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(54) **OCT OPTICAL PROBE AND OPTICAL TOMOGRAPHY IMAGING APPARATUS**

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(57) **ABSTRACT**

An OCT optical probe to be inserted into a subject includes: a cylindrical sheath to be inserted into a subject; an optical fiber disposed in the internal space of the sheath; a rotatably-supporting portion fixed to the optical fiber in the vicinity of a distal end of the optical fiber; a distal optical system to deflect light emitted from the distal end of the optical fiber toward the subject; a holding portion to hold the distal optical system such that the optical system is rotatably supported by the rotatably-supporting portion; and a flexible shaft covering the optical fiber in the internal space, wherein the holding portion is fixed to a distal end of the flexible shaft. Using the OCT optical probe of the invention, the problem of degradation of measurement accuracy due to optical insertion loss and optical reflection loss at a rotary joint can be eliminated inexpensively and safely.

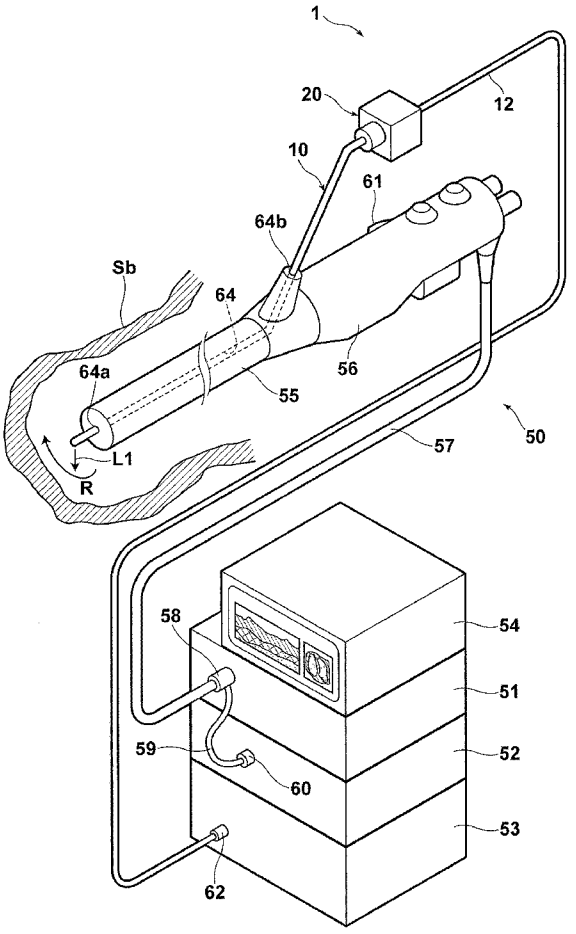


FIG.1

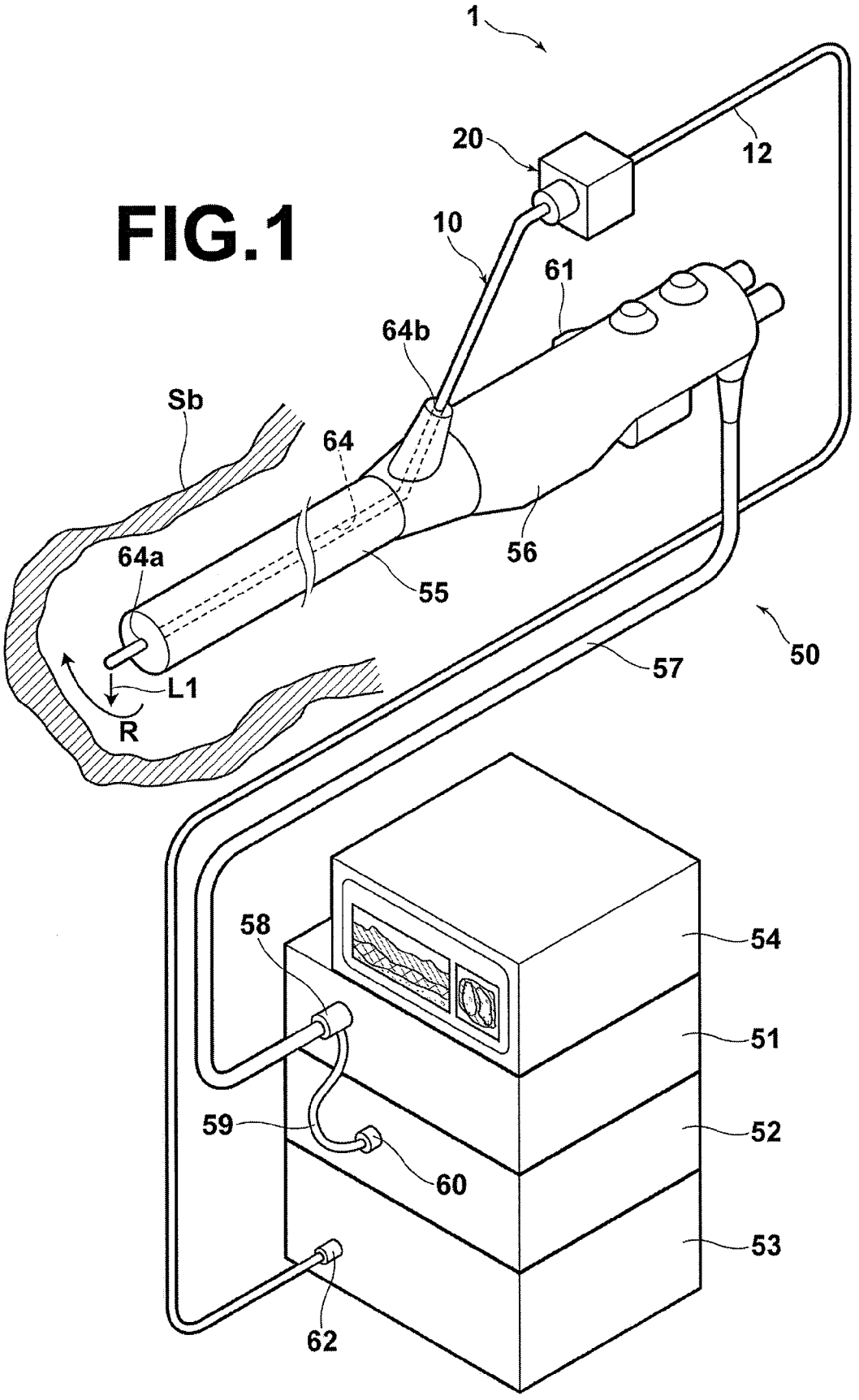


FIG.2

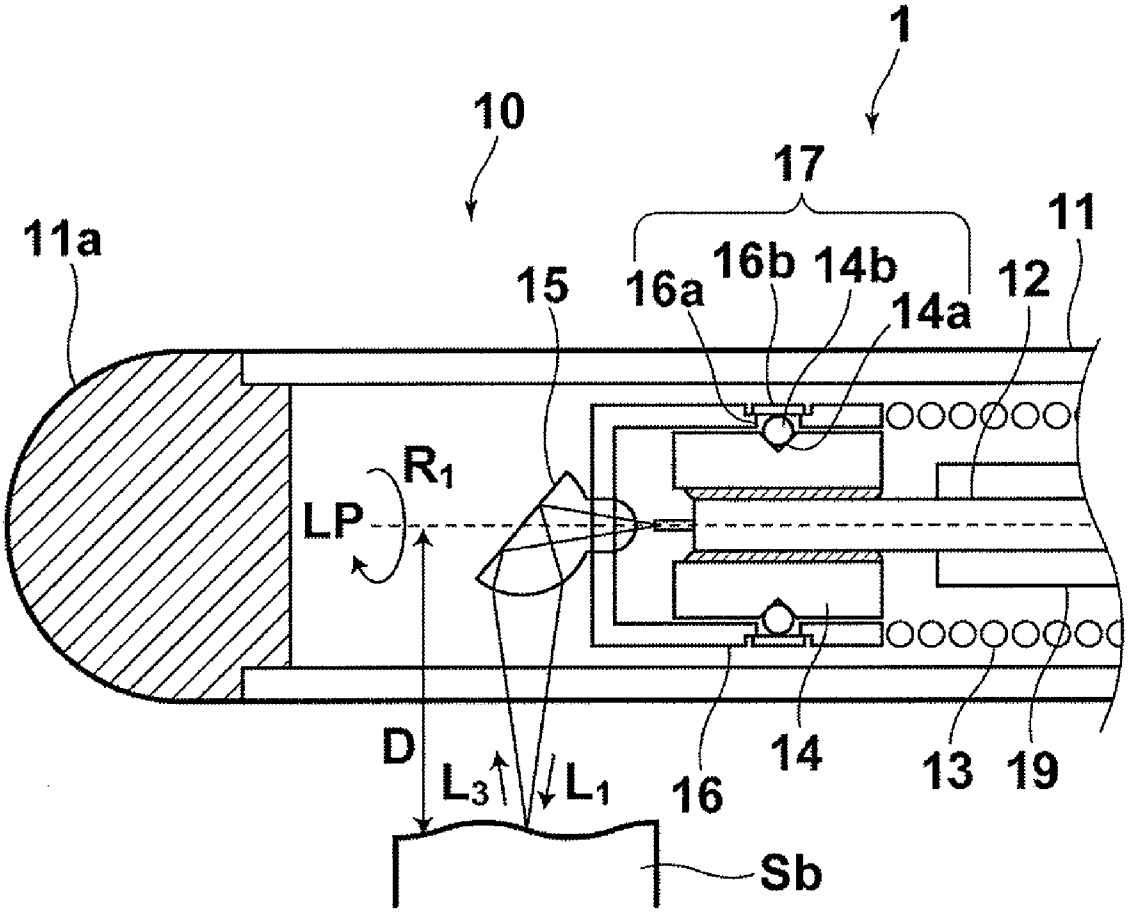


FIG.3A

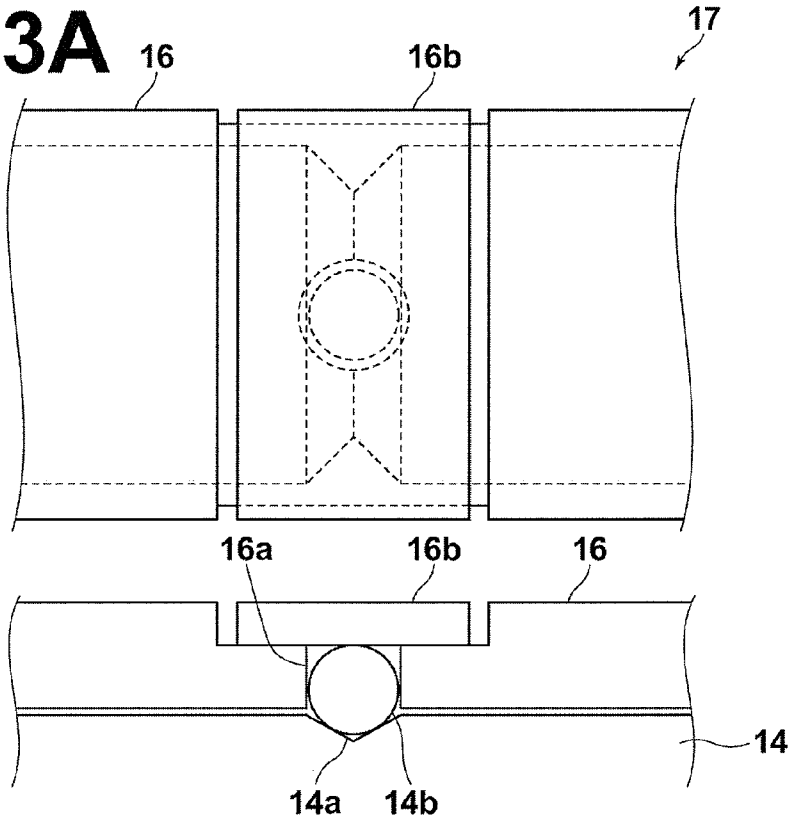


FIG.3B

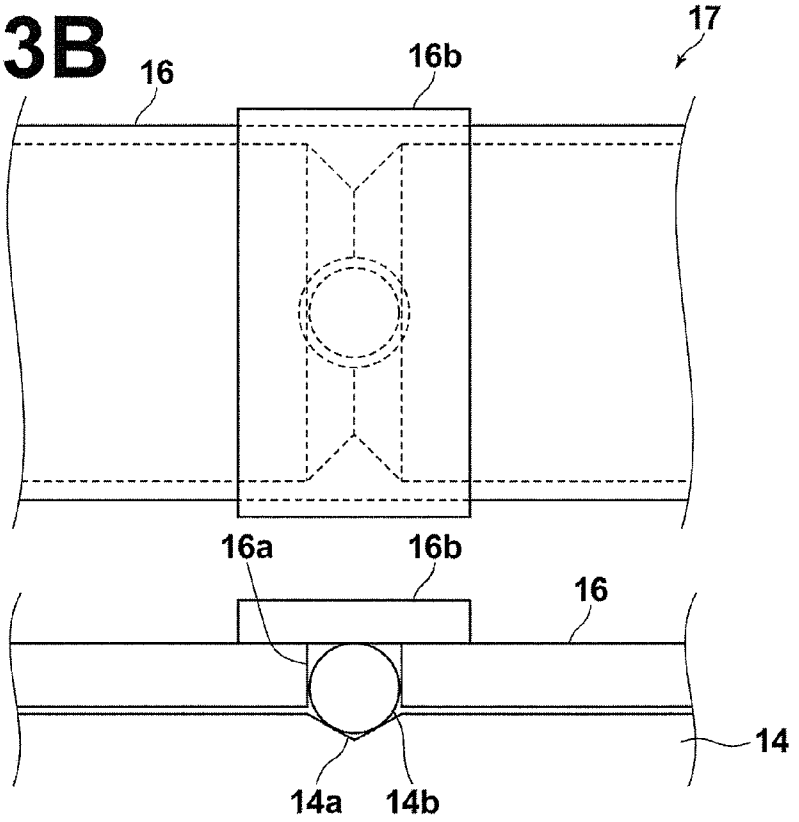


FIG.4

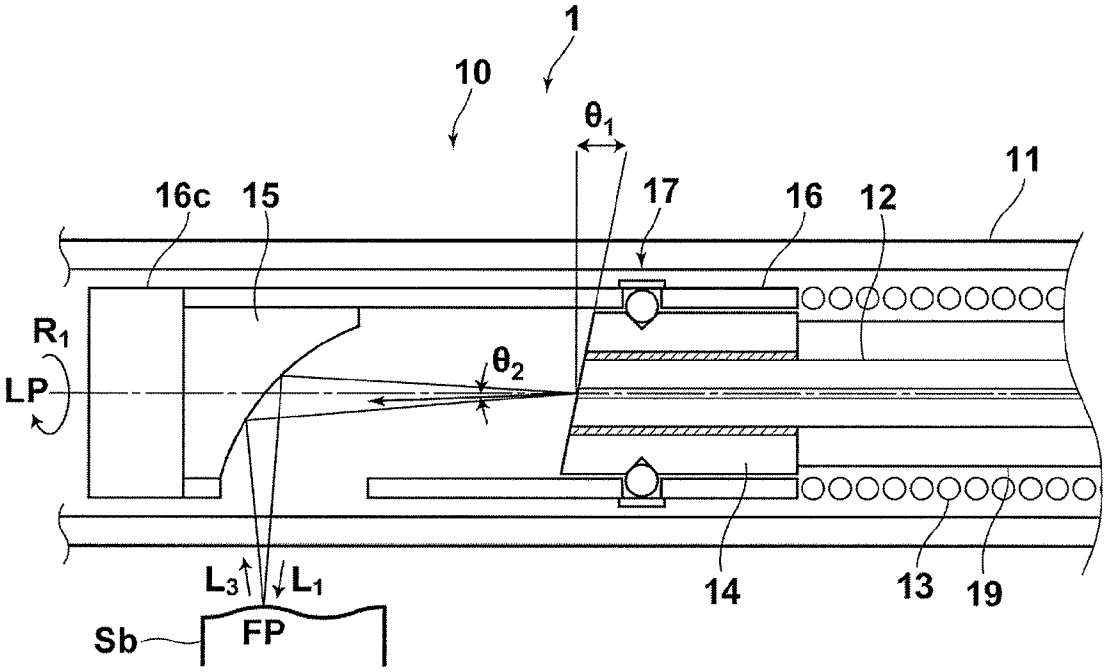


FIG.5A

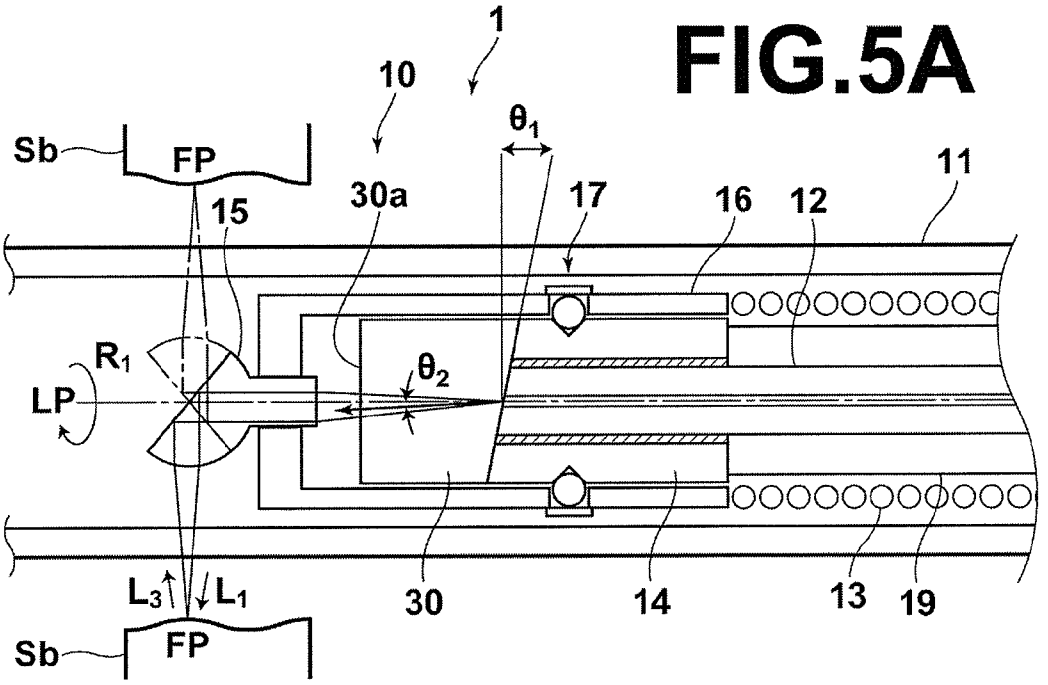

1
10
θ1
Sb
FP
15
30a
17
16
12
11
R1
LP
θ2
L3
L1
30
14
13
19
Sb
FP

FIG.5B

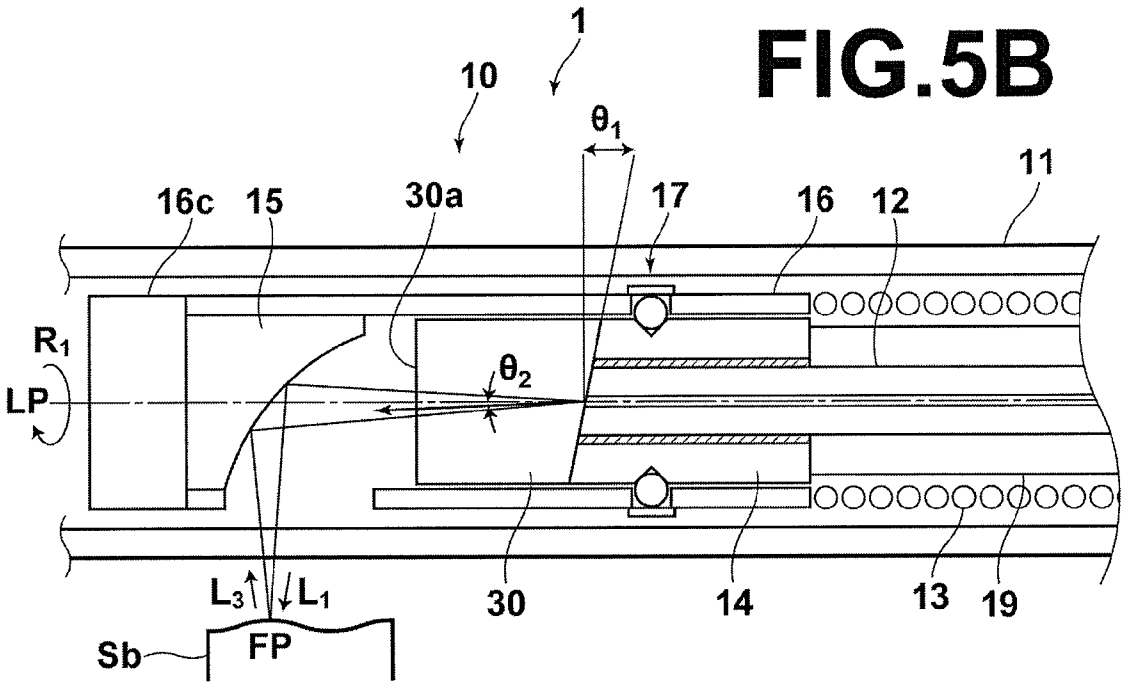

1
10
θ1
16c
15
30a
17
16
12
11
R1
LP
θ2
L3
L1
30
14
13
19
Sb
FP

FIG.6A

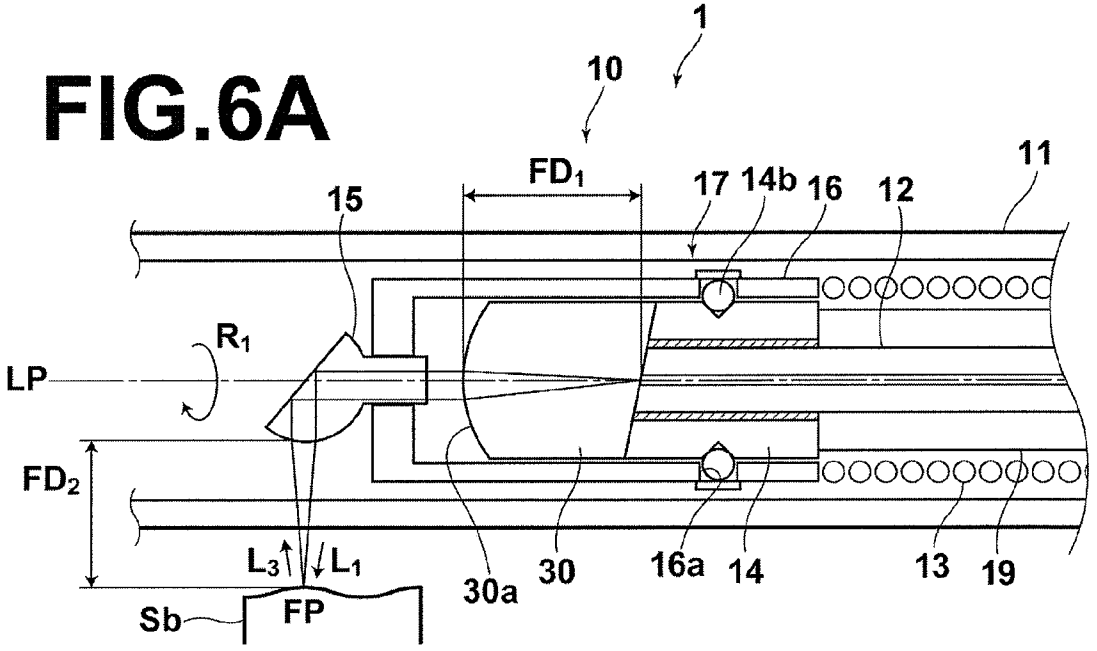

1
10
FD1
11
15
17
14b
16
12
R1
LP
FD2
L3
L1
30a
30
16a
14
13
19
Sb
FP

FIG.6B

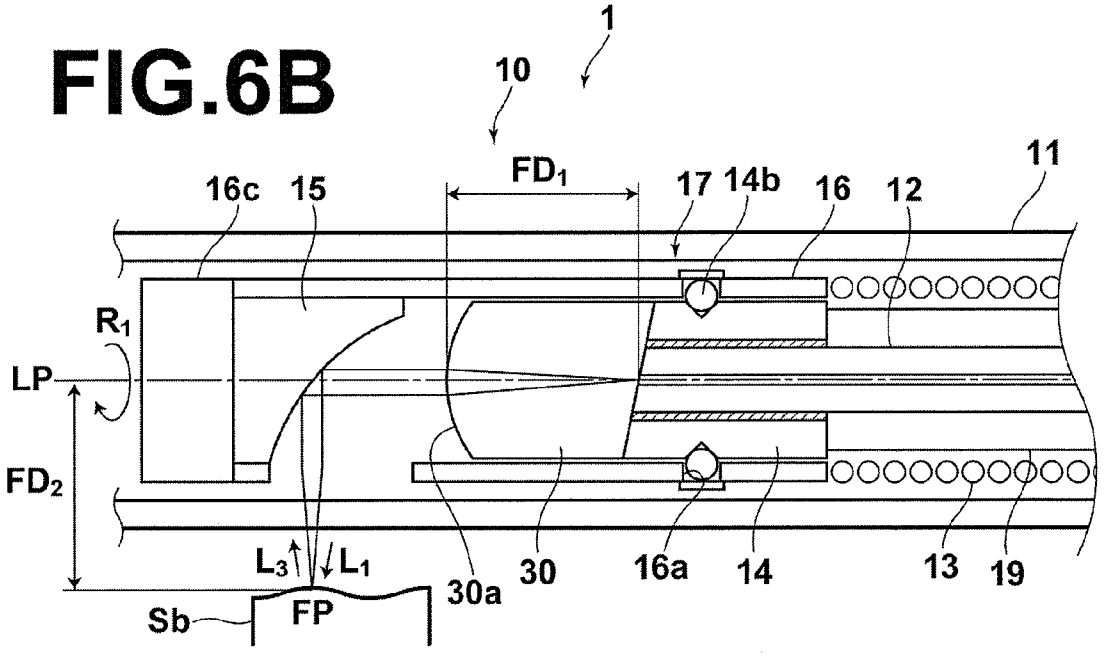

1
10
FD1
11
16c
15
17
14b
16
12
R1
LP
FD2
L3
L1
30a
30
16a
14
13
19
Sb
FP

FIG.7

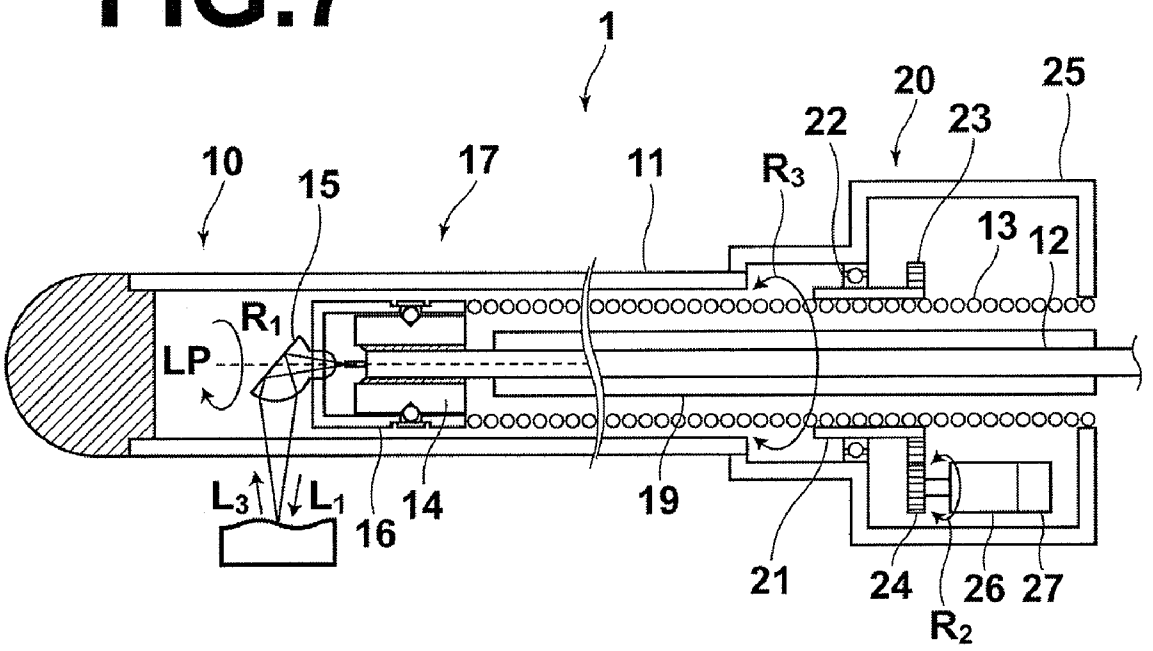


FIG.8

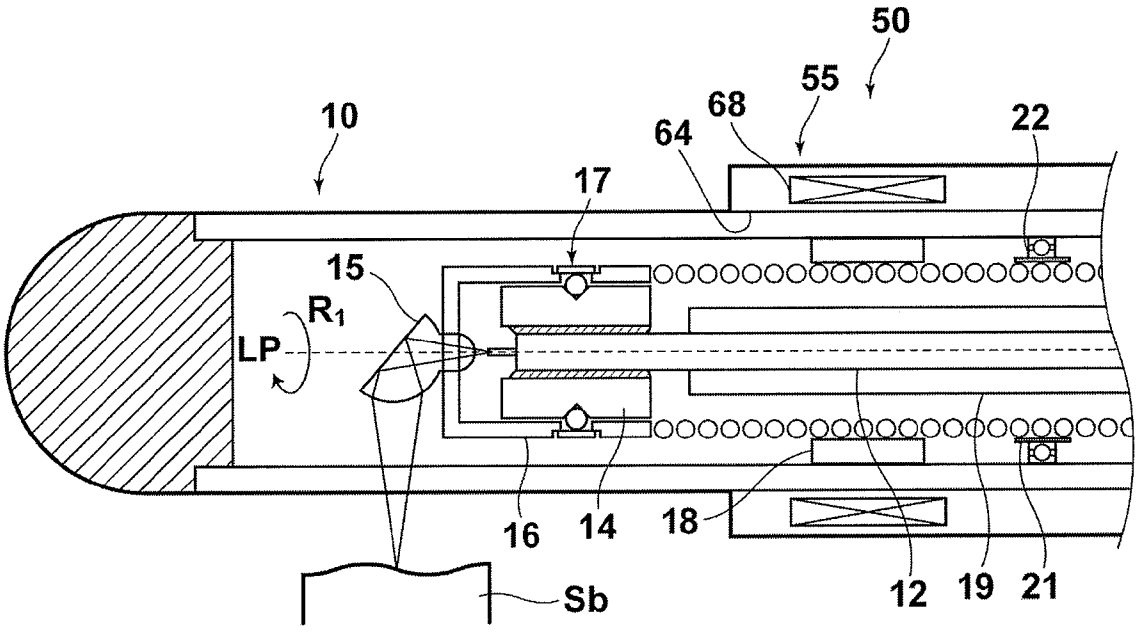


FIG.9

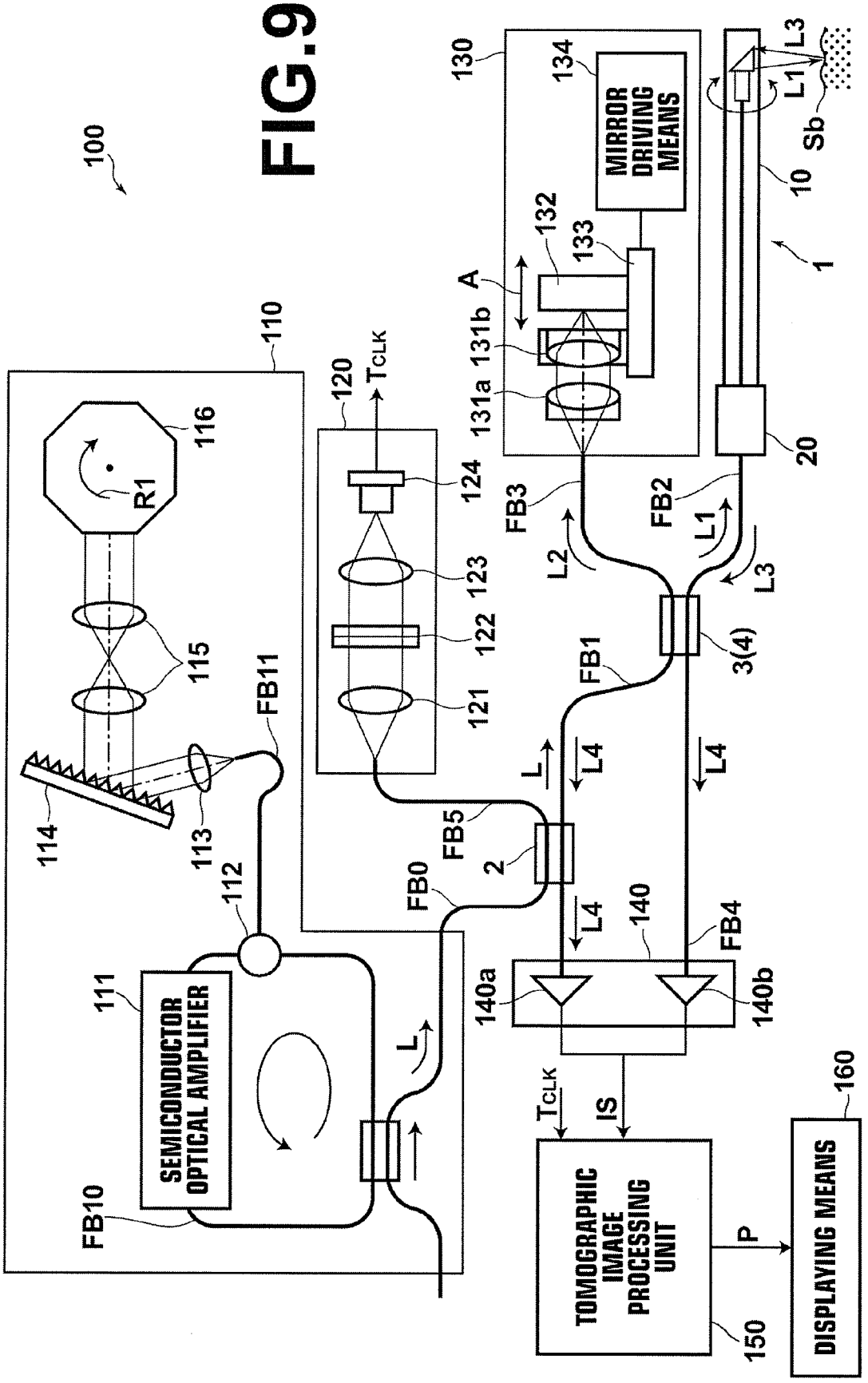

100
110
111
SEMICONDUCTOR OPTICAL AMPLIFIER
112
113
114
115
116
R1
FB10
FB11
120
TCLK
121
122
123
124
130
MIRROR DRIVING MEANS
131a
131b
132
133
134
A
1
10
20
Sb
L1
L2
L3
L4
FB0
FB1
FB2
FB3
FB4
FB5
2
3(4)
140
140a
140b
TCLK
IS
P
150
TOMOGRAPHIC IMAGE PROCESSING UNIT
160
DISPLAYING MEANS

FIG.10

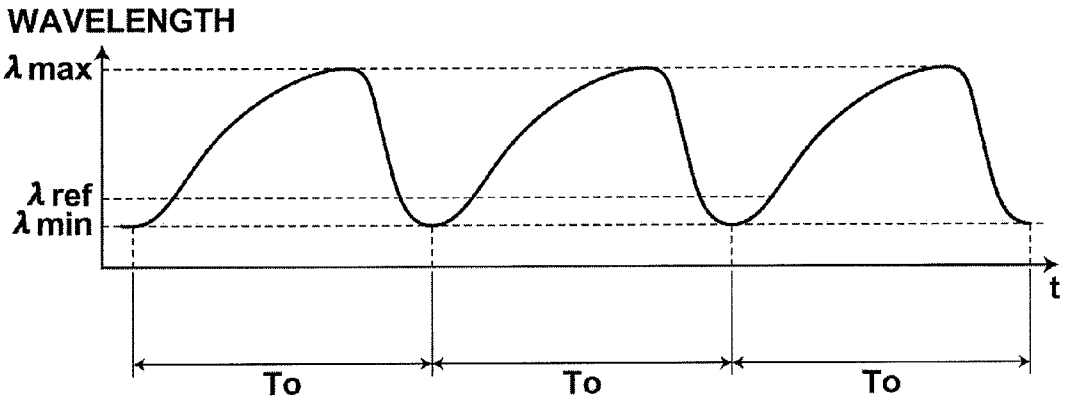


FIG.11A

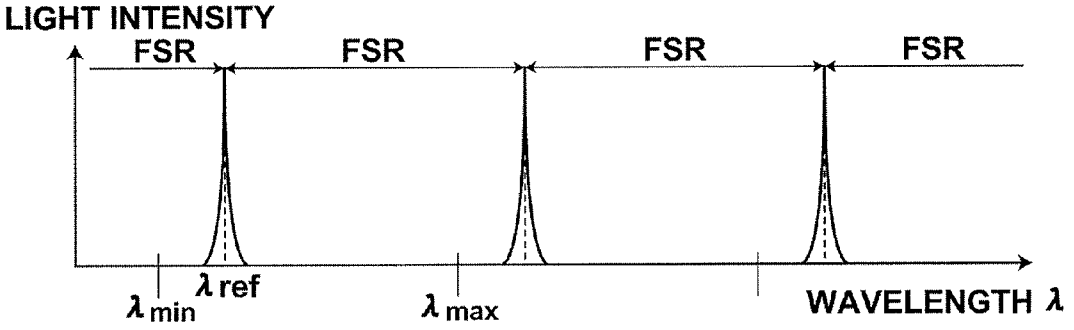


FIG.11B

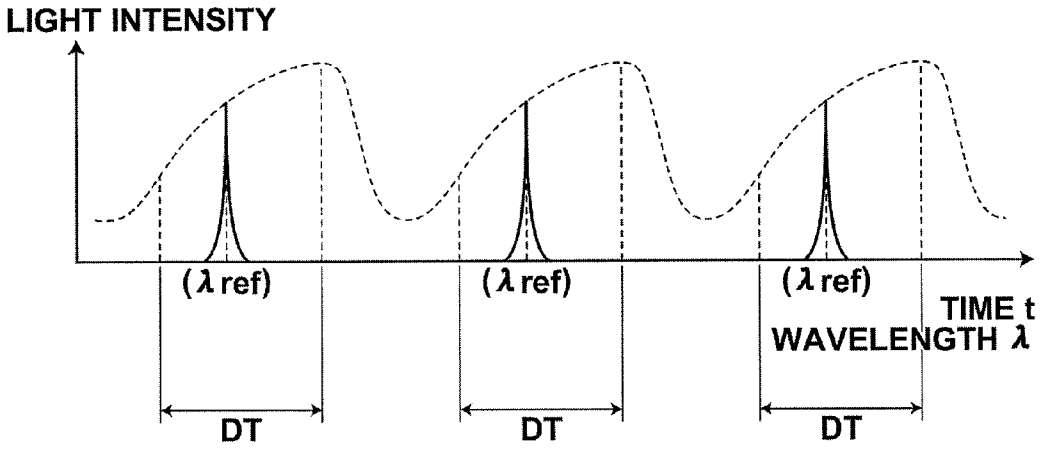


FIG.12

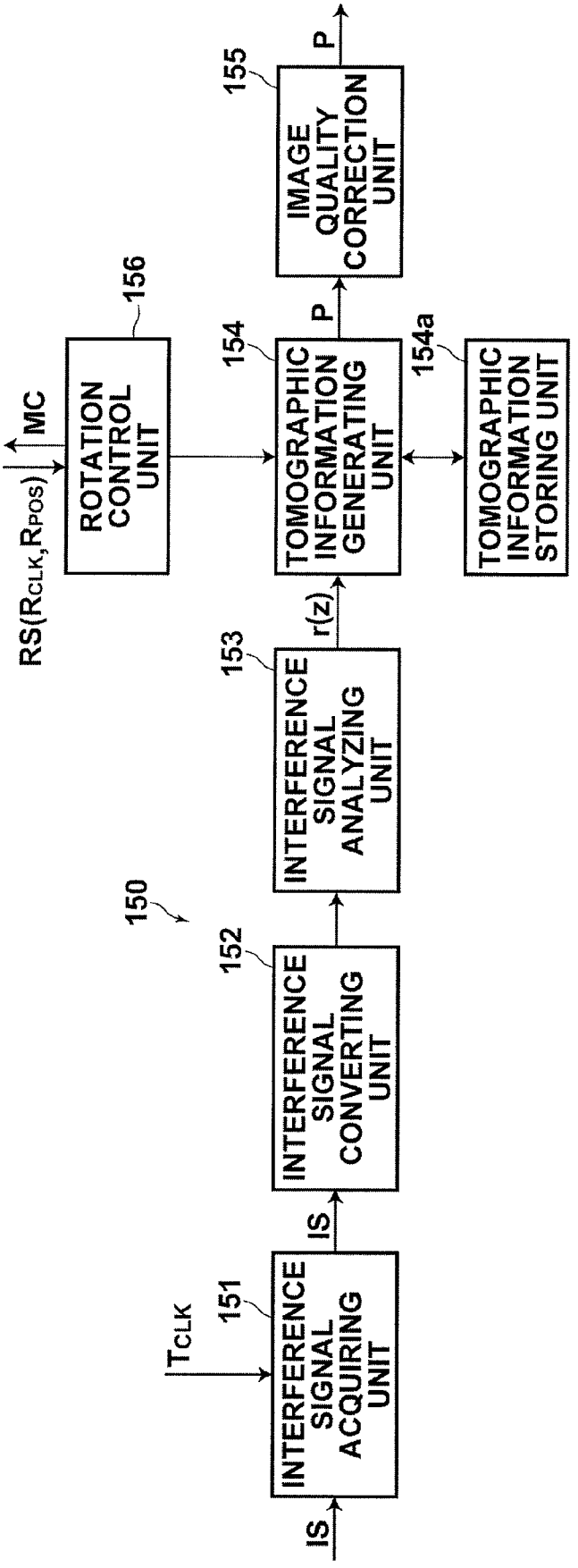

IS
INTERFERENCE SIGNAL ACQUIRING UNIT
151
T_{CLK}
IS
INTERFERENCE SIGNAL CONVERTING UNIT
152
150
INTERFERENCE SIGNAL ANALYZING UNIT
153
r(z)
TOMOGRAPHIC INFORMATION GENERATING UNIT
154
P
TOMOGRAPHIC INFORMATION STORING UNIT
154a
IMAGE QUALITY CORRECTION UNIT
155
P
ROTATION CONTROL UNIT
156
MC
$RS(R_{CLK}, R_{POS})$

FIG.13A

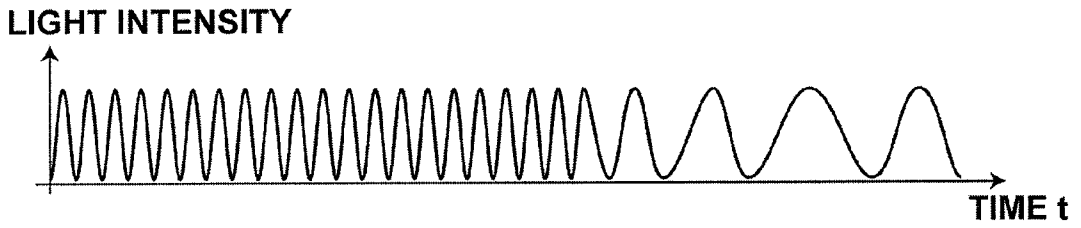


FIG.13B

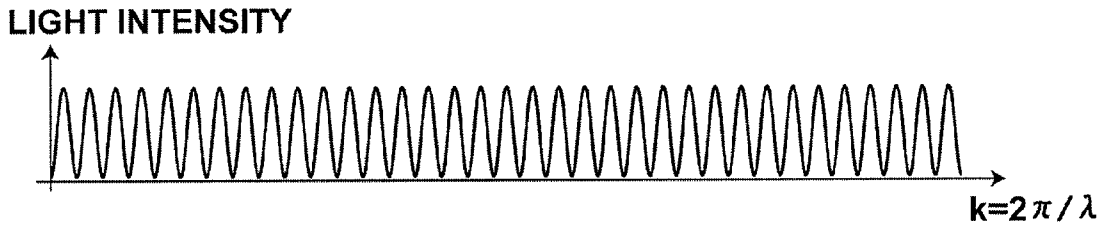


FIG.14

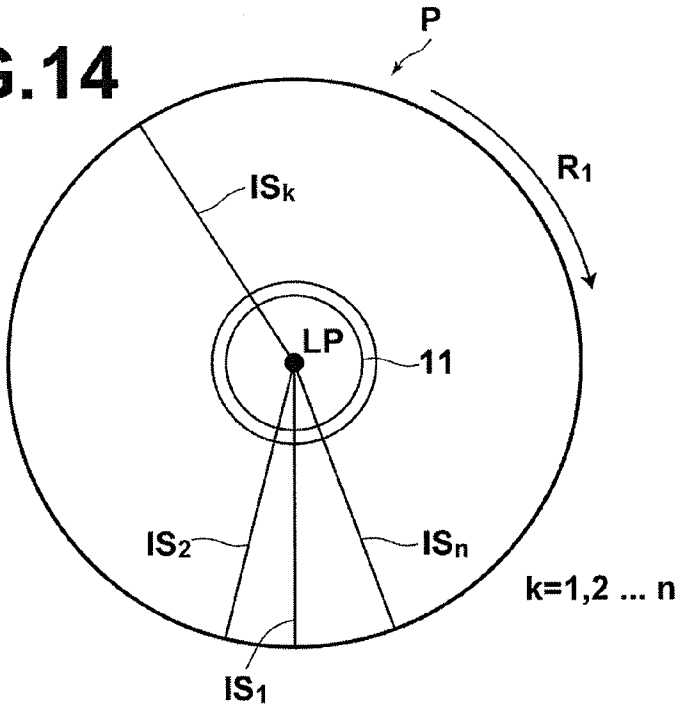


FIG.15

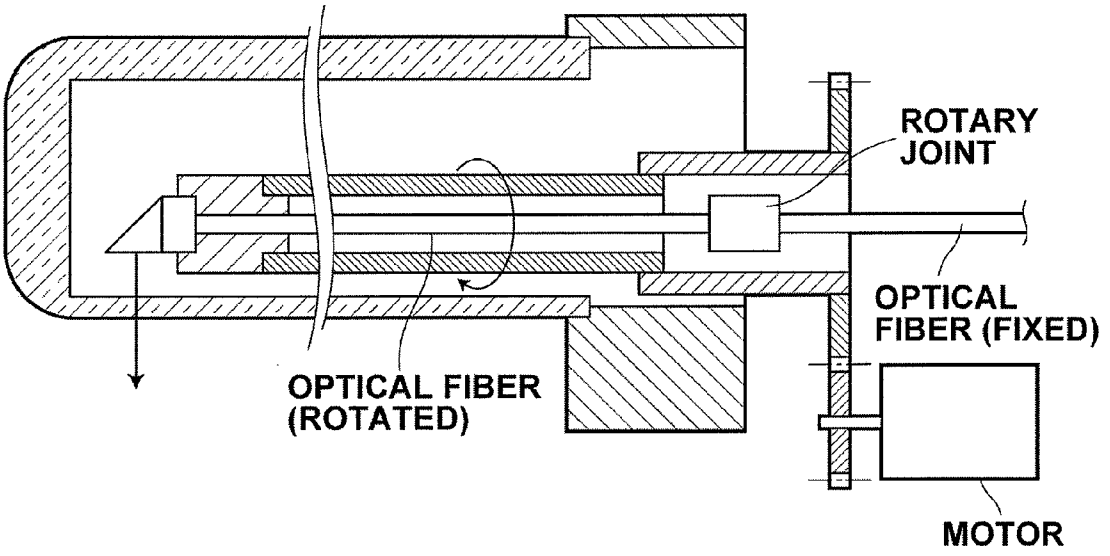
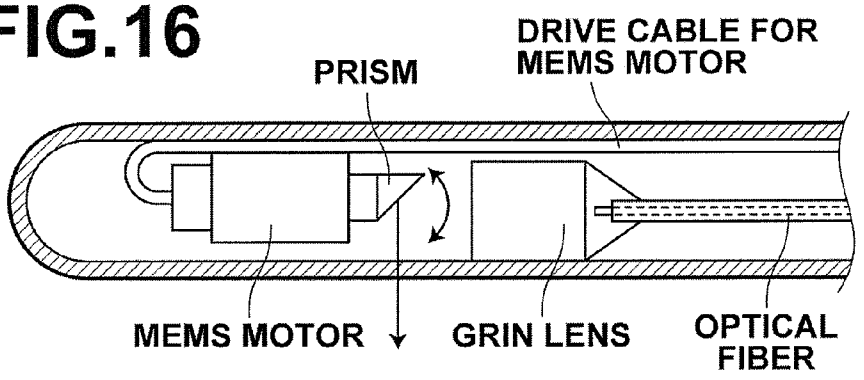

ROTARY JOINT
OPTICAL FIBER (FIXED)
OPTICAL FIBER (ROTATED)
MOTOR

FIG.16


PRISM
DRIVE CABLE FOR MEMS MOTOR
MEMS MOTOR
GRIN LENS
OPTICAL FIBER

OCT OPTICAL PROBE AND OPTICAL TOMOGRAPHY IMAGING APPARATUS

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to an OCT optical probe and an optical tomography imaging apparatus, and particularly to an OCT optical probe having a function of scanning with light in a circumferential direction with respect to the long axis of the OCT optical probe, and an optical tomography imaging apparatus that acquires an optical tomographic image of a subject to be measured through OCT (Optical Coherence Tomography) measurement using the OCT optical probe.

[0003] 2. Description of the Related Art

[0004] As a method for acquiring a tomographic image of a subject to be measured, such as a body tissue, a method using OCT measurement to acquire a tomographic image has been proposed. An OCT measurement system is one of optical interferometers. In the OCT measurement, low-coherent light emitted from a light source is divided into measurement light and reference light. The measurement light is applied to a subject to be measured, and then reflected light or backscattered light from the subject to be measured is combined with the reference light. Then, a tomographic image is acquired based on intensity of interference light formed between the reflected light and the reference light. Hereinafter, reflected light and backscattered light from the subject to be measured are collectively referred to as reflected light.

[0005] OCT measurement techniques are roughly classified into TD (Time Domain)-OCT measurement techniques and FD (Fourier Domain)-OCT measurement techniques.

[0006] In the TD-OCT measurement, the interference intensity is measured while the optical path length of the reference light is changed, thereby acquiring an intensity distribution of the reflected light corresponding to depth-wise positions in the subject to be measured.

[0007] In the FD-OCT measurement, the optical path lengths of the reference light and the signal light are fixed, and intensity of the interference light is measured for each spectral component of the light. Then, the thus acquired spectral interference intensity signals are subjected to frequency analysis, typically Fourier transformation, on a computer, thereby acquiring an intensity distribution of the reflected light corresponding to the depth-wise positions. Recently, the FD-OCT measurement is attracting attention since it does not require mechanical scanning on which the TD-OCT measurement relies, and therefore allows high speed measurement.

[0008] Typical systems that carry out the FD-OCT measurement include an SD (Spectral Domain)-OCT system and an SS (Swept Source)-OCT system.

[0009] The SD-OCT system uses wideband low-coherent light, decomposes the interference light into optical frequency components using a spectral means, measures intensity of the interference light for each optical frequency component using an arrayed photodetector, or the like, and applies Fourier transformation analysis to the thus acquired spectral interference waveform on a computer, to form a tomographic image.

[0010] The SS-OCT system uses, as a light source, a laser with optical frequency thereof swept with time, to measure temporal waveforms of signals corresponding to temporal changes of the optical frequency of the interference light, and applies Fourier transformation to the thus acquired spectral interference intensity signals on a computer, to form a tomographic image.

[0011] Further, it has been considered to combine any of the above-described optical tomography imaging systems with an endoscope for use in in-vivo measurement, and an OCT optical probe that can be inserted into a forceps channel of an endoscope has been known.

[0012] Such an OCT optical probe includes a distal end portion to be inserted in a body cavity, and a proximal end portion including a mechanism for moving light emitted from the distal end portion to scan in at least one-dimensional direction to acquire a tomographic image along a certain plane of the subject to be measured.

[0013] Japanese Patent No. 3104984 discloses an OCT optical probe that includes: a sheath to be inserted into a subject; a flexible shaft that is rotatable within the sheath about an axis extending in the longitudinal direction; an optical fiber covered with the flexible shaft; a distal optical system that deflects light emitted from the optical fiber at a substantially right angle with respect to the longitudinal direction, wherein the flexible shaft is rotated via a gear by a motor disposed at the proximal end, thereby rotating the distal optical system about the axis.

[0014] Jianping Su et al., "In vivo three-dimensional microelectromechanical endoscopic swept source optical coherence tomography", Optics Express, Vol. 15, Issue 16, pp. 10390-10396, 2007, discloses, along with the development of MEMS (Micro Electro Mechanical Systems) techniques, an OCT optical probe that includes an MEMS motor disposed within the sheath in the vicinity of the distal end of the OCT optical probe, and a distal optical system fixed to the output shaft of the MEMS motor to rotate, so that the distal optical system is rotated about the shaft.

[0015] However, the conventional OCT optical probe disclosed in Japanese Patent No. 3104984, as shown in FIG. **15**, includes a rotary joint disposed between the distal end portion inserted into a body cavity and the proximal end portion provided for moving the emitted light to scan. At the rotary joint, the optical fiber at the distal end portion side and the optical fiber at the proximal end portion side are optically coupled with the optical fibers being relatively rotated. Therefore, accuracy of the measurement may be degraded due to optical insertion loss and optical reflection loss caused, for example, by positional offset between optical axes of these fibers. Specifically, in a case where a commercially-available rotary joint is used, degradation of sensitivity due to the rotary joint is 10-20 dB.

[0016] In the OCT optical probe disclosed in Jianping Su et al., "In vivo three-dimensional microelectromechanical endoscopic swept source optical coherence tomography", Optics Express, Vol. 15, Issue 16, pp. 10390-10396, 2007, as shown in FIG. **16**, the light emitted from the distal end portion can be deflected to effect scanning without using a rotary joint. However, the MEMS motor is expensive and size reduction thereof is difficult, and therefore it may be difficult to insert the MEMS motor into the inner diameter of the forceps channel of the endoscope. Further, in order to prevent electrical shock to a human body, it is necessary to insulate a driving power supply to the MEMS motor at the distal end portion. In addition, a drive cable for the MEMS motor may block the light emitted from the distal end portion and affect image acquisition.

SUMMARY OF THE INVENTION

[0017] In view of the above-described circumstances, the present invention is directed to providing an OCT optical probe and an optical tomography imaging apparatus using the OCT optical probe, that can inexpensively and safely eliminate the prior art problem of degradation in measurement

accuracy due to optical insertion loss and optical reflection loss caused at optical coupling at a rotary joint disposed between an optical fiber at a distal end portion side and an optical fiber at a proximal end portion.

[0018] An OCT optical probe according to the invention includes: a substantially cylindrical sheath to be inserted into a subject, the sheath having an internal space; an optical fiber disposed in the internal space of the sheath along the longitudinal direction of the sheath; a rotatably-supporting portion integrally fixed to the optical fiber in the vicinity of a distal end of the optical fiber; a distal optical system to deflect light emitted from the distal end of the optical fiber toward the subject; a holding portion to hold the distal optical system such that the distal optical system is rotatably supported by the rotatably-supporting portion; and a flexible shaft covering the optical fiber in the internal space of the sheath, wherein the holding portion is fixed to a distal end of the flexible shaft. The term "substantially cylindrical" refers to a shape that may not necessarily be strictly cylindrical about a straight axis from one end to the other end, and the sheath may include a gently curved shape, such as a semispherical shape, at the distal end thereof. Further, the cross-sectional shape of the sheath may not necessarily be a mathematically-strict circle, and may be ellipsoidal, or the like. The "distal end" of the flexible shaft may not necessarily refer to the distal end of the flexible shaft, and may also refer to a position in the vicinity of the distal end.

[0019] The rotatably-supporting portion of the OCT optical probe according to the invention may include a bearing portion to rotatably support the holding portion.

[0020] Further, a fiber sheath to cover the optical fiber along the longitudinal direction may be provided between the optical fiber and the flexible shaft.

[0021] The distal end of the optical fiber of the OCT optical probe according to the invention may have an end face that is inclined by a predetermined angle with respect to a plane perpendicular to an optical axis of the optical fiber.

[0022] The OCT optical probe according to the invention may further include a cover glass, the proximal end of the cover glass may closely contact the distal end of the optical fiber, and the distal end of the cover glass may have a flat end face that is perpendicular to the optical axis.

[0023] The OCT optical probe according to the invention may further include a cover glass, the proximal end of the cover glass may closely contact the distal end of the optical fiber, and the distal end of the cover glass may have a convex end face that is adapted to collimate the light emitted from the distal end of the cover glass to be parallel to the optical axis.

[0024] An optical tomography imaging apparatus according to the invention is formed by an optical tomography imaging apparatus using any of the above-described measuring techniques, which employs the OCT optical probe according to the invention. Namely, the optical tomography imaging apparatus according to the invention includes: a light source unit to emit light; a light dividing unit to divide the light emitted from the light source unit into measurement light and reference light; an irradiation optical system to irradiate a subject to be measured with the measurement light; a combining unit to combine the reference light with reflected light of the measurement light reflected from the subject to be measured when the measurement light is applied to the subject; an interference light detecting unit to detect interference light formed between the combined reflected light and reference light; and a tomographic image processing unit to detect reflection intensity at a plurality of depth-wise positions in the subject to be measured based on frequency and intensity of the detected interference light, and to acquire a tomographic image of the subject to be measured based on the intensity of the reflected light at each of the depth-wise positions, wherein the irradiation optical system comprises the OCT optical probe of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] FIG. **1** is a perspective view illustrating the entire portion of an optical tomography imaging apparatus, to which an OCT optical probe **1** of the invention is applied,

[0026] FIG. **2** illustrates a distal end portion **10** of the OCT optical probe **1** of the invention,

[0027] FIG. **3**A illustrates a first embodiment of a bearing portion **17** of the OCT optical probe **1** of the invention,

[0028] FIG. **3**B illustrates a second embodiment of the bearing portion **17** of the OCT optical probe **1** of the invention,

[0029] FIG. **4** illustrates the OCT optical probe **1** of the invention including a reflecting member,

[0030] FIGS. **5**A and **5**B illustrate the OCT optical probe **1** of the invention including a cover glass,

[0031] FIGS. **6**A and **6**B illustrate the OCT optical probe **1** of the invention including a cover glass with a convex distal end face,

[0032] FIG. **7** illustrates a proximal end portion **20** of the OCT optical probe **1** of the invention,

[0033] FIG. **8** illustrates pivot movement of the proximal end portion **20** of the OCT optical probe **1** of the invention,

[0034] FIG. **9** is a schematic structural diagram of an optical tomography imaging apparatus **100**, to which the OCT optical probe **1** of the invention is applied,

[0035] FIG. **10** illustrates swept wavelength of light emitted from a light source unit **110**,

[0036] FIGS. **11**A and **11**B illustrate a period clock signal generated by a period clock generating unit **120**,

[0037] FIG. **12** is a schematic structural diagram of a tomographic image processing unit **150**,

[0038] FIG. **13**A illustrates an interference signal IS inputted to an interference signal acquiring unit **151**,

[0039] FIG. **13**B illustrates a rearranged interference signal IS,

[0040] FIG. **14** illustrates a tomographic image P generated by a tomographic information generating unit **154**,

[0041] FIG. **15** is a schematic diagram illustrating a conventional OCT optical probe, and

[0042] FIG. **16** is a schematic diagram illustrating an OCT optical probe employing an MEMS motor.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0043] Hereinafter, embodiments of the present invention will be described with reference to the drawings. First, outline of an optical tomography imaging apparatus is described. FIG. **1** is a perspective view illustrating the entire portion of the optical tomography imaging apparatus, to which an OCT optical probe **1** of the invention is applied.

[0044] The optical tomography imaging apparatus includes: an endoscope **50** including the OCT optical probe **1**; a light source unit **51**, to which the endoscope **50** is connected; a video processor **52**; an optical tomography processing unit **53**; and a monitor **54** connected to the video processor **52**.

[0045] The light source unit **51** applies measurement light L**1** to a portion of a subject to be measured Sb, from which a tomographic image P is acquired, as described later.

[0046] The endoscope **50** includes a flexible and elongated insert portion **55**, a manipulation unit **56** joined to the proxi-

mal end of the insert portion **55**, and a universal code **57** extending from a side of the manipulation unit **56**. A light source connector **58** is disposed at the end of the universal code **57**, and the light source connector **58** is removably connected to the light source unit **51**. A signal cable **59** extends from the light source connector **58**, and a signal connector **60**, which is removably connected to the video processor **52**, is disposed at the end of the signal cable **59**.

[0047] The insert portion **55** is inserted, for example, into a body cavity, and is used for observing the subject to be measured Sb. The distal end portion of the insert portion **55** is bendable, and a manipulation knob **61** for manipulating the distal end portion of the insert portion **55** to bend is provided at the manipulation unit **56**. A forceps channel **64**, which is a conduit shown by the dashed line in the drawing, is formed in the insert portion **55** along the longitudinal direction thereof, so that the OCT optical probe **1** or a treatment tool such as a forceps can be inserted through the forceps channel **64**. One end of the forceps channel **64** is open at the distal end of the insert portion **55** to form a distal end opening **64***a*. The other end of the forceps channel **64** forms a forceps insertion port **64***b*, which is located above the manipulation unit **56**. The OCT optical probe **1** is inserted through the forceps insertion port **64***b* and through the forceps channel **64**, and the distal end of the OCT optical probe **1** is projected from the distal end opening **64***a*, so that the measurement light L**1** can be applied to the subject to be measured Sb. It should be noted that, although not shown in the drawing, the distal end of the insert portion **55** is provided with an observation window used for observing the subject to be measured Sb, an illumination window through which the illumination light is applied, air and water supply nozzles used for removing dirt, and the like.

[0048] The OCT optical probe **1** includes a flexible and long distal end portion **10**, a proximal end portion **20** joined to the proximal end of the distal end portion **10**, and an optical fiber **12**.

[0049] The distal end portion **10** is inserted through the forceps channel **64**, which is shown by the dashed line in the drawing, to be inserted into a body cavity, as described above. The distal end portion **10** has a length of around 3 m.

[0050] One end of the optical fiber **12** is removably connected to the optical tomography processing unit **53** via an optical tomography connector **62**, and the other end of the optical fiber **12** is inserted through the proximal end portion **20** and the distal end portion **10** to extend to an area in the vicinity of the distal end of the distal end portion **10**.

[0051] Now, the OCT optical probe **1** of the invention is described in detail.

[0052] FIG. **2** illustrates an embodiment of the distal end portion **10** of the OCT optical probe **1**. The distal end portion **10** of the OCT optical probe **1** includes: a substantially cylindrical flexible sheath **11**; the optical fiber **12** contained in and extending along the longitudinal direction of the sheath **11**; a rotatably-supporting portion **14** integrally fixed to the optical fiber **12** in the vicinity of the distal end of the optical fiber **12**; a distal optical system **15** for collecting and directing the light emitted from the distal end of the optical fiber **12** to the subject; a holding portion **16** for holding the distal optical system **15** such that the distal optical system **15** is rotatably supported by the rotatably-supporting portion **14**; and a flexible shaft **13** covering the optical fiber **12**. The distal end of the sheath **11** is closed with a cap **11***a*.

[0053] The optical fiber **12** is inserted into and fixed to the rotatably-supporting portion **14** with an adhesive. The measurement light L**1** emitted from the distal end of the optical fiber **12** enters the distal optical system **15**, and reflected light L**3** enters the distal end of the optical fiber **12** via the distal optical system **15**.

[0054] Preventing unnecessary reflected light from the optical fiber **12** and distal optical system **15** can advantageously improve sensitivity to the interference signal. For example, the amount of reflected light at the distal end of the optical fiber **12** can be reduced by cutting the distal end of the optical fiber **12** obliquely. Further, the amount of reflected light re-entering the optical fiber **12** can be reduced by providing a curved light input surface at the distal optical system **15**. In addition, a cover glass, which has a refractive index matched with the optical fiber **12** and has a distal end face that is flat and perpendicular to an optical axis LP, may be provided between the distal end of the optical fiber **12** and the light entrance surface of the distal optical system **15**, and the proximal end of the cover glass may be closely bonded to the distal end of the optical fiber **12** with an adhesive. That is, according to this method, reflection at the distal end the optical fiber **12** can be reduced by refraction matching and re-entrance of the reflected light at the distal end of the cover glass into the optical fiber **12** can be reduced by spread of the measurement light L**1**, thereby reducing the amount of the light re-entering into the optical fiber **12**. The distal end of the cover glass may be provided with an AR coating. This method is applicable to either of the cases where the distal end of the optical fiber **12** is flat, and the distal end of the optical fiber **12** is obliquely cut. It should be noted that the structure for reducing the amount of the reflected light usable in the invention is not limited to those described above.

[0055] The distal optical system **15** has a substantially spherical shape. The distal optical system **15** deflects the measurement light L**1** emitted from the optical fiber **12** and collects and directs the measurement light L**1** toward the subject to be measured Sb. The distal optical system **15** also deflects the reflected light L**3** from the subject to be measured Sb and collects and directs the reflected light L**3** toward the optical fiber **12**. The focal length (focal position) of the distal optical system **15** is formed, for example, at a distance D=around 3 mm in the radial direction of the sheath **11** from the optical axis LP of the optical fiber **12**. The measurement light L**1** emitted from the distal optical system **15** is inclined by an angle of about seven degrees from a direction perpendicular to the optical axis LP. The distal optical system **15** is fixed to the holding portion **16** with an adhesive.

[0056] The holding portion **16** is fitted around the rotatably-supporting portion **14** such that a plurality of bearing balls **14***b* in a groove **14***a* formed in the outer circumferential surface of the rotatably-supporting portion **14** are respectively positioned in a plurality of holes **16***a* formed in the inner circumferential surface of the holding portion **16**, to form a bearing portion **17**. Thus, the holding portion **16** is held rotatably about the optical axis LP relative to the rotatably-supporting portion **14**.

[0057] The bearing portion **17** is described in detail. FIG. **3**A illustrates a first embodiment of the bearing portion **17** of the OCT optical probe **1**, and FIG. **3**B illustrates a second embodiment of the bearing portion **17** of the OCT optical probe **1**. FIGS. **3**A and **3**B each shows a side sectional view (at the bottom in the drawing) and a front view (at the top in the drawing) of the bearing portion **17**. In the first embodiment, the bearing balls **14***b* are prevented from falling off by a ring **16***b* being fitted around the groove formed in the outer circumference of the holding portion **16**, as shown in FIG. **3**A. The ring **16***b* may not necessary be completely fixed to the holding portion **16**, and may be rotatable within the groove. Further, the ring **16***b* may have a retainer structure that pre-

vents collision between the adjacent bearing balls **14***b*. In the second embodiment shown in FIG. **3**B, if the diameter of the bearing balls **14***b* is relatively large with respect to the thickness of the holding portion **16**, the bearing balls **14***b* can be prevented from falling off by fixing the inner circumference of the ring **16***b* to the outer circumference of holding portion **16** with an adhesive, or the like. If the bearing balls **14***b* project from the outer circumference surface of the holding portion **16**, a groove may be provided in the inner circumference surface of the ring **16***b*. It should be noted that, in the first and second embodiments, the ring **16***b* should not hinder the rotation of the bearing balls **14***b*. Further, the bearing portion **17** may use an oilless bush, or the like, in stead of the bearing balls **14***b* at the holding portion **16**, so that the holding portion **16** slidably rotates about the optical axis LP relative to the rotatably-supporting portion **14**.

[0058] Referring again to FIG. **2**, the flexible shaft **13** is formed by a closed coil spring of a metal wire that is closely wound in a spiral form. The distal end of the flexible shaft **13** is fixed to the holding portion **16**, so that the flexible shaft **13** and the holding portion **16** are rotatable about the optical axis LP relative to the rotatably-supporting portion **14**. It should be noted that the holding portion **16** may not necessary be fixed to the strictly distal end of the flexible shaft **13**, and may be fixed to a portion of the flexible shaft **13** in the vicinity of the distal end thereof. Further, a fiber sheath **19** is provided between the optical fiber **12** and the flexible shaft **13** to reduce rotation of the optical fiber **12** about the optical axis LP due to a frictional force from the rotating flexible shaft **13**. In addition, by bonding the fiber sheath **19** to the rotatably-supporting portion **14**, durability against frictional wear due to the rotating flexible shaft **13** can be increased. It should be noted that, in stead of providing the fiber sheath **19**, the flexible shaft **13** may have a double shaft structure formed by an outer shaft and an inner shaft which are independent from each other.

[0059] Now, another embodiment of the distal optical system is described. FIG. **4** illustrates the OCT optical probe **1** including a reflecting member. It should be noted that components shown in the drawing which are the same as those in the previous embodiment are designated by the same reference numerals, and explanations thereof are omitted.

[0060] In this embodiment, the distal optical system is formed by a reflecting member **15** having a concave surface, and is fixed to the holding portion **16**. Although the holding member **16** shown in FIG. **4** is formed by two parts in view of convenience of manufacture, this is not intended to limit the invention. Namely, a cap **16***c* for holding the reflecting member **15** is fitted on the holding member **16**. The concave surface deflects the measurement light L**1** emitted from the optical fiber **12** and collects and directs the measurement light L**1** toward the subject to be measured Sb. Further, the concave surface deflects the reflected light L**3** from the subject to be measured Sb and collects and directs the reflected light L**3** toward the optical fiber **12**. In this embodiment, the measurement light L**1** emitted from the optical fiber **12** and applied to the subject to be measured Sb is reflected only by the concave surface, and therefore, reflection surfaces that generate unnecessary reflected light can be reduced.

[0061] Further, in the embodiment shown in FIG. **4**, the end face of the rotatably-supporting portion **14** near the reflecting member **15** is polished together with the distal end of the optical fiber **12** so that the distal end face of the optical fiber **12** has a predetermined inclination angle θ**1** with respect to the plane perpendicular to the optical axis LP. In this manner, unnecessary reflected light at the distal end of the optical fiber **12** can be reduced, as described above. The inclination angle θ**1** is, for example, seven degrees based on APC (Angled PC) polishing standard, however, this is not intended to limit the invention. Further, polishing the optical fiber **12** together with the rotatably-supporting portion **14** is for convenience of manufacture, and this is not intended to limit the invention. It should be noted that inclining the distal end face of the optical fiber **12** with respect to the plane perpendicular to the optical axis LP is also applicable to the embodiment shown in FIG. **2**, in which the substantially spherical distal optical system **15** is employed.

[0062] FIGS. **5**A and **5**B illustrate the OCT optical probe **1** including a cover glass. In the case where the distal end face of the optical fiber **12** has the inclination angle θ**1** with respect to the plane perpendicular to the optical axis LP, the direction in which the measurement light L**1** is emitted has an emission angle θ**2** with respect to the optical axis LP. In general, if the inclination angle θ**1** is seven degrees, the emission angle is four degrees. Therefore, as the holding portion **16** rotates, as shown in FIG. **5**A, a focal position FP of the measurement light L**1** may be shifted in the direction of the optical axis LP between when the measurement light L**1** irradiates the upper portion of the subject to be measured Sb in the drawing and when the measurement light L**1** irradiates the lower portion of the subject to be measured Sb in the drawing.

[0063] As shown in FIGS. **5**A and **5**B, the cover glass **30** has a refractive index matched with that of the optical fiber **12**, and is positioned between the distal end of the optical fiber **12** and the substantially spherical distal optical system **15** or the reflecting member **15**. Further, the cover glass **30** is held by the rotatably-supporting portion **14**, the proximal end of the cover glass **30** is bonded to the distal end of the optical fiber **12**, and the distal end **30***a* of the cover glass **30** has a flat end face that is perpendicular to the optical axis. It should be noted that the distal end **30***a* of the cover glass may be provided with an AR coating. By providing the cover glass having the refractive index matched with the optical fiber **12**, the emission angle **92** of the measurement light L**1** can be reduced from that in a case where the measurement light L**1** is guided in the air without using the cover glass **30**. Specifically, by providing the cover glass **30**, the emission angle θ**2** can be reduced to substantially 0 degree.

[0064] FIGS. **6**A and **6**B illustrate the OCT optical probe **1** including a cover glass with a convex distal end face. Due to a clearance between the bearing balls **14***b* and the holes **16***a* formed in the outer circumference surface of the holding portion **16**, the holding portion **16** moves in the direction of the optical axis LP relatively to the rotatably-supporting portion **14**. Therefore, a distance between the distal end of the optical fiber **12** and the light entrance surface of the distal optical system **15** or the reflecting member **15** may fluctuate, and this may cause fluctuation of the spot size of the measurement light L**1** at the focal position FP. Specifically, the clearance between the bearing balls **14***b* and the holes **16***a* is around 100 μm, for example.

[0065] In the embodiment shown in FIGS. **6**A and **6**B, the convex face of the distal end **30***a* of the cover glass **30** serves to collimate the measurement light L**1** emitted from the distal end **30***a* to be parallel to the optical axis LP. Thus, the spot size of the measurement light L**1** at the focal position FP is determined by a ratio between a distance FD**1** from the distal end of the optical fiber **12** to the convex surface **30***a* and a distance FD**2** from the distal optical system **15** or reflecting member **15** to the focal position FP, and therefore the spot size at the focal position FP is less susceptible to the fluctuation of the distance from the distal end of the optical fiber **12** to the light entrance surface of the distal optical system **15** or the reflecting member **15**. In a case where the cover glass **30** is formed by a lens with distributed refractive index, the distance FD**1**

from the distal end of the optical fiber **12** to the convex surface **30***a* can be made shorter than that in a case where a lens with uniform refractive index is used.

[0066] Now, a first embodiment of the OCT optical probe **1** of the invention is described. FIG. **7** illustrates the first embodiment of the OCT optical probe **1**.

[0067] In the first embodiment, the sheath **11** is fitted in and fixed to a housing **25**, and a shaft bearing **22** is disposed in the housing **25**. The flexible shaft **13** is fixed to a shaft supporting member **21**, and the shaft supporting member **21** is held to be rotatable relative to the housing **25** via the shaft bearing **22**. The optical fiber **12** is fixed to the housing **25**. A driven gear wheel **23** is fixed to the outer circumference of the shaft supporting member **21**, and a driving gear wheel **24** is disposed to mesh with the driven gear wheel **23**. The driving gear wheel **24** is fixed to the output shaft of the motor **26**, which is disposed in the housing **25**. The motor **26** includes an encoder **27** for detecting a rotational angle. A control signal MC fed to the motor **26** and a rotation signal RS fed from the encoder **27** are transmitted via a control cable (not shown). Specifically, the rotation signal RS includes a rotation clock signal RCLK, which is generated for each rotation of the motor **26**, and a rotational angle signal R_{pos}.

[0068] Now, operation of the first embodiment is described. As the motor **26** rotates in the direction of arrow R**2**, the shaft supporting member **21** and the flexible shaft **13** fixed to the shaft supporting member **21** rotate, via the driven gear wheel **23** and the driving gear wheel **24**, relative to the housing **25** in the direction of arrow R**3**. This also makes the distal optical system **15**, which is fixed to the holding portion **16** at the distal end of the flexible shaft **13**, rotate via the bearing portion **17** relatively to the rotatably-supporting portion **14** about the optical axis LP in the direction of arrow R**1**. Therefore, the OCT optical probe **1** applies the measurement light L**1** emitted from the distal optical system **15** to the subject to be measured Sb with moving the measurement light L**1** to scan in the direction of arrow R**1** about the optical axis LP, i.e., along the circumferential direction of the sheath **11**. Specifically, the rotational frequency is around 10-30 Hz, however, this is not intended to limit the invention. If the processing speed of a tomographic image processing unit **150**, which will be described later, is high, a higher rotation speed can be used. The rotational frequency may not necessarily be fixed, and may be changed depending on the speed of movement of or the resolution required for the subject to be measured Sb. Specifically, a higher rotation speed maybe used for a subject to be measured Sb that has a high speed of movement or that does not require a high resolution, and a lower rotation speed may be used for a subject to be measured Sb that has a low speed of movement or that requires a high resolution.

[0069] Further, the distal optical system **15** can be pivoted about the optical axis LP within a predetermined range of angle by controlling the direction of rotation of the motor **26** according to the control signal MC based on the rotation signal RS. The range of pivot angle can be set to a desirable range based on the shape of the subject to be measured Sb. For example, for a subject to be measured Sb having a cylindrical shape, such as a bronchial tube, the range of pivot angle may be substantially 360 degrees about the longitudinal axis, and for a subject to be measured Sb having a flat shape, such as stomach wall, the range of pivot angle may be around 180 degrees about the longitudinal axis, however, this is not intended to limit the invention. The frequency of pivot is the same as the above-described frequency of rotation. Further, if the frequency of pivot is equal to the natural frequency of the flexible shaft **13**, the flexible shaft **13** is resonantly driven, and therefore a driving force can be reduced.

[0070] Now, a second embodiment of the OCT optical probe **1** of the invention is described. FIG. **8** illustrates the second embodiment of the invention. Components shown in FIG. **8** that are the same as those of the first embodiment are designated by the same reference numerals, and explanations thereof are omitted. Specifically, features of the second embodiment that are different from the first embodiment are described.

[0071] In the second embodiment shown in FIG. **8**, a permanent magnet **18** is disposed at the outer circumference of the flexible shaft **13**, and an electric magnet **68** is disposed at the outer circumference of the forceps channel **64** of the insert portion **55** of the endoscope **50**. Further, a magnetic sensor (not shown) may be disposed at the outer circumference of the permanent magnet **18** for detecting the rotational angle of the optical fiber **12**. A control signal MC fed to the electric magnet **68** and a rotation signal RS fed from the magnetic sensor are transmitted via a control cable (not shown). Specifically, the rotation signal RS include a rotation clock signal R_{CLK}, which is generated for each rotation of the flexible shaft **13**, and a rotational angle signal R_{pos}.

[0072] Now, operation of the second embodiment is described. When the electric magnet **68** is excited, the electric magnet **68** and the permanent magnet **18** interact with each other to establish a relationship of a stator and a rotor of a brushless motor, and thus the flexible shaft **13** rotates in the direction of arrow R**3** about the optical axis LP via the permanent magnet **18**.

[0073] Further, the direction of rotation of the optical fiber **12** may be inverted to make the distal optical system **15** pivot about the optical axis LP within a predetermined range of angle by controlling the order of excitation of the electric magnet **68** according to the control signal MC based on the rotation signal RS.

[0074] It should be noted that, in the second embodiment of the invention, the electric magnet **68** may be disposed at the outer circumference of the flexible shaft **13**, and the permanent magnet **18** may be disposed at the outer circumference of the forceps channel **64**. In this case, the distal end portion **10** is insulated so that the excitation of the electric magnet **68** at the outer circumference of flexible shaft **13** may not exert adverse effect, such as electrical shock, on the human body.

[0075] The operation effected by the rotation of the flexible shaft **13** is the same as that in the first embodiment, and explanation thereof is omitted. Further, the pivot angle and the frequency of rotation and pivot are the same as those in the first embodiment, and explanations thereof are omitted.

[0076] Now, the optical tomography imaging apparatus, to which the OCT optical probe **1** according to the invention is applied, is described. FIG. **9** is a schematic structural diagram of an optical tomography imaging apparatus **100**, to which the OCT optical probe **1** of the invention is applied.

[0077] The optical tomography imaging apparatus **100** is an optical tomography imaging apparatus using SS-OCT measurement. The optical tomography imaging apparatus **100** includes: a light source unit **110** for emitting laser light L; an optical fiber coupler **2** for dividing the laser light L emitted from the light source unit **110**; a period clock generating unit **120** for outputting a period clock signal T_{CLK} from the light divided by the optical fiber coupler **2**; a light dividing means **3** for dividing one of light beams divided by the optical fiber coupler **2** into the measurement light L**1** and the reference light L**2**; an optical path length adjusting unit **130** for adjusting the optical path length of the reference light L**2** divided by the light dividing means **3**; the OCT optical probe **1** for guiding the measurement light L**1** divided by the light dividing means **3** to the subject to be measured Sb; a combining

means **4** for combining the reference light L**2** with the reflected light L**3** from the subject to be measured Sb when the measurement light L**1** emitted from the OCT optical probe **1** is applied to the subject Sb; an interference light detecting unit **140** for detecting interference light L**4** formed between the reflected light L**3** and the reference light L**2** combined by the combining means **4**; a tomographic image processing unit **150** for acquiring a tomographic image P of the subject to be measured Sb by applying frequency analysis to the interference light L**4** detected by the interference light detecting unit **140**; and a displaying means **160** for displaying the tomographic image P.

[0078] The light source unit **110** in this apparatus emits the laser light L with the wavelengths thereof swept in a constant period T**0**. Specifically, the light source unit **110** includes a semiconductor optical amplifier (semiconductor gain medium) **111** and an optical fiber FB**10**. The optical fiber FB**10** is connected to opposite ends of the semiconductor optical amplifier **111**. When a driving current is injected, the semiconductor optical amplifier **111** emits weak light to one end of the optical fiber FB**10**, and amplifies the light inputted from the other end of the optical fiber FB**10**. As the driving current is supplied to the semiconductor optical amplifier **111**, pulsed laser light L generated by an optical resonator formed by the semiconductor optical amplifier **111** and the optical fiber FB**10** is emitted to the optical fiber FB**0**.

[0079] Further, a circulator **112** is coupled to the optical fiber FB**10**, so that a portion of light guided through the optical fiber FB**10** is emitted from the circulator **112** to an optical fiber FB**11**. The light emitted from the optical fiber FB**11** travels through a collimator lens **113**, a diffraction optical element **114** and an optical system **115**, and is reflected by a rotating polygon mirror **116**. The reflected light travels back through the optical system **115**, the diffraction optical element **114** and the collimator lens **113**, and re-enters the optical fiber FB**11**.

[0080] The rotating polygon mirror **116** rotates at a high speed, such as around 30,000 rpm, in the direction of arrow R**1**, and the angle of each reflection facet with respect to the optical axis of the optical system **115** varies. Therefore, among the spectral components of the light split by the diffraction optical element **114**, only the component of a particular wavelength range returns to the optical fiber FB**11**. The wavelength of the light returning to the optical fiber FB**11** is determined by an angle between the optical axis of the optical system **115** and the reflection facet. Then, the light of the particular wavelength range entering the optical fiber FB**11** is inputted from the circulator **112** to the optical fiber FB**10**. As a result, the laser light L of the particular wavelength range is emitted to the optical fiber FB**0**.

[0081] Therefore, when the rotating polygon mirror **116** rotates at a constant speed in the direction of arrow R**1**, the wavelength λ of the light re-entering the optical fiber FB**11** varies with time in a constant period. As shown in FIG. **10**, the light source unit **110** emits the laser light L with the wavelength thereof swept from a minimum sweep wavelength λmin to a maximum sweep wavelength λmax in a constant period T**0** (for example, about 50 μsec).

[0082] The wavelength-swept laser light L is emitted to the optical fiber FB**0**, and the laser light L is further inputted to branched optical fibers FB**1** and FB**5** by the optical fiber coupler **2**. The light emitted to the optical fiber FB**5** is guided to the period clock generating unit **120**.

[0083] The period clock generating unit **120** outputs the period clock signal T_{CLK} each time the wavelength of the laser light L emitted from the light source unit **110** is swept for one period. The period clock generating unit **120** includes optical lenses **121** and **123**, an optical filter **122** and a photodetector unit **124**. The laser light L emitted from the optical fiber FB**5** enters the optical filter **122** via the optical lens **121**. The laser light L transmitted through the optical filter **122** is then detected by the photodetector unit **124** via the optical lens **123**, and the period clock signal T_{CLK} is outputted to the tomographic image processing unit **150**.

[0084] As shown in FIG. **11**A, the optical filter **122** transmits only the laser light L having a set wavelength λref, and blocks the light of other wavelength bands. The optical filter **122** has a plurality of transmission wavelengths. The optical filter **122** has a FSR (free spectrum range), which is a light transmission period in which one of the plurality of transmission wavelengths is set within the wavelength band of λmin-λmax. Therefore, only the laser light L having the set wavelength λref within the wavelength band of λmin-λmax, within which the wavelength of the laser light L emitted from the light source unit **110** is swept, is transmitted, and the laser light L of other wavelength bands is blocked.

[0085] As shown in FIG. **11**B, the period clock signal T_{CLK} is outputted when the wavelength of the laser light L with the periodically swept wavelength emitted from the light source unit **110** is the set wavelength λref. By generating and outputting the period clock signal T_{CLK} using the laser light L actually emitted from the light source unit **110** in this manner, an interference signal IS of the wavelength band of the constant period T**0** (see FIG. **10**) can be acquired based on the set wavelength λref, even if the time taken for the intensity of the laser light L emitted from the light source unit **110** to reach a predetermined light intensity from the start of sweeping of the wavelength varies for each period. Thus, the period clock signal T_{CLK} can be outputted at timing when the interference signal IS of the wavelength band assumed for the tomographic image processing unit **150** should be acquired, thereby minimizing degradation of resolution.

[0086] The light dividing means **3** is formed, for example, by a 2×2 optical fiber coupler, and divides the laser light L guided from the light source unit **110** via the optical fiber FB**1** into the measurement light L**1** and the reference light L**2**. Two optical fibers FB**2** and FB**3** are optically connected to the light dividing means **3**, so that the measurement light L**1** is guided through the optical fiber FB**2** and the reference light L**2** is guided through the optical fiber FB**3**. It should be noted that the light dividing means 3 in this embodiment also serves as the combining means 4.

[0087] The optical fiber FB**2** is optically connected to the OCT optical probe **1**, so that the measurement light L**1** is guided to the OCT optical probe **1**. The OCT optical probe **1** applies the measurement light L**1** emitted from the distal end portion **10** to the subject to be measured Sb, and the reflected light L**3** is guided by the optical fiber FB**2** through the OCT optical probe **1**.

[0088] The optical path length adjusting unit **130** is disposed at the side of the optical fiber FB**3** from which the reference light L**2** is emitted. The optical path length adjusting unit **130** changes the optical path length of the reference light L**2** to adjust the position at which acquisition of the tomographic image is started. The optical path length adjusting unit **130** includes: a reflection mirror **132** for reflecting the reference light L**2** emitted from the optical fiber FB**3**; a first optical lens **131**a disposed between the reflection mirror **132** and the optical fiber FB**3**; and a second optical lens **131***b* disposed between the first optical lens **131***a* and the reflection mirror **132**.

[0089] The first optical lens **131***a* serves to collimate the reference light L**2** emitted from the optical fiber FB**3** and to

collect the reference light L2 reflected from the reflection mirror **132** onto the optical fiber FB3.

[0090] The second optical lens **131***b* serves to collect the reference light L2 collimated by the first optical lens **131***a* onto the reflection mirror **132** and to collimate the reference light L2 reflected from the reflection mirror **132**.

[0091] That is, the reference light L2 emitted from the optical fiber FB3 is collimated by the first optical lens **131***a*, and then is collected by the second optical lens **131***b* onto the reflection mirror **132**. Thereafter, the reference light L2 reflected from the reflection mirror **132** is collimated by the second optical lens **131***b*, and then is collected by the first optical lens **131***a* onto the optical fiber FB3.

[0092] The optical path length adjusting unit **130** further includes: a base **133** on which the second optical lens **131***b* and the reflection mirror **132** are fixed; and a mirror moving means **134** for moving the base **133** along the optical axis of the first optical lens **131***a*. The optical path length of the reference light L2 can be changed by moving the base **133** in the direction of arrow A.

[0093] The combining means **4** is formed by a 2×2 optical fiber coupler, as described above. The combining means **4** is adapted to combine the reference light L2 having the optical path length adjusted by the optical path length adjusting unit **130** with the reflected light L3 from the subject to be measured Sb, and emit the combined light to the interference light detecting unit **140** via the optical fiber FB4.

[0094] The interference light detecting unit **140** detects the interference light L4 between the reflected light L3 and the reference light L2 combined by the combining means **4**, and outputs the interference signal IS. It should be noted that, in this apparatus, the interference light L4 is divided into two parts by the light dividing means **3** and these parts are guided to the photodetectors **140***a* and **140***b* to be calculated, so that balanced detection is carried out. The interference signal IS is outputted to the tomographic image processing unit **150**.

[0095] FIG. **12** is a schematic structural diagram of the tomographic image processing unit **150**. The tomographic image processing unit **150** is implemented by executing a tomographic imaging program, which is installed in an auxiliary storage device of a computer (for example, personal computer), on the computer. The tomographic image processing unit **150** includes an interference signal acquiring unit **151**, an interference signal converting unit **152**, an interference signal analyzing unit **153**, a tomographic information generating unit **154**, an image quality correction unit **155** and a rotation control unit **156**.

[0096] The interference signal acquiring unit **151** acquires the interference signal IS for one period, which is detected by the interference light detecting unit **140**, based on the period clock signal T_{CLK} outputted from the period clock generating unit **120**. The interference signal acquiring unit **151** acquires the interference signal IS of a wavelength band DT (see FIG. **11**B) spanning between points before and after the output timing of the period clock signal T_{CLK}. It should be noted that the output timing of the period clock signal T_{CLK} may be set immediately after the start of the wavelength sweeping or immediately before the end of the wavelength sweeping, as long as it is within the wavelength band to be swept, so that the interference signal acquiring unit **151** can acquire the interference signal IS for one period based on the output timing of the period clock signal T_{CLK}.

[0097] The interference signal converting unit **152** rearranges the interference signal IS acquired by the interference signal acquiring unit **151** in equal intervals along the wavenumber k (=2π/λ) axis. FIG. **13**A illustrates the interference signal IS to be inputted to the interference signal acquiring unit **151**. FIG. **13**B illustrates the rearranged interference signal IS. Specifically, the interference signal converting unit **152** is provided in advance with a time-wavelength sweep characteristics data table or function of the light source unit **110**, and uses this time-wavelength sweep characteristics data table to rearrange the interference signal IS in equal intervals along the wavenumber k axis. This allows acquisition of highly accurate tomographic information by using a spectral analysis technique that assumes that the data is arranged in equal intervals in a frequency space, such as the Fourier transformation or processing using the maximum entropy method, to calculate the tomographic information from the interference signal IS. Details of this signal conversion technique is disclosed in U.S. Pat. No. 5,956,355.

[0098] The interference signal analyzing unit **153** acquires the tomographic information r(z) by applying a known spectral analysis technique, such as the Fourier transformation, the maximum entropy method, or the Yule-Walker method, to the interference signal IS converted by the interference signal converting unit **152**.

[0099] The rotation control unit **156** outputs the control signal MC to the motor **26** or the electric magnet **68**, and receives the rotation signal RS inputted from the encoder **27** or the magnetic sensor. As described above, the rotational position signal RS includes the rotation clock signal R_{CLK}, which is generated for each rotation of the motor **26** or the flexible shaft **13**, and the rotational angle signal R_{pos}.

[0100] The tomographic information generating unit **154** acquires the tomographic information r(z), which corresponds to scanning by the distal end portion **10** of the OCT optical probe **1** in the radial direction (in the direction of arrow R1 in the drawing), for one period (one line) acquired by the interference signal analyzing unit **153**, and generates a tomographic image P as shown in FIG. **14**. The tomographic information generating unit **154** stores the tomographic information r(z) for one line, which is sequentially acquired, in a tomographic information storing unit **154***a*.

[0101] The tomographic information generating unit **154** can generate the tomographic image P by reading the tomographic information r(z) for n lines at a time from the tomographic information storing unit **154***a* based on the rotation clock signal RCLK inputted to the rotation control unit **156**.

[0102] Alternatively, the tomographic information generating unit **154** can generate the tomographic image P by sequentially reading the tomographic information r(z) from the tomographic information storing unit **154***a* based on the rotational angle signal R_{pos} inputted to the rotation control unit **156**.

[0103] The image quality correction unit **155** applies correction, such as sharpness correction and smoothness correction, to the tomographic image P generated by the tomographic information generating unit **154**.

[0104] The displaying means **160** displays the tomographic image P, which has been subjected to the correction, such as sharpness correction and smoothness correction, applied by the image quality correction unit **155**.

[0105] As described above, in the OCT optical probe **1** of the invention and the optical tomography imaging apparatus **100** employing the OCT optical probe **1**, no rotary joint is provided, and the light emitted from the distal end of the optical fiber **12** directly enters the distal optical system **15**. Therefore, the problem of degradation of measurement accuracy due to the optical insertion loss and optical reflection loss at the rotary joint can be eliminated inexpensively and safely.

[0106] Also, in the optical tomography imaging apparatus **100** according to the invention, to which the above-described OCT probe **1** of the invention is applied, the problem of

degradation of measurement accuracy due to the optical insertion loss and optical reflection loss at the rotary joint can be eliminated inexpensively and safely.

[0107] Although the optical tomography imaging apparatus, to which the OCT optical probe **1** of the invention is applied, has been described as an SS-OCT apparatus in the above embodiment by way of example, the OCT optical probe **1** of the invention is also applicable to SD-OCT and TD-OCT apparatuses.

[0108] In the OCT optical probe of the invention, the distal optical system is rotated by the flexible shaft via the holding portion relative to the rotatably-supporting portion that is integrally fixed to the distal end portion of the optical fiber. Therefore, the light emitted from the light source unit is guided through the optical fiber and directly enters the distal optical system from the distal end of optical fiber.

[0109] Thus, it is not necessary to provide a rotary joint between the distal end portion and the proximal end portion of the OCT optical probe, and therefore the problem of optical insertion loss and optical reflection loss at the rotary joint can be avoided. Further, since no driving means, such as an MEMS motor, is provided in the vicinity of the distal end, problems such as increase of the outer diameter of the OCT optical probe and an adverse effect exerted on image acquisition by a drive cable for the MEMS motor can be avoided.

[0110] Using the OCT probe according to the invention, the problem of degradation of measurement accuracy due to the optical insertion loss and optical reflection loss at the rotary joint can be eliminated inexpensively and safely.

[0111] Also, in the optical tomography imaging apparatus according to the invention, to which the above-described OCT probe according to the invention is applied, the problem of degradation of measurement accuracy due to the optical insertion loss and optical reflection loss at the rotary joint can be eliminated inexpensively and safely.

What is claimed is:

1. An OCT optical probe comprising:

a substantially cylindrical sheath to be inserted into a subject, the sheath having an internal space;

an optical fiber disposed in the internal space of the sheath along the longitudinal direction of the sheath;

a rotatably-supporting portion integrally fixed to the optical fiber in the vicinity of a distal end of the optical fiber;

a distal optical system to deflect light emitted from the distal end of the optical fiber toward the subject;

a holding portion to hold the distal optical system such that the distal optical system is rotatably supported by the rotatably-supporting portion; and

a flexible shaft covering the optical fiber in the internal space of the sheath, wherein the holding portion is fixed to a distal end of the flexible shaft.

2. The OCT optical probe as claimed in claim **1**, wherein the rotatably-supporting portion comprises a bearing portion to rotatably support the holding portion.

3. The OCT optical probe as claimed in claim **1** further comprising a fiber sheath disposed between the optical fiber and the flexible shaft, the fiber sheath covering the optical fiber.

4. The OCT optical probe as claimed in claim **1**, wherein the distal end of the optical fiber comprises an end face inclined by a predetermined angle with respect to a plane perpendicular to an optical axis of the optical fiber.

5. The OCT optical probe as claimed in claim **1** further comprising a cover glass, a proximal end of the cover glass closely contacting the distal end of the optical fiber, and a distal end the cover glass comprising a flat end face perpendicular to the optical axis.

6. The OCT optical probe as claimed in claim **1** further comprising a cover glass, a proximal end of the cover glass closely contacting the distal end of the optical fiber, and a distal end of the cover glass comprising a convex end face adapted to collimate the light emitted from the distal end of the cover glass to be parallel to the optical axis.

7. An optical tomography imaging apparatus comprising:

a light source unit to emit light;

a light dividing unit to divide the light emitted from the light source unit into measurement light and reference light;

an irradiation optical system to irradiate a subject to be measured with the measurement light;

a combining unit to combine the reference light with reflected light of the measurement light reflected from the subject to be measured when the measurement light is applied to the subject;

an interference light detecting unit to detect interference light formed between the combined reflected light and reference light; and

a tomographic image processing unit to detect reflection intensity at a plurality of depth-wise positions in the subject to be measured based on frequency and intensity of the detected interference light, and to acquire a tomographic image of the subject to be measured based on the intensity of the reflected light at each of the depth-wise positions,

wherein the irradiation optical system comprises the OCT optical probe as claimed in claim **1**.

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