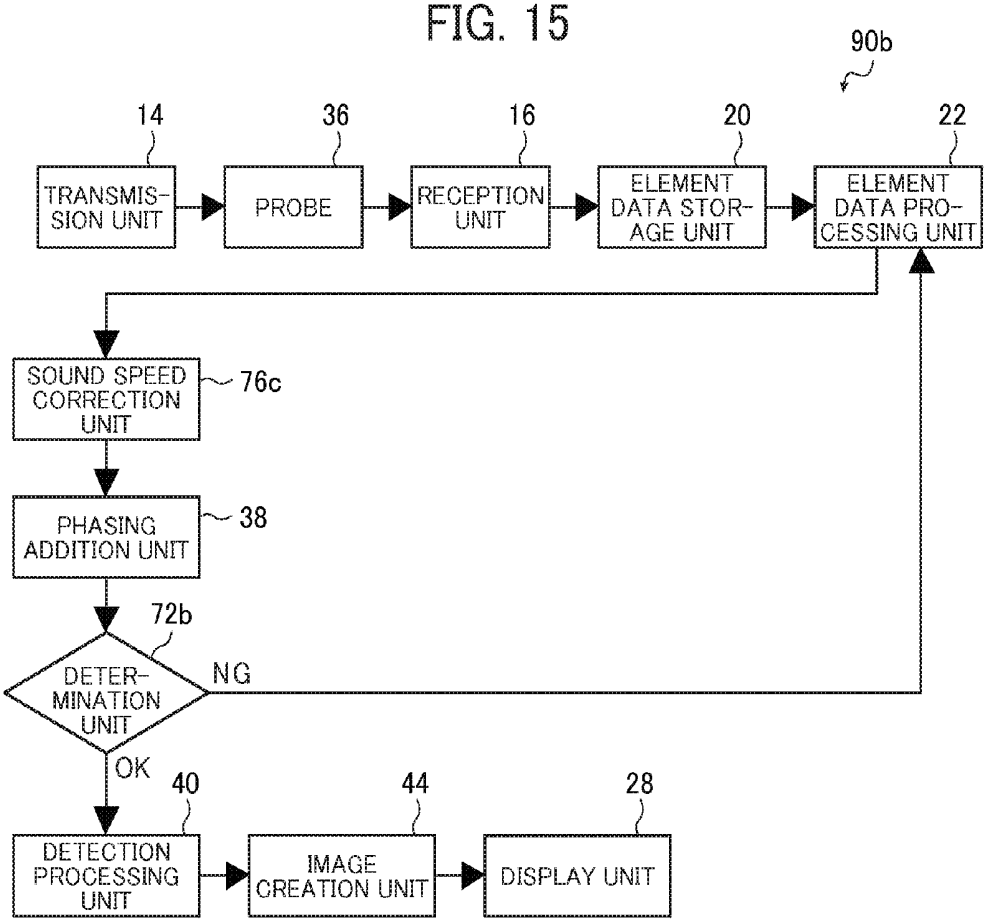

90b
14
36
16
20
22
TRANSMIS-SION UNIT
PROBE
RECEPTION UNIT
ELEMENT DATA STOR-AGE UNIT
ELEMENT DATA PRO-CESSING UNIT
SOUND SPEED CORRECTION UNIT
76c
PHASING ADDITION UNIT
38
72b
DETER-MINATION UNIT
NG
OK
40
44
28
DETECTION PROCESSING UNIT
IMAGE CREATION UNIT
DISPLAY UNIT

FIG. 16

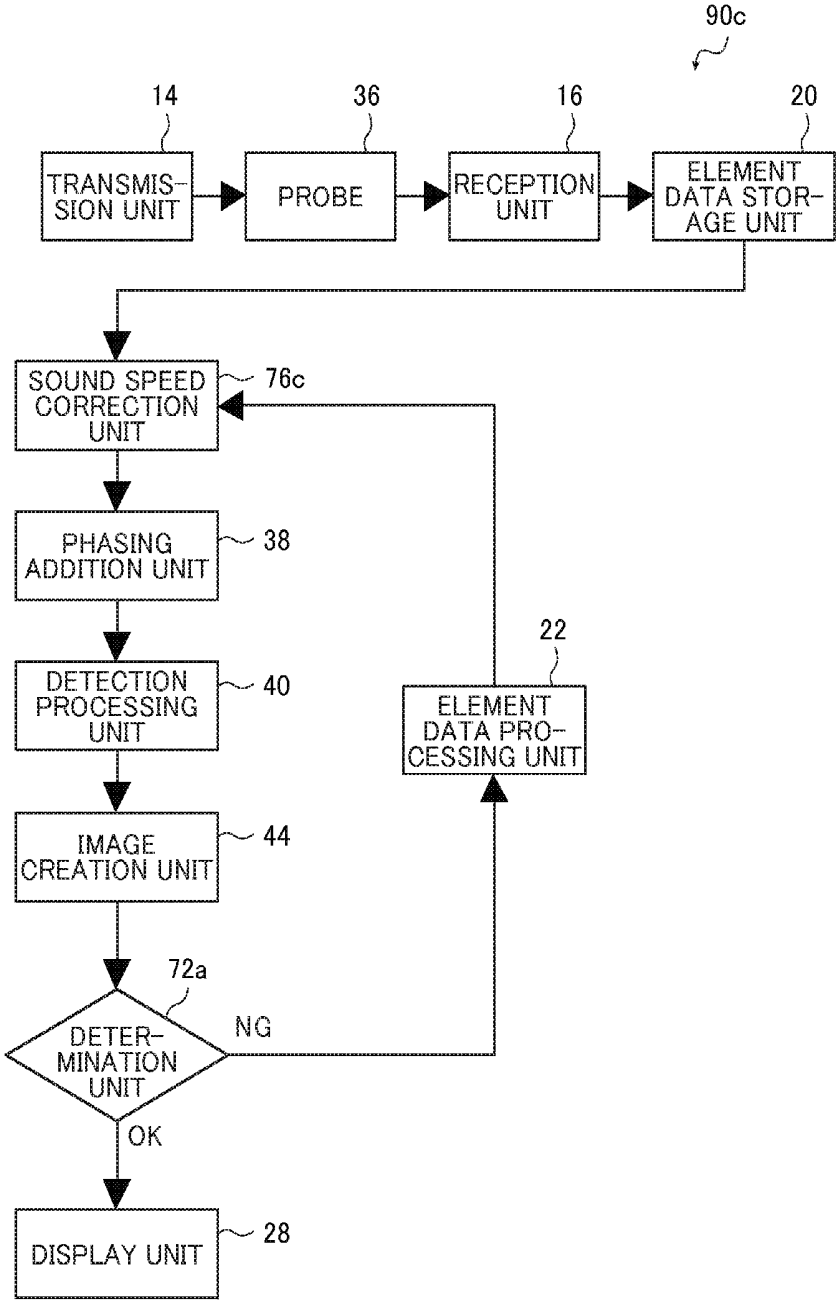

90c
14
36
16
20
TRANSMIS-SION UNIT
PROBE
RECEPTION UNIT
ELEMENT DATA STOR-AGE UNIT
SOUND SPEED CORRECTION UNIT
76c
PHASING ADDITION UNIT
38
DETECTION PROCESSING UNIT
40
22
ELEMENT DATA PRO-CESSING UNIT
IMAGE CREATION UNIT
44
72a
DETER-MINATION UNIT
NG
OK
DISPLAY UNIT
28

FIG. 17

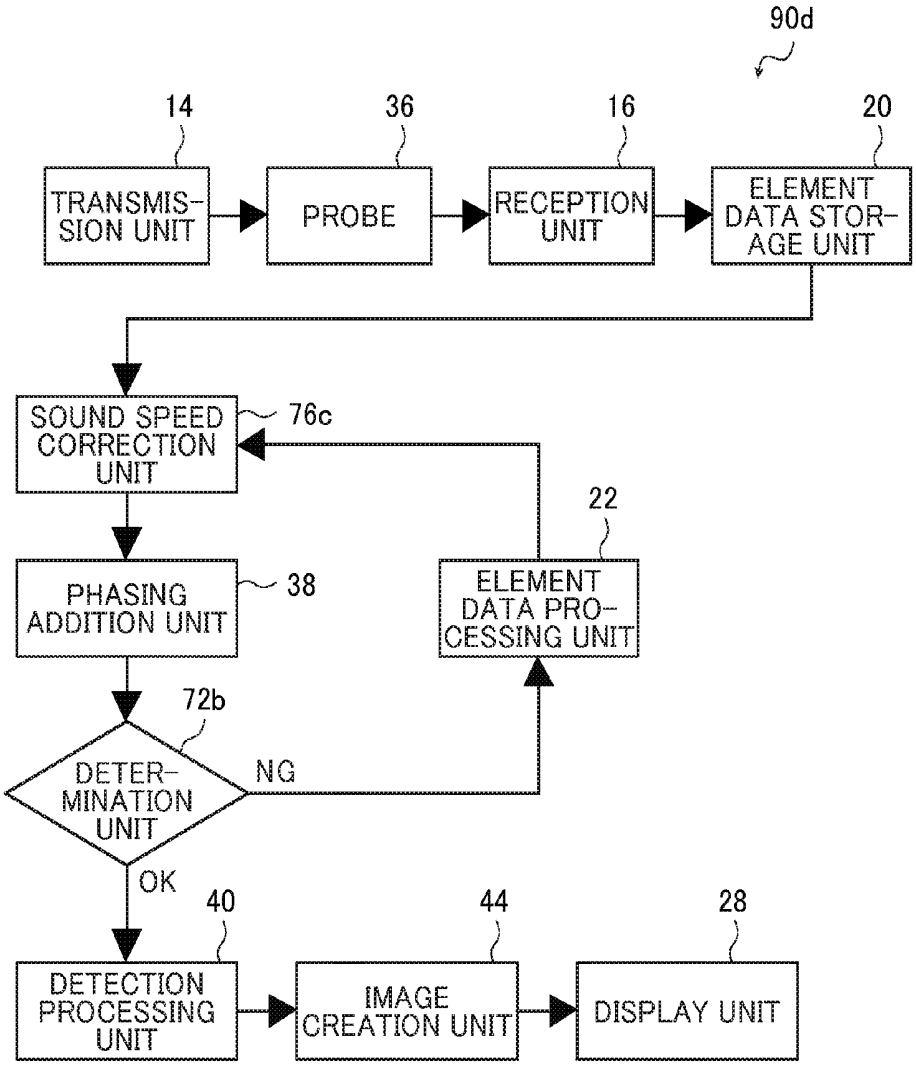

90d
14
36
16
20
TRANSMIS-SION UNIT
PROBE
RECEPTION UNIT
ELEMENT DATA STOR-AGE UNIT
SOUND SPEED CORRECTION UNIT
76c
22
PHASING ADDITION UNIT
38
ELEMENT DATA PRO-CESSING UNIT
72b
DETER-MINATION UNIT
NG
OK
40
44
28
DETECTION PROCESSING UNIT
IMAGE CREATION UNIT
DISPLAY UNIT

FIG. 18

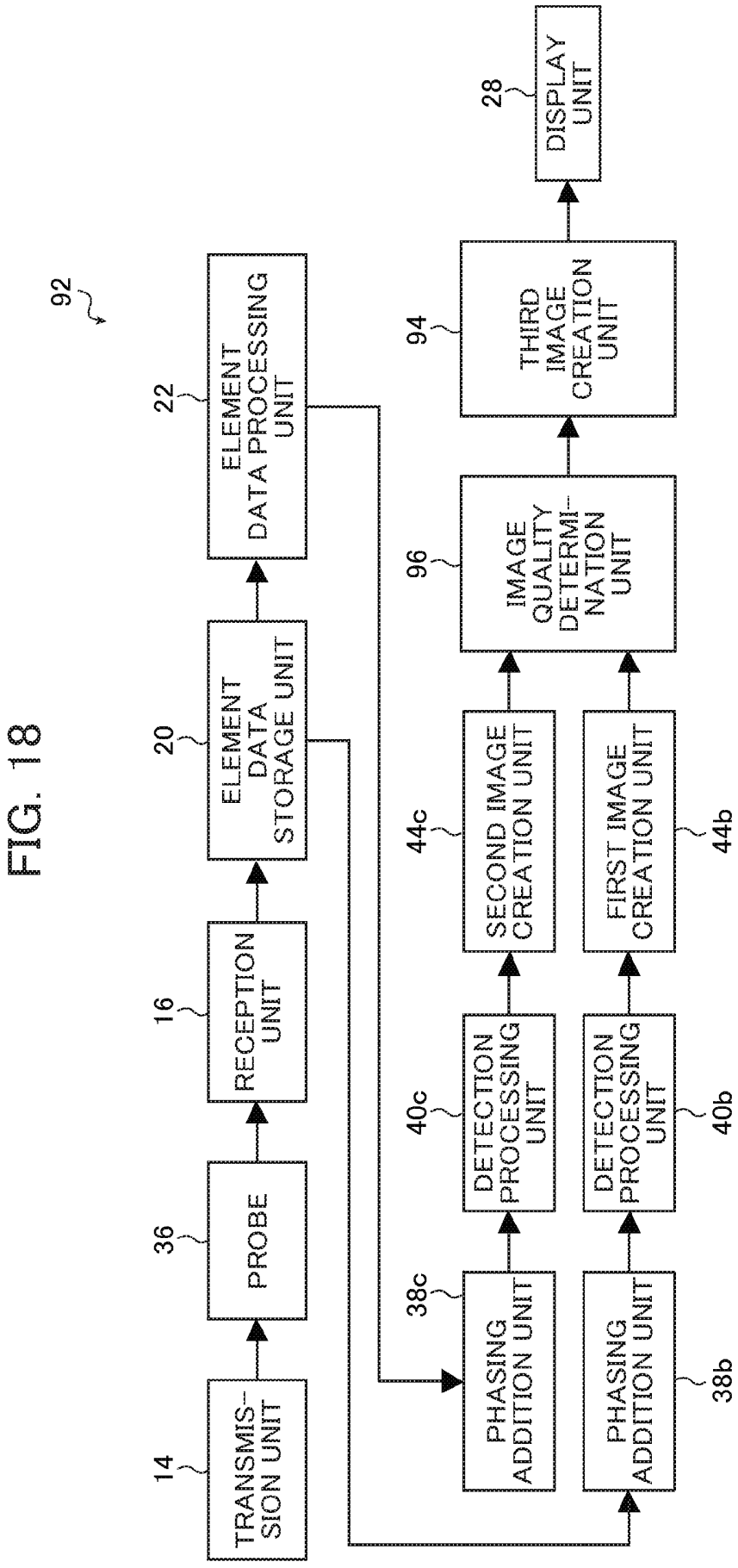

92
14
TRANSMIS-SION UNIT
36
PROBE
16
RECEPTION UNIT
20
ELEMENT DATA STORAGE UNIT
22
ELEMENT DATA PROCESSING UNIT
38c
PHASING ADDITION UNIT
38b
PHASING ADDITION UNIT
40c
DETECTION PROCESSING UNIT
40b
DETECTION PROCESSING UNIT
44c
SECOND IMAGE CREATION UNIT
44b
FIRST IMAGE CREATION UNIT
96
IMAGE QUALITY DETERMI-NATION UNIT
94
THIRD IMAGE CREATION UNIT
28
DISPLAY UNIT

FIG. 19

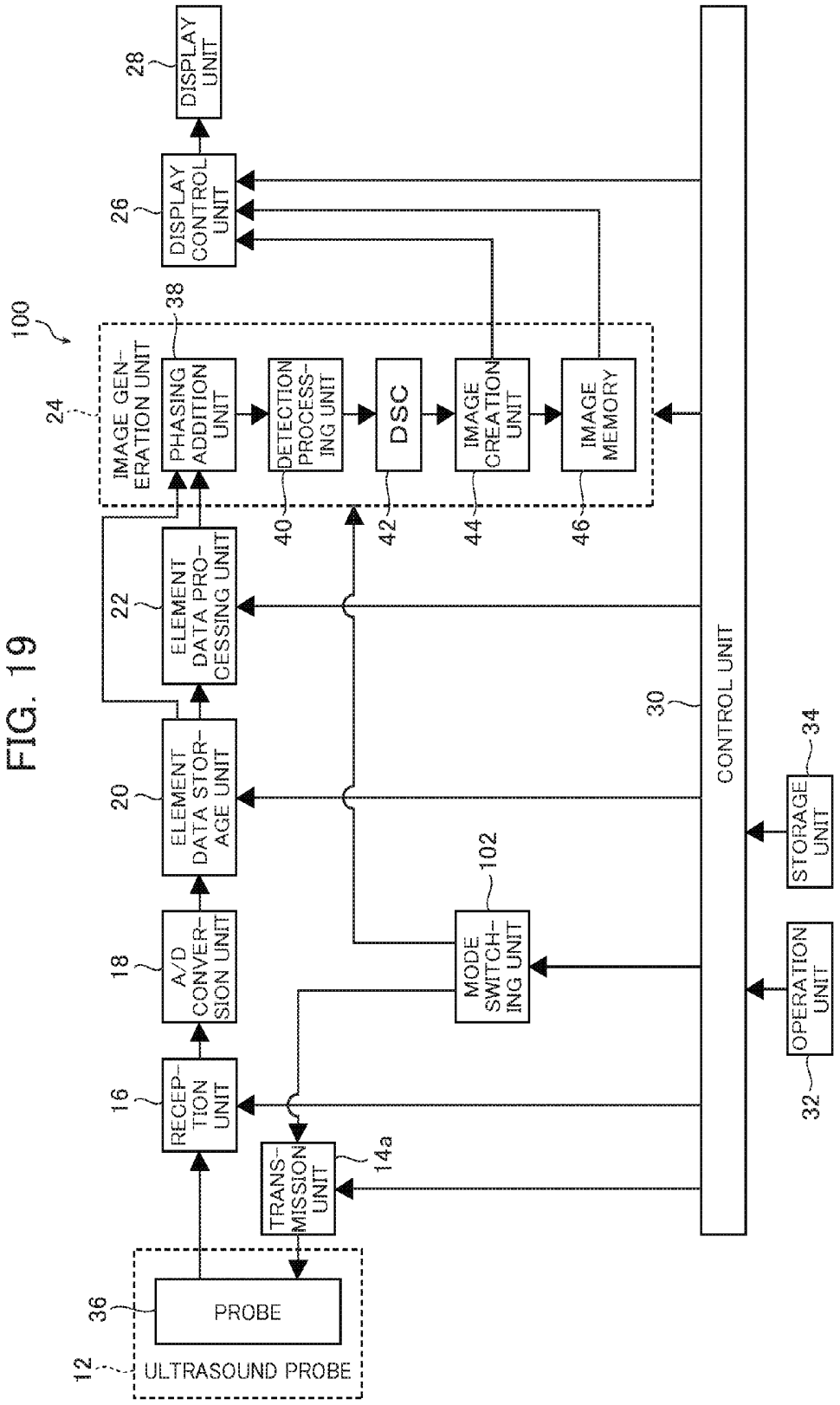

100
ULTRASOUND PROBE
12
PROBE
36
TRANS-MISSION UNIT
14a
RECEP-TION UNIT
16
A/D CONVER-SION UNIT
18
ELEMENT DATA STOR-AGE UNIT
20
ELEMENT DATA PRO-CESSING UNIT
22
IMAGE GEN-ERATION UNIT
24
PHASING ADDITION UNIT
38
DETECTION PROCESS-ING UNIT
40
DSC
42
IMAGE CREATION UNIT
44
IMAGE MEMORY
46
DISPLAY CONTROL UNIT
26
DISPLAY UNIT
28
MODE SWITCH-ING UNIT
102
CONTROL UNIT
30
OPERATION UNIT
32
STORAGE UNIT
34

FIG. 20

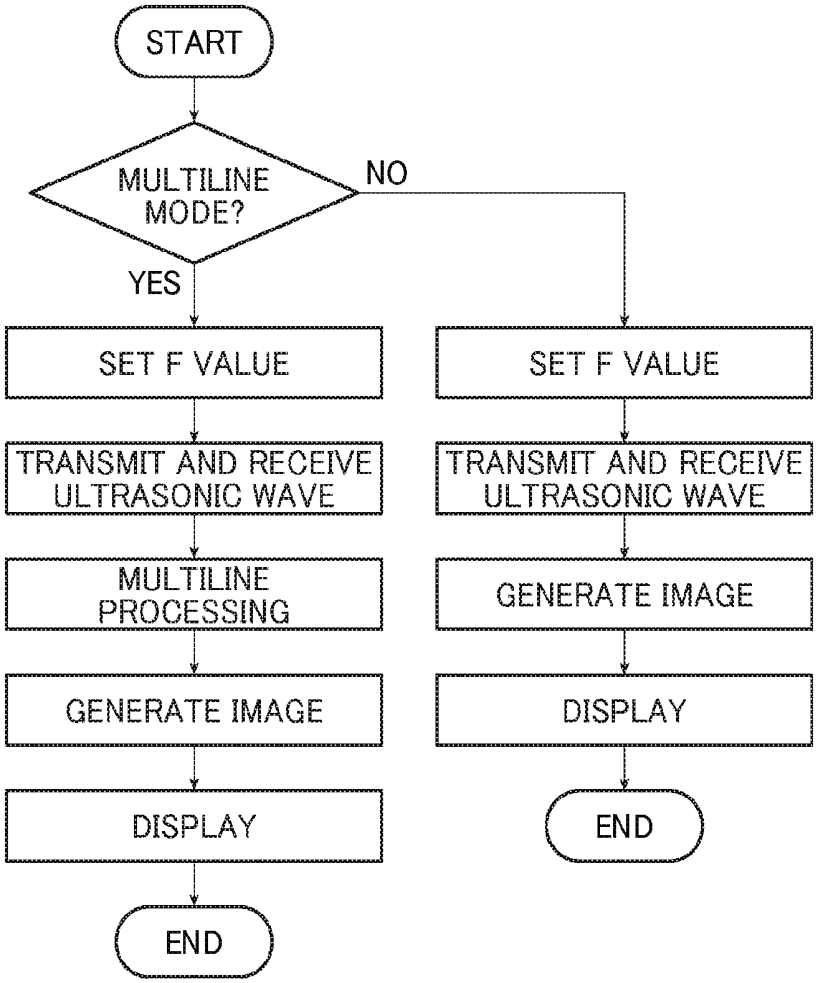


FIG. 21A

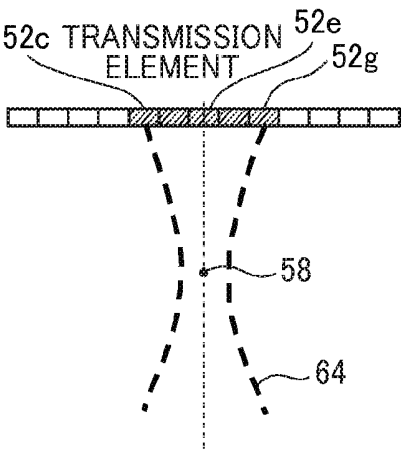


FIG. 21B

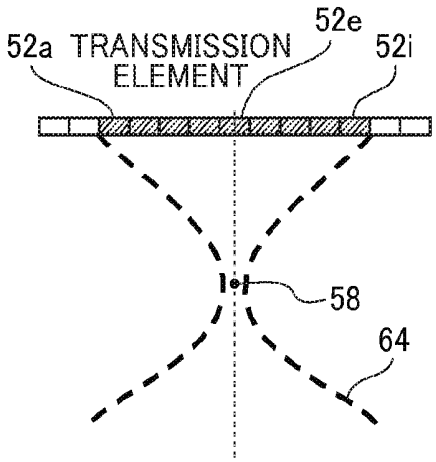


FIG. 22A

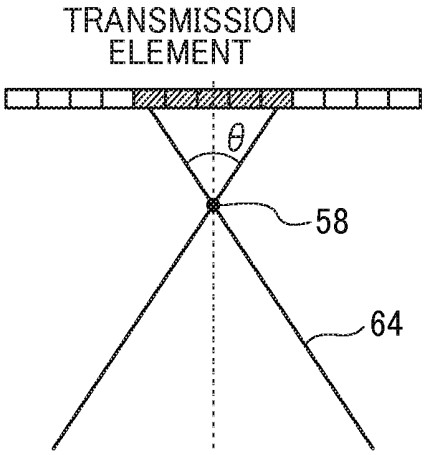


FIG. 22B

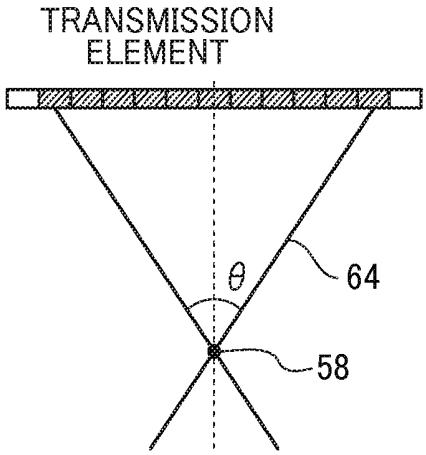


FIG. 23

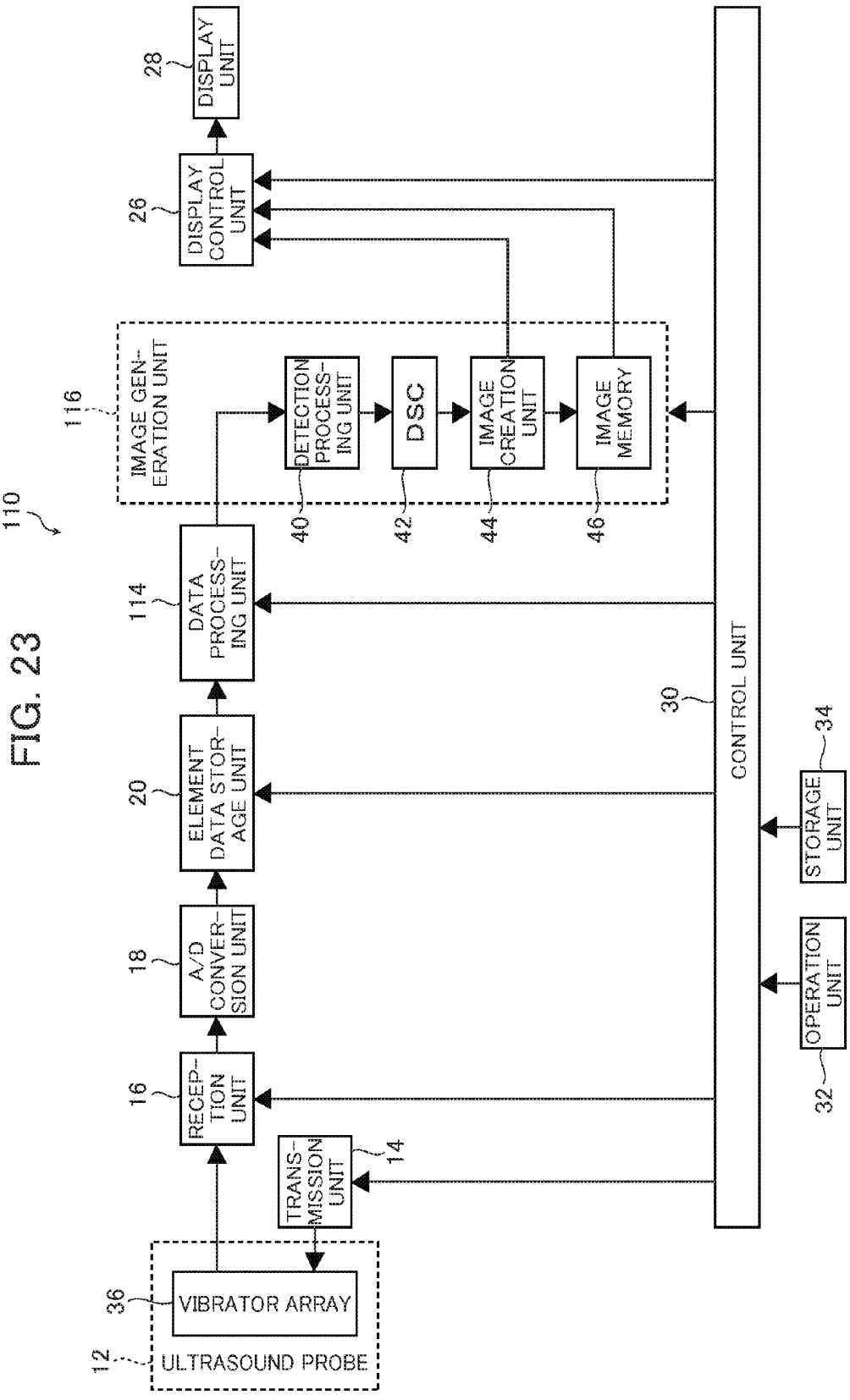

110
12
ULTRASOUND PROBE
36
VIBRATOR ARRAY
14
TRANS-MISSION UNIT
16
RECEP-TION UNIT
18
A/D CONVER-SION UNIT
20
ELEMENT DATA STOR-AGE UNIT
114
DATA PROCESS-ING UNIT
116
IMAGE GEN-ERATION UNIT
40
DETECTION PROCESS-ING UNIT
42
DSC
44
IMAGE CREATION UNIT
46
IMAGE MEMORY
26
DISPLAY CONTROL UNIT
28
DISPLAY UNIT
30
CONTROL UNIT
32
OPERATION UNIT
34
STORAGE UNIT

FIG. 24

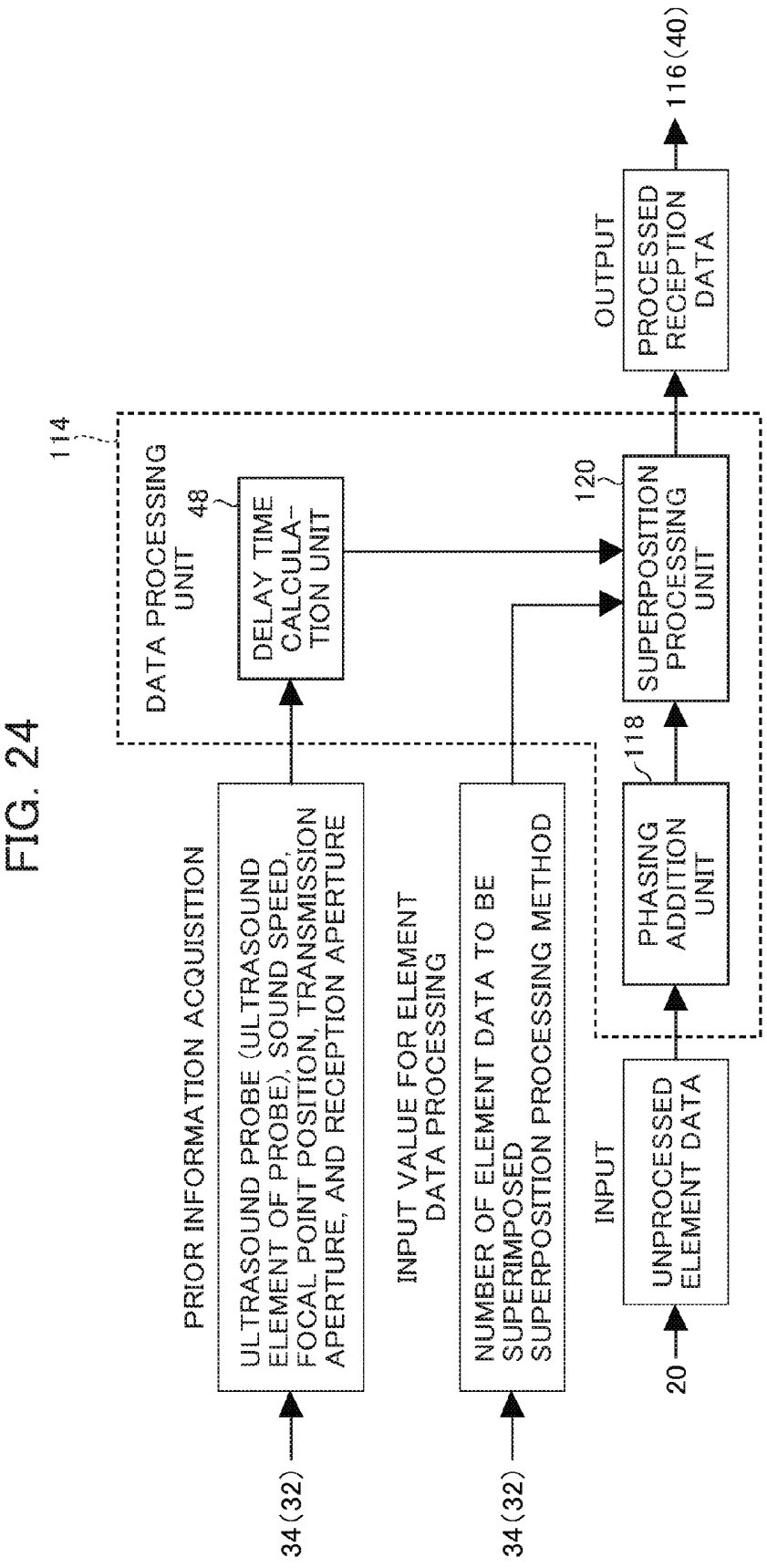

114
DATA PROCESSING UNIT
48
DELAY TIME CALCULATION UNIT
120
SUPERPOSITION PROCESSING UNIT
OUTPUT
PROCESSED RECEPTION DATA
116(40)
PRIOR INFORMATION ACQUISITION
ULTRASOUND PROBE (ULTRASOUND ELEMENT OF PROBE), SOUND SPEED, FOCAL POINT POSITION, TRANSMISSION APERTURE, AND RECEPTION APERTURE
INPUT VALUE FOR ELEMENT DATA PROCESSING
NUMBER OF ELEMENT DATA TO BE SUPERIMPOSED
SUPERPOSITION PROCESSING METHOD
118
PHASING ADDITION UNIT
INPUT
UNPROCESSED ELEMENT DATA
34(32)
34(32)
20

FIG. 25

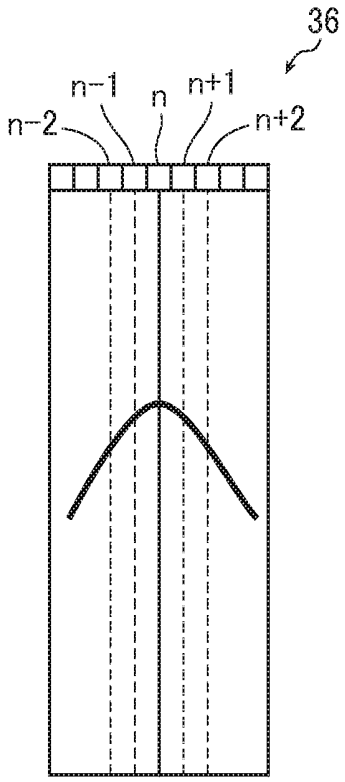


FIG. 26A

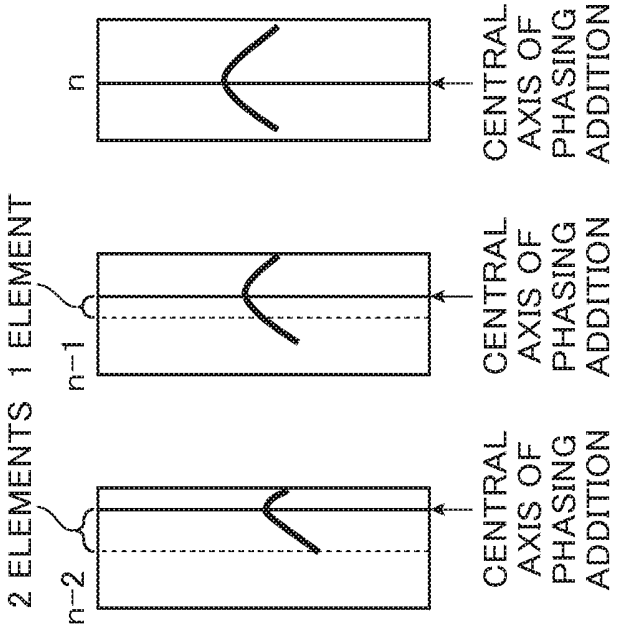


FIG. 26B

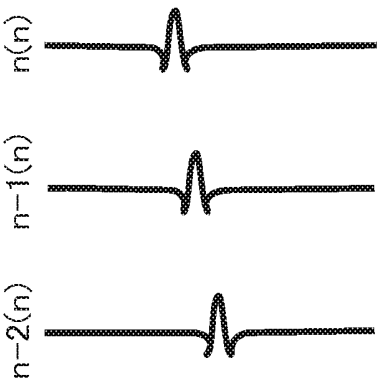
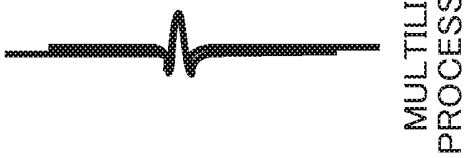


FIG. 26C



ULTRASONIC INSPECTION APPARATUS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a Continuation of PCT International Application No. PCT/JP2013/069010 filed on Jul. 11, 2013, which claims priority under 35 U.S.C. §119(a) to Japanese Application No. 2012-158009 filed on Jul. 13, 2012 and Japanese Application No. 2013-144809 filed on Jul. 10, 2013. Each of the above application(s) is hereby expressly incorporated by reference, in its entirety, into the present application.

BACKGROUND OF THE INVENTION

[0002] The present invention relates to an ultrasonic inspection apparatus for generating an ultrasound image to be used for inspection or diagnosis of an inspection target by imaging an inspection target such as organ in a living body by transmitting and receiving an ultrasonic beam.

[0003] An ultrasonic inspection apparatus using an ultrasound image such as an ultrasound diagnostic apparatus has hitherto been put into practical use in the field of medicine. In general, this kind of ultrasonic inspection apparatus has an ultrasound probe in which a plurality of elements (transducers) is installed, and an apparatus body connected to the ultrasound probe. In the ultrasonic inspection apparatus, an ultrasonic beam is transmitted from the plurality of elements of the ultrasound probe toward an inspection target (subject), an ultrasonic echo from the subject is received by the ultrasound probe, and a signal of the received ultrasonic echo is electrically processed in the apparatus body to generate an ultrasound image.

[0004] In an ultrasonic inspection apparatus, when an ultrasound image is generated, the ultrasonic beam is transmitted from the plurality of elements of the probe to an inspection target region of the subject, such as an organ in a living body or a lesion of the organ in a state of being focused thereon, and the ultrasonic echo from a reflector of the inspection target region such as a surface or an interface of the organ or the lesion is received through the plurality of elements. At this time, since ultrasonic echoes reflected by the same reflector are received by the plurality of elements, compared with an ultrasonic echo signal obtained by transmitting an ultrasonic beam from a transmission element and receiving an ultrasonic echo from a reflector located in a focal position of the ultrasonic beam transmitted with the transmission element, an ultrasonic echo signal obtained by receiving an ultrasonic echo reflected by the same reflector with another element different from the transmission element is delayed. Therefore, after an analog/digital (A/D) conversion is performed on the ultrasonic echo signals received by the plurality of elements to obtain element data, reception focus processing, that is, delay correction, phase matching, and phasing addition are performed on the element data to generate a sound ray signal, and an ultrasound image is generated based on the sound ray signal obtained in this way.

[0005] In the ultrasonic inspection technology, when the inspection target region of the subject is large, a large number of transmission ultrasonic beams are necessary, and the time required for image generation becomes long. Therefore, in order to improve the conventional technology in which the resolution of an ultrasound image generated depends on the width of the transmission ultrasonic beam, JP 2003-180688 A (Patent document 1) discloses a technology in which an ultrasound image is generated by using a system for generating an ultrasonic beam having a large width and an algorithm for converting a reception ultrasonic echo into image information.

[0006] In Patent document 1, first, an ultrasonic beam that is wider than a normal ultrasonic beam (see FIG. **12**B in Patent document 1) is designed and transmitted and reception data is obtained (see FIG. **4** therein). In Patent document 1, a polar coordinate (radius R and angle θ) is assigned to a wide beam, and an ultrasound image is generated based on the relationship between the reception data and the geometric coordinate. In the ultrasound image generated in this way, the frame rate of the image increases in comparison with the conventional technology, and the resolution of the image can be improved with respect to the image forming time.

[0007] Further, JP 2011-011045 A (Patent document 2) discloses an ultrasound diagnostic apparatus in which a wide ultrasonic beam covering an area of a tissue of a subject is transmitted from a plurality of elements (ultrasound transducers) while performing element shifting of more than one element; parallel raw data (element data) including information of the area of the tissue generated based on a plurality of reception signals due to the ultrasonic echo from the area of the tissue is converted into serial raw data; reception focus processing is performed on the converted raw data to generate an image signal (sound ray signal); and an ultrasound image is generated based on the obtained sound ray signal,

[0008] Patent document 2 discloses that when the sound ray signal is generated, one sound ray signal can be generated by transmitting the ultrasonic beam so that two adjacent areas overlap each other and performing signal processing (for example, reception focus processing) using the raw data (element data) obtained through a plurality of transmissions on one sampling point in the overlapped area, thereby a resolution which is degraded due to a widened SN ratio or aperture can be improved. Patent document 2 also discloses that one sound ray signal of which a resolution which is degraded due to the widened SN ratio or aperture is improved can be obtained by generating a plurality of sound ray signals for one sampling point based on the raw data obtained through the plurality of transmissions, and then obtaining an average value of the sound ray signals.

[0009] JP 2009-240700 A (Patent document 3) discloses an ultrasound diagnostic apparatus in which transmission ultrasonic waves emitted from a plurality of vibrator constituting a vibrator group for transmission are focused on a transmission focusing point to form a virtual point sound source; reception ultrasonic waves reflected from a plurality of continuous observation points due to the transmission ultrasonic waves emitted from the point sound source are received by a plurality of vibrators constituting a vibrator group for reception; reception phasing addition is performed on each of the reception signals of the channels obtained so that the observation point forms a reception focusing point; further, the same reception phasing addition is performed on the reception signal obtained using each of the vibrator group for reception and the vibrator group for transmission sequentially shifted in an arrangement direction of the vibrator; and transmission phasing addition of correcting a transmission delay caused by a difference in a propagation distance from each transmission focusing point to the observation point on the reception signal after the reception phasing addition.

[0010] In Patent document 3, a transmission beam and a reception beam having a narrow beam width that is approxi-

mately uniform in a depth direction of a subject can be formed with high precision and high sensitivity by performing the reception phasing addition and the transmission phasing addition on the reception signals obtained from the plurality of vibrators. Accordingly, Patent document 3 discloses that image data having excellent spatial resolution, contrast resolution and S/N can be generated and displayed.

SUMMARY OF THE INVENTION

[0011] However, in the technology disclosed in Patent document 1, since a wide ultrasonic beam is used, the strength of the ultrasonic beam decreases in comparison with the conventional technology, and accordingly, there are problems in that an SN ratio (S/N) is degraded, and a dedicated ultrasound probe for generating a wide ultrasonic beam is necessary.

[0012] Further, in the technology disclosed in Patent document 2, deterioration of the SN ratio or the resolution due to the wide ultrasonic beam is improved by overlapping adjacent areas of the wide ultrasonic beam from a plurality of elements. However, this merely obtains one sound ray signal by performing reception focus processing on a plurality of pieces of raw data with respect to one sampling point of the overlapped adjacent area, or obtains one sound ray signal by performing reception focus processing on a plurality of pieces of raw data to obtain the respective sound ray signals and calculating an average value thereof. Therefore, improvement of deterioration of the SN ratio or the resolution caused by the use of wide ultrasonic beam is limited, and accordingly, there are problems in that further improvement of the SN ratio cannot be achieved, and an ultrasound image of a sufficient SN ratio cannot be obtained.

[0013] In contrast, in the technology disclosed in Patent document 3, an image having higher quality than that in the conventional technology is obtained, but in order to creating data of one line, it is necessary to generate a plurality of transmission beams while changing a transmission position, and thus the number of transmissions increases in comparison with the conventional technology. Therefore, there are problems in that the frame rate is decreased and real-time properties are deteriorated.

[0014] The present invention has been made in order to solve the problems in the above-described prior art, and an object thereof is to provide an ultrasonic inspection apparatus capable of reducing influence of the spread of a transmission ultrasonic beam, increasing an SN ratio, increasing a resolution, and thus obtaining a sharp ultrasound image having an optimal spatial resolution with high resolution that does not depend on a width of a transmission ultrasonic beam, without using a dedicated ultrasound probe for generating a wide transmission ultrasonic beam and at a frame rate that is not different from the conventional frame rate, by superimposing pieces of element data acquired through transmission from two or more different elements when ultrasonic beams are transmitted from a plurality of elements of a ultrasound probe.

[0015] In order to achieve the aforementioned object, the present invention provides an ultrasonic inspection apparatus that inspects an inspection target using an ultrasonic beam, the ultrasonic inspection apparatus comprising:

[0016] a probe that transmits the ultrasonic beam, receives an ultrasonic echo reflected by the inspection target, and outputs an analog element signal according to the received ultrasonic echo, a plurality of elements being arranged in the probe;

[0017] a transmission unit configured to perform, a plurality of times, to cause the probe to transmit the ultrasonic beam so as to form a predetermined transmission focal point using the plurality of elements;

[0018] a reception unit configured to receive analog element signals output by the plurality of elements corresponding to the transmission of individual ultrasonic beams and perform predetermined processing;

[0019] an A/D conversion unit configured to perform A/D conversion on the analog element signal processed by the reception unit to obtain first element data that is a digital element signal; and

[0020] a data processing unit configured to generate second element data corresponding to any one of the pieces of first element data from a plurality of the pieces of first element data,

[0021] wherein the data processing unit changes conditions of acquisition of two or more of the pieces of first element data for generating the second element data depending on a depth of a position in which the second element data is obtained.

[0022] In the ultrasonic inspection apparatus, it is preferable for the transmission unit to perform at least one of changing of a central element and changing of a transmission direction of the ultrasonic beam and cause the probe to perform a plurality of transmissions of the ultrasonic beam.

[0023] Further, it is preferable for the data processing unit to generate the second element data using at least one of the plurality of pieces of first element data obtained through transmissions of the ultrasonic beam in which central elements are different from each other and the plurality of pieces of first element data obtained through transmissions of the ultrasonic beams in which transmission directions differ from each other.

[0024] It is preferable for the data processing unit to generate the second element data from the plurality of pieces of first element data obtained through transmissions of the ultrasonic beam in which transmission areas overlap.

[0025] It is preferable for the data processing unit to superimpose the plurality of pieces of first element data based on a reception time at which the element receives the ultrasonic echo and a position of the element to generate the second element data.

[0026] It is preferable for the data processing unit to include a delay time calculation unit configured to calculate a delay time of two or more pieces of the first element data, and a superposition processing unit configured to superimpose the two or more pieces of first element data based on the calculated delay time and a reception position of the element of the probe to generate the second element data.

[0027] It is preferable that the delay time calculation unit calculates the delay time of the two or more pieces of first element data based on at least one piece of information acquired in advance regarding the probe, a sound speed of the inspection target, a focal point position of the ultrasonic beam, a transmission aperture of the probe by the transmission unit, and a reception aperture of the probe by the reception unit, and the superposition processing unit superimposes the two or more pieces of first element data based on the number of pieces of first element data to be superimposed on a reception time among the two or more pieces of first element

data and a superposition processing method, that are set in advance, to generate at least one piece of second element data.

[0028] It is preferable for the data processing unit to generate the second element data from element data of only a superimposed portion when the two or more pieces of first element data are superimposed by the superposition processing unit.

[0029] It is preferable for the data processing unit to superimpose the two or more pieces of first element data after multiplying each of the pieces of first element data by a weighting coefficient.

[0030] It is preferable for the data processing unit to change the number of pieces of the first element data to be selected depending on the depth of the position in which the second element data is obtained.

[0031] It is preferable for the data processing unit adaptively superimposes the two or more pieces of first element data based on at least two or more different points on a time axis on a reception time of each piece of element data.

[0032] It is preferable for the different point on the time axis to be based on each transmission aperture of the probe by the transmission unit, and more preferable to be based on each transmission aperture when transmission is performed in at least two or more transmission apertures for each of the two or more pieces of first element data, or it is preferable for the different point on the time axis to be based on the sound speed of the inspection target.

[0033] It is preferable that when the transmission unit transmits the ultrasonic beams forming a transmission focal point of a different depth on the same transmission line for each transmission line, the reception unit acquires the plurality of pieces of first element data corresponding to the same transmission line, and the data processing unit generates the second element data from the plurality of pieces of first element data obtained through transmission and reception of the ultrasonic beam of the transmission focal point of the same depth for each depth of the transmission focal point.

[0034] It is preferable for the data processing unit to change the number of pieces of the first element data to be selected depending on the depth of the position in which the corresponding second element data is obtained based on a spatial spread of the ultrasonic beam within the inspection target, or it is preferable for the data processing unit to change the number of pieces of the first element data to be selected depending on the depth of the position in which the corresponding second element data is obtained based on a signal in a spatial position within the inspection target.

[0035] It is preferable for the data processing unit to change the number of pieces of the first element data to be selected depending on the depth of the position in which corresponding second element data is obtained based on a result of waveform analysis of the first element data.

[0036] It is preferable for the waveform analysis to include analyzing of relevance or a coherence characteristic of a waveform regarding a candidate of the first element data to be selected.

[0037] It is preferable for the data processing unit to obtain the optimal number of pieces of element data based on a signal in the plurality of pieces of second element data created by changing the number of pieces of the first element data to be selected.

[0038] It is preferable that the transmission unit determines a transmission focal point depth depending on the depth of the position in which the second element data is obtained, and causes the probe to perform transmission of the ultrasonic beam a plurality of times at the determined transmission focal point depth to acquire the plurality of pieces of first element data, and the data processing unit selects two or more pieces of the first element data for generating the second element data from among the plurality of pieces of first element data obtained through the transmission of the ultrasonic beam of the determined transmission focal point depth.

[0039] It is preferable that the transmission unit determines a transmission numerical aperture depending on the depth of the position in which the second element data is obtained, and causes the probe to perform the transmission of the ultrasonic beam using the determined transmission numerical aperture a plurality of times to acquire the plurality of pieces of first element data, and the data processing unit selects two or more pieces of the first element data for generating the second element data from among the plurality of pieces of first element data obtained through the transmission of the ultrasonic beam using the determined transmission numerical aperture.

[0040] It is preferable for the transmission unit to cause the probe to perform steering transmission.

[0041] It is preferable for the element data to include phase information and amplitude information.

[0042] It is preferable for the ultrasonic inspection apparatus to further include an element data storage unit configured to store at least one of the first element data and the second element data.

[0043] It is preferable for the data processing unit to perform phasing addition of each of the plurality of pieces of first element data to generate a plurality of pieces of first reception data directly before generating the second element data from the plurality of pieces of first element data, and generate second reception data corresponding to any one of the pieces of first reception data from the plurality of pieces of first reception data.

[0044] Further, in order to achieve the aforementioned object, the present invention provides an ultrasonic inspection apparatus that inspects an inspection target using an ultrasonic beam, the ultrasonic inspection apparatus comprising:

[0045] a probe that transmits the ultrasonic beam, receives an ultrasonic echo reflected by the inspection target, and outputs an analog element signal according to the received ultrasonic echo, a plurality of elements being arranged in the probe;

[0046] a transmission unit configured to perform, a plurality of times, to cause the probe to transmit the ultrasonic beam so as to form a predetermined transmission focal point using the plurality of elements;

[0047] a reception unit configured to receive analog element signals output by the plurality of elements corresponding to transmission of the individual ultrasonic beams and perform a predetermined processing;

[0048] an A/D conversion unit configured to perform A/D conversion on the analog element signal processed by the reception unit to obtain first element data that is a digital element signal;

[0049] a phasing addition unit configured to perform phasing addition on the plurality of pieces of first element data around a line corresponding to the same element to generate a plurality of pieces of first reception data; and

[0050] a data processing unit configured to generate second reception data corresponding to any one of the pieces of first reception data from a plurality of the pieces of first reception data,

[0051] wherein the data processing unit changes conditions of acquisition of two or more of the pieces of first reception data for generating the second reception data depending on a depth of a position in which the second reception data is obtained.

[0052] Moreover, in order to achieve the aforementioned object, the present invention provides an ultrasonic inspection apparatus that inspects an inspection target using an ultrasonic beam, the ultrasonic inspection apparatus comprising:

[0053] a probe that transmits the ultrasonic beam, receives an ultrasonic echo reflected by the inspection target, and outputs an analog element signal according to the received ultrasonic echo, a plurality of elements being arranged in the probe;

[0054] a transmission unit configured to perform, a plurality of times, to cause the probe to transmit the ultrasonic beam so as to form a predetermined transmission focal point using the plurality of elements;

[0055] a reception unit configured to receive analog element signals output by the plurality of elements corresponding to transmission of the individual ultrasonic beams and perform a predetermined processing;

[0056] an A/D conversion unit configured to perform A/D conversion on the analog element signal processed by the reception unit to obtain first element data that is a digital element signal;

[0057] a data processing unit configured to generate second element data corresponding to any one of the pieces of first element data from a plurality of the pieces of first element data; and

[0058] a mode switching unit configured to switch a first mode in which an ultrasound image is generated using the first element data and a second mode in which an ultrasound image is generated using the second element data generated by the data processing unit,

[0059] wherein an F value when the transmission unit causes the probe to transmit the ultrasonic beam is switched in response to switching of mode by the mode switching unit, and the data processing unit generates the second element data corresponding to any one of the pieces of first element data from a plurality of the pieces of first element data obtained based on the F value that is switched when the mode switching unit performs the switching of mode.

[0060] In the ultrasonic inspection apparatus, it is preferable for the data processing unit to generate the second element data corresponding to any one of the pieces of first element data from a plurality of the pieces of first element data obtained based on the F value that is switched when the mode switching unit performs the switching of mode.

[0061] Further, it is preferable for the F value when the second mode is selected to be smaller than the F value when the first mode is selected.

[0062] It is preferable for the first element data to be acquired by transmitting the ultrasonic beam so that the F value is constant regardless of the depth of the focal point position of the ultrasonic beam.

[0063] Furthermore, in order to achieve the aforementioned object, the present invention provides an ultrasonic inspection apparatus that inspects an inspection target using an ultrasonic beam, the ultrasonic inspection apparatus comprising:

[0064] a probe that transmits the ultrasonic beam, receives an ultrasonic echo reflected by the inspection target, and outputs an analog element signal according to the received ultrasonic echo, a plurality of elements being arranged in the probe;

[0065] a transmission unit configured to perform, a plurality of times, to cause the probe to transmit the ultrasonic beam so as to form a predetermined transmission focal point using the plurality of elements;

[0066] a reception unit configured to receive analog element signals output by the plurality of elements corresponding to transmission of the individual ultrasonic beams and perform a predetermined processing;

[0067] an A/D conversion unit configured to perform A/D conversion on the analog element signal processed by the reception unit to obtain first element data that is a digital element signal;

[0068] a data processing unit configured to generate second element data corresponding to any one of the pieces of first element data from a plurality of the pieces of first element data; and

[0069] at least one sound speed setting unit configured to determine a sound speed in the inspection target,

[0070] wherein the data processing unit generates the second element data based on the sound speed obtained in the sound speed setting unit.

[0071] In the ultrasonic inspection apparatus, it is preferable that the data processing unit calculates the delay time of two or more of the pieces of first element data using the sound speed within the inspection target, and superimposes the two or more of pieces of first element data based on the calculated delay time to generate second element data; that the at least one sound speed setting unit includes a first sound speed setting unit that sets sound speed of the inspection target to be used for delay time calculation in the data processing unit, and a phasing addition unit that performs phasing addition of the second element data, which is obtained by the data processing unit using the sound speed set in the first sound speed setting unit, to generate a sound ray signal, a first determination unit that determines the suitability of the sound ray signal obtained by the phasing addition unit, and an image generation unit that generates an ultrasound image based on the sound ray signal generated by the phasing addition unit are included; and that when a determination result of the first determination unit is "unsuitable", the first sound speed setting unit newly sets another sound speed again, the data processing unit calculates the delay time again using the sound speed set again and obtains the second element data based on the delay time calculated again, the phasing addition unit generates the sound ray signal again using the second element data obtained again, and the aforementioned processing in the first sound speed setting unit, the data processing unit and the phasing addition unit are repeated until the determination result of the first determination unit based on the sound ray signal generated again is "suitable", and when the determination result of the first determination unit is "suitable", the image generation unit generates an ultrasound image based on the sound ray signal.

[0072] Further, it is preferable for the first sound speed setting unit to set the sound speed in at least one point on the reception time for each element data.

[0073] It is preferable that a second sound speed setting unit that obtains an optimal sound speed of a reception side based on second element data generated when a determination result of the first determination unit is "suitable", a phasing addition unit that performs phasing addition of the second

element data using the optimal sound speed obtained by the second sound speed setting unit to generate a sound ray signal, and a second determination unit that determines the suitability of the sound ray signal obtained by the phasing addition unit are included; and that when the determination result of the second determination unit is "unsuitable", the second sound speed setting unit obtains the optimal sound speed again based on the second element data, the phasing addition unit generates the sound ray signal again using the optimal sound speed obtained again, and the aforementioned processing in the second sound speed setting unit and the phasing addition unit are repeated until the determination result of the second determination unit based on the sound ray signal generated again is "suitable", and when the determination result of the second determination unit is "suitable", the image generation unit generates the ultrasound image based on the sound ray signal.

[0074] Further, it is preferable for the second sound speed setting unit to set the sound speed in at least one point on the reception time for each element data.

[0075] It is preferable that a third sound speed setting unit that obtains an optimal sound speed of a reception side based on the first element data, a phasing addition unit that performs phasing addition of the first element data using the optimal sound speed obtained by the third sound speed setting unit to generate a sound ray signal, and a third determination unit that determines the suitability of the sound ray signal obtained by the phasing addition unit are included; and that when the determination result of the third determination unit is "unsuitable", the third sound speed setting unit obtains the optimal sound speed again based on the first element data, the phasing addition unit generates the sound ray signal again using the optimal sound speed obtained again, and the aforementioned processing in the third sound speed setting unit and the phasing addition unit are repeated until the determination result of the third determination unit based on the sound ray signal generated again is "suitable", and when the determination result of the third determination unit is "suitable", the delay time calculation unit sets the obtained optimal sound speed as the sound speed of the inspection target.

[0076] It is preferable for the third sound speed setting unit to set the sound speed in at least one point on the reception time for each element data.

[0077] It is preferable for the third sound speed setting unit to be the same as the second sound speed setting unit.

[0078] It is preferable for the third determination unit to be the same as the second determination unit.

[0079] Further, it is preferable that the at least one sound speed setting unit includes a fourth sound speed setting unit that obtains an optimal sound speed of a reception side based on the second element data generated using the predetermined sound speed in the data processing unit, and a phasing addition unit that generates a sound ray signal by performing phasing addition of the second element data using the optimal sound speed obtained by the fourth sound speed, a fourth determination unit that determines the suitability of the sound ray signal obtained by the phasing addition unit, and an image generation unit that generates an ultrasound image based on the sound ray signal generated by the phasing addition unit are included; and that when the determination result of the fourth determination unit is "unsuitable", the data processing unit performs processing of generating the second element data again using the optimal sound speed obtained by the fourth sound speed setting unit, the fourth sound speed setting unit obtains the optimal sound speed again based on the second element data generated again, the phasing addition unit generates the sound ray signal using the optimal sound speed obtained again, and the aforementioned processing in the data processing unit, the fourth sound speed setting unit and the phasing addition unit are repeated until the determination result of the fourth determination unit based on the sound ray signal generated again is "suitable", and when the determination result of the fourth determination unit is "suitable", the image generation unit generates the ultrasound image based on the sound ray signal.

[0080] Further, it is preferable for the fourth sound speed setting unit to set the sound speed in at least one point on the reception time of each element data.

[0081] It is preferable for the fourth sound speed setting unit to be the same as the second sound speed setting unit and third sound speed setting unit.

[0082] It is preferable for the fourth determination unit to be the same as the second determination unit and the third determination unit.

[0083] In addition, in order to achieve the aforementioned object, the present invention provides an ultrasonic inspection apparatus that inspects an inspection target using an ultrasonic beam, the ultrasonic inspection apparatus comprising:

[0084] a probe that transmits the ultrasonic beam, receives an ultrasonic echo reflected by the inspection target, and outputs an analog element signal according to the received ultrasonic echo, a plurality of elements being arranged in the probe;

[0085] a transmission unit configured to perform, a plurality of times, to cause the probe to transmit the ultrasonic beam so as to form a predetermined transmission focal point using the plurality of elements;

[0086] a reception unit configured to receive analog element signals output by the plurality of elements corresponding to transmission of the individual ultrasonic beams and perform a predetermined processing;

[0087] an A/D conversion unit configured to perform A/D conversion on the analog element signal processed by the reception unit to obtain first element data that is a digital element signal;

[0088] a data processing unit configured to generate second element data corresponding to any one of the pieces of first element data from a plurality of the pieces of first element data;

[0089] a first image generation unit configured to generate a first ultrasound image based on the first element data;

[0090] a second image generation unit configured to generate a second ultrasound image based on the second element data;

[0091] an image quality determination unit configured to compare image quality of the first ultrasound image generated by the first image generation unit with image quality of the second ultrasound image generated by the second image generation unit; and

[0092] a third image generation unit configured to generate a third ultrasound image for being used in an ultrasonic inspection from the first ultrasound image and the second ultrasound image based on a result of an image quality determination performed by the image quality determination unit.

[0093] In the ultrasonic inspection apparatus, it is preferable for the image quality determination unit to perform the image quality determination using any one of a brightness

value, contrast and graininess of the first ultrasound image and second ultrasound image, or using a combination of two or more of them.

[0094] Further, it is preferable for the third image generation unit to adopt any one of the first ultrasound image and the second ultrasound image as the ultrasound image for being used in the ultrasonic inspection based on a result of the image quality determination of the image quality determination unit.

[0095] It is preferable that a region division unit configured to divide the first ultrasound image and the second ultrasound image into a plurality of regions is further included; the image quality determination unit performs the image quality determination of the first ultrasound image and second ultrasound image for each of the regions divided by the region division unit; and the third image generation unit selects any one of the first ultrasound image and the second ultrasound image for each of the regions, as an ultrasound image of the corresponding region, based on a result of the image quality determination of the image quality determination unit, and combine the images selected in the respective regions to generate the third ultrasound image.

[0096] According to the present invention, when ultrasonic beams are transmitted from the plurality of elements of the ultrasound probe, by superimposing the pieces of element data acquired through the transmission from two or more different elements, it is possible to reduce the influence of the spread of the transmission ultrasonic beam, to increase an SN ratio, to increase resolution, and thus to obtain a sharp ultrasound image having an optimal spatial resolution with high resolution that does not depend on the width of the transmission beam, without using a dedicated ultrasound probe for generating a wide transmission ultrasonic beam and at a frame rate that is not different from the conventional frame rate.

BRIEF DESCRIPTION OF THE DRAWINGS

[0097] FIG. **1** is a block diagram conceptually illustrating an example of a configuration of an ultrasonic inspection apparatus of Embodiment 1 according to the present invention.

[0098] FIG. **2** is a block diagram conceptually illustrating an example of a configuration of an element data processing unit of the ultrasonic inspection apparatus illustrated in FIG. **1**.

[0099] FIGS. **3**A and **3**C are illustrative diagrams when ideal ultrasonic beams are transmitted from an element just above a reflection point of a subject and an element that is not just above the reflection point, respectively, and FIGS. **3**B and **3**D are illustrative diagrams illustrating respective pieces of element data obtained.

[0100] FIGS. **4**A and **4**C are illustrative diagrams when actual ultrasonic beams are transmitted from an element just above a reflection point of a subject and an element that is not just above the reflection point, respectively, and FIGS. **4**B and **4**D are illustrative diagrams illustrating respective pieces of element data obtained.

[0101] FIGS. **5**A and **5**B are illustrative diagrams illustrating the distance of a transmission path and a reception path of an ultrasonic beam in the case of a true reflection ultrasonic echo and a reflection signal of a ghost, respectively, and FIGS. **5**C and **5**D are illustrative diagrams illustrating element data obtained by a plurality of elements and respective delay times thereof.

[0102] FIGS. **6**A, **6**B and **6**C, as well as **6**D, **6**E and **6**F are illustrative diagrams illustrating pieces of element data obtained by a plurality of elements, a delay time thereof, and a superposition state of pieces of element data in the case of a true signal and a ghost, respectively, and FIGS. **6**G and **6**H are illustrative diagrams illustrating a superposition state of pieces of element data corresponding to the plurality of elements, and a result of superposition processing thereof, respectively.

[0103] FIG. **7** is a block diagram illustrating, along a process flow, primary units of the ultrasonic inspection apparatus of Embodiment 1 of the present invention illustrated in FIG. **1**.

[0104] FIGS. **8**A and **8**B are block diagrams conceptually illustrating, along a process flow, an example of primary units of an ultrasonic inspection apparatus of Embodiment 2 of the present invention.

[0105] FIG. **9** is a block diagram conceptually illustrating, along a process flow, an example of primary units of the ultrasonic inspection apparatus of Embodiment 3 of the present invention.

[0106] FIG. **10**A is a block diagram conceptually illustrating an example of a configuration of a sound speed correction unit of the ultrasonic inspection apparatus illustrated in FIG. **9**, and FIG. **10**B is a diagram schematically illustrating an example of an ultrasound image in which a region of interest is set in a region-of-interest setting unit of the sound speed correction unit illustrated in FIG. **10**A.

[0107] FIG. **11** is a block diagram illustrating, along a process flow, details of an example of an optimal sound speed calculation unit of the sound speed correction unit illustrated in FIG. **10**A.

[0108] FIG. **12** is a block diagram conceptually illustrating, along a process flow, another example of primary units of an ultrasonic inspection apparatus of Embodiment 3 of the present invention.

[0109] FIG. **13** is a block diagram conceptually illustrating, along a process flow, an example of primary units of an ultrasonic inspection apparatus of Embodiment 4 of the present invention.

[0110] FIG. **14** is a block diagram conceptually illustrating, along a process flow, an example of primary units of an ultrasonic inspection apparatus of Embodiment 5 of the present invention.

[0111] FIG. **15** is a block diagram conceptually illustrating, along a process flow, another example of primary units of an ultrasonic inspection apparatus of Embodiment 5 of the present invention.

[0112] FIG. **16** is a block diagram conceptually illustrating, along a process flow, another example of primary units of an ultrasonic inspection apparatus of Embodiment 5 of the present invention.

[0113] FIG. **17** is a block diagram conceptually illustrating, along a process flow, another example of primary units of an ultrasonic inspection apparatus of Embodiment 5 of the present invention.

[0114] FIG. **18** is a block diagram conceptually illustrating, along a process flow, an example of primary units of an ultrasonic inspection apparatus of Embodiment 6 of the present invention.

[0115] FIG. **19** is a block diagram conceptually illustrating an example of a configuration of an ultrasonic inspection apparatus of Embodiment 7 of the present invention.

[0116] FIG. **20** is a flowchart illustrating an operation of the ultrasonic inspection apparatus illustrated in FIG. **19**.

[0117] FIGS. **21**A and **21**B are schematic diagrams illustrating switching of an F value.

[0118] FIGS. **22**A and **22**B are schematic diagrams illustrating the position of a transmission focal point and a numerical aperture when the F value is constant.

[0119] FIG. **23** is a block diagram conceptually illustrating an example of a configuration of an ultrasonic inspection apparatus of Embodiment 8 of the present invention.

[0120] FIG. **24** is a block diagram conceptually illustrating an example of a configuration of a data processing unit of the ultrasonic inspection apparatus illustrated in FIG. **23**.

[0121] FIG. **25** is a diagram conceptually illustrating element data and an element.

[0122] FIGS. **26**A to **26**C are diagrams illustrating phasing addition and superposition processing of the data processing unit illustrated in FIG. **24**.

DETAILED DESCRIPTION OF THE INVENTION

[0123] Hereinafter, an ultrasonic inspection apparatus according to the present invention will be described in detail based on preferred embodiments shown in the accompanying drawings.

Embodiment 1

[0124] FIG. **1** is a block diagram conceptually illustrating an example of a configuration of an ultrasonic inspection apparatus of Embodiment 1 according to the present invention.

[0125] An ultrasonic inspection apparatus **10** includes an ultrasound probe **12**, a transmission unit **14** and a reception unit **16** that are connected to the ultrasound probe **12**, an A/D conversion unit **18**, an element data storage unit **20**, an element data processing unit **22**, an image generation unit **24**, a display control unit **26**, a display unit **28**, a control unit **30**, an operation unit **32**, and a storage unit **34**, as illustrated in FIG. **1**.

[0126] The ultrasound probe **12** includes a probe **36** used in an ordinary ultrasonic inspection apparatus.

[0127] The probe **36** has a plurality of elements, that is, transducers which are one-dimensionally or two-dimensionally arranged. When an ultrasound image of an inspection target (hereinafter referred to as a subject) is imaged, each of the plurality of ultrasound transducers transmits an ultrasonic beam toward the subject in accordance with a driving signal supplied from the transmission unit **14**, receives an ultrasonic echo from the subject, and outputs a reception signal. In the present embodiment, each of a predetermined number of ultrasound transducers constituting one group among the plurality of ultrasound transducers of the probe **36** generates each component of one ultrasonic beam, and the one group of the predetermined number of ultrasound transducers generates one ultrasonic beam to be transmitted to the subject.

[0128] Each ultrasound transducer is constituted by an element, that is, a vibrator in which electrodes are formed at both ends of a piezoelectric substance formed of, for example, a piezoelectric ceramic represented by PZT (lead zirconate titanate), a polymer piezoelectric element represented by PVDF (polyvinylidene fluoride), a piezoelectric single crystal represented by PMN-PT (lead magnesium niobate-lead titanate solid solution), or the like. Namely, it can be said that the probe **36** is a vibrator array in which a plurality of vibrators are one-dimensionally or two-dimensionally arranged as a plurality of ultrasound element.

[0129] If a pulsed or continuous-wave voltage is applied across the electrodes of the vibrator, the piezoelectric substance expands and contracts, whereby pulsed or continuous-wave ultrasonic waves are generated from the vibrator, and the generated ultrasonic waves are synthesized to form an ultrasonic beam. When receiving propagating ultrasonic wave, each vibrator expands and contracts to generate an electric signal and the electric signal is output as a reception signal of the ultrasonic wave.

[0130] The transmission unit **14** includes a plurality of pulsers, for example. The transmission unit **14** adjusts the amount of delay of each driving signal so that ultrasonic beam components transmitted from the one group of the predetermined number of ultrasound transducers (hereinafter, ultrasound transducer is referred to as a ultrasound element) of the probe **36** forms one ultrasonic beam, depending on a sound speed or a distribution of sound speed set based on a transmission delay pattern selected according to a control signal from the control unit **30**, and supplies the adjusted driving signals to the plurality of ultrasound elements constituting the group.

[0131] The reception unit **16** receives the ultrasonic echo, which is generated by an interaction between the ultrasonic beam and the subject, from the subject by each ultrasound element of the probe **36** according to a control signal from the control unit **30** to generate a reception signal, amplifies and outputs the reception signal, that is, an analog element signal for each ultrasound element, and supplies the amplified analog element signal to the A/D conversion unit **18**.

[0132] The element data storage unit **20** sequentially stores digital element data (hereinafter referred to simply as element data) output from the A/D conversion unit **18**. The element data is data indicating a relationship between position (element position) and reception time, and signal strength, and includes phase information and amplitude information.

[0133] Further, the element data storage unit **20** stores information (for example, a depth of a reflection position of the ultrasound waves, a density of scanning lines, or a parameter indicating a width of a field of view) regarding a frame rate input from the control unit **30** in association with the digital element data.

[0134] When at least two or more target regions overlapping each other in a target region on a position coordinate of two or more dimension, are inspected according to a control signal from the control unit **30**, the element data storage unit **20** stores and holds two or more pieces of element data which are respectively generated for the two or more target regions from the ultrasonic echoes respectively received by the reception unit **16** for the two or more target regions. The element data stored and held in the element data storage unit **20** includes two or more pieces of element data, each of which includes reception data at every reception time.

[0135] The element data processing unit **22** is a characteristic unit in the present invention, and superimposes two or more pieces of element data respectively generated for two or more target regions (hereinafter referred to as unprocessed element data), which have been stored and held in the element data storage unit **20**, while matching time on the reception time, based on control of the control unit **30** to generate element data subjected to this superposition processing (hereinafter, element data having been subjected to the superposition processing is referred to as processed element data).

[0136] Specifically, based on control of the control unit **30**, the element data processing unit **22** superimposes pieces of element data obtained through transmission of a predetermined number of (a plurality of) ultrasonic beams in which central ultrasound transducers (central element) are different and transmission areas of the ultrasonic beams overlap among the pieces of element data stored in the element data storage unit **20**, based on the time at which the ultrasound transducer receives the ultrasonic echo and a position of the ultrasound transducer to generate the processed element data corresponding to the element data (element data of an element of interest to be described below).

[0137] Details of the element data processing unit **22** will be described below.

[0138] The image generation unit **24** generates a sound ray signal (reception data) from the processed element data supplied from the element data processing unit **22** under the control of the control unit **30**.

[0139] The image generation unit **24** includes a phasing addition unit **38**, a detection processing unit **40**, a DSC **42**, an image creation unit **44**, and an image memory **46**.

[0140] The phasing addition unit **38** selects a reception delay pattern from among a plurality of reception delay patterns stored in advance according to a reception direction set in the control unit **30**, gives a delay to each piece of the element data depending on a sound speed or a distribution of sound speed set based on the selected reception delay pattern, and adds pieces of the element data together to thereby perform reception focus processing. Reception data (sound ray signal) in which the focus of the ultrasonic echo is narrowed down is generated by this reception focus processing.

[0141] The phasing addition unit **38** supplies the reception data to the detection processing unit **40**.

[0142] The detection processing unit **40** performs correction of attenuation due to distance on the reception data generated in the phasing addition unit **38** depending on the depth of the reflection position of the ultrasonic beam, and then performs envelope detection processing to generate B-mode image data that is tomographic image information regarding a tissue of the subject.

[0143] The DSC (digital scan converter) **42** converts (raster-converts) the B-mode image data generated in the detection processing unit **40** into image data corresponding to a scanning system of a normal television signal.

[0144] The image creation unit **44** performs various necessary image processing such as gradation processing on the B-mode image data input from the DSC **42** to create B-mode image data to be subjected to an inspection or a display, and then outputs the created B-mode image data for inspection or for display to the display control unit **46** for the purpose of displaying, or stores the B-mode image data in the image memory **46**.

[0145] The image memory **46** temporarily stores the B-mode image data for inspection created in the image creation unit **44**. The B-mode image data for inspection stored in the image memory **46** is read by the display control unit **26** to be displayed on the display unit **28** as necessary.

[0146] The display control unit **26** causes the display unit **28** to display an ultrasound image based on the B-mode image data for inspection subjected to the image processing by the image creation unit **44**.

[0147] The display unit **28** includes, for example, a display device such as an LCD and displays an ultrasound image under the control of the display control unit **26**.

[0148] The control unit **30** controls the respective units of the ultrasonic inspection apparatus **10** based on an instruction input from the operation unit **32** by an operator.

[0149] Here, when various information, in particular, information necessary for delay time calculation used in the element data processing unit **22** and the phasing addition unit **38** of the image generation unit **24** and information necessary for the element data processing in the element data processing unit **22** are input by the operator through the operation unit **32**, the control unit **30** supplies, as necessary, the various information input from the operation unit **32** to the respective units such as the transmission unit **14**, the reception unit **16**, the element data storage unit **20**, the element data processing unit **22**, the image generation unit **24**, and the display control unit **26**.

[0150] The operation unit **32** is used when the operator performs input operation, and may be constituted by a keyboard, a mouse, a trackball, a touch panel, or the like.

[0151] The operation unit **32** includes an input device in which the operator performs, as necessary, the input operation for inputting various information, in particular, information used in the aforementioned delay time calculation such as information on the plurality of ultrasound elements of the probe **36** of the ultrasound probe **12**, a sound speed in the inspection target region of the subject, a focal position of the ultrasonic beam, and a transmission aperture and a reception aperture of the probe **36** and information on the element data processing such as the number of pieces of the element data to be superimposed and a superposition processing method.

[0152] The storage unit **34** stores various information input from the operation unit **32**, in particular, stores aforementioned information on the probe **12**, the sound speed, the focal position, the transmission aperture, and the reception aperture; the aforementioned information on the element data processing such as the number of pieces of the element data to be superimposed and a superposition processing method; or information necessary for the processing or operation of the respective units controlled by the control unit **30** such as the transmission unit **14**, the reception unit **16**, the element data storage unit **20**, the element data processing unit **22**, the image generation unit **24**, and the display control unit **26**, and an operation program or a processing program for causing the respective units to execute the processing or operation as well. The storage unit **34** may be constituted by a recording medium such as a hard disk, a flexible disk, an MO, an MT, a RAM, a CD-ROM a DVD-ROM, or the like.

[0153] The element data processing unit **22**, the phasing addition unit **38**, the detection processing unit **40**, the DCS **42**, the image creation unit **44**, and the display control unit **26** are constituted by a CPU and an operation program for causing the CPU to execute various processing, but these may be constituted by digital circuits.

[0154] Here, the element data processing unit **22** will be described in detail based on FIG. **2**.

[0155] The element data processing unit **22** includes a delay time calculation unit **48** and a superposition processing unit **50**, as illustrated in FIG. **2**.

[0156] The delay time calculation unit **48** acquires, in advance, information on the plurality of ultrasound elements of the probe **36** of the ultrasound probe **12**, the sound speed in the inspection target region of the subject, the focal position of the ultrasonic beam, the transmission aperture and the reception aperture of the probe **36**, and the like, which is input from the operation unit **32** or input from the operation unit **32**

and stored in the storage unit **34**, and calculates the delay time of the element data received by each of the ultrasound elements of the reception aperture based on a geometric arrangement of the ultrasound element (transmission element) of the transmission aperture which forms and transmits an ultrasonic beam and the ultrasound element of the reception aperture which receives the ultrasonic echo caused by the ultrasonic beam from the subject.

[0157] The superposition processing unit **50** reads two or more pieces of unprocessed element data respectively generated for two or more target regions stored and held in the element data storage unit **20** based on information on element data processing such as the number of pieces of element data to be superimposed and a superposition processing method, which is input from the operation unit **32** or input from the operation unit **32** and stored in the storage unit **34**, and superimposes the two or more pieces of unprocessed element data while matching the reception time and matching absolute positions of the element of the probe which receives an ultrasonic echo based on the respective delay time calculated by the delay time calculation unit **48** to generate the processed element data.

[0158] Next, element data processing performed in the element data processing unit **22** will be described in detail.

[0159] First, a relationship between an ultrasonic beam (hereinafter referred to simply as a transmission beam) transmitted from an ultrasound element for transmission of the probe **36** of the ultrasound probe **12** (hereinafter referred to simply as a transmission element) and element data obtained by an ultrasound element for reception of the probe **36** (hereinafter referred to simply as a reception element) when the transmission beam is transmitted from the transmission element to a subject and an ultrasonic echo generated by interaction of the transmission beam with the subject is received by the reception element to obtain element data will be described.

[0160] When the ultrasonic echo is received using seven ultrasound elements (hereinafter also referred to simply as elements) **52***a* to **52***g* and seven ultrasound elements **52***b* to **52***h* as reception elements to acquire element data as respectively illustrated in FIGS. **3**A and **3**C, in an ideal case in which a transmission beam **56** transmitted to an inspection target region including a reflection point **54** is ideally narrowed down to be smaller than an element interval, if the central element **52***d* just above the reflection point **54** in the inspection target region among the elements **52***a* to **52***g* is used as the transmission element to transmit the transmission beam **56**, and the ultrasonic echo is received using the reception elements **52***a* to **52***g* to acquire the element data, as illustrated in FIG. **3**A, a focal point **58** of the transmission beam **56** is on a straight line that connects the element **52***d* with the reflection point **54**, the transmission beam **56** is transmitted up to the reflection point **54**, and accordingly, the ultrasonic echo reflected from the reflection point **54** is generated. The ultrasonic echo from the reflection point **54** is received by the reception elements **52***a* to **52***g* via the reception path **60** spreading at a predetermined angle, and element data **62** as illustrated in FIG. **3**B is obtained by the reception elements **52***a* to **52***g*.

[0161] In contrast, in a case in which the center of the transmission elements is shifted by one element in an element direction (a right direction in FIG. **3**C) relative to the reflection point **54**, the transmission beam **56** is transmitted using the element **52***e* adjacent to the element **52***d* just above the reflection point **54** as the transmission element, and the ultrasonic echo is received by the reception elements **52***b* to **52***h*, as illustrated in FIG. **3**C, since the reflection point **54** is not on the transmission direction of the transmission beam **56**, that is, on a straight line that connects the transmission element **52***e* with the focal point **58**, the transmission beam **56** is not transmitted to the reflection point **54**. Therefore, the ultrasonic echo reflected from the reflection point **54** is not generated, the reception elements **52***b* to **52***h* do not receive the ultrasonic echo, and accordingly, a reflected signal from the reflection point is not obtained as illustrated in FIG. **3**D (signal strength of the element data becomes "0").

[0162] However, an actual transmission beam **64** is wider than the element interval, as illustrated in FIGS. **4**A and **4**C.

[0163] Here, in a case in which the transmission beam **64** is transmitted using the element **52***d* just above the reflection point **54** as a transmission element as illustrated in FIG. **4**A, the focal point **58** is on a straight line that connects the element **52***d* and the reflection point **54** even when the transmission beam **56** is wide, and thus, the transmission beam **64** is reflected from the reflection point **54** and the ultrasonic echo is generated, similarly to the case illustrated in FIG. **3**A. As a result, the ultrasonic echo from the reflection point **54** is received by the reception elements **52***a* to **52***g* via the reception path **60** spreading at a predetermined angle, and true element data **66** as illustrated in FIG. **4**B is obtained by the reception elements **52***a* to **52***g*, similarly to the case illustrated in FIG. **3**A.

[0164] In contrast, in a case in which similarly to the case illustrated in FIG. **3**C, the center of the transmission elements is shifted by one element in an element direction (a right direction in FIG. **4**C) relative to the reflection point **54**, the transmission beam **64** is transmitted using the element **52***e* adjacent to the element **52***d* just above the reflection point **54** as the transmission element, and the ultrasonic echo is received by the reception elements **52***b* to **52***h*, as illustrated in FIG. **4**C, since the transmission beam **64** is wide, the transmission beam **64** is transmitted to the reflection point **54** even when the reflection point **54** is not on the transmission direction, that is, on a straight line that connects the transmission element **52***e* with the focal point **58**. Therefore, an ultrasonic echo that does not originally exist, that is, a so-called reflection signal of a ghost is generated from the reflection point **54**, the reflection signal of the ghost from the reflection point **54** is received by the reception elements **52***b* to **52***h* via the reception path **60** spreading at a predetermined angle, and element data **68** of the ghost as illustrated in FIG. **4**D is obtained by the reception elements **52***b* to **52***h*.

[0165] Such element data **68** of the ghost becomes a cause of a decrease in precision of the ultrasound image generated from the element data.

[0166] The element data processing unit **22** calculates the delay time corresponding to the element data in the delay time calculation unit **48** and superimposes two or more pieces of element data based on this delay time and an absolute position of the element in the superposition processing unit **50** to thereby generate processed element data that is highly precise element data in which the true element data is emphasized and the element data of the ghost is attenuated.

[0167] Here, since the total (propagation distance) of a transmission path of the transmission beam **64** from the transmission element **52***e* to the reflection point **54** via the focal point **58** and a reception path of the reflection signal of the ghost from the reflection point **54** to the respective reception

elements **52***b* to **52***h* illustrated in FIG. **4**C is longer than the total (propagation distance) of a transmission path of the transmission beam **64** from the transmission element **52***d* to the reflection point **54** via the focal point **58** and a reception path of the true reflection ultrasonic echo from the reflection point **54** to the respective reception elements **52***a* to **52***g* illustrated in FIG. **4**A, the element data **68** of the ghost as illustrated in FIG. **4**D is delayed relative to the true element data **66** as illustrated in FIG. **4**B.

[0168] In the delay time calculation unit **48** of the element data processing unit **22** of the present invention, a time difference, that is, a delay time between the true element data and the element data of the ghost is calculated from a geometric arrangement of the transmission element, the focal point of the ultrasonic beam, the reflection point of the subject, and the reception elements. Therefore, information such as the shape of the ultrasound probe **12** (element interval, linear, convex or the like), the sound speed in the inspection target region of the subject, the focal position, the transmission aperture, and the reception aperture is necessary for calculation of the delay time. In the delay time calculation unit **48**, these pieces of information input by the operation unit **32** or stored in the storage unit **34** is acquired to calculate the delay time. The delay time can be calculated, for example, from a difference of a propagation time which is calculated from the total length (propagation distance) of the transmission path of the transmission beam from the transmission element to the reflection point via the focal point and the reception path of the true reflection ultrasonic echo or the reflection signal of the ghost from the reflection point to the reception elements, which is calculated from the geometric arrangement of the transmission element, the focal point of the ultrasonic beam, the reflection point of the subject, and the reception elements, and the sound speed thereof.

[0169] In the present invention, for example, the lengths of the transmission path of the transmission beam and the reception path in the case of the true reflection ultrasonic echo and the reflection signal of the ghost can be obtained, as illustrated in FIGS. **5**A and **5**B.

[0170] In the case of the true reflection ultrasonic echo, as illustrated in FIG. **5**A, the transmission element **52***d* agrees with the reception element **52***d* (the center of reception elements **52***a* to **52***g*), and the focal point **58** and the reflection point **54** are arranged just under the element. Accordingly, if it is assumed that a position of the element **52***d* just above the reflection point **54** is a coordinate (x0, 0) in an two-dimensional xy coordinate, an element interval is Le, a position of the focal point **58** is a coordinate (x0, df), and a position of the reflection point **54** is a coordinate (x0, z), the coordinate of the position of the transmission element **52***d* is the same as the coordinate (x0, 0) of the element **52***d* just above the reflection point **54**, and a length (transmission path distance) Lta of the transmission path **61** of the transmission beam from the transmission element **52***d* to the reflection point **54** via the focal point **58** and a length (reception path distance) Lra of the reception path **60** of the true reflection ultrasonic echo from the reflection point **54** to the reception element **52***d* can be calculated as Lta=Lra=z.

[0171] Therefore, the propagation distance Lua of the ultrasound waves in the case of the true reflection ultrasonic echo becomes Lua=Lta+Lra=2z.

[0172] In the case of the reflection signal of the ghost, as illustrated in FIG. **5**B, the position of the transmission element **52***e* is shifted by one element in a horizontal direction (x direction: right direction in FIG. **5**B) relative to the reflection point **54**, and the focal point **58** is arranged just under the transmission element **52***e* unlike in the case of FIG. **5**A. However, the reflection point **54** is arranged directly under the reception element **52***d*. If it is assumed that the position of the reception element **52***d* just above the reflection point **54** is a coordinate (x0, 0) in a two-dimensional xy coordinate as in the case of FIG. **5**A, an element interval is Le, and a position of the reflection point **54** is a coordinate (x0, z), the position of the transmission element **52***e* is a coordinate (x0+Le, 0) and the position of the focal point **58** is a coordinate (x0+Le, df). Accordingly, a length (transmission path distance) Ltb of the transmission path **61** of the transmission beam from the transmission element **52***e* to the reflection point **54** via the focal point **58** can be calculated as $Ltb=df+\sqrt{\{(z-df)^2+Le^2\}}$, and a length (reception path distance) Lrb of the reception path **60** of the reflection signal of the ghost from the reflection point **54** to the reception element **52***d* can be calculated as Lrb=z.

[0173] Therefore, the propagation distance Lub of the ultrasound waves in the case of the reflection signal of the ghost becomes $Lub=Ltb+Lrb=df+\sqrt{\{(z-df)^2+Le^2\}}+z$.

[0174] Thus, a value obtained by dividing the propagation distance Lua of the ultrasound waves that is a total of the distance Lta of the transmission path **61** and the distance Lra of the reception path **60** obtained in the geometric arrangement illustrated in FIG. **5**A by the sound speed becomes a propagation time of the true reflection ultrasonic echo, and a value obtained by dividing the propagation distance Lub of the ultrasound waves that is a total of the distance Ltb of the transmission path **61** and the distance Lrb of the reception path **60** obtained in the geometric arrangement illustrated in FIG. **5**B by the sound speed becomes a propagation time of the reflection signal of the ghost. The delay time is obtained from a difference between the propagation time of the true ultrasonic echo when x coordinate of the reflection point **54** agrees with that of the transmission element **52** (**52***d*) and the propagation time of the reflection signal of the ghost when the x coordinates of the reflection point **54** and the transmission element **52** (**52***e*) are respectively shifted by one element interval.

[0175] While the geometrical model of FIGS. **5**A and **5**B is a model in which the transmission path **61** passes through the focal point **58**, the present invention is not limited thereto and, for example, the transmission path may be a path directly reaching the reflection point **54** without passing through the focal point **58**.

[0176] Further, while the geometrical model of FIGS. **5**A and **5**B corresponds to the linear probe, the present invention is not limited thereto and, in other probes, the same geometrical calculation can also be performed using the shape of the probe. For example, in the case of a convex probe, a geometrical model can be set using the radius of the probe and an angle of an element interval, and the calculation can be performed in the same way.

[0177] Further, in the case of steering transmission, the delay time of the element data of the true ultrasonic echo and the element data of a neighboring ghost can be calculated based on a positional relationship between the transmission element and the reflection point using a geometrical model (not illustrated) that considers information such as a transmission angle.

[0178] Further, the present invention is not limited to a method of calculating the delay time based on the geometrical

model, and the delay time may be obtained by a method in which a high brightness reflection point corresponding to each of measurement conditions of the device is measured in advance, from the measurement result thereof, the delay time of the respective measurement conditions are calculated and stored in the device, and the delay time of the same measurement condition as a selected measurement condition is read therefrom.

[0179] Element data **66** of the true signal at the center and element data **68** of the ghost near the true signal are illustrated in FIG. **5**C, and an example of the delay time of the element data **68** of the ghost relative to the element data **66** obtained from the above-described geometrical calculation is illustrated in FIG. **5**D. The element data **68** of the ghost signal is symmetrically delayed in terms of time, round the element data **66** of the true signal, as illustrated in FIG. **5**D.

[0180] The delay time calculated by the delay time calculation unit **48** of the element data processing unit **22** in this way can also be used for delay correction in the phasing addition unit **38**.

[0181] Although described below in detail, in the present invention, on the element data obtained through the transmission of the ultrasonic beam in which a certain element of interest is the central element (transmission and reception of the element of interest), the element data obtained through the transmission of the ultrasonic beam in which the central element is different and at least a part of the ultrasonic beam is overlapped with the ultrasonic beam for the element of interest, is superimposed, while matching the reception time of the ultrasonic echo and the position of the element, to thereby generate processed element data (second element data) of the element of interest (rebuild the element data of the element of interest).

[0182] In FIG. **5**, the reflection point **54** indicates a position of a certain sampling point (output position of the element data) located just under the element of interest (in the same position in an azimuth direction/on a straight line that connects the element of interest with the focal point). In the present invention, a transmission and reception path to and from the sampling point just under the element of interest in the transmission and reception of the element of interest is regarded as a transmission and reception path of true element data, and a transmission and reception path to and from the same sampling point in the transmission and reception of ultrasound wave (transmission and reception of a neighboring element) in which the central element is different is regarded as a transmission and reception path of the ghost. The delay time is calculated from a difference between both transmission and reception paths, and the superposition is performed using this delay time, while matching the time of the element data. In other words, the delay time is calculated on the assumption that the element data obtained through the transmission and reception of the element of interest is true element data and the element data obtained through the transmission and reception in which the central element is different is the element data of the ghost, and the superposition of the element data is performed.

[0183] In the present invention, the delay time is calculated in the same way for all samplings points (output positions of all the pieces of element data), and superposition of the element data is performed to generate the processed element data of each element. At this time, it is preferable for a plurality of sampling points to also be set in a depth direction (y direction) on the same line.

[0184] Here, actually, even when the position of the sampling point (reflection point) is shifted in the azimuth direction (x direction), the length of the reception path (reception path distance Lrb) does not change. Therefore, for each element of interest, the delay time with respect to the element data due to transmission and reception in which the central element is different may be calculated for each sampling point of the depth direction (y direction).

[0185] Further, in this superposition processing, it is not necessary to recognize which element data is the true element data. That is, as described in detail below using FIG. **6**, in this superposition process, if the element data of the element of interest is true element data, the element data is emphasized automatically and remains, and if it is element data of the ghost, the element data is canceled. That is, when the element data of the element of interest is true element data, the processing using the delay time matches and the signal is emphasized, and when the element data of the element of interest is element data of the ghost, the processing using the delay time does not match and the signal is canceled.

[0186] Then, in the superposition processing unit **50** of the element data processing unit **22** of the present invention, processing of superimposing the element data of the true ultrasonic echo and the element data of the neighboring ghost is performed using the delay time calculated by the delay time calculation unit **48** as described above.

[0187] While the number of pieces of element data to be superimposed and information on superposition processing method are necessary in the superposition processing in the superposition processing unit **50**, these may be input by the operation unit **32** in advance or may be stored in the storage unit **34**.

[0188] FIGS. **6**A to **6**H illustrate a specific example of the superposition processing when the number of pieces of element data is 5 and the number of pieces of superimposed element data is 3, which is performed by the superposition processing unit **50**.

[0189] FIG. **6**A illustrates a state in which five pieces of element data are displayed side by side and an ultrasonic beam is transmitted and a reflection signal is received for each piece of element data. A horizontal axis of each piece of element data indicates the reception element, and a central element at the time of transmission of the ultrasonic beam is at the center in each piece of element data. The vertical axis indicates reception time.

[0190] In the central element data among the five pieces of element data, the reflection point is just under the central element of the element data (a central element among the reception elements), that is, a central element at the time of transmission (transmission element), and a reflection signal from the reflection point is received. That is, this reflection signal is a true signal, and the central element data indicates a true signal.

[0191] For two pieces of element data on both sides other than the central element data, there is not a reflection point just under the central element at the time of transmission. However, an ultrasonic beam hits the reflection point just under the transmission element of the central element data due to the spread of the transmission ultrasonic beam, and thus, a reflection signal, that is, a ghost is generated and reflected. Since propagation time of ultrasound wave to the reflection point becomes longer as the ghost becomes farther away from the true signal, the reception time of the ghost becomes later than that of the true signal. Further, the recep-

tion element by which the reflection signal from the reflection point is first received is an element just above the reflection point. However, since the center of the horizontal axis of the element data is a central element at the time of transmission of the ultrasonic beam, and the transmission is performed while shifting this central element by one element for each piece of element data, an absolute position of the element is shifted by one element in each piece of element data. That is, in the central element data, the reception element by which the reflection signal from the reflection point is first received is the central element, whereas in the two pieces of element data on both sides of the central element data, it is shifted by one element relative to the central element data. That is, in the element data on the right side, it is shifted by one element to the left, and in the element data on the left side, it is shifted by one element to the right. Further, in the two pieces of element data at both ends, the reception element by which the reflection signal from the reflection point is first received is shifted by two elements relative to the central element data. That is, in the element data at a right end, it is shifted by two elements to the left, and in the element data at a left end, it is shifted by two elements to the right. Thus, the reception time of the ghost signal is not only delayed relative to the true signal, but also shifted relative to the direction of the reception elements.

[0192] In FIG. **6**B, an example of the delay of the reception time relative to the central element data among five pieces of element data illustrated in FIG. **6**A is illustrated.

[0193] When the central element data is the element data of the element of interest, the superposition processing unit **50** performs delay time correction by the number of pieces of element data to be superimposed including the element data of the element of interest as the center (in the illustrated example, three pieces of element data) using the delay time illustrated in FIG. **6**B, and horizontally shifts each piece of element data by the difference in element position between the element data to be shifted and the element data of the element of interest (difference between the positions of the central element) (in the illustrated example, by one element toward both sides), that is, performs phase matching, and then, the superposition processing unit **50** superimposes pieces of unprocessed element data corresponding to the pieces of element data to be superimposed (in the illustrated example, three pieces of element data) to obtain one piece of processed element data of the element of interest.

[0194] The processed element data of the element data of the element of interest obtained in this way is illustrated in FIG. **6**C.

[0195] Element data of the element of interest illustrated in FIG. **6**A is the element data of the true signal. Accordingly, when the delay time correction and the horizontal shift are performed on the unprocessed element data of adjacent element data on both sides of the element data of the element of interest for phasing, unprocessed element data of the adjacent element data and unprocessed element data of the element of interest are phased and overlapped each other in a high brightness position, as illustrated in FIG. **6**C. Therefore, for example, when these pieces of element data are added together, obtained element data has a great value (high brightness value) and, for example, even when an average value is calculated, an emphasized value (high brightness value) is obtained.

[0196] In contrast, FIG. **6**D illustrates the same element data as that in FIG. **6**A, but illustrates an example of a case in which adjacent element data on the left side of the central element data, that is, a ghost, is assumed to be element data of the element of interest.

[0197] FIG. **6**E is the same as FIG. **6**B, and illustrates an example of the delay of the reception time relative to the central element data among the five pieces of element data illustrated in FIG. **6**A. That is, since FIGS. **6**A and **6**D illustrate the same element data, the delay of the reception time relative to the central element data among the five pieces of element data illustrated in FIG. **6**D is equivalent.

[0198] In the superposition processing unit **50**, the delay time correction is performed by the number of pieces of element data to be superimposed including the element data of the element of interest as the center (in the illustrated example, three pieces of element data) using the delay time illustrated in FIG. **6**E (that is, the same as FIG. **6**B), each piece of element data is horizontally shifted by the difference in element position between the element data to be shifted and the element data of the element of interest (difference between the positions of the central element) (in the illustrated example, by one element toward both sides), and then, pieces of unprocessed element data corresponding to the pieces of element data to be superimposed (in the illustrated example, three pieces of element data) are superimposed to obtain one piece of processed element data of the element of interest.

[0199] The processed element data of the element data of the element of interest obtained in this way is illustrated in FIG. **6**F.

[0200] The element data of the element of interest illustrated in FIG. **6**D is element data of the ghost. Accordingly, even when the delay time correction and the horizontal shift are performed on the unprocessed element data of the adjacent element data on both sides of the element data of the element of interest for phasing, the unprocessed element data of the adjacent element data and the unprocessed element data of the element of interest are not phased and overlapped each other as illustrated in FIG. **6**F. Therefore, for example, when the three pieces of element data are added together, the pieces of element data are not phased, and thus, signals of which the phase are inverted, or the like are cancelled each other. Accordingly, an adding value is not great, and for example, when an average value is calculated, only a small value is obtained.

[0201] For the other element data, a superposition state of adjacent three pieces of element data with respect to each of the five pieces of element data in the illustrated example, which has been subjected to the above delay time correction and the above horizontal shift as element data of the element of interest, is illustrated in FIG. **6**G. A result of performing the superposition processing, such as addition processing or averaging processing, on the element data, is illustrated in FIG. **6**H.

[0202] As illustrated in FIG. **6**H, in the element data of the element of interest when the coordinates of the transmission element and the reflection point match as illustrated in FIG. **6**A, the element data of the true signal is obtained as processed element data having a high brightness value. In contrast, in four pieces of element data, including two pieces of element data on both sides, pieces of element data of the ghost that are not phased are added together or averaged, and accordingly, the pieces of element data are cancelled each other. Thus, a value of the processed element data of the ghost becomes smaller than a value of the processed element data

having a high brightness value that is the element data of the true signal. Therefore, it is possible to reduce the influence of the element data of the ghost on the element data of the true signal or to cause the influence to be small such that the influence is negligible.

[0203] Therefore, influence of the ghost can be similarly eliminated by performing the phasing addition or the detection processing on the processed element data to generate the reception data and generate the ultrasound image. That is, the ultrasound image can be generated using element data that is equivalent to element data in which a focal point is formed at all points of the sound ray. Accordingly, it is possible to generate a high-resolution ultrasound image having excellent sharpness and high brightness.

[0204] In the following description, the generation of the processed element data is also referred to as multiline processing.

[0205] In the present invention, the central element is a central element in an azimuth direction when a numerical aperture of transmission (the number of elements that perform transmission of ultrasonic wave) is an odd number.

[0206] On the other hand, when the numerical aperture is an even number, any one of central elements in the azimuth direction is the central element, or it is assumed that an element exists at the center in the azimuth direction, and the hypothetical element is the central element. That is, when the numerical aperture is the even number, the calculation may be performed on the assumption that a focal point is on a line at the center of the apertures.

[0207] Further, in a superposition processing method in the superposition processing unit **50**, as well as addition, an average value or a median value may be calculated or a coefficient may be multiplied (weighted) and then addition may be performed. Further, calculation of the average value or the median value is considered to be equivalent to the application of an averaging filter or a median filter at an element data level, but an inverse filter performed in normal image processing may be applied in place of the averaging filter or the median filter. Alternatively, pieces of element data to be superimposed may be compared. When the pieces of element data are similar, a maximum value may be taken. When the pieces of element data are not similar, an average value may be taken. When there is a deviation of a distribution, a middle value may be taken. The present invention is not limited to these, and superposition processing may be changed based on the feature amount of each piece of element data to be superimposed.

[0208] Further, the number of pieces of element data to be superimposed on the element data of the element of interest is not limited to 2 in the illustrated example, and the number thereof may be 1 or may be 3 or more. That is, the number of pieces of element data to be superimposed on the element data of the element of interest may be appropriately set according to the required processing speed (for example, a frame rate) or image quality.

[0209] It is preferable for the number of pieces of element data to be superimposed to be set based on the degree of the beam width of the ultrasonic beam. Therefore, when the beam width is changed depending on the depth, the number of pieces of element data to be superimposed may be changed depending on the depth. Further, since the beam width depends on the transmission numerical aperture, the number of pieces of element data to be superimposed may be changed depending on the transmission numerical aperture. Alternatively, the number of pieces of element data to be superimposed may be changed based on a feature amount such as a brightness value of the image, or may be changed based on a result of performing waveform analysis of the element data and evaluating a correlation or coherence between the pieces of element data. Otherwise, the optimal number of pieces of element data to be superimposed may be selected from a plurality of images created by changing the number of pieces of element data to be superimposed.

[0210] Further, the present invention is not limited to changing the number of pieces of element data to be superimposed depending on the depth. The depth of the transmission focal point, the transmission numerical aperture, or the like may be changed depending on a spatial depth of a superposition position (sampling point), and multiline processing may be performed using first element data obtained by performing transmission of the ultrasonic beam under the changed transmission condition.

[0211] For example, multiline processing is performed using the first element data obtained by setting a transmission focal point in a position depending on the depth of the sampling point so that the sampling point and the focal point become a predetermined distance from one another. Accordingly, precision of the multiline processing can be uniform regardless of the depth of the sampling point. Further, it is more preferable to set the position of the transmission focal point and the numerical aperture depending on the depth of the sampling point so that the F value is constant regardless of the depth of the transmission focal point (see FIGS. **22**A and **22**B). Accordingly, the precision of the multiline processing can be more uniform regardless of the depth of the sampling point.

[0212] Further, ultrasonic beams forming transmission focal points of a different depth on the same transmission line may be transmitted to each transmission line, a plurality of pieces of first element data corresponding to the same transmission line may be acquired, and the element data processing unit **22** may perform multiline processing using the first element data of the same focal point depth in different transmission lines for each depth of the transmission focal point. In this case, the calculation of the delay time may be performed based on each depth of the transmission focal point (reception time of element data).

[0213] While in the above-described multiline processing, the processed element data of the element data of the element of interest is generated by superimposing the pieces of element data obtained through the transmission of the plurality of ultrasonic beams in which the central elements are different and the transmission directions of the ultrasonic beams are parallel (the angles are the same), the present invention is not limited thereto.

[0214] For example, the processed element data may be generated by superimposing the pieces of element data obtained through the transmission of the plurality of ultrasonic beams in which the central elements are the same and the transmission directions (angles) are different. In this case, selection of a ultrasonic beam by which the element data to generate the processed data is obtained (that is, selection of a direction of the sound ray by which the processed data is generated) may be set as default depending on, for example, a diagnosis portion, a type of the probe, or the like, or may be performed by an operator.

[0215] Further, the processed element data may be generated using both element data obtained through transmission

of the parallel ultrasonic beams in which the central elements are different and element data obtained through transmission of ultrasonic beams in which the central elements are the same and the transmission directions are different.

[0216] As a result of the superposition, as described above, signals are phased in the element data of the true signal, whereas signals are not phased in the ghost, and thus, signals of various phases are cancelled each other and weakened as a result of the superposition processing, such as addition. Accordingly, the true signal remains as element data having a valid value such as, for example, element data having high brightness, and the ghost signal can be obtained as element data having an attenuated value such as, for example, element data having low brightness.

[0217] An operation and action of the ultrasonic inspection apparatus of the present invention, and a method of creating an ultrasound image will be described.

[0218] FIG. **7** is a block diagram illustrating, along a process flow, primary units of an ultrasonic inspection apparatus of Embodiment 1 illustrated in FIG. **1**.

[0219] When an operator causes the ultrasound probe **12** to come in contact with a surface of a subject and starts measurement, as illustrated in FIG. **1**, an ultrasonic beam is transmitted from the probe **36** according to a driving signal supplied from the transmission unit **14**, and an ultrasonic echo from the subject is received by the probe **36** and an analog element signal is output therefrom as a reception signal, as illustrated in FIG. **7**.

[0220] The reception unit **16** amplifies the analog element signal and supplies the amplified analog element signal to the A/D conversion unit **18**. The A/D conversion unit **18** converts the amplified analog element signal into digital element data, and supplies the digital element data to the element data storage unit **20** to cause the element data storage unit **20** to store and hold the digital element data.

[0221] The delay time calculation unit **48** (FIG. **2**) of the element data processing unit **22** calculates a delay time (for example, FIGS. **6**B and **6**E which are the same) of unprocessed element data of the signal of the neighboring ghost relative to the unprocessed element data of the true signal based on, for example, the geometric arrangement of the transmission element, the focal point, the reflection point, and the reception element, and the sound speed of the inspection target region of the subject that is input and set in advance (for example, calculates the delay time using the geometrical model illustrated in FIG. **5**).

[0222] Then, the element data processing unit **22** reads unprocessed element data from the element data storage unit **20**, and sets the element data to be processed as element data of the element of interest, and in the superposition processing unit **50** (FIG. **2**), phases and superimposes the element data of the element of interest and neighboring unprocessed element data using the delay time calculated by the delay time calculation unit **48** to obtain the processed element data. Accordingly, if the element data is unprocessed element data including the true signal, emphasized processed element data is obtained, and if the element data is unprocessed element data of the ghost, the attenuated processed element data is obtained.

[0223] The element data processing unit **22** supplies the processed element data obtained in this way to the phasing addition unit **38** of the image generation unit **24**.

[0224] The phasing addition unit **38** of the image generation unit **24** performs the reception focus processing on the element data to generate reception data (sound ray signal), and supplies the reception data to the detection processing unit **40**. The detection processing unit **40** processes the sound ray signal to generate a B-mode image signal. The DSC **42** raster-converts the B-mode image signal, and then, the image creation unit **44** performs image processing on the raster-converted B-mode image signal to create an ultrasound image. The created ultrasound image is stored in the image memory **46**, and displayed on the display unit **28** by the display controller **26**.

[0225] Thus, since the ultrasonic inspection apparatus **10** of Embodiment 1 of the present invention creates an ultrasound image using the processed element data in which the ghost signal is attenuated and the true signal is emphasized in the element data processing unit **22**, it is possible to obtain a sharp ultrasound image having a high SN ratio and an optimal spatial resolution with high resolution that does not depend on the width of the transmission beam, without using a dedicated ultrasound probe for generating a wide transmission ultrasonic beam and at a frame rate that is not different from the conventional frame rate.

[0226] The ultrasonic inspection apparatus of Embodiment 1 of the present invention is basically configured as described above.

[0227] In the ultrasonic inspection apparatus **10** of Embodiment 1 of the present invention, the sound speed within the inspection target, that is, the inspection target region of the subject which is necessary when the delay time is calculated by the delay time calculation unit **48** of the element data processing unit **22** and when delay time used in the phasing addition unit **38** is calculated is given. However, the present invention is not limited thereto, and when the sound speed within the inspection target is not known, an optimal sound speed may be set in the ultrasonic inspection apparatus as described below.

Embodiment 2

[0228] Next, an ultrasonic inspection apparatus of Embodiment 2 of the present invention will be described based on FIGS. **8**A and **8**B.

[0229] Each of FIGS. **8**A and **8**B is a block diagram conceptually illustrating, along a process flow, an example of primary units of an ultrasonic inspection apparatus of Embodiment 2 of the present invention.

[0230] Since ultrasonic inspection apparatuses **70***a* and **70***b* illustrated in FIGS. **8**A and **8**B have the same configuration as the ultrasonic inspection apparatus **10** illustrated in FIGS. **1** and **7** except that determination units **72***a* and **72***b* and a sound speed changing unit **74** are included, the same components are denoted with the same reference signs and detailed description thereof will be omitted.

[0231] First, the ultrasonic inspection apparatus **70***a* illustrated in FIG. **8**A will be described. FIG. **8**A illustrates, along a process flow, the primary units of the ultrasonic inspection apparatus **70***a*, as in FIG. **7**.

[0232] The ultrasonic inspection apparatus **70***a* includes the transmission unit **14**, the probe **36**, the reception unit **16**, the element data storage unit **20**, the element data processing unit **22**, the phasing addition unit **38**, the detection processing unit **40**, the image creation unit **44**, a determination unit **72***a*, a sound speed changing unit **74**, and the display unit **28**, as illustrated in FIG. **8**A.

[0233] Here, since the processing in the probe **36**, the transmission unit **14**, the reception unit **16**, and the element data

storage unit **20** and the first time processing in the element data processing unit **22**, the phasing addition unit **38**, the detection processing unit **40** and the image creation unit **44** are performed as in the ultrasonic inspection apparatus **10** illustrated in FIGS. **1** and **7**, description thereof will be omitted.

[0234] In the first time processing, the element data processing unit **22** performs processing on the element data using an initial value of the sound speed set in advance, and then, sends the processed element data to the phasing addition unit **38**. The phasing addition unit **38** performs reception focus processing, that is, phasing addition using an appropriate sound speed value such as a sound speed value close to a living body to generate a sound ray signal (reception data). The detection processing unit **40** performs detection processing on the generated sound ray signal to generate a B-mode image signal. The image creation unit **44** performs image processing on the generated B-mode image signal to generate an ultrasound image.

[0235] The determination unit **72***a* is provided between the image creation unit **44** and the display unit **28**, and performs a determination based on the ultrasound image created by the image creation unit **44**, for example, based on the image quality index such as a brightness value or sharpness of the ultrasound image, or sharpness of the brightness value, or a degree of convergence of the sound speed, using the created ultrasound image. The determination unit **72***a*, for example, determines "suitable" or OK when the image quality index such as the brightness value or the sharpness of the ultrasound image, or the sharpness of the brightness value is higher than a predetermined value and preferably, is highest or when the sound speed is converged in a predetermined range, and otherwise determines "unsuitable" or NG.

[0236] When the determination unit **72***a* determines OK, the ultrasound image created by the image creation unit **44** is sent to the display unit **28** and displayed on the display screen.

[0237] On the other hand, when the determination unit **72***a* determines NG, the process proceeds to the sound speed changing unit **74**.

[0238] The sound speed changing unit **74** sets the optimal sound speed when the sound speed in the inspection target necessary for delay time calculation in the delay time calculation unit **48** of the element data processing unit **22** is not known. The sound speed changing unit **74** initially changes an initial value of the sound speed set in advance into a new sound speed value and sets the new sound speed value, and from the second time, changes a previously set sound speed value into a new sound speed value and sets the new sound speed value.

[0239] Here, while any method may be used to change the sound speed value as long as the method is capable of obtaining an optimal sound speed value to which the determination unit **72***a* gives the determination of OK, it is preferable to increase or decrease the sound speed at predetermined intervals from the initial value of the sound speed. The change of the sound speed value may be sequentially performed at predetermined speed intervals over a predetermined sound speed range. For example, when a living body such as a human body is a target, the sound speed can be sequentially changed from 1400 m/s to 1700 m/s in a predetermined step of 1 m/s to 50 m/s, such as a step of 10 m/s.

[0240] When the sound speed changing unit **74** changes the sound speed into a new sound speed value, the process returns from the sound speed changing unit **74** to the element data processing unit **22**. In the second time and subsequent processing, the delay time calculation unit **48** of the element data processing unit **22** calculates the delay time again using the new sound speed value. Thereafter, the superposition processing unit **50** performs the superposition processing on two or more pieces of unprocessed element data using the delay time calculated by the delay time calculation unit **48** to obtain processed element data.

[0241] After the processed element data is obtained in the element data processing unit **22**, the phasing addition unit **38** performs reception focus processing on the processed element data obtained in the element data processing unit **22** based on the new sound speed value changed by the sound speed changing unit **74** to generate a sound ray signal. As in the first time processing, the detection processing unit **40** performs the detection processing and the image creation unit **44** performs the image processing to create an ultrasound image. The determination unit **72***a* performs the determination with respect to the ultrasound image.

[0242] Here, if the determination of the determination unit **72***a* is OK, the ultrasound image created by the image creation unit **44** is displayed on the display unit **28**.

[0243] On the other hand, if the determination of the determination unit **72***a* is NG, the changing into a new sound speed value in the sound speed changing unit **74**, the calculation of the delay time in the delay time calculation unit **48** of the element data processing unit **22** using the new sound speed value, the generation of the processed element data in the superposition unit **50**, the generation of the sound ray signal based on the new sound speed value in the phasing addition unit **38**, the detection processing in the detection processing unit **40**, and the creation of the ultrasound image in the image creation unit **44** are repeated until the determination of the determination unit **72***a* is OK, that is, until an optimal sound speed is set.

[0244] Even when the changing into the new sound speed value in the sound speed changing unit **74** is all performed in a predetermined sound speed range, for example, even when the changing is performed at predetermined intervals in the predetermined entire sound speed range, if the determination of the determination unit **72***a* is not OK, for example, a sound speed value when a determination closest to a determination criteria is obtained may be adopted as the optimal sound speed.

[0245] A method of changing the sound speed value and a method of setting the sound speed in the sound speed changing unit **74** is not particularly limited in the present invention. As described above, the changing of the sound speed value may be sequentially performed at predetermined intervals in a predetermined sound speed range, and the determination unit **72***a* may perform the determination each time the above-described processing is performed using the changed sound speed value, or the changing of the sound speed value may be cyclopedically performed at predetermined intervals in the predetermined entire sound speed range, the above-described processing may be performed using all sound speed values in the predetermined entire sound speed range, and then, the determination unit **72***a* may perform the determination. Alternatively, the changing of the sound speed value and the setting of the optimal sound speed may be exploratorily performed. For example, when the changing and the setting are exploratorily performed, an initial value of the set sound speed starts from a value close to the living body as far as possible. For example, if the image quality index such as the sharpness of

the image increases as a result of the determination when the sound speed value is changed toward a positive side, the sound speed value may be further changed, and this operation may be repeated until the image quality index such as the sharpness of the image decreases. Or, when the sound speed value is first changed toward a negative side, if the image quality index such as the sharpness of the image decreases as a result of the determination, the sound speed value may be changed toward the positive side. In this way, a next sound speed value may be appropriately changed through a comparison with a previous sound speed value so that the sound speed value is converged on a predetermined sound speed value, and the converged sound speed value may be set as an optimal sound speed.

[0246] When the changing of the sound speed value and the setting of the optimal sound speed in the sound speed changing unit **74** are performed, the region in which the sound speed value is set is not particularly limited. The same sound speed value may be set for the entire subject or the entire inspection target area, the subject or the inspection target region may be divided into small areas and the sound speed value may be set for each small region, or the sound speed value may be set point by point in units of pixels. Further, the sound speed value may be set for a region of interest of the subject or the inspection target region, and the sound speed value set in the region of interest may be used as an optimal sound speed.

[0247] Even in these cases, since the sound speed value in the position of the reflection point to be calculated may be adopted as the sound speed value used for calculation of the delay time, it is understood that there is no difference between calculation methods.

[0248] In the ultrasonic inspection apparatus **70***a* illustrated in FIG. **8**A, the determination unit **72***a* is provided between the image creation unit **44** and the display unit **28**, but the present invention is not limited thereto, and the determination unit **72***b* may be provided between the phasing addition unit **38** and the detection processing **40**, as in the ultrasonic inspection apparatus **70***b* illustrated in FIG. **8**B.

[0249] In the ultrasonic inspection apparatus **70***b* illustrated in FIG. **8**B, since the processing in the probe **36**, the transmission unit **14**, the reception unit **16**, and the element data storage unit **20**, the processing in the detection processing unit **40**, the image creation unit **44**, and the display unit **28**, and the first time processing in the element data processing unit **22** and the phasing addition unit **38** are performed as in the ultrasonic inspection apparatus **70***a* illustrated in FIG. **8**A, description thereof will be omitted.

[0250] The determination unit **72***b* is provided between the phasing addition unit **38** and the detection processing unit **40**. The determination unit **72***b* performs the determination based on the sound ray signal generated by the phasing addition unit **38** performing the reception focal point processing, for example, based on the image quality index such as a brightness value or sharpness of the image, or the sharpness of the brightness value obtained using the sound ray signal, or sharpness of the brightness value, or a degree of convergence of the sound speed. Similarly to the determination unit **72***a*, the determination unit **72***b*, for example, determines OK when the image quality index such as the brightness value or the sharpness of the image, or the sharpness of the brightness value is higher than a predetermined value and preferably, is highest or when the sound speed is converged in a predetermined range, and determines NG when the image quality index such as the brightness value or the sharpness do not reach the predetermined value or the highest value, or when the sound speed is not converged in the predetermined range.

[0251] When the determination unit **72***b* determines OK, the sound ray signal generated in the phasing addition unit **38** is subjected to the detection processing in the detection processing unit **40**, and then, the creation of the ultrasound image in the image creation unit **44**, and the display of the ultrasound image in the display unit **28** are performed.

[0252] On the other hand, when the determination unit **72***b* determines NG, the process proceeds to the second time and subsequent processing. The sound speed changing unit **74** changes the sound speed value into a new sound speed value, and the process proceeds to the element data processing unit **22**. The delay time calculation unit **48** of the element data processing unit **22** calculates the delay time again using the new sound speed value changed by the sound speed changing unit **74**. Thereafter, the superposition processing unit **50** performs the superposition processing on two or more pieces of unprocessed element data using the delay time calculated using the new sound speed value to obtain processed element data.

[0253] After the processed element data is obtained in the element data processing unit **22**, the phasing addition unit **38** performs reception focus processing on the processed element data obtained by the element data processing unit **22** based on the new sound speed value changed by the sound speed changing unit **74** to generate a sound ray signal (reception data), and the determination unit **72***b* performs the determination based on the sound ray signal generated by the phasing addition unit **38**, as in the first time processing.

[0254] Thus, in the second time and subsequent processing, the respective processing in the sound speed changing unit **74**, the element data processing unit **22**, the phasing addition unit **38** and the determination unit **72***b* are repeated until the determination of the determination unit **72***b* is OK. After the determination unit **72***b* determines OK, the ultrasound image is displayed on the display unit **28** through the respective processing in the detection processing unit **40** and the image creation unit **44**.

[0255] Thus, in the ultrasonic inspection apparatuses **70***a* and **70***b* of Embodiment 2 of the present invention, an ultrasound image is created using the processed element data in which the ghost signal is attenuated and the true signal is emphasized in the element data processing unit **22**. Accordingly, it is possible to obtain a sharp ultrasound image having a high SN ratio and an optimal spatial resolution with high resolution that does not depend on the width of the transmission beam, without using a dedicated ultrasound probe for generating a wide transmission ultrasonic beam and at a frame rate that is not different from the conventional frame rate.

[0256] The ultrasonic inspection apparatuses of Embodiment 2 of the present invention are basically configured as described above.

[0257] In the ultrasonic inspection apparatuses **70***a* and **70***b* of Embodiment 2 of the present invention, when the determination result in the determination units **72***a* and **72***b* is OK, an ultrasound image created by the image creation unit **44** is directly displayed on the display unit **28** (**70***a*), or an ultrasound image created through the detection processing in the detection processing unit **40** and the image processing in the image creation unit **44** is displayed on the display unit **28** (**70***b*). However, the present invention is not limited thereto, and after the determination result of the determination unit is

OK, an optimal sound speed of the reception side may be obtained, and the reception focus processing (phasing addition processing), the detection processing, and the image processing may be performed using the obtained optimal sound speed to create and display an ultrasound image.

Embodiment 3

[0258] Next, an ultrasonic inspection apparatus of Embodiment 3 of the present invention will be described based on FIGS. **9** to **12**.

[0259] Each of FIG. **9** and FIG. **12** is a block diagram conceptually illustrating, along a process flow, an example of primary units of the ultrasonic inspection apparatus of Embodiment 3 of the present invention. FIG. **10**A is a block diagram conceptually illustrating an example of a configuration of a sound speed correction unit of the ultrasonic inspection apparatus illustrated in FIG. **9**. FIG. **10**B is a diagram schematically illustrating an example of an ultrasound image in which a region of interest is set in a region-of-interest setting unit of the sound speed correction unit illustrated in FIG. **10**A. FIG. **11** is a block diagram illustrating, along a process flow, details of an example of an optimal sound speed calculation unit of the sound speed correction unit illustrated in FIG. **10**A.

[0260] The ultrasonic inspection apparatuses **70***c* and **70***d* illustrated in FIGS. **9** and **12** respectively have exactly the same configuration as the ultrasonic inspection apparatuses **70***a* and **70***b* illustrated in FIGS. **8**A and **8**B except that sound speed correction units **76** and **76***a* are respectively provided in subsequent stages of the determination units **72***a* and **72***b*, and the reception focus processing (phasing addition processing), the detection processing, the image processing, and the displaying of the ultrasound image are performed using an optimal sound speed set by the sound speed correction units **76** and **76***a*. Accordingly, the same components are denoted with the same reference signs and detailed description thereof will be omitted.

[0261] First, an ultrasonic inspection apparatus **70***c* illustrated in FIG. **9** will be described. FIG. **9** is a block diagram illustrating, along a process flow, the primary units of the ultrasonic inspection apparatus **70***c*, as in FIG. **8**A.

[0262] The ultrasonic inspection apparatus **70***c* includes the transmission unit **14**, the probe **36**, the reception unit **16**, the element data storage unit **20**, the element data processing unit **22**, the phasing addition unit **38**, the detection processing unit **40**, the image creation unit **44**, the determination unit **72***a*, the sound speed changing unit **74**, a sound speed correction unit **76**, a phasing addition unit **38***a*, a detection processing unit **40***a*, an image creation unit **44***a*, and the display unit **28**, as illustrated in FIG. **9**.

[0263] Here, since the processing in the probe **36**, the transmission unit **14**, the reception unit **16** and the element data storage unit **20**, and the processing in the element data processing unit **22**, the phasing addition unit **38**, the detection processing unit **40**, the image creation unit **44**, the determination unit **72***a*, and the sound speed changing unit **74** until the determination unit **72***a* determinates OK are performed as in the ultrasonic inspection apparatus **70***a* illustrated in FIG. **8**A, description thereof will be omitted.

[0264] The sound speed correction unit **76** is provided between the determination unit **72***a* and the phasing addition unit **38***a*, and is intended to obtain an optimal sound speed of the reception side, that is, a sound speed optimal for the inspection target region of the subject, and accordingly, a sound speed optimal for ultrasound image thereof, to be used in the phasing addition unit **38***a*. For example, the sound speed correction unit **76** changes the set sound speed v over a predetermined entire sound speed range, which is estimated as a sound speed range in the inspection target region, at predetermined sound speed intervals, and cyclopedically obtains an optimal sound speed based on an image quality index such as a brightness value or a sharpness of the image in the inspection target region, or a degree of convergence of the sound speed. Specifically, for example, when a living body such as a human body is a target, the set sound speed v is changed from 1400 m/s to 1650 m/s or 1700 m/s with a predetermined increment (step) of 1 m/s to 50 m/s, such as an increment of 10 m/s.

[0265] For example, a sound speed correction method disclosed in JP 2011-92686 A may be used as a sound speed correction method in the sound speed correction unit **76**. In the sound speed correction method disclosed in this publication, it is necessary to form transmission focal point in each region of interest. However, in the present invention, since element data enabling the transmission focal point to be artificially formed even in any depth is obtained through the superposition processing of the superposition processing unit in the element data processing unit **22**, it is not necessary to set the transmission focal point for each region of interest. However, even in the present invention, it is understood that the transmission focal point may be set for each region of interest, as in the sound speed correction method disclosed in the publication.

[0266] For example, as will be described below in detail, the sound speed correction unit **76** changes the set sound speed v in the inspection target region, a phasing addition unit **38***d* of an optimal sound speed calculation unit **80** performs reception focus processing (phasing addition processing) using the element data such as the unprocessed element data supplied without being processed from the element data storage unit **20** directly or via the element data processing unit **22** or the processed element data supplied from the element data processing unit **22** based on the setting speed v in each setting speed v to generate a sound ray signal, and an image creation unit **44***d* forms an ultrasound image from this sound ray signal, and calculates an image quality index such as a brightness value or sharpness of the image in the inspection target region in each set sound speed v, as illustrated in FIG. **11**.

[0267] A comparison determination unit **86** compares the image quality indexes such as the brightness values or the sharpness of the image in the respective set sound speeds v, and determines, for example, the set sound speed v at which the obtained value of image quality index such as the brightness value or the sharpness is greatest. A sound speed setting unit **88** sets the determined set sound speed v as an optimal sound speed value.

[0268] That is, the sound speed correction unit **76** may perform the changing of the sound speed value and the setting of the optimal sound speed cyclopedically or exploratorily, similar to the sound speed changing unit **74**.

[0269] When the sound speed correction unit **76** performs the changing of the sound speed value and the setting of the optimal sound speed, the region in which the sound speed value is set is not particularly limited. The same sound speed value may be set for the entire subject or the entire inspection target area, the subject or the inspection target region may be divided into small areas and the sound speed value may be set for each small region, or the sound speed value may be set

point by point in units of pixels. Further, the sound speed value may be set for the region of interest of the subject or the inspection target region, and the sound speed value set in the region of interest may be used as an optimal sound speed, as will be described below.

[0270] Even in these cases, since the sound speed value in the position of the reflection point to be calculated may be adopted as the sound speed value used for calculation of the delay time, it is understood that there is no difference between calculation methods.

[0271] Further, it is understood that the sound speed correction unit **76** may merely use, as an optimal sound speed, the sound speed value set by the sound speed changing unit **74** and used in the phasing addition unit **38** when the determination result in the determination unit **72***a* is OK.

[0272] In Embodiment 3, after the determination result in the determination unit **72***a* is OK, the optimal sound speed of the reception side is lastly set by the sound speed correction unit **76**.

[0273] The phasing addition unit **38***a* has exactly the same configuration and function as the phasing addition unit **38**, and performs reception focus processing in which a delay is given to the processed element data obtained by the element data processing unit **22** based on the optimal sound speed set by the sound speed correction unit **76** and addition is performed to generate a sound ray signal.

[0274] The detection processing unit **40***a* has exactly the same configuration and function as the detection processing unit **40**, and performs processing such as envelope detection processing on the sound ray signal generated by the phasing addition unit **38***a* to thereby generate B-mode image data that is tomographic image information regarding a tissue of the subject.

[0275] The image creation unit **44***a* has exactly the same configuration and function as the image creation unit **44**, and performs image processing on the B-mode image data generated by the detection processing unit **40***a* to generate an ultrasound image.

[0276] Thereafter, the ultrasound image generated in this way is displayed on the display unit **28**.

[0277] While the sound speed correction unit **76** may set the optimal sound speed used in the phasing addition unit **38***a* based on the ultrasound image in the inspection target region of the subject as described above, a sound speed optimal for the region of interest of the inspection target region of the subject, that is, a sound speed optimal for the region of interest of the ultrasound image may be set based on the region of interest of the ultrasound image.

[0278] This sound speed correction unit is illustrated in FIG. **10**A.

[0279] The sound speed correction unit **76** calculates the optimal sound speed of the region of interest under the control of the control unit **30** (see FIG. **1**), and includes a region-of-interest setting unit **77**, a region-of-interest data acquisition unit **78**, and the optimal sound speed calculation unit **80**, as illustrated in FIG. **10**A.

[0280] The region-of-interest setting unit **77** sets the region of interest ROI in response to input from the operation unit **32** (see FIG. **1**) by an operator.

[0281] FIG. **10**B is a diagram schematically illustrating an example of the ultrasound image in which the region of interest ROI is set. In the ultrasound image illustrated in FIG. **10**B, a target portion P such as a tissue (organ) or a lesion desired to be observed is imaged, and the region of interest ROI is set to surround the target portion P.

[0282] The region-of-interest setting unit **77** supplies information on the set region of interest ROI to the region-of-interest data acquisition unit **78**.

[0283] The region-of-interest setting unit **77** is not limited to a configuration in which the region of interest ROI is set in response to the input from the operation unit **32**, and may have a configuration in which the ultrasound image (B-mode image signal) created by the image creation unit **44** of the image generation unit **24** (see FIG. **1**) is analyzed and the region of interest ROI is set.

[0284] For example, the region-of-interest setting unit **77** may determine that a position (pixel) in which a difference in a brightness value between adjacent pixels in the ultrasound image created by the image creation unit **44** is equal to or greater than a predetermined value is an edge of a structural region (a tissue or a lesion), determine that a region surrounded by the edge or a region including a large number of edges is the structural region, that is, the target portion P, extract the target portion P, and set a region including the target portion P and having a predetermined shape and size as the region of interest ROI.

[0285] When the ultrasound image is analyzed and the region of interest ROI is set, the structural region may be considered as a type of region. Alternatively, the structural region may be considered as two or more regions depending on continuity of the edge, a level of the brightness value, or the like, each region may be determined to be the target portion P and extracted, and the region of interest ROI may be set for each target portion P.

[0286] The region-of-interest data acquisition unit **78** reads unprocessed element data in a position corresponding to the region of interest ROI from the unprocessed element data stored in the element data storage unit **20** based on information of the region of interest ROI supplied from the region-of-interest setting unit **77**, and supplies the unprocessed element data to the optimal sound speed calculation unit **80**.

[0287] The region-of-interest data acquisition unit **78** is not limited to the configuration in which the unprocessed element data in the position corresponding to the region of interest ROI is read from the element data storage unit **20**, and the processed element data in the position corresponding to the region of interest ROI may be supplied from the element data processing unit **22** to the optimal sound speed calculation unit **80**. Alternatively, a configuration in which, after the region of interest ROI is set, the probe **36** performs transmission of ultrasonic wave in a state of being focused on the set region of interest ROI, and element data obtained by transmitting ultrasonic waves to the region of interest ROI and receiving ultrasonic echoes is acquired as the element data in the position corresponding to the region of interest ROI may be adopted.

[0288] The optimal sound speed calculation unit **80** is a unit that calculates and sets the optimal sound speed value in the set region of interest ROI.

[0289] Here, the optimal sound speed value is a set sound speed value in which contrast and/or sharpness of an ultrasound image is highest when the set sound speed is variously changed and reception focus processing is performed based on each of the set sound speeds to form the ultrasound image. For example, a determination of the optimal sound speed value can be performed based on the contrast of the image, a spatial frequency in a scan direction, dispersion or the like, as described in JP 8-317926 A.

[0290] The optimal sound speed calculation unit **80** is intended to cyclopedically obtain and set the optimal sound speed value, in which the element data corresponding to the region of interest ROI supplied from the region-of-interest data acquisition unit **78** is an input value, and the optimal sound speed value is an output value.

[0291] The optimal sound speed calculation unit **80** may include, for example, an optimal sound speed calculation unit that cyclopedically searches for a predetermined sound speed search range, and sets an optimal sound speed value. The optimal sound speed calculation unit **80** includes a sound speed search range setting unit **82**, a sound speed start value setting unit **83**, the phasing addition unit **38***d*, a detection processing unit **40***d*, the image creation unit **44***d*, an image quality index calculation unit **84**, a sound speed determination unit **85**, the comparison determination unit **86**, a sound speed value updating unit **87**, and the sound speed setting unit **88**, as illustrated in FIG. **11**.

[0292] In the optimal sound speed calculation unit **80**, at the time of setting the optimal sound speed, first, the sound speed search range setting unit **82** sets a search range of the sound speed and a sound speed change width when an input value such as element data corresponding to the region of interest ROI is input from the region-of-interest data acquisition unit **78**. For example, the sound speed search range setting unit **82** sets a sound speed start value Vst for sound speed search start, a sound speed end value Vend for sound speed search end, and a step width (increment: sound speed change width) ΔV for change of sound speed value. For example, in the case of a living body or the like, the sound speed start value Vst is set to 1400 m/s, the sound speed end value Vend is set to 1700 m/s, and the sound speed change width ΔV is set to 10 m/s.

[0293] Subsequently, the sound speed start value setting unit **83** sets the set sound speed v to the sound speed start value Vst (for example, 1400 m/s). Then, the phasing addition unit **38***d* performs reception focus processing using the element data corresponding to the region of interest ROI supplied from the region-of-interest data acquisition unit **78** based on the set sound speed v that is the sound speed start value Vst to perform phasing addition and generate a sound ray signal. Then, the detection processing unit **40***d* performs detection processing on the generated sound ray signal to generate a B-mode image signal. Also, the image creation unit **44***d* generates an ultrasound image from the produced B-mode image signal.

[0294] Thereafter, the image quality index calculation unit **84** calculates an image quality index at the set sound speed v from the generated ultrasound image, that is, an image quality index such as a brightness value or sharpness of the image, for example, sharpness of the image of the region of interest ROI at each set sound speed v. The calculated image quality index is associated with the set sound speed value v, and held in the image quality index calculation unit **84**, such as a memory.

[0295] Then, the sound speed determination unit **85** performs a determination as to whether the set sound speed v and the sound speed end value Vend are equal by comparing the set sound speed v with the sound speed end value Vend.

[0296] In the determination of the sound speed determination unit **85**, when the set sound speed v is equal to the sound speed end value Vend (v=Vend), the process proceeds to the comparison determination unit **86**, and when the set sound speed v is not equal to the sound speed end value Vend (v≠Vend), the process proceeds to the sound speed value updating unit **87**.

[0297] When the process proceeds to the sound speed value updating unit **87**, the sound speed value updating unit **87** adds the sound speed change width ΔV to the current set sound speed v to set a new set sound speed v (v=v+ΔV).

[0298] Thereafter, the process returns to the phasing addition unit **38***d*. The phasing addition in the phasing addition unit **38***d*, the detection processing in the detection processing unit **40***d*, the image creation in the image creation unit **44***d*, the calculation and holding of the image quality index in the image quality index calculation unit **84**, and the determination in the sound speed determination unit **85** are performed based on the new set sound speed v.

[0299] When the determination result in the sound speed determination unit **85** is v Vend, the process proceeds to the sound speed value updating unit **87**, as described above. The setting of the new set sound speed v in the sound speed value updating unit **87**, the phasing addition in the phasing addition unit **38***d* based on the new set sound speed v, the detection processing in the detection processing unit **40***d*, the image creation in the image creation unit **44***d*, the calculation and holding of the image quality index in the image quality index calculation unit **84**, and the determination in the sound speed determination unit **85** are repeated until v becomes v=Vend. That is, these processing steps are repeatedly performed while changing the value of the set sound speed by ΔV until the sound speed end value Vend of the end of the sound speed range arrives. For example, the set sound speed v is changed with an increment of 10 m/s from 1400 m/s to 1700 m/s.

[0300] On the other hand, when the determination result of the sound speed determination unit **85** is v=Vend, the image quality index is obtained for all set sound speeds v in the search range of the sound speed. Accordingly, as described above, the process proceeds to the comparison determination unit **86**, and the comparison determination unit **86** reads the image quality index obtained for each sound speed value, which is stored in the image quality index calculation unit **84**. The comparison determination unit **86** compares the image quality indexes in the respective set sound speeds v, such as the sharpness (sharpness values) of the ultrasound image, and determines the set sound speed (sound speed value) v when the image quality is highest, for example, when the sharpness (sharpness value) of the ultrasound image is highest. The sound speed setting unit **88** adopts and sets the sound speed (sound speed value) v determined by the comparison determination unit **86** as an optimal sound speed.

[0301] Thus, the optimal sound speed calculation unit **80** calculates the optimal sound speed.

[0302] In the optimal sound speed calculation unit **80** illustrated in FIG. **11**, while the processing of changing the sound speed value is repeatedly performed, the present invention is not limited thereto, and all search sound speed values can be calculated in parallel using multi-thread of a GPU or the like, and the image quality index can be obtained in all the sound speed values at a time.

[0303] The element data used in the phasing addition performed by the phasing addition unit **38***d* of the optimal sound speed calculation unit **80** may be the unprocessed element data supplied from the element data storage unit **20** or may be the processed element data supplied from the element data processing unit **22**. The unprocessed element data may be the unprocessed element data directly supplied from the element data storage unit **20** or may be unprocessed element data supplied without being processed from the element data processing unit **22**.

[0304] The optimal sound speed calculation unit **80** supplies the optimal sound speed value calculated and set in this way to the phasing addition unit **38** of the image generation unit **24**.

[0305] When the ultrasound image is generated, by setting the region of interest in the ultrasound image and obtaining the optimal sound speed value in the region of interest, as described above, can be obtained effects that the spatial resolution of the image of the region of interest, that is, a tissue or a lesion desired to be observed is optimized and the optimal sound speed value is obtained in a short time.

[0306] The sound speed correction unit **76** illustrated in FIG. **10**A includes the region-of-interest setting unit **77**, the region-of-interest data acquisition unit **78**, and the optimal sound speed calculation unit **80**. However, when the sound speed correction unit **76** sets, as the region for which the same sound speed value is set, the entire subject or the entire inspection target region, as described above, the region-of-interest setting unit **77** may be omitted or the entire subject or the entire inspection target region may be set as the region of interest and the region-of-interest data acquisition unit **78** may acquire all pieces of data of the entire subject or the entire inspection target region. Further, when the subject or the inspection target region is divided into small regions and the sound speed value is set for each small regions, or when the sound speed value is set point by point in units of pixels, the region-of-interest setting unit **77** may set one point of the small region or the pixel unit as the region of interest, and the region-of-interest data acquisition unit **78** may acquire data of the one point of the small region or the pixel unit.

[0307] While in the ultrasonic inspection apparatus **70***c* illustrated in FIG. **9**, the determination unit **72***a* is provided between the image creation unit **44** and the display unit **28**, as in the ultrasonic inspection apparatus **70***a* illustrated in FIG. **8**A, the present invention is not limited thereto, and the determination unit **72***b* may be provided between the phasing addition unit **38** and the detection processing unit **40** as in the ultrasonic inspection apparatus **70***b* illustrated in FIG. **8**B, like the ultrasonic inspection apparatus **70***d* illustrated in FIG. **12**.

[0308] The ultrasonic inspection apparatus **70***d* illustrated in FIG. **12** includes the transmission unit **14**, the probe **36**, the reception unit **16**, the element data storage unit **20**, the element data processing unit **22**, the phasing addition unit **38**, a determination unit **72***b*, the sound speed changing unit **74**, a sound speed correction unit **76***a*, the phasing addition unit **38***a*, the detection processing unit **40**, the image creation unit **44**, and the display unit **28**.

[0309] Here, since the processing in the probe **36**, the transmission unit **14**, the reception unit **16**, and the element data storage unit **20**, the processing in the element data processing unit **22**, the phasing addition unit **38**, the determination unit **72***b* and the sound speed changing unit **74** until the determination result in the determination unit **72***b* is OK, and the processing in the detection processing unit **40**, the image creation unit **44**, and the display unit **28** after the determination result in the determination unit **72***b* is OK are performed as in the ultrasonic inspection apparatus **70***a* illustrated in FIG. **8**B, description thereof will be omitted.

[0310] In the ultrasonic inspection apparatus **70***d* of Embodiment 3, the sound speed correction unit **76***a* is provided between the determination unit **72***b* and the phasing addition unit **38***a*, has the same configuration and function as the sound speed correction unit **76** illustrated in FIG. **9** or **10**A, and is intended to obtain an optimal sound speed of the reception side, that is, a sound speed optimal for the inspection target region of the subject, and accordingly, a sound speed optimal for the ultrasound image thereof, to be used in the phasing addition unit **38***a* of the subsequent stage. Naturally, the sound speed correction unit **76***a* may determine the sound speed value set by the sound speed changing unit **74** and used in the phasing addition unit **38** to be the optimal sound speed as it is, when the determination result in the determination unit **72***b* is OK.

[0311] In the ultrasonic inspection apparatus **70***d*, the optimal sound speed of the reception side is set by the sound speed correction unit **76***a* after the determination result in the determination unit **72***b* is OK.

[0312] Then, in the phasing addition unit **38***a*, a delay is given to the processed element data obtained by the element data processing unit **22**, based on the optimal sound speed set by the sound speed correction unit **76***a* to perform the reception focus processing, and the sound ray signal is generated.

[0313] Then, in the detection processing unit **40**, the detection processing is performed on the sound ray signal generated by the phasing addition unit **38***a*, and B-mode image data is generated.

[0314] Then, in the image creation unit **44**, an ultrasound image is created from the B-mode image data generated by the detection processing unit **40**.

[0315] Thereafter, the ultrasound image created in this way is displayed on the display unit **28**.

[0316] Thus, since the ultrasonic inspection apparatuses **70***c* and **70***d* of Embodiment 3 of the present invention create an ultrasound image using the processed element data that is processed using an optimal sound speed and in which the ghost signal is attenuated and the true signal is emphasized in the element data processing unit **22**, it is possible to obtain a sharp ultrasound image having a high SN ratio and an optimal spatial resolution with high resolution that does not depend on the width of the transmission beam, without using a dedicated ultrasound probe for generating a wide transmission ultrasonic beam and at a frame rate that is not different from the conventional frame rate.

[0317] The ultrasonic inspection apparatus of Embodiment 3 of the present invention is basically configured as described above.

Embodiment 4

[0318] Next, an ultrasonic inspection apparatus of Embodiment 4 of the present invention will be described based on FIG. **13**.

[0319] FIG. **13** is a block diagram conceptually illustrating, along a process flow, an example of primary units of the ultrasonic inspection apparatus of Embodiment 4 of the present invention.

[0320] An ultrasonic inspection apparatus **11** includes the transmission unit **14**, the probe **36**, the reception unit **16**, the element data storage unit **20**, a sound speed correction unit **76***b*, the element data processing unit **22**, the phasing addition unit **38**, the detection processing unit **40**, the image creation unit **44**, and the display unit **28**, as illustrated in FIG. **13**.

[0321] Since the ultrasonic inspection apparatus **11** illustrated in FIG. **13** has exactly the same configuration as the ultrasonic inspection apparatus **10** illustrated in FIGS. **1** and **7** except that the sound speed correction unit **76***b* is included, the same components are denoted with the same reference signs and detailed description thereof will be omitted.

[0322] Further, in the ultrasonic inspection apparatus **11**, the processing in the probe **36**, the transmission unit **14**, the reception unit **16**, and the element data storage unit **20**, and the processing in the phasing addition unit **38**, the detection processing unit **40**, the image creation unit **44**, and the display unit **28** are performed as in the ultrasonic inspection apparatus **10** illustrated in FIG. **7**. Accordingly, description thereof will be omitted.

[0323] In the ultrasonic inspection apparatus **11** of Embodiment 4, the sound speed correction unit **76***b* performs sound speed correction on the element data before being subjected to element data processing to obtain an optimal sound speed, and the element data processing unit **22** calculates a delay time based on the obtained optimal sound speed and performs a superposition processing.

[0324] The sound speed correction unit **76***b* is provided between the element data storage unit **20** and the element data processing unit **22**, has the same configuration and function as the sound speed correction unit **76** illustrated in FIG. **9** or **10**A, and is intended to obtain an optimal sound speed of the reception side, that is, a sound speed optimal for the inspection target region of the subject, to be used to calculate the delay time in the delay time calculation unit **48** of the element data processing unit **22** of the subsequent stage and perform reception focus processing in the phasing addition unit **38** of the subsequent stage.

[0325] In the element data processing unit **22**, the delay time calculation unit **48** calculates the delay time of neighboring unprocessed element data relative to the element data of the element of interest using the optimal sound speed of the inspection target region of the subject set by the sound speed correction unit **76***b* and a geometric arrangement of the transmission element, the focal point, the reflection point, and the reception element, as described above.

[0326] Then, in the element data processing unit **22**, the superposition processing unit **50** phases and superimposes the element data of the element of interest and neighboring unprocessed element data to obtain the processed element data using the delay time calculated by the delay time calculation unit **48**, and supplies the processed element data to the phasing addition unit **38**.

[0327] Then, in the phasing addition unit **38**, a delay is given to the processed element data supplied from the element data processing unit **22** based on the optimal sound speed set by sound speed correction unit **76***b* to perform reception focus processing, and a sound ray signal is generated.

[0328] Then, in the detection processing unit **40**, the detection processing is performed on the sound ray signal generated by the phasing addition unit **38** to generate B-mode image data, and in the image creation unit **44**, an ultrasound image is created from the B-mode image data generated by the detection processing unit **40**. The ultrasound image is displayed on the display unit **28**.

[0329] Thus, in the ultrasonic inspection apparatus **11** of Embodiment 4 of the present invention, an ultrasound image is created using the processed element data in which the ghost signal is attenuated and the true signal is emphasized, which is processed in the element data processing unit **22** using the optimal sound speed set by the sound speed correction unit **76***b*. Accordingly, it is possible to obtain a sharp ultrasound image having a high SN ratio and an optimal spatial resolution with high resolution that does not depend on the width of the transmission beam, without using a dedicated ultrasound probe for generating a wide transmission ultrasonic beam and at a frame rate that is not different from the conventional frame rate.

[0330] The ultrasonic inspection apparatus of Embodiment 4 of the present invention is basically configured as described above.

Embodiment 5

[0331] Next, an ultrasonic inspection apparatus of Embodiment 5 of the present invention will be described based on FIGS. **14** to **17**.

[0332] Each of FIGS. **14** to **17** is a block diagram conceptually illustrating, along a process flow, an example of primary units of the ultrasonic inspection apparatus according to Embodiment 5 of the present invention.

[0333] Ultrasonic inspection apparatuses **90***a* to **90***d* illustrated in FIGS. **14** to **17** have exactly the same configuration as the ultrasonic inspection apparatus **10** illustrated in FIGS. **1** and **7** except that a sound speed correction unit **76***c* and determination units **72***a* and **72***b* are included. Accordingly, the same components are denoted with the same reference signs and detailed description thereof will be omitted.

[0334] First, the ultrasonic inspection apparatus **90***a* illustrated in FIG. **14** will be described. FIG. **14** illustrates, along a process flow, the primary units of the ultrasonic inspection apparatus **90***a*, as in FIG. **7**.

[0335] The ultrasonic inspection apparatus **90***a* includes the transmission unit **14**, the probe **36**, the reception unit **16**, the element data storage unit **20**, the element data processing unit **22**, a sound speed correction unit **76***c*, the phasing addition unit **38**, the detection processing unit **40**, the image creation unit **44**, the determination unit **72***a*, and the display unit **28**, as illustrated in FIG. **14**.

[0336] Here, the processing in the probe **36**, the transmission unit **14**, the reception unit **16**, and the element data storage unit **20**, and the first time processing in the element data processing unit **22**, the detection processing unit **40**, and the image creation unit **44** are performed as in the ultrasonic inspection apparatus **10** illustrated in FIGS. **1** and **7**. Accordingly, description thereof will be omitted.

[0337] The sound speed correction unit **76***c* is provided between the element data processing unit **22** and the phasing addition unit **38** of the image generation unit **24**, has the same configuration and function as the sound speed correction unit **76** illustrated in FIG. **9** or **10**A, and is intended to obtain an optimal sound speed of the reception side, that is, a sound speed optimal for the inspection target region of the subject, to be used to perform reception focus processing in the phasing addition unit **38** of the subsequent stage on the processed element data obtained by the element data processing unit **22** of the preceding stage. For example, the sound speed correction unit **76***c* may change the set sound speed v with an increment of 10 m/s from 1400 m/s to 1700 m/s and the determination unit **72***a* may perform a determination based on the image quality index such as the brightness value or the sharpness of the image or the degree of convergence of the sound speed to obtain the optimal sound speed. Needless to say, the sound speed correction unit **76***c* may determine an initial value of the sound speed set in advance, which is used to calculate the delay time in the delay time calculation unit **48** of the element data processing unit **22**, as an optimal sound speed as it is.

[0338] In first time processing, the element data processing unit **22** performs element data processing using an initial

value of the sound speed set in advance. That is, in the element data processing unit **22**, the delay time calculation unit **48** calculates the delay time using the initial value of the sound speed set in advance, the superposition processing unit **50** performs superposition processing on two or more pieces of unprocessed element data using the calculated delay time to obtain processed element data, and the sound speed correction unit **76***c* of the subsequent stage obtains the optimal sound speed of the reception side and sends the optimal sound speed to the phasing addition unit **38** of the subsequent stage together with the processed element data.

[0339] The phasing addition unit **38** performs reception focus processing in which a delay is given to the processed element data obtained by the element data processing unit **22** based on the optimal sound speed set by the sound speed correction unit **76***c* and addition is performed, and generates a sound ray signal.

[0340] Then, the detection processing unit **40** performs the detection processing on the generated sound ray signal to generate a B-mode image signal, and the image creation unit **44** performs the image processing on the generated B-mode image signal to create an ultrasound image.

[0341] The determination unit **72***a* has the same configuration and function as the determination unit **72***a* illustrated in FIG. **8**A or **9**, performs a determination based on the ultrasound image created by the image creation unit **44** using the created ultrasound image to determine "suitable" or OK, for example, when the image quality index such as the sharpness of the brightness value of the ultrasound image is higher than a predetermined value, and otherwise determine "unsuitable" or NG.

[0342] When the determination unit **72***a* determines OK, the ultrasound image created by the image creation unit **44** is sent to the display unit **28** and displayed on the display screen.

[0343] On the other hand, when the determination unit **72***a* determines NG, the process returns to the element data processing unit **22**. In second time and subsequent processing, the delay time calculation unit **48** of the element data processing unit **22** calculates the delay time using the optimal sound speed set by the sound speed correction unit **76***c* again. Thereafter, the superposition processing unit **50** performs the superposition processing on the two or more pieces of unprocessed element data using the delay time calculated using the optimal sound speed to obtain processed element data.

[0344] After the element data processing unit **22** obtains the processed element data in this way, the sound speed correction unit **76***c* newly sets a new optimal sound speed, the phasing addition unit **38** performs reception focus processing on the processed element data obtained by the element data processing unit **22** based on the new optimal sound speed newly set by the sound speed correction unit **76***c* to generate a sound ray signal (reception data), the detection processing unit **40** performs the detection processing as in the first process, the image creation unit **44** performs image processing to create an ultrasound image, and the determination unit **72***a* performs the determination.

[0345] As described above, in the second time and subsequent processing, the respective processing in the element data processing unit **22**, the sound speed correction unit **76***c*, the phasing addition unit **38**, the detection processing unit **40**, the image creation unit **44** and the determination unit **72***a* are repeated until the determination of the determination unit **72***a* is OK. After the determination of the determination unit **72***a* is OK, an ultrasound image is displayed on the display unit **28**.

[0346] Even when the setting of the new optimal sound speed in the sound speed correction unit **76***c* is all performed in a predetermined sound speed range, for example, even when the setting is performed at predetermined intervals in the predetermined entire sound speed range, if the determination of the determination unit **72***a* is not OK, for example, a sound speed value when a determination closest to a determination criteria is obtained may be adopted as the optimal sound speed.

[0347] Next, the ultrasonic inspection apparatus **90***b* illustrated in FIG. **15** will be described.

[0348] The ultrasonic inspection apparatus **90***b* illustrated in FIG. **15** has exactly the same configuration as the ultrasonic inspection apparatus **90***a* illustrated in FIG. **14** except that the determination unit **72***b* is provided between the phasing addition unit **38** and the detection processing unit **40**, whereas in the ultrasonic inspection apparatus **90***a* illustrated in FIG. **14**, the determination unit **72***a* is provided between the image creation unit **44** and the display unit **28**. Accordingly, the same components are denoted with the same reference signs and detailed description thereof will be omitted.

[0349] The ultrasonic inspection apparatus **90***b* includes the transmission unit **14**, the probe **36**, the reception unit **16**, the element data storage unit **20**, the element data processing unit **22**, the sound speed correction unit **76***c*, the phasing addition unit **38**, the determination unit **72***b*, the detection processing unit **40**, the image creation unit **44**, and the display unit **28**, as illustrated in FIG. **15**.

[0350] Here, since the processing in the probe **36**, the transmission unit **14**, the reception unit **16**, and the element data storage unit **20**, the processing in the detection processing unit **40**, the image creation unit **44**, and the display unit **28**, and the first time processing in the element data processing unit **22**, the sound speed correction unit **76***c*, and the phasing addition unit **38** are performed as in the ultrasonic inspection apparatus **90***a* illustrated in FIG. **14**, description thereof will be omitted.

[0351] After the element data processing unit **22** obtains the processed element data, the sound speed correction unit **76***c* obtains an optimal sound speed of the reception side, that is, a sound speed optimal for the inspection target region of the subject, to be used in the phasing addition unit **38**. For example, the sound speed correction unit **76***c* may change the set sound speed v with a predetermined sound speed increment in a predetermined sound speed range, and the determination unit **72***b* may obtain the optimal sound speed through a determination based on the image quality index such as the brightness value or the sharpness of the image or the degree of convergence of sound speed.

[0352] The phasing addition unit **38** performs reception focus processing in which a delay is given to the processed element data obtained by the element data processing unit **22** based on the optimal sound speed set by the sound speed correction unit **76***c* and addition is performed, and generates a sound ray signal (reception data).

[0353] The determination unit **72***b* has the same configuration and function as the determination unit **72***b* illustrated in FIG. **8**B or **12**, and performs a determination based on the image quality index such as the brightness value or the sharpness of the image, or the sharpness of the brightness value, or the degree of convergence of the sound speed using the sound

ray signal generated by the reception focus processing in the phasing addition unit **38**. The determination unit **72***b* determines OK when the image quality index such as the brightness value or the sharpness is highest, and determines NG when the image quality index such as the brightness value or the sharpness does not reach the highest value.

[0354] When the determination unit **72***b* determines OK, the process proceeds to the detection processing unit **40**, and the detection processing unit **40** performs an envelope detection processing or the like on the sound ray signal generated by the phasing addition unit **38** to thereby generate B-mode image data that is tomographic image information regarding the tissue of the subject. Therefore, an ultrasound image is created by the image creation unit **44** and displayed on the display unit **28**.

[0355] On the other hand, when the determination unit **72***b* determines NG, the process returns to the element data processing unit **22**, and the delay time calculation unit **48** of the element data processing unit **22** calculates the delay time again using the optimal sound speed set by the sound speed correction unit **76***c*. Thereafter, the superposition processing unit **50** performs the superposition processing on the two or more pieces of unprocessed element data using the delay time calculated using the optimal sound speed to obtain processed element data.

[0356] After the element data processing unit **22** obtains the processed element data in this way, the sound speed correction unit **76***c* newly sets an optimal sound speed, the phasing addition unit **38** performs the reception focus processing on the processed element data obtained by the element data processing unit **22** based on the new optimal sound speed newly set by the sound speed correction unit **76***c* to generate a sound ray signal (reception data), and the determination unit **72***b* performs the determination based on the image quality index such as the brightness value or the sharpness of the image, or the degree of convergence of sound speed using the sound ray signal generated by the phasing addition unit **38**.

[0357] If the determination of the determination unit **72***b* is OK, the generation of the B-mode image data in the detection processing unit **40**, the creation of the ultrasound image in the image creation unit **44**, and the displaying of the ultrasound image in the display unit **28** are performed.

[0358] In contrast, if the determination of the determination unit **72***b* is NG, the calculation of the delay time in the delay time calculation unit **48** of the element data processing unit **22** using the optimal sound speed set by the sound speed correction unit **76***c*, the generation of the processed element data in the superposition processing unit **50**, the new setting of the sound speed in the sound speed correction unit **76***c*, and the generation of the sound ray signal for the processed element data obtained by the element data processing unit **22** based on the optimal sound speed newly set by the sound speed correction unit **76***c* in the phasing addition unit **38** are repeated until the determination is OK, that is, until the optimal sound speed is set.

[0359] While the sound speed correction unit **76***c* is provided in the subsequent stage of the element data processing unit **22** in the ultrasonic inspection apparatuses **90***a* and **90***b* illustrated in FIGS. **14** and **15**, the present invention is not limited thereto, and the sound speed correction unit **76***c* may be provided in a preceding stage of the element data processing unit **22**.

[0360] FIGS. **16** and **17** are block diagrams illustrating primary units of the ultrasonic inspection apparatuses **90***c* and **90***d* along a process flow as in FIGS. **14** and **15**. The ultrasonic inspection apparatuses **90***c* and **90***d* include the same components as the ultrasonic inspection apparatuses **90***a* and **90***b* illustrated in FIGS. **14** and **15** except for the difference of the process flow.

[0361] The ultrasonic inspection apparatus **90***c* illustrated in FIG. **16** includes the probe **36**, the transmission unit **14**, the reception unit **16**, the element data storage unit **20**, the sound speed correction unit **76***c*, the phasing addition unit **38**, the element data processing unit **22**, the detection processing unit **40**, the image creation unit **44**, the determination unit **72***a*, and the display unit **28**.

[0362] The ultrasonic inspection apparatus **90***d* illustrated in FIG. **17** includes the probe **36**, the transmission unit **14**, the reception unit **16**, the element data storage unit **20**, the sound speed correction unit **76***c*, the phasing addition unit **38**, the determination unit **72***b*, the element data processing unit **22**, the detection processing unit **40**, the image creation unit **44**, and the display unit **28**.

[0363] Here, in the ultrasonic inspection apparatuses **90***c* and **90***d* illustrated in FIGS. **16** and **17**, the processing in the probe **36**, the transmission unit **14**, the reception unit **16**, and the element data storage unit **20** are performed as in the ultrasonic inspection apparatuses **90***a* and **90***b* illustrated in FIGS. **14** and **15**. Accordingly, description thereof will be omitted.

[0364] The sound speed correction unit **76***c* of the ultrasonic inspection apparatuses **90***c* and **90***d* illustrated in FIGS. **16** and **17** is different from the sound speed correction unit **76***c* of the ultrasonic inspection apparatuses **90***a* and **90***b* illustrated in FIGS. **14** and **15** in that the sound speed correction unit **76***c* is provided between the element data storage unit **20** and the phasing addition unit **38** in the first time processing. However, since the sound speed correction unit **76***c* is provided between the element data processing unit **22** and the phasing addition unit **38** in the second time and subsequent processing, the sound speed correction unit **76***c* of the ultrasonic inspection apparatuses **90***c* and **90***d* is exactly the same as the sound speed correction unit **76***c* of the ultrasonic inspection apparatus **90***a* and **90***b* illustrated in FIGS. **14** and **15**. They are also exactly the same as each other in that the optimal sound speed of the reception side to be used in the phasing addition unit **38**, that is, the sound speed optimal for the inspection target region of the subject is obtained. Accordingly, detailed description thereof will be omitted. In the first time processing, the optimal sound speed is initially set in the sound speed correction unit **76***c*, but naturally, the initial value of the sound speed set in advance may be set as the optimal sound speed as it is.

[0365] First, the ultrasonic inspection apparatus **90***c* illustrated in FIG. **16** will be described.

[0366] In the ultrasonic inspection apparatus **90***c* illustrated in FIG. **16**, the sound speed correction unit **76***c* sets the optimal sound speed of the reception side of the inspection target region of the subject for the unprocessed element data read from the element data storage unit **20**, in the first time processing. The phasing addition unit **38** performs reception focus processing in which a delay is given to the unprocessed element data based on the optimal sound speed set by the sound speed correction unit **76***c* and addition is performed, and generates a sound ray signal (reception data). Then, the detection processing unit **40** performs the detection processing on the generated sound ray signal to generate a B-mode

image signal, and the image creation unit **44** performs image processing on the generated B-mode image signal to create an ultrasound image.

[0367] The determination unit **72***a* performs a determination based on the ultrasound image created by the image creation unit **44** using the created ultrasound image and determines "suitable" or OK, for example, when the image quality index such as the sharpness of the brightness value of the ultrasound image is higher than a predetermined value, and otherwise determines "unsuitable" or NG.

[0368] When the determination unit **72***a* determines OK, the ultrasound image created by the image creation unit **44** is sent to the display unit **28** and displayed on the display screen.

[0369] On the other hand, when the determination unit **72***a* determines NG, second time and subsequent processing is performed, and the process returns to the element data processing unit **22**. The delay time calculation unit **48** of the element data processing unit **22** calculates the delay time again using the optimal sound speed set by the sound speed correction unit **76***c*, and the superposition processing unit **50** performs superposition processing on the two or more pieces of unprocessed element data using the delay time calculated using the optimal sound speed to obtain the processed element data.

[0370] In the second time and subsequent processing, after the element data processing unit **22** obtains the processed element data in this way, the sound speed correction unit **76***c* newly sets a new optimal sound speed, the phasing addition unit **38** performs reception focus processing on the processed element data obtained by the element data processing unit **22** based on the new optimal sound speed newly set by the sound speed correction unit **76***c* to generate a sound ray signal (reception data), the detection processing unit **40** performs the detection processing as in the first time processing, the image creation unit **44** performs image processing to create an ultrasound image, and the determination unit **72***a* performs the determination.

[0371] As described above, in the second time and subsequent processing, the respective processing in the element data processing unit **22**, the sound speed correction unit **76***c*, the phasing addition unit **38**, the detection processing unit **40**, the image creation unit **44** and the determination unit **72***a* are repeated until the determination unit **72***a* determines OK. After the determination unit **72***a* determines OK, the ultrasound image is displayed on the display unit **28**.

[0372] Even when the setting of the new optimal sound speed in the sound speed correction unit **76***c* is all performed in a predetermined sound speed range, for example, even when the setting is performed at predetermined intervals in the predetermined entire sound speed range, if the determination of the determination unit **72***a* is not OK, for example, a sound speed value when a determination closest to a determination criteria is obtained may be set as the optimal sound speed.

[0373] Next, the ultrasonic inspection apparatus **90***d* illustrated in FIG. **17** will be described.

[0374] In the ultrasonic inspection apparatus **90***d* illustrated in FIG. **17**, first, the sound speed correction unit **76***c* sets the optimal sound speed of the reception side of the inspection target region of the subject for the unprocessed element data read from the element data storage unit **20**, in the first time processing.

[0375] The phasing addition unit **38** performs reception focus processing of giving a delay based on the optimal sound speed set by the sound speed correction unit **76***c* and performing addition on the unprocessed element data read from the element data storage unit **20** in the first time processing, and on the processed element data obtained in the element data processing unit **22** in the second time and subsequent processing, to thereby generate a sound ray signal (reception data).

[0376] The determination unit **72***b* is provided between the phasing addition unit **38**, and the detection processing unit **40** and the element data processing unit **22**. In the first time processing, the determination unit **72***b* automatically determines NG. In the second time and subsequent processing, the determination unit **72***b* performs the determination based on the image quality index such as the brightness value or the sharpness of the image, or the degree of convergence of the sound speed using the sound ray signal (reception data) generated by the reception focus processing in the phasing addition unit **38**, as in the determination unit **72***b* of the ultrasonic inspection apparatus **90***b* illustrated in FIG. **15**. The determination unit **72***b* determines OK when the image quality index such as the brightness value or the sharpness is highest, and determines NG when the image quality index such as the brightness value or the sharpness does not reach the highest value.

[0377] When the determination unit **72***b* determines OK, the process proceeds to the detection processing unit **40** as in the ultrasonic inspection apparatus **90***b* illustrated in FIG. **15**. The detection processing unit **40** performs processing such as an envelope detection processing or the like on the sound ray signal generated by the phasing addition unit **38** to thereby generate B-mode image data that is tomographic image information regarding the tissue of the subject. Thereafter, the ultrasound image is created by the image creation unit **44** and displayed on the display unit **28**.

[0378] On the other hand, when the determination unit **72***b* determines NG, the second time and subsequent processing is performed. The process proceeds to the element data processing unit **22**. The delay time calculation unit **48** of the element data processing unit **22** calculates the delay time using the optimal sound speed set by the sound speed correction unit **76***c*. Thereafter, the superposition processing unit **50** performs the superposition processing on two or more pieces of unprocessed element data using the delay time calculated using the optimal sound speed to obtain processed element data.

[0379] After the processed element data is obtained in the element data processing unit **22** in this way, the process returns to the sound speed correction unit **76***c* and the optimal sound speed is newly set. The phasing addition unit **38** performs the reception focus processing on the processed element data obtained in the element data processing unit **22** based on the optimal sound speed newly set by the sound speed correction unit **76***c* to generate a sound ray signal (reception data), and the determination unit **72***b* performs the determination based on the image quality index such as the brightness value or the sharpness of the image or the degree of convergence of the sound speed using the sound ray signal generated by the phasing addition unit **38**.

[0380] In the second time and subsequent processing, if the determination of the determination unit **72***b* is OK, the generation of the B-mode image data in the detection processing unit **40**, the creation of the ultrasound image in the image creation unit **44**, and the displaying of the ultrasound image on the display unit **28** are performed.

[0381] In contrast, if the determination of the determination unit **72***b* is NG, the calculation of the delay time in the delay time calculation unit **48** of the element data processing unit **22** using the new optimal sound speed set by the sound speed correction unit **76***c*, the generation of the processed element data in the superposition processing unit **50**, the new setting of the optimal sound speed in the sound speed correction unit **76***c*, and the generation of the sound ray signal based on the optimal sound speed newly set by the sound speed correction unit **76***c* for the processed element data obtained by the element data processing unit **22** in the phasing addition unit **38** are repeated until the determination is OK, that is, until the optimal sound speed is set.

[0382] The present invention is not limited to the determination unit **72***a* or **72***b* being provided between the phasing addition unit **38** and the detection processing unit **40** in the ultrasonic inspection apparatuses **90***a* to **90***d*, and the determination unit **72***a* or **72***b* may be provided between the detection processing unit **40** and the image creation unit **44**. Further, the present invention is not limited to the sound speed correction unit **76***c* being provided between the element data processing unit **22** or the element data storage unit **20** and the phasing addition unit **38**, and the sound speed correction unit **76***c* may be provided between (an NG side of) the determination unit **72***a* or **72***b* and the element data processing unit **22**.

[0383] Thus, in the ultrasonic inspection apparatuses **90***a* to **90***d* of Embodiment 5 of the present invention, since the delay time calculation unit of the element data processing unit **22** calculates the delay time using the optimized optimal sound speed, it is possible to create an ultrasound image using the processed element data in which the ghost signal is most appropriately attenuated and the true signal is most appropriately emphasized, and to obtain a sharp ultrasound image having a high SN ratio and an optimal spatial resolution with high resolution that does not depend on the width of the transmission beam, without using a dedicated ultrasound probe for generating a wide transmission ultrasonic beam and at a frame rate that is not different from the conventional frame rate.

[0384] The ultrasonic inspection apparatus of Embodiment 5 of the present invention is basically configured as described above.

Embodiment 6

[0385] Next, an ultrasonic inspection apparatus of Embodiment 6 of the present invention will be described based on FIG. **18**.

[0386] FIG. **18** is a block diagram conceptually illustrating, along a process flow, an example of primary units of the ultrasonic inspection apparatus of Embodiment 6 of the present invention.

[0387] The ultrasonic inspection apparatus **92** illustrated in FIG. **18** has exactly the same configuration as the ultrasonic inspection apparatus **10** illustrated in FIG. **7** which includes the phasing addition unit **38**, the detection processing unit **40**, and the image creation unit **44**, except that phasing addition units **38***b* and **38***c*, detection processing units **40***b* and **40***c*, first and second image creation units **44***b* and **44***c*, a third image creation unit **94**, and an image quality determination unit **96**. Accordingly, the same components are denoted with the same reference signs and detailed description thereof will be omitted.

[0388] The ultrasonic inspection apparatus **92** includes the transmission unit **14**, the probe **36**, the reception unit **16**, the element data storage unit **20**, the element data processing unit **22**, the phasing addition units **38***b* and **38***c*, the detection processing units **40***b* and **40***c*, the first image creation unit **44***b*, the second image creation unit **44***c*, the third image creation unit **94**, the image quality determination unit **96**, and the display unit **28**, as illustrated in FIG. **18**.

[0389] Here, since the phasing addition unit **38***c*, the detection processing unit **40***c*, and the second image creation unit **44***c* respectively have exactly the same configuration as the phasing addition unit **38**, the detection processing unit **40**, and the image creation unit **44** illustrated in FIG. **7**, detailed description thereof will be omitted.

[0390] In contrast, the phasing addition unit **38***b*, the detection processing unit **40***b* and the first image creation unit **44***b* are different from the phasing addition unit **38***c*, the detection processing unit **40***c* and the second image creation unit **44***c* in which the processed element data is a processing target in that their processing target is not the processed element data processed in the element data processing unit **22**, but the unprocessed element data stored and held in the element data storage unit **20**, and they perform the conventional processing thereon. However, they are exactly the same in processing function.

[0391] In such ultrasonic inspection apparatus **92**, in the superposition processing in the element data processing unit **22**, if the unprocessed element data is a right-left symmetric point-like reflection, the element data processing is performed to remove a ghost component, thereby generating processed element data. Then, through the processing in the phasing addition unit **38***c*, the detection processing unit **40***c* and the second image creation unit **44***c*, a sharp ultrasound image of the present invention having a high SN ratio and an optimal spatial resolution with high resolution that does not depend on the width of the transmission beam is generated using the processed element data in which the ghost signal is attenuated and the true signal is emphasized.

[0392] In contrast, in the superposition processing in the element data processing unit **22**, if the unprocessed element data is right-left asymmetrical, the unprocessed element data is regarded as a speckle. In this case, if the element data processing of the element data processing unit **22** is not desired to be performed, a conventional ultrasound image is generated through the processing in the phasing addition unit **38***b*, the detection processing unit **40***b* and the first image creation unit **44***b* using the unprocessed element data stored and held in the element data storage unit **20**, which has not been subjected to the element data processing.

[0393] Then, the image quality determination unit **96** compares image quality of a first ultrasound image created by the first image creation unit **44***b* that performs the conventional image processing on the unprocessed element data with image quality of a second ultrasound image created by the second image creation unit **44***c* from the processed element data obtained by the element data processing in the element data processing unit **22** of the present invention, based on the symmetry of the unprocessed element data, and performs a determination as to whether the first ultrasound image or the second ultrasound image is to be adopted based on a result of the comparison. Specifically, in the image quality comparison, the image quality determination unit **96** compares the image qualities using any one of a brightness value, contrast and graininess of the image or a combination of two or more

of them. For example, when the brightness values are compared, it is determined that an image having a higher brightness is adopted.

[0394] Then, the third image creation unit **94** creates an ultrasound image for being displayed on the display unit **28** from the first ultrasound image and the second ultrasound image based on a result of the image quality determination performed by the image quality determination unit **96**.

[0395] Specifically, the third image creation unit **94** selects any one of the first ultrasound image and the second ultrasound image as the ultrasound image to be displayed on the display unit **28**, based on the image quality determination result of the image quality determination unit **96**. For example, when the image quality determination unit **96** compares the brightness values of the first ultrasound image and the second ultrasound image, an image having a higher brightness value is adopted.

[0396] Alternatively, a region division unit that divides the first ultrasound image and the second ultrasound image into predetermined regions may be further provided, the image quality determination unit **96** may determine the image quality for each divided region at the time of the image quality comparison, and the third image creation unit **94** may select any one of the first ultrasound image and the second ultrasound image for each region based on the image quality determination result, and combine the images selected in the respective regions to generate an ultrasound image for being displayed on the display unit **28**.

[0397] In the superposition processing in the element data processing unit **22**, when an average value is used, a brightness value is likely to be lower in comparison with a case in which the element data processing is not performed. In this case, a high brightness image can be obtained by adopting the first ultrasound image generated in the conventional processing. Therefore, the third image creation unit **94** may compare the first ultrasound image created by the first image creation unit with the second ultrasound image created by the second image creation unit, and may adopt the first ultrasound image if the first ultrasound image created by the first image creation unit has a higher brightness in a distribution of high brightness reflection points. Alternatively, the third image creation unit **94**, for example, may take an average value of the brightness values of the first ultrasound image and the second ultrasound image for each pixel for a region of which the image quality determination results are the same to generate the ultrasound image. Alternatively, a weighted average value may be taken depending on the image quality determination result.

[0398] It is needless to say that the ultrasonic inspection apparatuses of Embodiments 2 to 5 described above may be applied to this Embodiment 6.

[0399] Thus, in the ultrasonic inspection apparatus of Embodiment 6 of the present invention, it is possible to constantly generate an ultrasound image having high brightness.

[0400] In Embodiments 1 to 6 described above, the configuration in which the multiline processing is performed using first element data acquired through transmission and reception of ultrasonic waves to generate second element data, and an ultrasound image is generated using the second element data is adopted. However, the present invention is not limited thereto, and a configuration in which a first mode of generating an ultrasound image by use of the first element data and a second mode of generating an ultrasound image by use of the second element data are switchable may be adopted.

Embodiment 7

[0401] Next, an ultrasonic inspection apparatus of Embodiment 7 of the present invention will be described based on FIGS. **19** and **20**.

[0402] FIG. **19** is a block diagram conceptually illustrating an example of the configuration of the ultrasonic inspection apparatus of Embodiment 7 of the present invention, and FIG. **20** is a flowchart illustrating an operation of the ultrasonic inspection apparatus **100** illustrated in FIG. **19**.

[0403] The ultrasonic inspection apparatus **100** illustrated in FIG. **19** has exactly the same configuration as the ultrasonic inspection apparatus **10** illustrated in FIG. **1** except that a transmission unit **14***a* is included instead of the transmission unit **14**, and a mode switching unit **102** is included. Accordingly, the same components are denoted with the same reference signs and detailed description thereof will be omitted.

[0404] The ultrasonic inspection apparatus **100** illustrated in FIG. **19** has a configuration in which a first mode (normal mode) in which an ultrasound image is generated using first element data and a second mode (multiline processing mode) in which an ultrasound image is generated using second element data are switchable, and in the ultrasonic inspection apparatus **100**, an F value when the ultrasonic beam is transmitted, that is, a ratio of depth of focus and numerical aperture is switched in response to switching of the mode.

[0405] The ultrasonic inspection apparatus **100** includes the ultrasound probe **12**, the transmission unit **14**, the reception unit **16**, the A/D conversion unit **18**, the element data storage unit **20**, the element data processing unit **22**, the image generation unit **24**, the display control unit **26**, the display unit **28**, the control unit **30**, the operation unit **32**, the storage unit **34**, and the mode switching unit **102**, as illustrated in FIG. **19**.

[0406] The mode switching unit **102** is a unit that switches the first mode (normal mode) in which the ultrasound image is generated in the image generation unit **24** using unprocessed element data (the first element data) that is not subjected to multiline processing and the second mode (multiline processing mode) in which the ultrasound image is generated using processed element data (the second element data) subjected to multiline processing by the element data processing unit **22**, based on an instruction input from the operation unit **32** or an instruction from the control unit **30**.

[0407] The mode switching unit **102** supplies mode information on the selected mode to the image generation unit **24** and the transmission unit **14***a*.

[0408] The transmission unit **14***a* has basically the same configuration as the transmission unit **14** of the ultrasonic inspection apparatus **10** of Embodiment 1 illustrated in FIG. **1** except that the F value of the ultrasonic beam to be transmitted is switched according to the selected mode based on the mode information supplied from the mode switching unit **102** and the ultrasonic beam is transmitted.

[0409] Specifically, when the multiline processing mode is selected, the transmission unit **14***a* causes the probe **36** to perform transmission of an ultrasonic beam of which the F value is smaller than the F value in the normal mode.

[0410] A schematic diagram illustrating an example of the F value in the normal mode is illustrated in FIG. **21**A, and a schematic diagram illustrating an example of the F value in the multiline processing mode is illustrated in FIG. **21**B.

[0411] In the normal mode, the transmission unit **14***a* transmits a transmission beam (ultrasonic beam) **56** that forms a predetermined focal point **58** using five elements **52***c* to **52***g*, including the element **52***e* that is a central element, as transmission elements, as illustrated in FIG. **21**A.

[0412] On the other hand, in the multiline processing mode, the transmission unit **14***a* transmits the transmission beam **56** forming a predetermined focal point **58** using nine elements **52***a* to **52***i*, including the element **52***e* that is a central element, as transmission elements, as illustrated in FIG. **21**B. In this case, the depth of the focal point **58** is set to the same depth as in the normal mode. Thus, in the multiline processing mode, the F value, that is, "depth of focus/numerical aperture" is smaller than the F value in the normal mode.

[0413] When the F value is great, the transmission beam **64** cannot be sufficiently narrowed down as illustrated in FIG. **21**A, and thus, the waveform of the transmission beam **64** becomes similar to a plane wave. In contrast, when the F value is small, the transmission beam **64** can be narrowed down, as illustrated in FIG. **21**B. When the transmission beam **64** is narrowed down, the focal point **58** approaches one point, and thus, a state similar to the geometrical model (see FIG. **5**) for calculating the delay time in the delay time calculation unit **48** of the element data processing unit **22** can be formed.

[0414] That is, the geometrical model used when the delay time is calculated in the delay time calculation unit **48** regards the focal point as one virtual sound source. Therefore, by decreasing the F value and narrowing down the focal point, a state more similar to the model can be formed, and thus, precision of the superposition processing of the element data in the multiline processing can be improved and an image of higher quality can be obtained, compared with the case in which the F value is not switched.

[0415] As illustrated in the flow chart of FIG. **20**, in the ultrasound diagnostic apparatus **100** of Embodiment 7, when the mode is switched to the multiline processing mode by the mode switching unit **102**, the transmission unit **14***a* sets a small F value and performs transmission and reception of ultrasonic wave. The element data processing unit **22** performs the multiline processing using the first element data obtained through transmission and reception with the small F value to generate the second element data. The image generation unit **24** generates an ultrasound image using the second element data, and the display control unit **26** displays the ultrasound image on the display unit **28**.

[0416] On the other hand, when the mode is switched to the normal mode by the mode switching unit **102**, the transmission unit **14***a* sets a great F value, performs transmission and reception of ultrasonic wave, and acquires the first element data. The image generation unit **24** generates an ultrasound image using the first element data, and the display control unit **26** displays the ultrasound image on the display unit **28**.

[0417] In each mode, it is preferable to set the position of the transmission focal point and the numerical aperture so that the F value is constant regardless of the depth of the focal point position of the ultrasonic beam. That is, it is preferable to set the focal point position and the numerical aperture so that a spread θ of the ultrasonic beam **64** is constant even when plural ultrasonic beams **64** forming different focal points **58** in a depth direction are transmitted, as illustrated in FIGS. **22**A and **22**B.

[0418] Needless to say, the ultrasonic inspection apparatuses of Embodiments 2 to 6 described above may be applied to this Embodiment 7.

[0419] While the configuration in which the multiline processing in the element data processing unit **22** is performed using the first element data is adopted in Embodiments 1 to 7 described above, the present invention is not limited thereto, and a configuration in which the multiline processing is performed using first reception data obtained by performing phasing addition on the first element data may be adopted.

Embodiment 8

[0420] Next, an ultrasonic inspection apparatus of Embodiment 8 of the present invention will be described based on FIG. **23**.

[0421] FIG. **23** is a block diagram conceptually illustrating an example of the configuration of the ultrasonic inspection apparatus of Embodiment 8 of the present invention.

[0422] The ultrasonic inspection apparatus **110** illustrated in FIG. **23** has exactly the same configuration as the ultrasonic inspection apparatus **10** illustrated in FIG. **1** except that a data processing unit **114** is included instead of the element data processing unit **22**, and an image generation unit **116** is included instead of the image generation unit **24**. Accordingly, the same components are denoted with the same reference signs and detailed description thereof will be omitted.

[0423] The ultrasonic inspection apparatus **110** illustrated in FIG. **23** includes the ultrasound probe **12**, the transmission unit **14** and the reception unit **16** that are connected to the ultrasound probe **12**, the A/D conversion unit **18**, the element data storage unit **20**, the data processing unit **114**, the image generation unit **116**, the display control unit **26**, the display unit **28**, the control unit **30**, the operation unit **32**, and the storage unit **34**.

[0424] FIG. **24** is a block diagram conceptually illustrating the configuration of the data processing unit **114**.

[0425] The data processing unit **114** includes a phasing addition unit **118**, a delay time calculation unit **48**, and a superposition processing unit **120**.

[0426] The phasing addition unit **118** performs phasing addition on the first element data read from the element data storage unit **20** to perform reception focus processing and generates first reception data.

[0427] Here, the phasing addition unit **118** respectively performs phasing addition on a plurality of pieces of element data to be superimposed in the superposition processing unit **120** to be described below, on the basis of the same element (line).

[0428] The superposition processing unit **120** causes the phasing addition unit **118** to read the element data from the element data storage unit **20** based on information on data processing such as a number of pieces of data to be superimposed and a superposition processing method, and acquires the first reception data generated by the phasing addition unit **118**.

[0429] Further, the superposition processing unit **120** superimposes two or more pieces of first reception data while matching time on the reception time based on the delay time corresponding to each piece of reception data calculated by the delay time calculation unit **48** to generate processed (second) reception data.

[0430] The phasing addition unit **118** and the superposition processing unit **120** will be described in detail using FIGS. **25** and **26**.

[0431] FIG. **25** conceptually illustrates element data, and a vibrator array **36** in a position corresponding thereto.

[0432] The element data illustrated in FIG. **25** is (first) element data obtained by performing transmission and reception of ultrasonic wave using an n-th element as a central element. This element data is referred to n-th element data.

[0433] In the following description, for example, reception data generated by performing phasing addition on the n-th element data on the basis of an (n−2)-th line is referred to as the (n(n−2))-th reception data. That is, the reception data obtained by performing phasing addition on the n-th element data on the basis of an i-th line is referred to as n(i)-th reception data.

[0434] FIGS. **26**A to **26**C are diagrams illustrating the phasing addition in the phasing addition unit **118** and the superposition processing in the superposition processing unit **120**.

[0435] FIG. **26**A illustrates (n−2)-th element data, (n−1)-th element data, and n-th element data.

[0436] As an example, a case of generating the processed reception data corresponding to the n-th reception data using the (n−2)-th, (n−1)-th, and n-th reception data is considered.

[0437] When processed reception data corresponding to the n-th reception data is generated, the phasing addition unit **118** performs phasing addition of each piece of element data on the basis of the n-th element. That is, in FIG. **26**A, the phasing addition of each piece of element data is performed on the basis of a line indicated by a solid line. The first reception data ((n−2(n))-th reception data, (n−1(n))-th reception data, and n(n)-th reception data) illustrated in FIG. **26**B is generated through the phasing addition.

[0438] Then, the superposition processing unit **120** superimposes the pieces of first reception data generated by the phasing addition unit **118** while matching time based on the delay time corresponding to each piece of received data calculated by the delay time calculation unit **48** to generate processed received data corresponding to the n-th reception data as illustrated in FIG. **26**C.

[0439] The data processing unit **114** supplies the processed reception data to the image generation unit **116**.

[0440] The image generation unit **116** includes a detection processing unit **40**, a DSC **42**, an image creation unit **44**, and an image memory **46**.

[0441] In the image generation unit **116**, the detection processing unit **40** generates B-mode image data by performing attenuation correction and envelope detection processing on the reception data. Further, the DSC **42** raster-converts the B-mode image data into image data corresponding to a scanning system of a normal television signal, and the image creation unit **44** performs a predetermined image processing such as gradation processing.

[0442] The image creation unit **44** stores the generated B-mode image data in the image memory **46** and/or sends the generated B-mode image data to the display control unit **26** to display the B-mode image of the subject on the display unit **28**.

[0443] While the ultrasound diagnostic apparatus **110** illustrated in FIG. **23** has a configuration in which the phasing addition is performed on the first element data received while shifting the central axis to generate the first reception data, and then, the multiline processing is performed on the first reception data to generate the second reception data, the prevent invention is not limited thereto. A configuration in which after only horizontal shifting (see FIG. **6**) is performed on each of the pieces of first element data directly before the second reception data is generated, phasing addition is performed to generate the first reception data, and multiline processing is performed on the first reception data to generate the second reception data may be adopted.

[0444] Needless to say, the ultrasonic inspection apparatus of Embodiments 2 to 7 described above may be applied to this Embodiment 8.

[0445] While the present invention has been described above in detail, naturally, the present invention is not limited to the above-described embodiments and may be improved or modified in various ways within the scope that does depart from the gist of the present invention.

[0446] For example, the respective components illustrated in FIGS. **1**, **7**, **8**A, **8**B, **9**, **11** to **19**, and **23** may be configured as hardware or may be configured as software executed by a computer or the like.

[0447] Further, the primary units of the ultrasonic inspection apparatus are shown as various processing blocks in the process flow in the embodiments illustrated in FIGS. **7**, **8**A, **8**B, **9**, and **12** to **18**, and the optimal sound speed calculation unit of the sound speed correction unit of the ultrasonic inspection apparatus is shown as various processing blocks in the process flow in the example illustrated in FIG. **11**. Accordingly, the phasing addition unit **38** is denoted with different reference signs **38**, **38***a*, **38***b*, **38***c*, and **38***d*, the detection processing unit **40** is denoted with different reference signs **40**, **40***a*, **40***b*, **40***c*, and **40***d*, and the image creation unit **44** is denoted with different reference signs **44**, **44***a*, **44***b*, **44***c*, and **44***d*. However, the respective phasing addition units **38**, **38***a*, **38***b*, **38***c*, and **38***d*, the respective detection processing units **40**, **40***a*, **40***b*, **40***c*, and **40***d*, and the respective image creation units **44**, **44***a*, **44***b*, **44***c*, and **44***d* may be different hardware or software, or may be the same hardware or software used in different sequences.

What is claimed is:

1. An ultrasonic inspection apparatus that inspects an inspection target using an ultrasonic beam, the ultrasonic inspection apparatus comprising:

a probe that has a plurality of elements being arranged in the probe, and uses the plurality of elements to transmit the ultrasonic beam, receive an ultrasonic echo reflected by the inspection target, and output an analog element signal according to the received ultrasonic echo;

a transmission unit configured to perform, a plurality of times, to cause the probe to transmit the ultrasonic beam so as to form a predetermined transmission focal point using the plurality of elements;

a reception unit configured to receive analog element signals output by the plurality of elements corresponding to the transmission of individual ultrasonic beams and perform predetermined processing;

an A/D conversion unit configured to perform A/D conversion on the analog element signal processed by the reception unit to obtain first element data that is a digital element signal; and

a data processing unit configured to generate second element data corresponding to any one of the pieces of first element data from a plurality of the pieces of first element data,

wherein the data processing unit changes conditions of acquisition of two or more of the pieces of first element data for generating the second element data depending on a depth of a position in which the second element data is obtained.

2. The ultrasonic inspection apparatus according to claim 1, wherein the transmission unit performs at least one of changing of a central element and changing of a transmission direction of the ultrasonic beam and causes the probe to perform a plurality of transmissions of the ultrasonic beam.

3. The ultrasonic inspection apparatus according to claim 2, wherein the data processing unit generates the second element data using at least one of the plurality of pieces of first element data obtained through transmissions of the ultrasonic beam in which central elements are different from each other and the plurality of pieces of first element data obtained through transmissions of the ultrasonic beams in which transmission directions differ from each other.

4. The ultrasonic inspection apparatus according to claim 1, wherein the data processing unit generates the second element data from the plurality of pieces of first element data obtained through transmissions of the ultrasonic beam in which transmission areas overlap.

5. The ultrasonic inspection apparatus according to claim 1, wherein the data processing unit superimposes the plurality of pieces of first element data based on a reception time at which the element receives the ultrasonic echo and a position of the element to generate the second element data.

6. The ultrasonic inspection apparatus according to claim 1, wherein the data processing unit includes:

a delay time calculation unit configured to calculate a delay time of two or more pieces of the first element data, and a superposition processing unit configured to superimpose the two or more pieces of first element data based on the calculated delay time and a reception position of the element of the probe to generate the second element data.

7. The ultrasonic inspection apparatus according to claim 6,

wherein the delay time calculation unit calculates the delay time of the two or more pieces of first element data based on at least one piece of information acquired in advance regarding the probe, a sound speed of the inspection target, a focal point position of the ultrasonic beam, a transmission aperture of the probe set by the transmission unit, and a reception aperture of the probe set by the reception unit, and

the superposition processing unit superimposes the two or more pieces of first element data based on the number of pieces of first element data to be superimposed among the two or more pieces of first element data and a superposition processing method, that are set in advance, to generate at least one piece of second element data.

8. The ultrasonic inspection apparatus according to claim 6, wherein the data processing unit generates the second element data from element data of only a superimposed portion when the two or more pieces of first element data are superimposed by the superposition processing unit.

9. The ultrasonic inspection apparatus according to claim 1, wherein the data processing unit superimposes the two or more pieces of first element data after multiplying each of the pieces of first element data by a weighting coefficient.

10. The ultrasonic inspection apparatus according to claim 1, wherein the data processing unit changes the number of pieces of the first element data to be selected depending on the depth of the position in which the second element data is obtained.

11. The ultrasonic inspection apparatus according to claim 1, wherein the data processing unit adaptively superimposes the two or more pieces of first element data based on at least two or more different points on a time axis on a reception time of each piece of element data.

12. The ultrasonic inspection apparatus according to claim 11, wherein the different point on the time axis is based on each transmission aperture of the probe by the transmission unit.

13. The ultrasonic inspection apparatus according to claim 11, wherein the different point on the time axis is based on each transmission aperture when transmission is performed in at least two or more transmission apertures for each of the two or more pieces of first element data.

14. The ultrasonic inspection apparatus according to claim 11, wherein the different point on the time axis is based on the sound speed of the inspection target.

15. The ultrasonic inspection apparatus according to claim 11,

wherein when the transmission unit transmits the ultrasonic beams forming a transmission focal point of a different depth on the same transmission line for each transmission line, the reception unit acquires the plurality of pieces of first element data corresponding to the same transmission line, and

the data processing unit generates the second element data from the plurality of pieces of first element data obtained through transmission and reception of the ultrasonic beam of the transmission focal point of the same depth for each depth of the transmission focal point.

16. The ultrasonic inspection apparatus according to claim 10, wherein the data processing unit changes the number of pieces of the first element data to be selected depending on the depth of the position in which the corresponding second element data is obtained based on a spatial spread of the ultrasonic beam within the inspection target.

17. The ultrasonic inspection apparatus according to claim 10, wherein the data processing unit changes the number of pieces of the first element data to be selected depending on the depth of the position in which the corresponding second element data is obtained based on a signal in a spatial position within the inspection target.

18. The ultrasonic inspection apparatus according to claim 10, wherein the data processing unit changes the number of pieces of the first element data to be selected depending on the depth of the position in which corresponding second element data is obtained based on a result of waveform analysis of the first element data.

19. The ultrasonic inspection apparatus according to claim 18, wherein the waveform analysis includes analyzing relevance or a coherence characteristic of a waveform regarding a candidate of the first element data to be selected.

20. The ultrasonic inspection apparatus according to claim 10, wherein the data processing unit obtains the optimal number of pieces of element data based on a signal in the plurality of pieces of second element data created by changing the number of pieces of the first element data to be selected.

21. The ultrasonic inspection apparatus according to claim 1,

wherein the transmission unit determines a transmission focal point depth depending on the depth of the position in which the second element data is obtained, and causes the probe to perform transmission of the ultrasonic beam a plurality of times at the determined transmission focal point depth to acquire the plurality of pieces of first element data, and

the data processing unit selects two or more pieces of the first element data for generating the second element data from among the plurality of pieces of first element data obtained through the transmission of the ultrasonic beam of the determined transmission focal point depth.

22. The ultrasonic inspection apparatus according to claim **1**,

wherein the transmission unit determines a transmission numerical aperture depending on the depth of the position in which the second element data is obtained, and causes the probe to perform the transmission of the ultrasonic beam using the determined transmission numerical aperture a plurality of times to acquire the plurality of pieces of first element data, and

the data processing unit selects two or more pieces of the first element data for generating the second element data from among the plurality of pieces of first element data obtained through the transmission of the ultrasonic beam using the determined transmission numerical aperture.

23. The ultrasonic inspection apparatus according to claim **1**, wherein the transmission unit causes the probe to perform steering transmission.

24. The ultrasonic inspection apparatus according to claim **1**, wherein the element data include phase information and amplitude information.

25. The ultrasonic inspection apparatus according to claim **1**, further comprising:

an element data storage unit configured to store at least one of the first element data and the second element data.

26. The ultrasonic inspection apparatus according to claim **1**, wherein the data processing unit performs phasing addition of each of the plurality of pieces of first element data to generate a plurality of pieces of first reception data directly before generating the second element data from the plurality of pieces of first element data, and generates second reception data corresponding to any one of the pieces of first reception data from the plurality of pieces of first reception data.

27. An ultrasonic inspection apparatus that inspects an inspection target using an ultrasonic beam, the ultrasonic inspection apparatus comprising:

a probe that has a plurality of elements being arranged in the probe, and uses the plurality of elements to transmit the ultrasonic beam, receive an ultrasonic echo reflected by the inspection target, and output an analog element signal according to the received ultrasonic echo;

a transmission unit configured to perform, a plurality of times, to cause the probe to transmit the ultrasonic beam so as to form a predetermined transmission focal point using the plurality of elements;

a reception unit configured to receive analog element signals output by the plurality of elements corresponding to transmission of the individual ultrasonic beams and perform a predetermined processing;

an A/D conversion unit configured to perform A/D conversion on the analog element signal processed by the reception unit to obtain first element data that is a digital element signal;

a phasing addition unit configured to perform phasing addition on the plurality of pieces of first element data around a line corresponding to the same element to generate a plurality of pieces of first reception data; and

a data processing unit configured to generate second reception data corresponding to any one of the pieces of first reception data from a plurality of the pieces of first reception data,

wherein the data processing unit changes conditions of acquisition of two or more of the pieces of first reception data for generating the second reception data depending on a depth of a position in which the second reception data is obtained.

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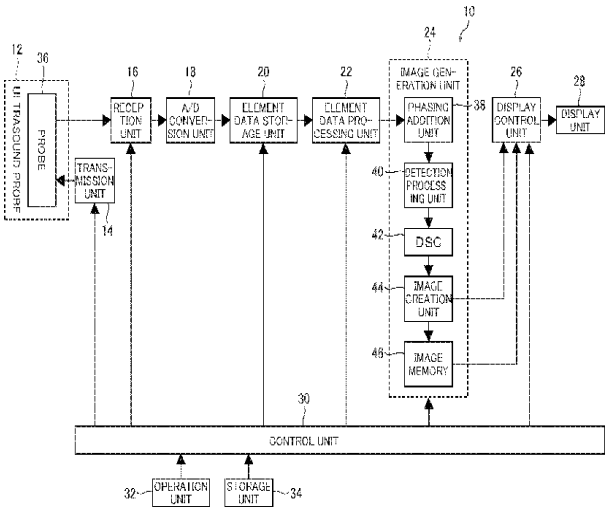
一种超声波检查装置，包括：探针;传输单元，被配置为使探测器发射超声波束;接收单元，被配置为接收探针输出的模拟元件信号; A / D转换单元，被配置为对模拟元件信号执行A / D转换以获得第一元件数据;数据处理单元，被配置为从多个第一元素数据生成第二元素数据，其中数据处理单元改变获取两个或更多个第一元素数据的条件，用于根据第一元素数据生成第二元素数据。获得第二元素数据的位置的深度。