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(54) **ULTRASONIC DIAGNOSTIC APPARATUS AND METHOD OF MEASURING VELOCITY WITH ULTRASONIC WAVES**

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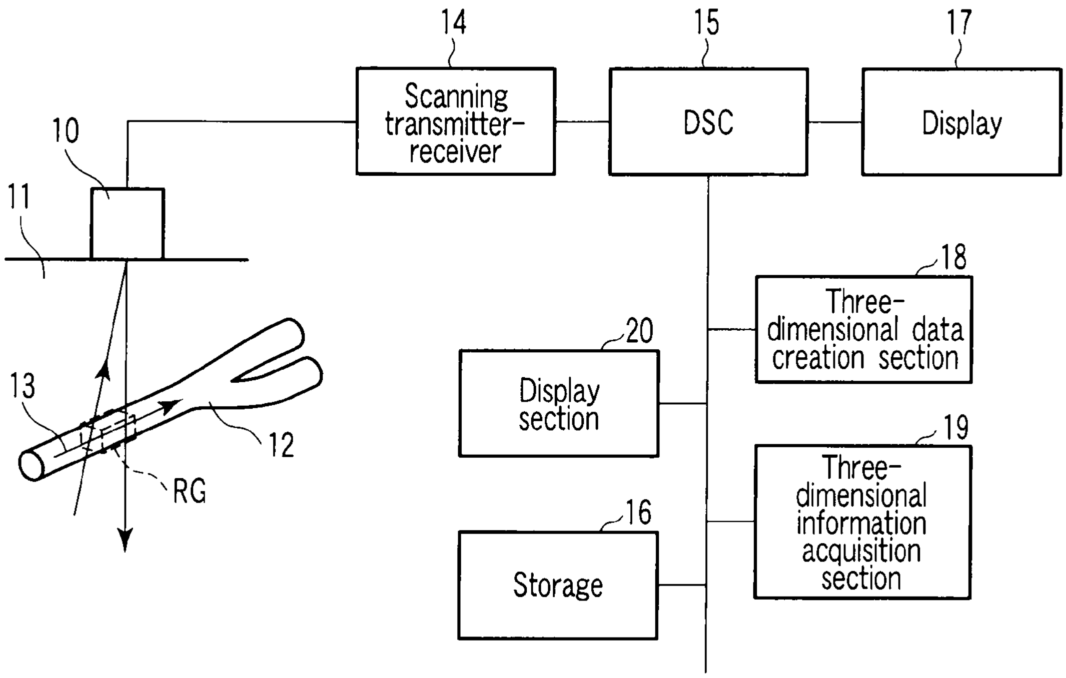
(52) **U.S. Cl.** **600/455**

(57) **ABSTRACT**

A multiple ultrasonic beam is transmitted from an ultrasonic probe, and a velocity of blood flow, azimuth and elevation angle of a sample such as a blood flow are acquired by a three-dimensional information acquisition section, as three-dimensional fluid information in a range gate, based on a Doppler signal output from the ultrasonic probe.



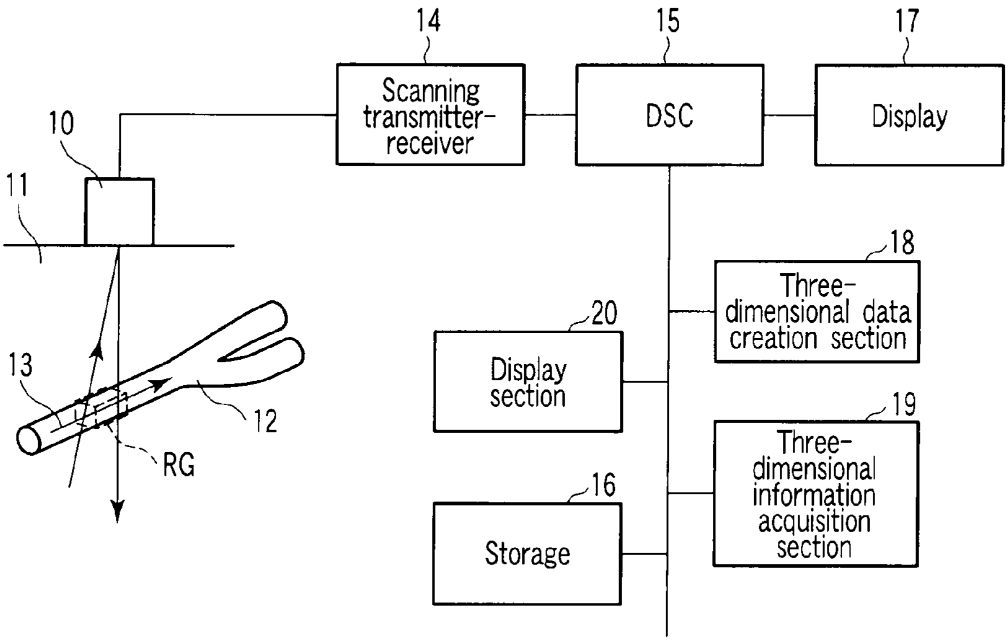

14
15
17
10
11
Scanning transmitter-receiver
DSC
Display
18
Three-dimensional data creation section
20
Display section
13
12
RG
19
Three-dimensional information acquisition section
16
Storage

FIG. 1

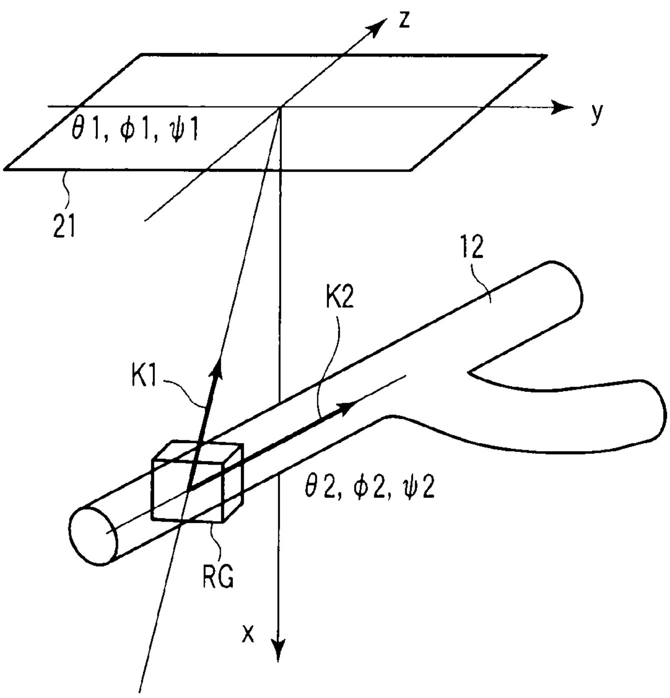
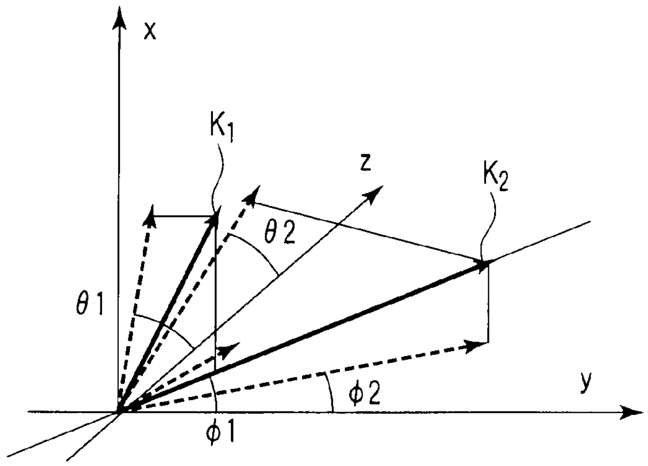
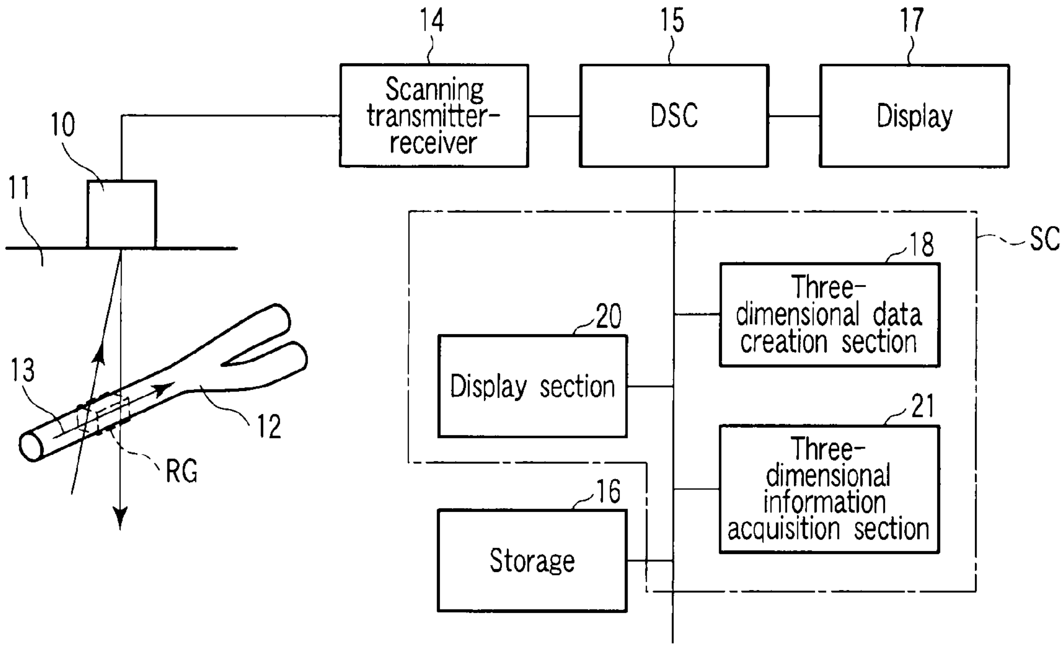

z
y
θ1, ϕ1, ψ1
21
12
K2
K1
θ2, ϕ2, ψ2
RG
x

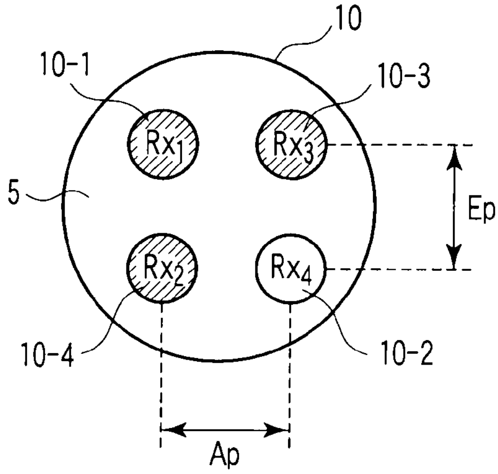
FIG. 2


x
K1
z
K2
θ2
θ1
y
φ2
φ1

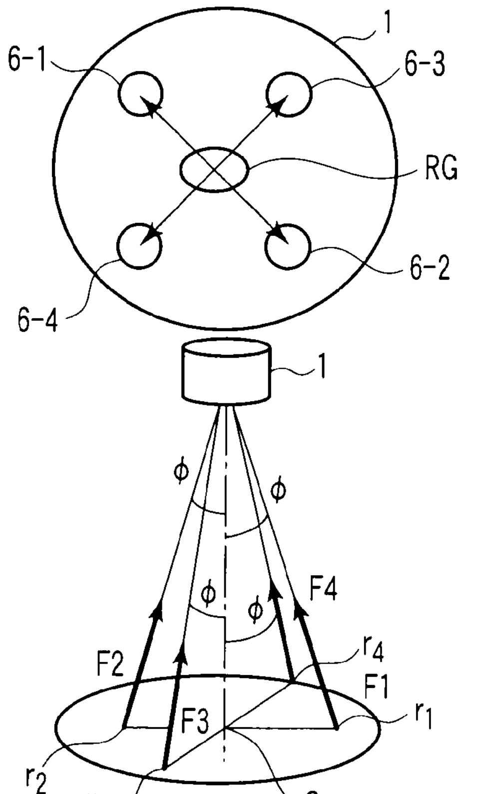
F I G. 3


14
15
17
Scanning transmitter-receiver
DSC
Display
10
11
SC
18
Three-dimensional data creation section
20
Display section
13
12
RG
21
Three-dimensional information acquisition section
16
Storage

F I G. 4


10
10-1
10-3
Rx1
Rx3
5
Ep
Rx2
Rx4
10-4
10-2
Ap

F I G. 5


1
6-1
6-3
RG
6-4
6-2
1
ϕ
ϕ
ϕ
ϕ
F4
F2
r4
F1
F3
r1
r2
r3
G

F I G. 6

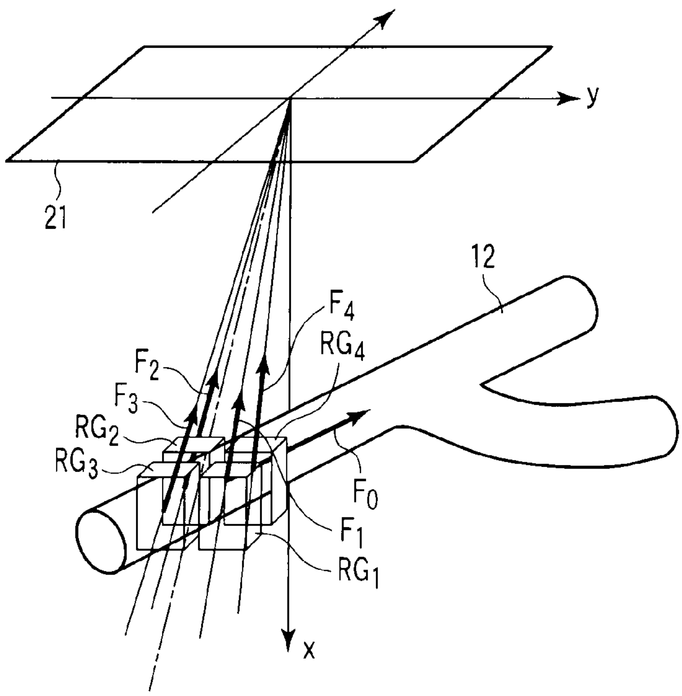


FIG.7

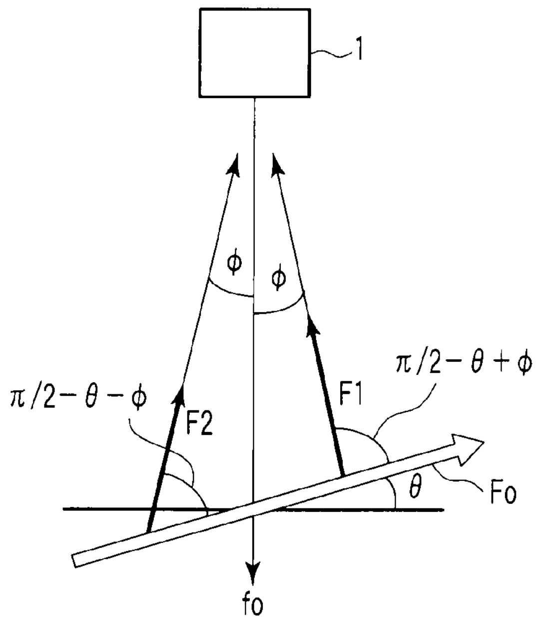


FIG.8

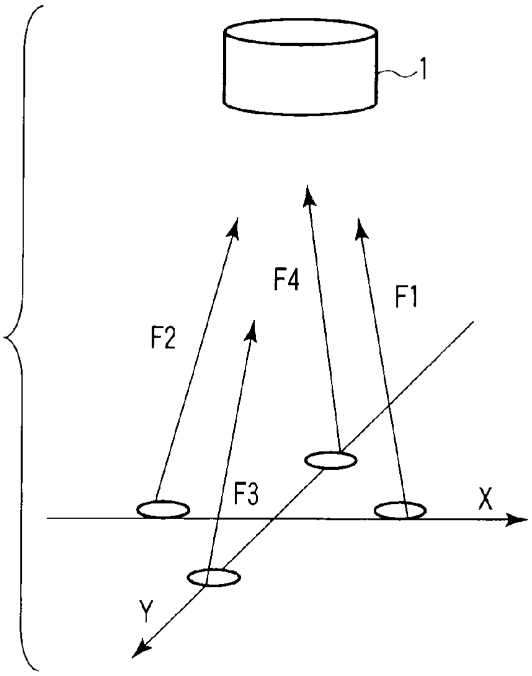


FIG. 9

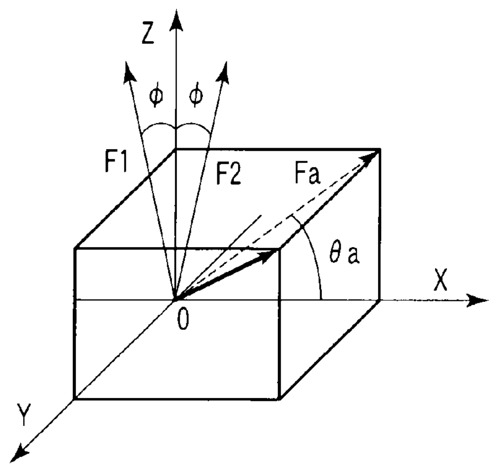


FIG. 10

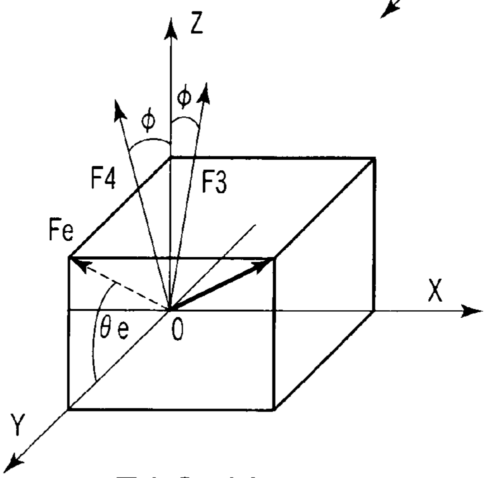


FIG. 11

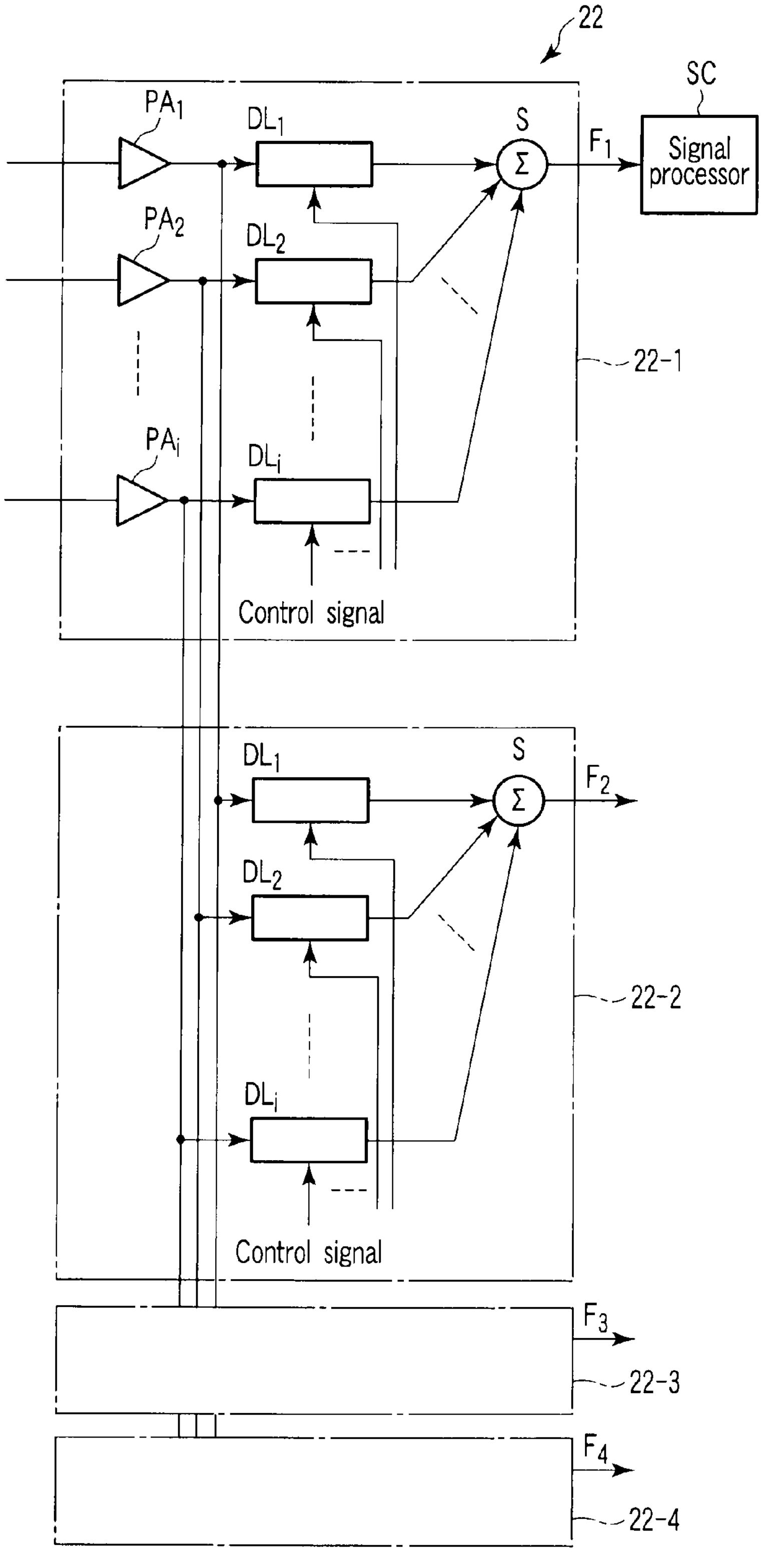
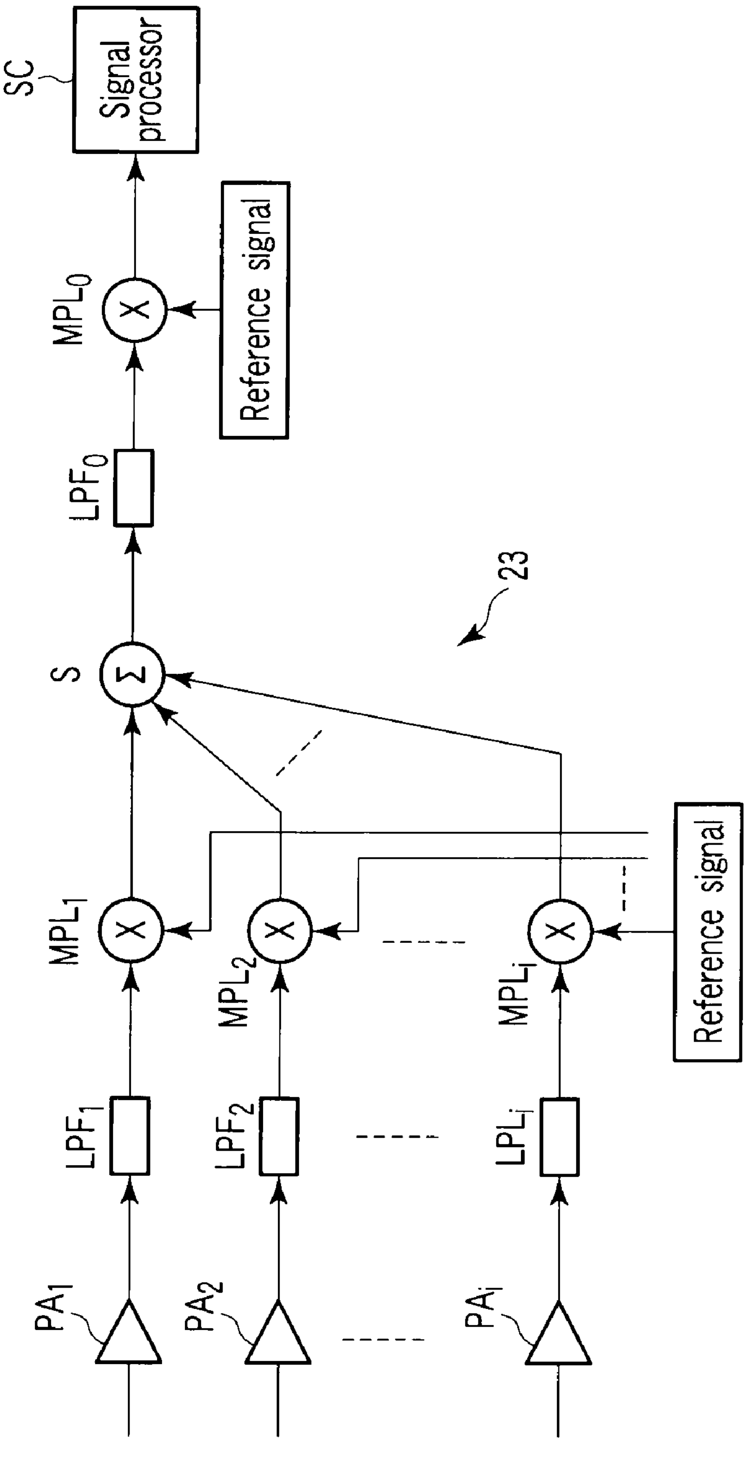
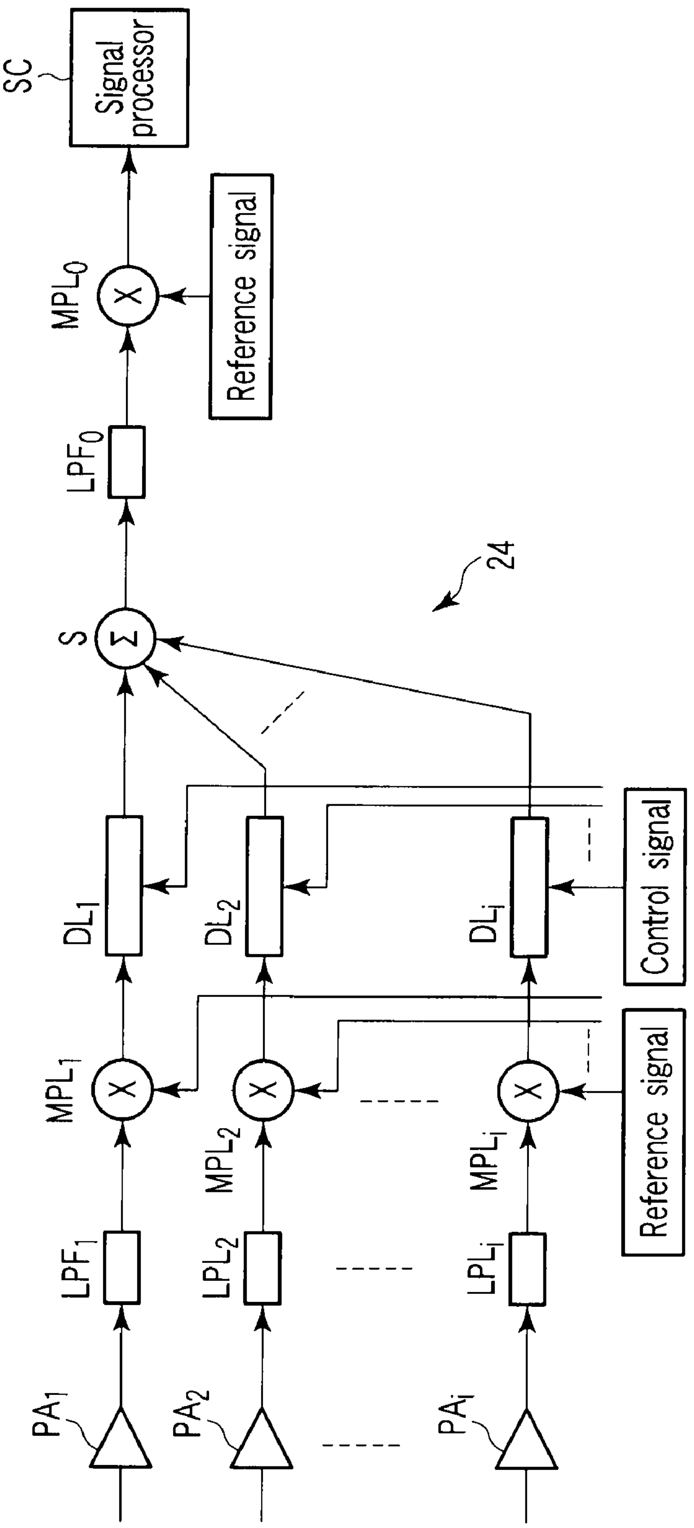

22
SC
Signal processor
PA1
PA2
PAi
DL1
DL2
DLi
S
Σ
F1
22-1
Control signal
DL1
DL2
DLi
S
Σ
F2
22-2
Control signal
F3
22-3
F4
22-4

FIG. 12



SC
Signal processor
Reference signal
MPL0
LPF0
S
23
MPL1
MPL2
MPLi
Reference signal
LPF1
LPF2
LPLi
PA1
PA2
PAi

F I G. 13



SC
Signal processor
Reference signal
MPL0
LPF0
24
S
Σ
DL1
DL2
DLi
Control signal
MPL1
MPL2
MPLi
Reference signal
LPF1
LPL2
LPLi
PA1
PA2
PAi

FIG. 14

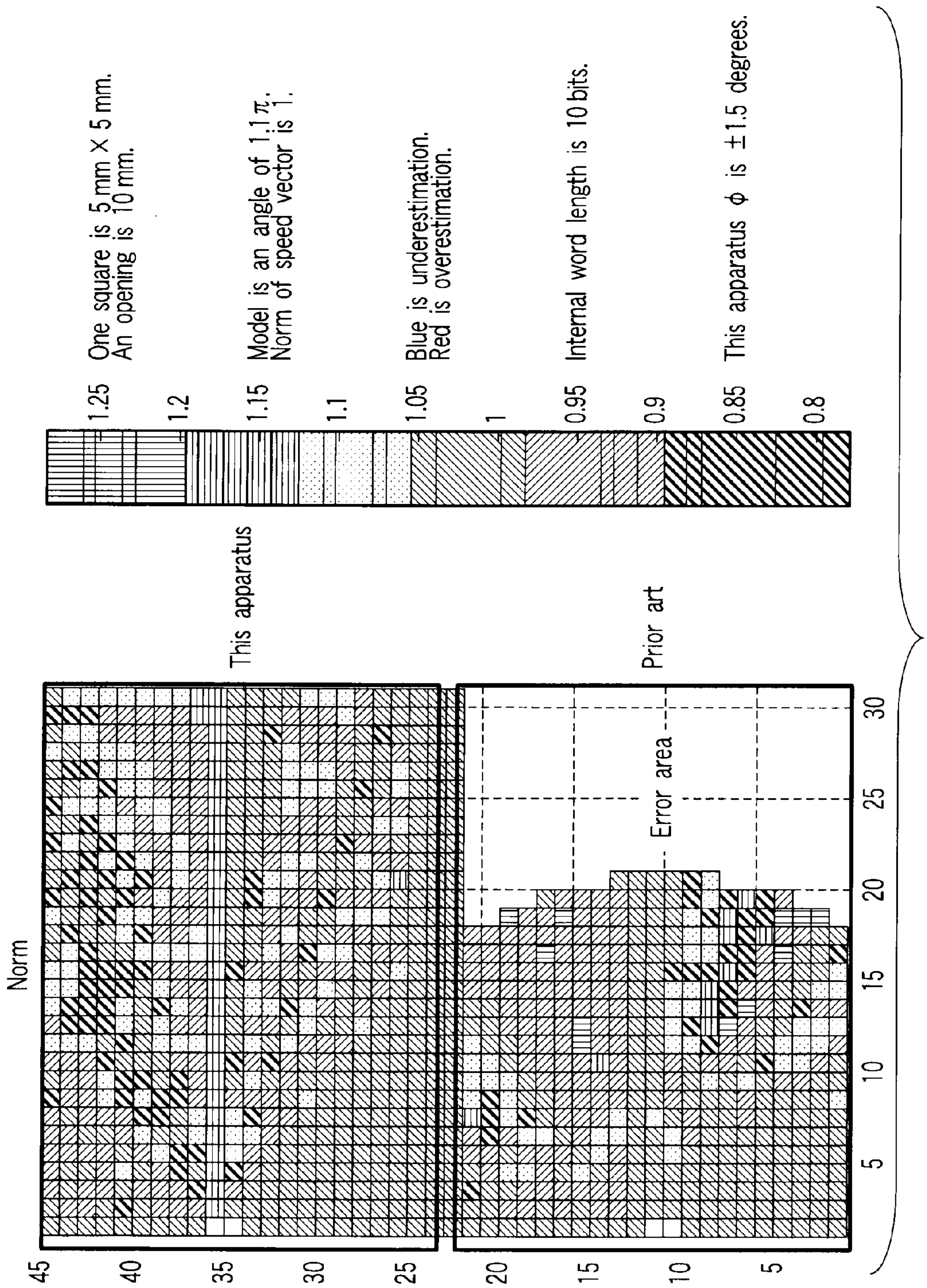

Norm
This apparatus
Prior art
Error area
45
40
35
30
25
20
15
10
5
5
10
15
20
25
30
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
One square is 5 mm × 5 mm.
An opening is 10 mm.
Model is an angle of 1.1 π.
Norm of speed vector is 1.
Blue is underestimation.
Red is overestimation.
Internal word length is 10 bits.
This apparatus φ is ±1.5 degrees.

FIG. 15

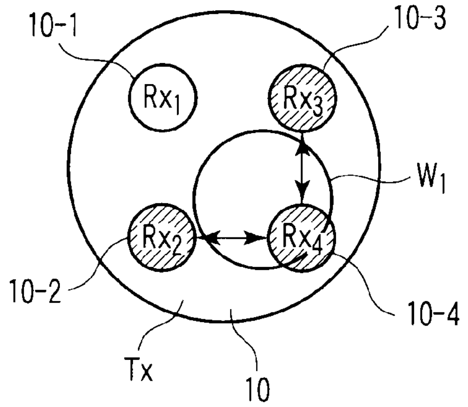


FIG. 16A

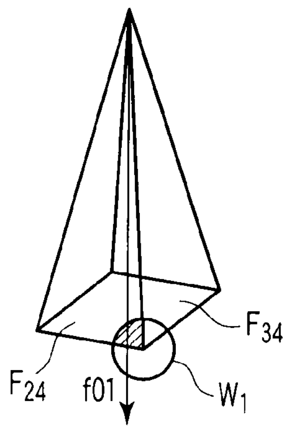


FIG. 16B

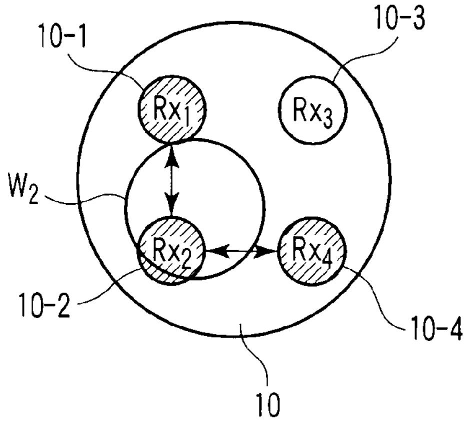


FIG. 17A

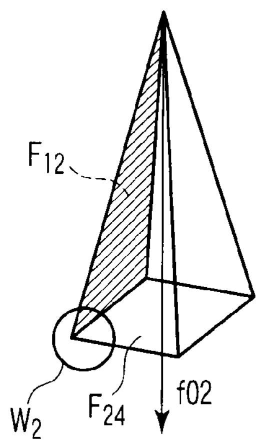


FIG. 17B

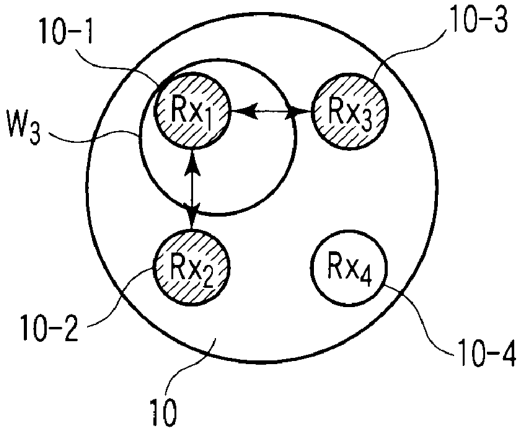


FIG. 18A

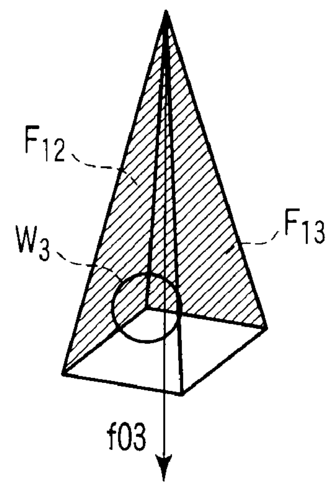


FIG. 18B

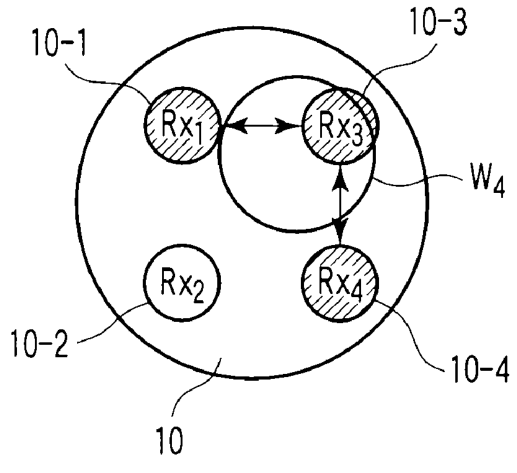


FIG. 19A

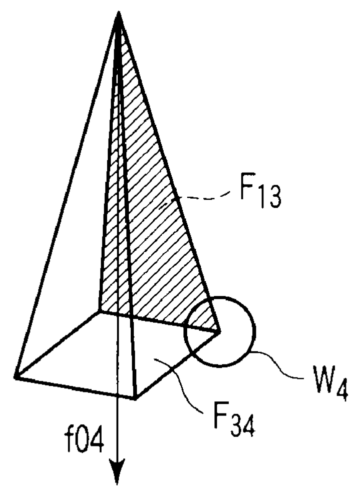


FIG. 19B

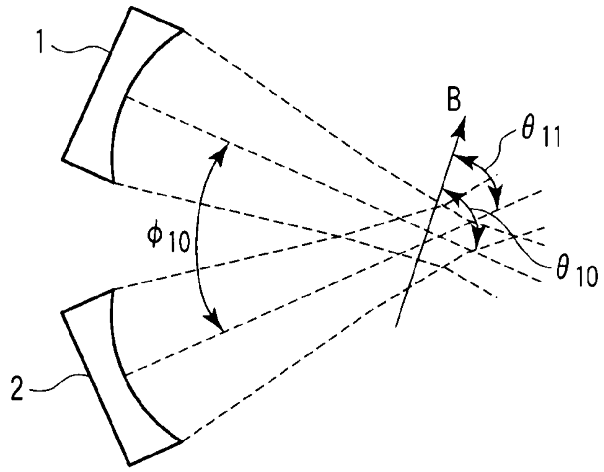


FIG. 20
(PRIOR ART)

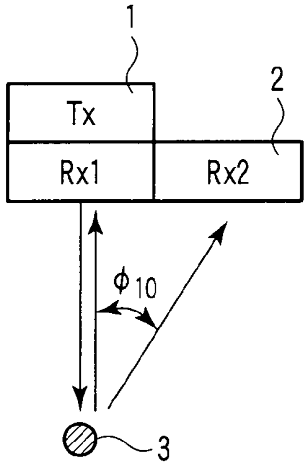


FIG. 21
(PRIOR ART)

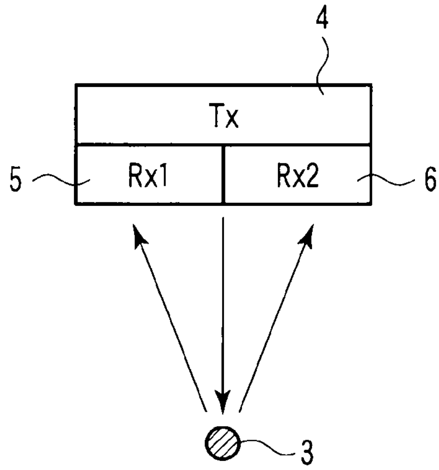


FIG. 22
(PRIOR ART)

ULTRASONIC DIAGNOSTIC APPARATUS AND METHOD OF MEASURING VELOCITY WITH ULTRASONIC WAVES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is based upon and claims the benefit of priority from prior Japanese Patent Application No. 2007-149466, filed Jun. 5, 2007, the entire contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to Doppler angle correction for obtaining an absolute value of a velocity of blood flow by measuring a Doppler angle. In particular, the present invention relates to an ultrasonic diagnostic apparatus, which measures a velocity of a sample such as fluid, for example, blood flowing in a living body such as a human body, and a method of measuring a velocity with ultrasonic waves.

[0004] 2. Description of the Related Art

[0005] An ultrasonic Doppler diagnostic apparatus emits an ultrasonic beam into a living body, and receives a wave reflected from blood flowing in a blood vessel in a living body, for example. An ultrasonic Doppler diagnostic apparatus measures a velocity of blood flow by using the Doppler effect caused by a reflected wave frequency shifted slightly from an incident frequency when an ultrasonic beam is reflected from a blood flow.

[0006] However, as an ultrasonic Doppler diagnostic apparatus is influenced by an angle formed by a blood flow direction and a direction of a wave reflected from a blood flow, it is difficult to directly measure the velocity in the direction of blood flow. Namely, an ultrasonic Doppler diagnostic apparatus creates two-dimensional ultrasonic sectional image data based on a Doppler signal output from an ultrasonic probe, and displays the data in a display section. The user or doctor tries to determine a true value of a velocity of blood flow by Doppler angle correction based on the image data in the direction of a blood vessel included in the two-dimensional ultrasonic sectional image data. However, the velocity of blood flow obtained by the Doppler angle correction in the two-dimensional ultrasonic sectional image data is insufficient to compensate for the influence in the depth direction that is a three-dimensional direction. Thus, the velocity of blood flow obtained by the Doppler angle correction lacks reliability.

[0007] Doppler angle correction is usually performed by measuring a velocity of blood flow in a range gate (RG), or a part where the flow of blood is measured by emitting an ultrasonic beam by using a pulse Doppler (PWD) method. Doppler angle correction is not performed in color Doppler tomography.

[0008] Doppler angle correction is available in the following technologies. A first technology is Jorgen Arendet Jensen, "Estimation of blood velocities using ultrasound: A signal processing approach", Cambridge University Pres, New York, 1996. In the first technology, a velocity of blood flow is measured in two dimensions. In the first technology, an ultrasonic beam transmitter-receiver **1** and a receiver **2** are provided at an angle ϕ_{10} as shown in FIG. **20**. A velocity of blood flow is obtained in two dimensions based on the angle ϕ_{10} and the angles θ_{10} and θ_{11} formed by the transmitter-receiver **1** and receiver **2** in the direction of blood flow vector B. FIG. **21** is a schematic diagram showing the transmitter-receiver **1** and receiver **2**. The drawing is called a Jensen model. Tx indicates a transmitter. Rx **1** and Rx **2** indicate a receiver. The receiver (Rx **2**) receives a wave reflected from a blood vessel **12**.

[0009] A second technology is Robin Steel and Peten J. Fish, "Error Propagation Bounds in Dual and Triple Bean Vecter Doppler Ultrasound", IEEE TRANSACTIONS ON ULTRASONICS, FERROELECTRICS, AND FREQUENCY CONTROL, VOL, 49, no. 9, September 2002. The second technology discloses that a velocity of blood flow is measured in three dimensions. The second technology has a transmitter (Tx) **4** and two receivers (Rx **1** and Rx **2**) **5** and **6**. The transmitter (Tx) **4** transmits an ultrasonic beam to an area including a blood vessel **12**. The receivers (Rx **1** and Rx **2**) **5** and **6** receive waves reflected from the blood vessel **12**.

[0010] It is an object of the present invention to provide an ultrasonic diagnostic apparatus, which can exactly obtain a velocity and direction of an example such as a blood flow, and a method of measuring a velocity with ultrasonic waves.

BRIEF SUMMARY OF THE INVENTION

[0011] According to a first aspect of the invention, there is provided an ultrasonic diagnostic apparatus comprising an ultrasonic probe which transmits a multiple ultrasonic beam to a sample flowing in a specific area, and receives a wave reflected from each part set at very small intervals in the sample; and a three-dimensional information acquisition section which acquires three dimensional fluid information including at least a three-dimensional flow direction of the sample in the specific area based on a Doppler signal output from an ultrasonic probe.

[0012] According to a second aspect of the invention, there is provided an ultrasonic diagnostic apparatus comprising an ultrasonic probe which transmits a multiple ultrasonic beam to a sample flowing in a specific area, and receives waves reflected from parts adjacent to each other in the sample in the specific area; and a three-dimensional information acquisition section which acquires three dimensional fluid information including at least a three-dimensional flow direction of the sample in the specific area based on a Doppler signal output from the ultrasonic probe.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

[0013] FIG. **1** is a block diagram of a first embodiment of an ultrasonic Doppler diagnostic apparatus according to the invention;

[0014] FIG. **2** is a schematic diagram for explaining estimation of a direction and magnitude of blood flow by the same apparatus;

[0015] FIG. **3** is a diagram showing a direction of a received beam and a direction of a blood vessel for explaining estimation of a direction and magnitude of blood flow by the same apparatus;

[0016] FIG. **4** is a block diagram showing a second embodiment of an ultrasonic Doppler diagnostic apparatus according to the invention;

[0017] FIG. **5** is a schematic diagram of a two-dimensional surface of an ultrasonic probe in the same apparatus;

[0018] FIG. **6** is a view for explaining a method of Doppler angle correction applied to the same apparatus;

[0019] FIG. 7 is a schematic diagram for explaining estimation of a direction and magnitude of blood flow by the same apparatus;

[0020] FIG. 8 is a schematic diagram for explaining Doppler angle correction on a two-dimensional cross section in the same apparatus;

[0021] FIG. 9 is a schematic diagram for explaining a method of Doppler angle correction applied to the same apparatus;

[0022] FIG. 10 is a schematic diagram for explaining a method of Doppler angle correction applied to the same apparatus;

[0023] FIG. 11 is a schematic diagram for explaining a method of Doppler angle correction applied to the same apparatus;

[0024] FIG. 12 is a block diagram of a reception delay adder circuit using a delay circuit in the same apparatus;

[0025] FIG. 13 is a is a block diagram of a reception delay adder circuit using a multiplier in the same apparatus;

[0026] FIG. 14 is a is a block diagram of a reception delay adder circuit combining a delay circuit and a multiplier in the same apparatus;

[0027] FIG. 15 is a diagram showing the result of error evaluation simulation for the estimation of the velocity of an example such as a blood flow for the same apparatus;

[0028] FIG. 16A is a diagram for explaining an example of using an ultrasonic oscillator in the same apparatus;

[0029] FIG. 16B is diagram for explaining an example of using an ultrasonic oscillator in the same apparatus;

[0030] FIG. 17A is diagram for explaining an example of using an ultrasonic oscillator in the same apparatus;

[0031] FIG. 17B is diagram for explaining an example of using an ultrasonic oscillator in the same apparatus;

[0032] FIG. 18A is diagram for explaining an example of using an ultrasonic oscillator in the same apparatus;

[0033] FIG. 18B is diagram for explaining an example of using an ultrasonic oscillator in the same apparatus;

[0034] FIG. 19A is diagram for explaining an example of using an ultrasonic oscillator in the same apparatus;

[0035] FIG. 19B is diagram for explaining an example of using an ultrasonic oscillator in the same apparatus;

[0036] FIG. 20 is a layout of a transmitter-receiver and a receiver for explaining conventional Doppler angle correction;

[0037] FIG. 21 is a schematic diagram showing the same transmitter-receiver and receiver; and

[0038] FIG. 22 is a schematic diagram showing a transmitter-receiver and a receiver for explaining another conventional Doppler angle correction.

DETAILED DESCRIPTION OF THE INVENTION

[0039] Hereinafter, an explanation will be given on a first embodiment of the invention with reference to the accompanying drawings.

[0040] FIG. 1 is a block diagram of an ultrasonic Doppler diagnostic apparatus. An ultrasonic probe **10** emits a multiple ultrasonic beam pulse consisting of a plurality of beams to a specific area including a sample **13** (hereinafter called a range gate RG), and receives a wave reflected from the range gate RG. The sample **13** is fluid such as blood flowing in a blood vessel **12** in a living body **11** such as a human body. The ultrasonic probe **10** is composed of ultrasonic oscillators arranged on a two-dimensional plane. The ultrasonic probe **10** transmits a multiple ultrasonic beam, and receives waves reflected from the ultrasonic oscillators.

[0041] A scanning transmitter-receiver **14** electrically scans the ultrasonic oscillators of the ultrasonic probe **10**, thereby sequentially driving the ultrasonic oscillators and outputting a multiple ultrasonic beam for scanning. The scanning transmitter-receiver **14** detects a Doppler signal from each output signal from each ultrasonic oscillator when receiving a wave reflected from the range gate RG.

[0042] A digital scan converter (hereinafter called a DSC) **15** converts the Doppler signal output from the scanning transmitter-receiver **14**, and stores such signal in a storage **16** such as an image memory. The DSC **15** reads the digital Doppler signal stored in the storage **16** according to the scanning of a display **17**, converts such signal to an analog signal, and displays an ultrasonic image of the range gate RG in the display **17**. The ultrasonic image of the range gate RG includes the sample **13** such as blood flowing in the blood vessel **12** in the living body **11** such as a human body. The DSC **15** has a three-dimensional image data creation section **18**, a three-dimensional information acquisition section **19**, and a display section **20**. The DSC **15** is connected to the display **17**.

[0043] The three-dimensional image data creation section **18** converts the Doppler signal output from the scanning transmitter-receiver **14** to a digital signal, and stores a digital Doppler signal for a preset scanning period in the storage **16**, thereby obtaining a plurality of sectional image data (stack data). By reconfiguring the obtained sectional image data, the three-dimensional data creation section **18** creates three-dimensional ultrasonic image data (volume data) of the range gate RG including the sample **13** such as blood flowing in the blood vessel **12** in the living body **11**.

[0044] The three-dimensional information acquisition section **19** acquires three-dimensional fluid information including at least three-dimensional flow direction of the sample **13** included in the three-dimensional ultrasonic image data of a specific area, or the range gate RG, created by the three-dimensional data creation section **18**. The three-dimensional information acquisition section **19** acquires three-dimensional fluid information based on the direction and magnitude of each reflected wave received by the ultrasonic probe **10** based on each Doppler signal output from the ultrasonic probe **10**.

[0045] Namely, as shown in FIG. **2** and FIG. **3**, the ultrasonic probe **10** has a probe surface **21** with ultrasonic oscillators arranged on a two-dimensional plane. The vector directions of the received beam K_1 from the range gate RG are assumed as θ_1, ϕ_1 and ϕ_1, respectively. The vector directions of the blood vessel in its traveling direction are assumed as θ_2, ϕ_2 and ϕ_2, respectively. The three-dimensional information acquisition section **19** acquires fluid vector data K_2 as three-dimensional fluid information in the range gate RG, based on a velocity of blood flow expressed by the vector of the received beam K_1, vector directions θ_1, ϕ_1 and ϕ_1 of the received beam K_1, vector directions θ_2, ϕ_2 and ϕ_2 of the blood vessel **13** in its traveling direction. The fluid vector data K_2 indicates a three-dimensional flow direction of the sample **13** such as a blood flow, and a flow rate of blood of the sample **13** such as a blood flow.

[0046] Next, an explanation will be given on the operation of the apparatus configured as explained above.

[0047] In the ultrasonic probe **10**, the ultrasonic oscillators are electronically scanned by the scanning transmitter-receiver **14**, the ultrasonic oscillators are sequentially driven, and a multiple ultrasonic beam is emitted. The multiple ultrasonic beam is transmitted to a range gate RG in the living body **11** such as a human body, for example. The ultrasonic probe **10** receives a wave reflected from an area including the range gate RG, and outputs a signal from each ultrasonic oscillator. The scanning transmitter-receiver **14** detects a Doppler signal from the output signal from each ultrasonic oscillator when receiving the wave reflected from the range gate RG.

[0048] The DSC **15** converts a Doppler signal output from the scanning transmitter-receiver **14** to a digital signal, and stores such signal in the storage **16** such as an image memory. The DSC **15** reads the digital Doppler signal stored in the storage **16** according to the scanning of the display **17**. The DSC **15** converts the digital Doppler signal to an analog signal, and displays an ultrasonic image of the range gate RG in the living body **11** such as a human body, real time in the display **17**. Namely, the three-dimensional data creation section **18** of the DSC **15** converts the Doppler signal output from the scanning transmitter-receiver **14** to a digital signal, and stores the digital Doppler signal for a preset scanning period it in the storage **16**. As a result, the three-dimensional image data creation section **18** acquires a plurality of sectional image data (stack data). By reconfiguring the obtained sectional image data, the three-dimensional image data creation section **18** creates three-dimensional ultrasonic image data (volume data) of the range gate RG in the living body **11** such as a human body.

[0049] The three-dimensional information acquisition section **19** acquires three-dimensional fluid information including at least three-dimensional flow direction of the sample **13** included in the three-dimensional ultrasonic image data of a specific area, or the range gate RG in the living body **11** such as a human body, created by the three-dimensional data creation section **18**.

[0050] Namely, as shown in FIG. **2** and FIG. **3**, the three-dimensional information acquisition section **19** acquires fluid vector data K_2 indicating a three-dimensional flow direction and flow rate of the sample **13** such as a blood flow in the range gate RG as three-dimensional fluid information, based on a velocity of blood flow expressed by the vector of the received beam K_1, vector directions θ_1, ϕ_1 and ϕ_1 of the received beam K_1, and directions θ_2, ϕ_2 and ϕ_2 of the blood vessel **13** in its traveling direction.

[0051] As explained above, according to the first embodiment, the ultrasonic probe **10** emits a multiple ultrasonic beam to the range gate RG including the sample **13** such as blood flowing in the blood vessel **12** in the living body **11** such as a human body, receives waves reflected from parts arranged at very small intervals in the sample **13**, and acquires the fluid vector data K_2 indicating a three-dimensional flow direction and flow rate of the sample **13** such as a blood flow in the range gate RG, based on the Doppler signal output from the ultrasonic probe **10**. Therefore, the flow velocity and direction of a sample such as a blood flow can be exactly acquired.

[0052] Next, a second embodiment of the invention will be explained with reference to the accompanying drawings. The same parts as in FIG. **1** are given the same reference numbers, and detailed explanation on these same parts will be omitted.

[0053] FIG. **4** is a block diagram of an ultrasonic Doppler diagnostic apparatus. The ultrasonic probe **10** emits a multiple ultrasonic beam pulse consisting of a plurality of beams to a specific area (hereinafter called a range gate RG) including the sample **13** that is fluid such as blood flowing in the blood vessel **12** in the living body **11** such as a human body, and receives a wave reflected from a range gate RG. The ultrasonic probe **10** uses a scan beam so-called n*m. The values of n and m are 2 or more. Here, a scan beam of 2*2 (2 by 2) is used.

[0054] The ultrasonic probe **10** comprises ultrasonic oscillators (Tx and Rx) arranged on a two-dimensional plane. The ultrasonic probe **10** transmits a multiple ultrasonic beam, and receives waves reflected from the ultrasonic oscillators (Tx and Rx). FIG. **5** is a schematic diagram of a two-dimensional probe surface of the ultrasonic probe **10**. The ultrasonic probe **10** can receive a wave reflected from the range gate RG by using four ultrasonic oscillators **10-1** to **10-4** (Rx **1** to Rx **4**), for example, of the ultrasonic oscillators arranged on the two-dimensional plane. When the ultrasonic oscillators **10-1**, **10-3** and **10-4** are used, an interval between the ultrasonic oscillators **10-1** and **10-4** is assumed as an elevation pitch Ep. An interval between the ultrasonic oscillators **10-1** and **10-3** is assumed as an azimuth pitch Ap.

[0055] The digital scan converter (hereinafter called a DSC) **15** converts a Doppler signal output from the scanning transmitter/receiver **14** to a digital signal, and reads the digital Doppler signal by a signal processor SC according to the scanning of the display **17**. The DSC **15** converts the read digital Doppler signal to an analog signal, and displays an ultrasonic image of the range gate RG real time in the display **17**. The range gate RG, as explained above, includes the sample **13** such as blood flowing in the blood vessel **12** in the living body **11** such as a human body. The digital Doppler signal is stored in the storage **16** such as an image memory.

[0056] The signal processor SC has functions as a three-dimensional image data creation section **18**, a three-dimensional information acquisition section **21**, and a display section **20**.

[0057] The three-dimension information acquisition section **21** acquires three-dimensional fluid information including at least three-dimensional flow direction of the sample **13** included in the three-dimensional ultrasonic image data of a specific area, or the range gate RG in the living body **11** such as a human body, created by the three-dimensional data creation section **18**. Namely, the three-dimensional information acquisition section **21** acquires a velocity (a velocity of blood flow), an azimuth angle, and an elevation angle of the sample **13** such as a blood flow as three-dimensional fluid information, based on fluid vector data indicating a three-dimensional flow direction and blood flow rate of the sample **13** such as a blood flow included in the three-dimensional ultrasonic image data.

[0058] Now, an explanation will be given on calculation of a norm of fluid vector data indicating the blood flow rate in the sample **13** such as a blood flow. An angle formed by a direction of ultrasonic beam and a flow direction of the sample **13** such as a blood flow (hereinafter called a blood flow direction) is called a Doppler angle. In measurement of a velocity of blood flow by the ultrasonic Doppler method, a Doppler deviation frequency to be detected is proportional to the product of a cosine of a velocity of blood flow and a Doppler angle, and depends on a Doppler angle. Obtaining an absolute value of a velocity of blood flow by measuring a Doppler angle is called a Doppler angle correction. The Doppler angle correction is used for calculation of a norm (a velocity of blood flow) of the fluid vector data indicating the blood flow rate in the sample **13** such as a blood flow. The Doppler angle correction will be explained.

[0059] As shown in FIG. **6**, the angles formed by four directions in the elevation and azimuth, crossing the range gate RG including the sample **13** such as a blood flow, are the same ϕ. The range gate RG including the sample **13** such as a blood flow exists at the center of the four ultrasonic beams. Blood is assumed to be uniformly flowing in the range gate RG.

[0060] As the angle ϕ (hereinafter called the elevation angle) formed by the four directions in the elevation and azimuth is small, the distance from the center G to the reflection points r_1 to r_4 of the received beam F_1 to F_4 is assumed to be the same depending upon the swing angle when scanning an ultrasonic beam. The elevation angle ϕ is previously known.

[0061] Directions of received beams F_1 to F_4 are assumed to be faced in the same direction even at the center of the range gate RG. The received beams F_1 to F_4 are to be expressed by a vector.

[0062] FIG. **7** shows the relationship between the received beam F_1 to F_4 and the range gate RG when a multiple ultrasonic beam is transmitted from the ultrasonic probe **10**. The range gate RG comprises a plurality of part set at very small intervals on the blood vessel **12**, for example four small range gates RG**1** to RG**4**. Received beams F_1 to F_4 are waves reflected from small range gates RG**1** to RG**4**, respectively.

[0063] First, an explanation will be given on a method of calculation on a two-dimensional cross section by referring to FIG. **8**.

[0064] The received beams F_1 to F_4 are received by the ultrasonic oscillators **10-1** to **104**, respectively at four locations in the ultrasonic probe **10**.

[0065] The scanning transmitter-receiver **14** electronically scans the ultrasonic oscillators of the ultrasonic probe **10**, and detects a Doppler signal from the output signal from the ultrasonic oscillators **10-1** to **104**, respectively. The three-dimensional information acquisition section **21** performs the following calculation based on a Doppler signal received by the ultrasonic oscillators **10-1** to **104**, respectively.

[0066] Scalar of the received beams F_1 to F_4 are assumed as f_1 to f_4, respectively, and a fluid vector indicating a blood flow rate in the sample **13** such as a blood flow, or an unknown blood flow vector, is assumed as F_0. f_0 indicates a velocity of blood flow that is the scalar of the blood flow vector F_0. An angle θ is assumed as an azimuth. Therefore,

$$f_1=f_0*\sin(\pi/2-\theta+\phi)$$

$$f_2=f_0*\sin(\pi/2-\theta-\phi)$$

[0067] Expressing by other equations,

$$f_1=f_0*\cos(\theta-\phi)$$

$$f_2=f_0*\cos(\theta+\phi)$$

[0068] The above equations are developed as follows.

$$f_1=f_0*(\sin\theta*\cos\phi-\cos\theta*\sin\phi)$$

$$f_2=f_0*(\sin\theta*\cos\phi+\cos\theta*\sin\phi)$$

However,

$$\tan\theta=\{(f_1+f_2)/(f_2-f_1)\}*\tan\phi$$

[0069] The azimuth θ can be obtained by the following equation.

$$\theta=\tan^{-1}\{(f_1+f_2)/(f_2-f_1)\}*\tan\phi$$

[0070] The flow velocity f_0 of the sample **13** such as a blood flow after the angle correction can be obtained by the following equation.

$$f0=\frac{1}{2}*\sqrt{\frac{(f2+f1)^2}{\cos^2\phi}+\frac{(f2-f1)^2}{\sin^2\phi}}$$

[0071] Developing the above equation as a three-dimensional equation,

$$\theta a=\frac{1}{2}\sqrt{\frac{(f2+f1)^2}{\cos^2\phi}+\frac{(f2-f1)^2}{\sin^2\phi}}\quad \theta a=\tan^{-1}\left(\frac{f1+f2}{f2-f1}*\tan\phi\right)$$

$$fe=\frac{1}{2}\sqrt{\frac{(f4+f3)^2}{\cos^2\phi}+\frac{(f4-f3)^2}{\sin^2\phi}}\quad \theta e=\tan^{-1}\left(\frac{f4+f3}{f4-f3}*\tan\phi\right)$$

[0072] Namely, as shown in FIGS. **9** to **11**, a cross section in the azimuth direction (X-Z plane) is calculated from the received beams F_1 and F_2, and a projection vector of a cross section in the elevation direction (Y-Z plane) is calculated from the received beams F_3 and F_4 by using a two-dimensional method.

[0073] As a result, the flow velocity f_o of the three-dimensional blood flow vector F_0 can be obtained.

$$\vec{f0}=(fa*\cos\theta a,fe*\cos\theta e,fe*\sin\theta e)$$

$$\text{or } (fa*\cos\theta a,fe*\cos\theta e,fa*\sin\theta a)$$

$$|f0|=\sqrt{fe^2+(fa*\cos\theta a)^2}\text{ or }\sqrt{fa^2+(fe*\cos\theta e)^2}$$

[0074] Therefore, the three-dimensional information acquisition section **21** acquires the velocity of blood flow f_o, azimuth θ, and elevation angle ϕ of the sample **13** such as a blood flow as three-dimensional fluid information, which are expressed by the three-dimensional blood flow vector F_o started from the range gate RG.

[0075] The elevation angle ϕ is previously known. In this case, the three-dimensional information acquisition section **21** uses a multiple ultrasonic beam such as a 2 by 2 scan beam, and acquires the velocity of blood flow f_o, azimuth θ, and elevation angle ϕ of the sample **13** such as two or more blood flows, by two or more beam.

[0076] The DSC **15** converts a Doppler signal output from the scanning transmitter-receiver **14** to a digital signal, and sends such signal to the signal processor. The ultrasonic probe **10** comprises ultrasonic oscillators arranged on a two-dimensional plane. As each ultrasonic oscillator sends a multiple ultrasonic beam, and receives a reflected wave, a reception delay adder circuit as described below is provided.

[0077] FIG. **12** is a block diagram of a reception delay adder circuit **22** using a delay line. The reception delay adder circuit **22** comprises four channels of reception delay adder circuit **22-1** to **22-4**, for example, corresponding to the received beams F_1 to F_4 when a multiple ultrasonic beam is transmitted from the ultrasonic probe **10**. The reception delay adder circuit **22** is provided with preamplifiers PA_1 to PA_i.

The preamplifiers PA_1 to PA_i are provided corresponding to the ultrasonic oscillators of the ultrasonic probe **10**, and used to amplify a Doppler signal output from each ultrasonic oscillator.

[0078] Namely, the preamplifiers PA_1 to PA_i correspond to the number i of the arranged ultrasonic oscillators. The output terminals of preamplifiers PA_1 to PA_i are connected to delay circuits DL_1 to DL_i, respectively. The delay circuits DL_1 to DL_i are controlled by a control signal received from a main controller in the DSC **15**, for example. The delay circuits DL_1 to DL_i compensate for a delay between the beginning and end of one scan of a multiple ultrasonic beam in the ultrasonic probe **10**, and creates one three-dimensional ultrasonic image data. The delay circuits DL_1 to DL_i are set to different delay time according to the scanning positions of a multiple ultrasonic beam. The output terminals of the delay circuit DL_1 to DL_i are connected to an adder S. The adder S adds the outputs of the delay circuits DL_1 to DL_i, and sends the added outputs to the signal processor SC.

[0079] The reception delay adder circuit **22-2** is provided with delay circuits DL_1 to DL_i. The delay circuits DL_1 to DL_i are controlled by a control signal received from a main controller in the DSC **15**, for example. The delay circuits DL_1 to DL_i compensate for a delay between the beginning and end of one scan of a multiple ultrasonic beam in the ultrasonic probe **10**, and creates one three-dimensional ultrasonic image data. The delay circuits DL_1 to DL_i are set to different delay time according to the scanning positions of a multiple ultrasonic beam. The output terminals of the delay circuit DL_1 to DL_i are connected to the adder S. The adder S adds the outputs of the delay circuits DL_1 to DL_i, and sends the added outputs to the signal processor SC. The signal processor SC may be provided exclusively for the reception delay adder circuit **22-2**.

[0080] As in the reception delay adder circuit **22-2**, the reception delay adder circuits **22-3** and **22-4** are provided with delay circuits DL_1 to DL_i. The configurations of the reception delay adder circuits **22-3** and **22-4** are the same as the reception delay adder circuit **22-2**, and an illustration of a concrete configuration is omitted in FIG. **12**. The delay circuits DL_1 to DL_i are controlled by a control signal received from a main controller in the DSC **15**, for example. The delay circuits DL_1 to DL_i compensate for a delay between the beginning and end of one scan of a multiple ultrasonic beam in the ultrasonic probe **10**, and creates one three-dimensional ultrasonic image data. The delay circuits DL_1 to DL_i are set to different delay time according to the scanning positions of a multiple ultrasonic beam. The output terminals of the delay circuit DL_1 to DL_i are connected to the adder S. The adder S adds the outputs of the delay circuits DL_1 to DL_i, and sends the added outputs to the signal processor SC. The signal processor SC may be provided exclusively for the reception delay adder circuits **22-2** and **22-4**.

[0081] FIG. **13** is a block diagram of a reception delay adder circuit **23** using a multiplier. The output terminals of amplifiers PA_1 to PA_i are connected to multipliers MPL_1 to MPL_i through low-pass filters LPF_1 to LPF_i, respectively. The multipliers MPL_1 to MPL_i receive a reference signal from a main controller, and multiply a Doppler signal passing through each low-pass filter LPF_1 to LPF_i by a reference signal. The output terminals of the multipliers MPL_1 to MPLi are connected to the adder S. The adder S adds the outputs of the multipliers MPL_1 to MPL_i. The output terminal of the adder S is connected to a multiplier MPL_0 through a low-pass filter LPF_0. The multiplier MPL_0 multiplies the output signal of the low-pass filter LPF_0 by a reference signal, and sends the product to the signal processor SC.

[0082] FIG. **14** is a block diagram of a reception delay adder circuit **24** combining a delay circuit and a multiplier. The same parts as in FIG. **12** and FIG. **13** are given the same reference numbers, and detailed explanation on these same parts will be omitted. The output terminals of amplifiers PA_1 to PA_i are connected to multipliers MPL_1 to MPL_i through low-pass filters LPF_1 to LPF_i, respectively. The output terminals of the multipliers MPL_1 to MPLi are connected to the adder S through delay circuits DL_1 to Dl_i. The output terminal of the adder S is connected to a multiplier MPL_0 through the low-pass filter LPF**0**. The multiplier MPL_0 multiplies the output signal of the low-pass filter LPF_0 by a reference signal, and sends the product to the signal processor SC.

[0083] A display section **20** displays a velocity of blood flow f_0, azimuth θ and elevation angle ϕ of the sample **13** such as two or more blood flows, which are acquired by the three-dimensional acquisition section **21** as two or more beam, in the display **10**. The display section **20** displays the three-dimensional ultrasonic image data of the range gate RG including the sample **13** such as a flood flow flowing in the blood vessel **12**, for example, which are created by the three-dimensional image data creation section **18**.

[0084] The display section **20** displays a spectrum, which expresses a velocity component f_o of a blood flow by assuming a blood flow going to the ultrasonic probe **10** as positive and a flood flow leaving from the ultrasonic probe **10** as negative, according to a Doppler deviation frequency based on a Doppler signal, in the display **17**. In this case, as the three-dimensional information acquisition section **21** acquires the velocity of blood flow f_0 of the sample **13** such as a blood flow from two or more beams, IQ data in which these velocity of blood flow f_o are added is used. The Doppler angle correction is performed by 1/cos θ/cos ϕ. When displaying the three-dimensional ultrasonic image data of the range gate RG including the sample **13** such as a blood flow in the display **10**, the display section **20** displays an angle compensation mark in the display **10** on a volume and multi-plane corresponding to the position of the range gate RG on the screen of the display **10**, according to the azimuth θ and elevation angle ϕ.

[0085] The display section **20** displays the sample **13** such as a blood flow in the display **10** in colors corresponding to the velocity of blood flow f_o, azimuth θ and elevation angle ϕ acquired by the three-dimensional acquisition section **21**. Namely, the display section **20** uses the Munsell color system. The Munsell color system consists of Munsell hue H, Munsell chroma S and Munsell value I. Munsell hue H and Munsell chroma S and Munsell value I form an HSI color space.

[0086] First, the display section **20** converts the velocity of blood flow f_o, azimuth θ and elevation angle ϕ of the sample **13** such as a blood flow, to information about the HIS color space by using a previously set HIS conversion table. The HIS conversion table consists of the following equations, for example. In such equations, a**1**-a**3**, b**1**-b**3**, and c**1**-c**3** are optional constants. The constants a**1**-a**3**, b**1**-b**3**, and c**1**-c**3** can be varied according to the colors corresponding to the velocity of blood flow f_o, azimuth θ and elevation angle ϕ of the sample **13** such as a blood flow, when displaying in the display **10**.

$$\begin{bmatrix} H \\ S \\ I \end{bmatrix} \begin{bmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{bmatrix} \begin{bmatrix} \theta \\ \phi \\ f0 \end{bmatrix}$$

[0087] Next, the display section **20** converts the information about the HIS color space to RGB information by using a preset RGB conversion table. The RGB information consists of red (R), green (G) and blue (B).

[0088] Then, the display section **20** colors the three-dimensional ultrasonic image data of the range gate RG including the sample **13** such as a blood flow, according to the RGB information, and displays the colored three-dimensional ultrasonic image data in the display **10**. As a result, the display **10** displays the color three-dimensional ultrasonic image data corresponding to the velocity of blood flow f_o, azimuth θ and elevation angle φ of the sample **13** such as a blood flow.

[0089] Next, an explanation will be given on the operation of the apparatus configured as above described.

[0090] In the ultrasonic probe **10**, the ultrasonic oscillators are electronically scanned by the scanning transmitter-receiver **14**, the ultrasonic oscillators are sequentially driven, and a multiple ultrasonic beam is emitted. The multiple ultrasonic beam is transmitted to the range gate RG in the living body **2** such as a human body, for example. The ultrasonic probe **10** receives a wave reflected from an area including the range gate RG, and outputs a signal from each ultrasonic oscillator. The scanning transmitter-receiver **14** detects a Doppler signal from the output signal from each ultrasonic oscillator when receiving the wave reflected from the range gate RG.

[0091] Next, the DSC **8** converts a Doppler signal output from the scanning transmitter-receiver **14** to a digital signal, and stores the digital Doppler signal in the storage **9** such as an image memory. The DSC **8** reads the digital Doppler signal stored in the storage **9** according to the scanning of the display **10**, converts the digital Doppler signal into an analog signal, and displays an ultrasonic image of the range gate RG in the living body **2** such as a human body, in real time on the display **10**.

[0092] Namely, the three-dimensional data creation section **18** of the DSC **8** converts a Doppler signal output from the scanning transmitter-receiver **14** to a digital signal, and stores the digital Doppler signal for a preset scanning period in the storage **9**, thereby obtaining two or more sectional image data (stack data). By reconfiguring the obtained sectional image data, the three-dimensional image data creation section **18** creates three-dimensional ultrasonic image data (volume data) of the range gate RG in the living body **2** such as a human body.

[0093] Next, the three-dimensional information acquisition section **21** acquires three-dimensional fluid information including at least three-dimensional flow direction of the sample **13** included in the three-dimensional ultrasonic image data of a specific area, or the range gate RG in the living body **11** such as a human body, created by the three-dimensional data creation section **18**. Namely, the three-dimensional information acquisition section **21** acquires a velocity (a velocity of blood flow), azimuth and elevation angle of the sample **13** such as a blood flow as three-dimensional fluid information, based on fluid vector data indicating a three-dimensional flow direction and flow rate of the sample **13** such as a blood flow included in the three-dimensional ultrasonic image data. The three-dimensional information acquisition section **21** uses Doppler angle correction for calculation of a norm (a flood flow velocity) of the fluid vector data indicating the blood flow rate in the sample **13** such as a blood flow as above explained.

[0094] By using such Doppler angle correction, the three-dimensional information acquisition section **21** acquires the velocity of blood flow f_o, azimuth θ, and elevation angle φ of the sample **13** such as a blood flow as three-dimensional fluid information, which are expressed by the three-dimensional blood flow vector F_o started from the range gate RG. In this case, the three-dimensional information acquisition section **21** uses a multiple ultrasonic beam such as a 2 by 2 scan beam, and acquires the velocity of blood flow f_o, azimuth θ, and elevation angle φ of the sample **13** such as a blood flow of a plurality of blood flow, by two more beams.

[0095] A display section **20** displays the velocity of blood flow f_0, azimuth θ and elevation angle φ of the sample **13** such as blood flows, which are acquired by the three-dimensional acquisition section **21** as two or more beam, in the display **10**. The display section **20** displays the three-dimensional ultrasonic image data of the range gate RG including the sample **13** such as a flood flow flowing in the blood vessel **12**, for example, which are created by the three-dimensional image data creation section **18**, in the display **10**. The display section **20** displays a spectrum, which expresses a velocity component f_o of blood flow by assuming a blood flow going to the ultrasonic probe **10** as positive and a flood flow leaving from the ultrasonic probe **10** as negative, according to a Doppler deviation frequency based on a Doppler signal, in the display **17**.

[0096] The display section **20** displays the sample **13** such as a blood flow in the display **10** in colors corresponding to the velocity of blood flow f_o, azimuth θ and elevation angle φ acquired by the three-dimensional acquisition section **21**. Namely, the display section **20** converts the velocity of blood flow f_o, azimuth θ and elevation angle φ of the sample **13** such as a blood flow, to information about the HIS color space by using a previously set HIS conversion table.

[0097] Next, the display section **20** converts the information about the HIS color space to RGB information by using a preset RGB conversion table.

[0098] Then, the display section **20** colors the three-dimensional ultrasonic image data of the range gate RG including the sample **13** such as a blood flow, according to the RGB information, and displays the colored three-dimensional ultrasonic image data in the display **10**. As a result, the display **10** displays the color three-dimensional ultrasonic image data corresponding to the velocity of blood flow f_o, azimuth θ and elevation angle φ of the sample **13** such as a blood flow.

[0099] As above described, according to the second embodiment, the ultrasonic probe **10** transmits a multiple ultrasonic beam, and the three-dimensional information acquisition section **21** acquires the velocity of blood flow f_0, azimuth θ and elevation angle φ of the sample **13** such as a blood flow as three-dimensional fluid information in the range gate RG. Therefore, the velocity of blood flow f_0, azimuth θ and elevation angle φ of the sample **13** such as a blood flow can be exactly acquired. As the elevation angle φ of each received beam F**1** to F_4 is constant, even if the distance from the ultrasonic probe **10** to the sample **13** becomes long, the velocity of blood flow f_0, azimuth θ and elevation angle φ of the sample **13** such as a blood flow can be exactly acquired without decreasing the accuracy of Doppler angle correction.

[0100] The sample **13** such as a blood flow is displayed in the display **10** in colors corresponding to the velocity of blood flow f_o, azimuth θ and elevation angle ϕ acquired by the three-dimensional acquisition section **21**. Therefore, the velocity of blood flow f_o, azimuth θ and elevation angle ϕ of the sample **13** such as a blood flow can be confirmed from the color of the three-dimensional ultrasonic image displayed in the display **10**.

[0101] FIG. **15** shows a result of error evaluation simulation for estimation of the velocity f_o of the example **13** such as a blood flow. The drawing shows the results of the error evaluation simulation by the first technology (the literature by Jorgen Arendet Jensen) and the error evaluation simulation by Dr. Jensen shown in FIG. **21**. As the elevation angle ϕ becomes larger when a 2 by 2 scan beam is used, the accuracy of Doppler angle correction is increased. In the prior art, when the distance from the ultrasonic probe **10** to the sample **13** becomes long, the accuracy of Doppler angle correction is decreased, and an error may occur when a critical point is exceeded. Therefore, in the prior art, it is impossible to acquire exact velocity of blood flow f_o, azimuth θ and elevation angle ϕ of the sample **13** such as a blood flow.

[0102] Further, as a multiple ultrasonic beam such as a 2 by 2 scan beam is used, the velocity of blood flow f_o, azimuth θ and elevation angle ϕ of the sample **13** such as a blood flow can be acquired by two or more beams. For example, the average $(f_{01}+f_{02}+ . . . +f_{0j}/j)$ of two or more blood flow velocities $f_{01}, f_{02}, . . . , f_{0j}$ is displayed, Doppler angle correction is manually performed, and the displays of the velocity of blood flow f_o, azimuth θ and elevation angle ϕ of the velocity compensated three-dimensional blood flow vector F_0 may be switched.

[0103] When the azimuth θ formed by a multiple ultrasonic beam sent from the ultrasonic probe **10** and a received beam becomes small, blood information necessary for color mapping in the range gate RG, for example, is more exactly reflected. In contrast, when the azimuth θ formed by a multiple ultrasonic beam sent from the ultrasonic probe **10** and a received beam becomes large, the measurement accuracy of the velocity of blood flow f_o is increased.

[0104] Therefore, first of all, the ultrasonic probe **10** sets the distance to the sample **13** such as a blood flow short. The distance from the ultrasonic probe **10** to the sample **13** may be previously set, or optionally set. In this state, the ultrasonic probe **10** increases the azimuth θ formed by a multiple ultrasonic beam and a received beam, and acquires the velocity of blood flow f_0.

[0105] Then, the ultrasonic probe **10** sets the distance to the sample **13** long. The distance from the ultrasonic probe **10** to the sample **13** at this time may be previously set, or optionally set. In this state, the ultrasonic probe **10** increases the azimuth θ formed by a multiple ultrasonic beam and a received beam, and acquires the velocity of blood flow f_0.

[0106] Therefore, blood flow information necessary for color mapping in the range gate RG, for example, can be exactly measured, and the measurement accuracy of the velocity of blood flow f_o is increased.

[0107] The present invention is not to be limited to the embodiment described herein. The invention may be modified by modifying the components in a practical stage without departing from its spirit and essential characteristics. The invention may be embodied in other forms by appropriately combining the components disclosed in the embodiment described herein. For example, some components may be deleted from the total components shown in the embodiment. Further, the components of different embodiment may be combined.

[0108] The ultrasonic oscillators (Rx **1** to Rx **4**) **10-1** to **10-4** in the ultrasonic probe **10** may be used as shown in FIGS. **16**A and **16**B to FIGS. **19**A and **19**B, for example. FIG. **16**A shows a measurement area W_1 of a flow velocity k in a blood flow direction, for example, as the sample **13** when the ultrasonic oscillators (Rx **2** to RX **4**) **10-2** to **10-4** are used. FIG. **16**B shows a transmitted multiple ultrasonic beam f_{01} and received beams F_{24} and F_{34}.

[0109] FIG. **17**A shows a measurement area W_2 of a flow velocity in a blood flow direction, for example, as the sample **13** when the ultrasonic oscillators (Rx **1**, Rx **2** and RX **4**) **10-1**, **10-2** and **10-4** are used. FIG. **17**B shows a transmitted multiple ultrasonic beam f_{02}, and received beams F_{24} and F_{12}.

[0110] FIG. **18**A shows a measurement area W_3 of a flow velocity in a blood flow direction, for example, as the sample **13** when the ultrasonic oscillators (Rx **1** to Rx **3**) **10-1** to **10-3** are used. FIG. **18**B shows a transmitted multiple ultrasonic beam f_{03}, and received beams F_{12} and F_{13}.

[0111] FIG. **19**A shows a measurement area W_4 of a flow velocity in a blood flow direction, for example, as the sample **13** when the ultrasonic oscillators (Rx **1**, Rx **3** and Rx **4**) **10-1**, **10-3** and **10-4** are used. FIG. **19**B shows a transmitted multiple ultrasonic beam f_{04}, and received beams F_{13} and F_{34}.

[0112] When a velocity of blood flow in a range gate RG that is a part to measure a blood flow, for example by emitting an ultrasonic beam by using a pulse Doppler method (PWD), the shape of the range gate RG can be changed. In biplane color scanning in an ultrasonic diagnostic apparatus, or in a scanning method for acquiring two intersecting sectional images substantially real time, the thickness azimuth can be changed in the biplane color scanning.

[0113] The ultrasonic oscillators (Rx **1** to Rx **4**) **10-1** to **10-4** in the ultrasonic probe **10** may be changed in the elevation angle ϕ to receive a wave reflected from a range gate RG. For example, when a 2 by 2 scan beam is used, when the elevation angle ϕ is increased, the accuracy in acquiring the velocity of blood flow f_o, azimuth θ and elevation angle ϕ of the sample **13** such as a blood flow is increased.

[0114] The three-dimensional information acquisition section **18** may be configured to acquire fluid vector data indicating a three-dimensional flow direction and flow rate of the sample **13** for two or more parts based on a Doppler signal output from the ultrasonic probe **10**, and to acquire the velocity of at least the sample **13** by adding and averaging these fluid vector data. For example, the three-dimensional information acquisition section **18** is configured to acquire the velocity of the sample **13** such as a blood flow, by adding and averaging the fluid vectors indicting the received beams F_1 to F_4 from four small range gates RG_1 to R_4 shown in FIG. **7**. In color Doppler tomography, a blood velocity is indicated by color. For example, blood flow information is overlapped in colors on a monochrome B-mode image. Therefore, color blood information may be acquired from the velocity of the sample **13** such as a blood flow acquired by the three-dimensional acquisition section **18**.

[0115] The three-dimensional information acquisition section **18** may acquire fluid vector data indicating a three-dimensional flow direction and blood flow rate of the sample **13** such as a blood flow in two or more parts, based on a Doppler signal output from the ultrasonic probe **10**. For example, the acquisition section **18** acquires fluid vector indicating the received beams F_1 to F_4 from four small range gates RG_1 to RG_4 shown in FIG. **7**. A velocity change is obtained by normalizing acceleration between these fluid vectors, or between the fluid vectors at one or both of elevation pitch and azimuth pitch. A parameter to evaluate a degree of dispersion may be obtained based on the velocity change, or color mapping of a speed distribution of the sample **13** such as a blood flow may be obtained from the evaluation parameter.

[0116] As a blood flow vector F_0 exists on the three-dimensional coordinates of a vector or three-dimensional ultrasonic image data, the vector F_0 can be displayed by a normal fluid postprocessor. For example, such data can be displayed as a contour plot, a vector plot in a flow line display, a modification diagram, a graph, or a particle trace in a flow track trace.

[0117] As elevation information is included, in addition to azimuth information, in the sectional image data obtained from three-dimensional ultrasonic image data acquired by an ultrasonic diagnostic apparatus including biplane scanning, an accurate norm (a velocity of blood flow) of fluid vector data indicating a blood flow rate of the sample **13** such as a blood flow can be obtained with compensation made for the thickness direction of the sectional image data.

[0118] Further, whether a blood flow is going to or leaving from the thickness direction can be displayed by color mapping in the sectional image data. For example, a blood flow leaving from or going to the ultrasonic probe **10** can be set to red or blue, and a blood flow leaving from or going to the thickness direction of sectional image data can be displayed in red or blue.

[0119] By using the velocity of blood flow f_o, azimuth θ and elevation angle ϕ of the sample **13**, a blood flow on intersecting planes can be displayed by a vector quantity, an arrow and a flow line, for example, according to each plane, upon display of biplane blue eyes.

What is claimed is:

1. An ultrasonic diagnostic apparatus comprising:

an ultrasonic probe which transmits a multiple ultrasonic beam to a sample flowing in a specific area, and receives a wave reflected from each part set at very small intervals in the sample; and

a three-dimensional information acquisition section which acquires three dimensional fluid information including at least a three-dimensional flow direction of the sample in the specific area based on a Doppler signal output from the ultrasonic probe.

2. The ultrasonic diagnostic apparatus according to claim **1**, wherein the three-dimensional information acquisition section acquires the three dimensional fluid information based on at least the magnitude and direction of the reflected wave received by the ultrasonic probe based on the Doppler signal output from the ultrasonic probe.

3. An ultrasonic diagnostic apparatus comprising:

an ultrasonic probe which transmits a multiple ultrasonic beam to a sample flowing in a specific area, and receives waves reflected from parts adjacent to each other in the sample in the specific area; and

a three-dimensional information acquisition section which acquires three dimensional fluid information including at least a three-dimensional flow direction of the sample in the specific area based on a Doppler signal output from the ultrasonic probe.

4. The ultrasonic diagnostic apparatus according to claim **3**, wherein the ultrasonic probe has ultrasonic oscillators arranged at equal pitches in the vertical and horizontal directions to receive the waves reflected from the parts, and

the ultrasonic oscillators receive the waves reflected from the parts at the same elevation angle.

5. The ultrasonic diagnostic apparatus according to claim **4**, wherein the ultrasonic oscillators receive the wave reflected from the parts adjacent to each other at four locations at the same elevation angle.

6. The ultrasonic diagnostic apparatus according to claim **4**, wherein the ultrasonic oscillators have a variable elevation angle to receive the reflected wave.

7. The ultrasonic diagnostic apparatus according to claim **3**, wherein the three-dimensional information acquisition section acquires fluid vector data indicating a three-dimensional flow direction and flow rate of the sample based on the Doppler signal output from the ultrasonic probe, and acquires a flow velocity, azimuth and elevation angle of the sample as the three-dimensional fluid information based on the fluid vector data.

8. The ultrasonic diagnostic apparatus according to claim **3**, wherein the three-dimensional information acquisition section acquires the three-dimensional fluid information based on at least the magnitude and direction of each wave reflected from the parts received by the ultrasonic probe based on the Doppler signal outputs corresponding to the parts output from the ultrasonic probe.

9. The ultrasonic diagnostic apparatus according to claim **3**, wherein the three-dimensional information acquisition section acquires fluid vector data indicating a three-dimensional flow direction and flow rate of the sample for each of the parts based on the Doppler signal output from the ultrasonic probe, and acquires at least a velocity of the sample by adding and averaging the fluid vector data.

10. The ultrasonic diagnostic apparatus according to claim **3**, wherein the three-dimensional information acquisition section acquires fluid vector data indicating a three-dimensional flow direction and flow rate of the sample for each of the parts based on the Doppler signal output from the ultrasonic probe, acquires a velocity change by normalizing the fluid vector data at each pitch in the vertical and horizontal directions in which the ultrasonic oscillators are arranged, and makes color mapping of a velocity distribution of the sample based on the velocity change.

11. The ultrasonic diagnostic apparatus according to claim **3**, wherein a three-dimensional ultrasonic image of an area including the sample is obtained by one of a pulse Doppler method and a color Doppler tomography.

12. The ultrasonic diagnostic apparatus according to claim **7**, further comprising a display section which displays the sample in colors corresponding to the velocity, azimuth and elevation angle of the sample acquired by the three-dimensional acquisition section.

13. The ultrasonic diagnostic apparatus according to claim **1** or **3**, wherein the ultrasonic probe increases an azimuth of the multiple ultrasonic beam as the distance to the sample is decreased, and decreases the azimuth of the multiple ultrasonic beam as the distance to the sample is increased.

14. A method of measuring a velocity with ultrasonic waves comprising:

transmitting a multiple ultrasonic beam from an ultrasonic probe to a sample flowing in a specific area, and receiving a wave reflected from each part set at very small intervals in the sample; and

acquiring three-dimensional fluid information including at least a three-dimensional flow direction of the sample in the specific area based on a Doppler signal output from the ultrasonic probe.

15. The method of measuring a velocity with ultrasonic waves according to claim **14**, wherein each wave reflected from each part adjacent to each other in the sample in the specific area is received by the ultrasonic probe.

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摘要(译)

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