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(54) **SHEET PRODUCING DEVICE AND SHEET PRODUCING METHOD**

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(57) **ABSTRACT**

The present disclosure is a sheet producing device for producing a multi-layer sheet by applying a coating material to a sheet material. The sheet producing device includes a radiation light source that emits radiation light, a division part that divides the radiation light into measurement light to be incident on the multi-layer sheet and reference light with which a reference surface is to be irradiated, and an optical member that emits the measurement light onto the multi-layer sheet and receives the measurement light reflected by the multi-layer sheet. An interference detector that detects interference light between the measurement light reflected by the multi-layer sheet and the reference light reflected by the reference surface, and a thickness calculator that calculates a thickness of the sheet material and a thickness of the coating material of the multi-layer sheet based on the detected interference light are further included. As a result, the tact time from the production of the multi-layer sheet to the calculation of the thickness can be shortened.
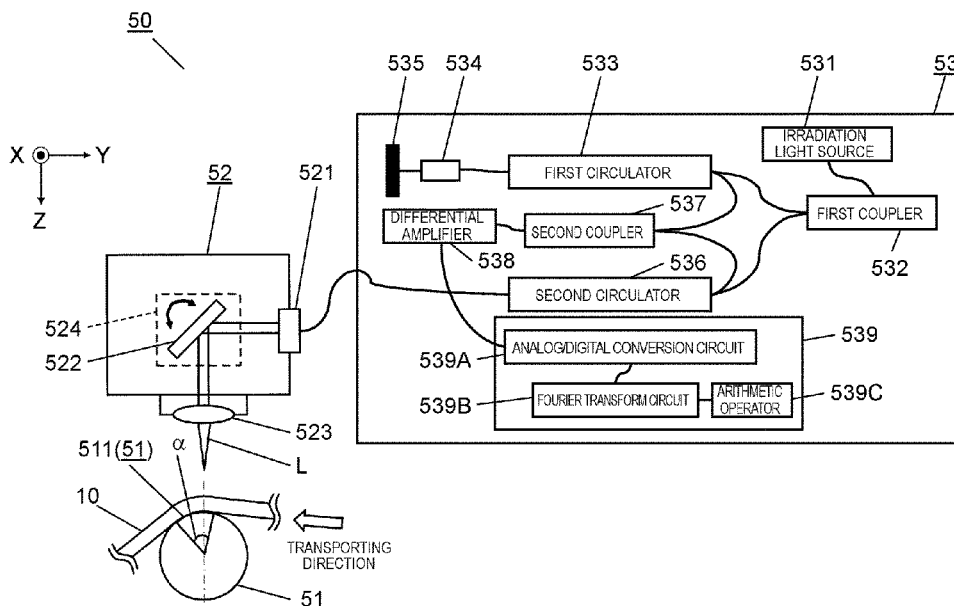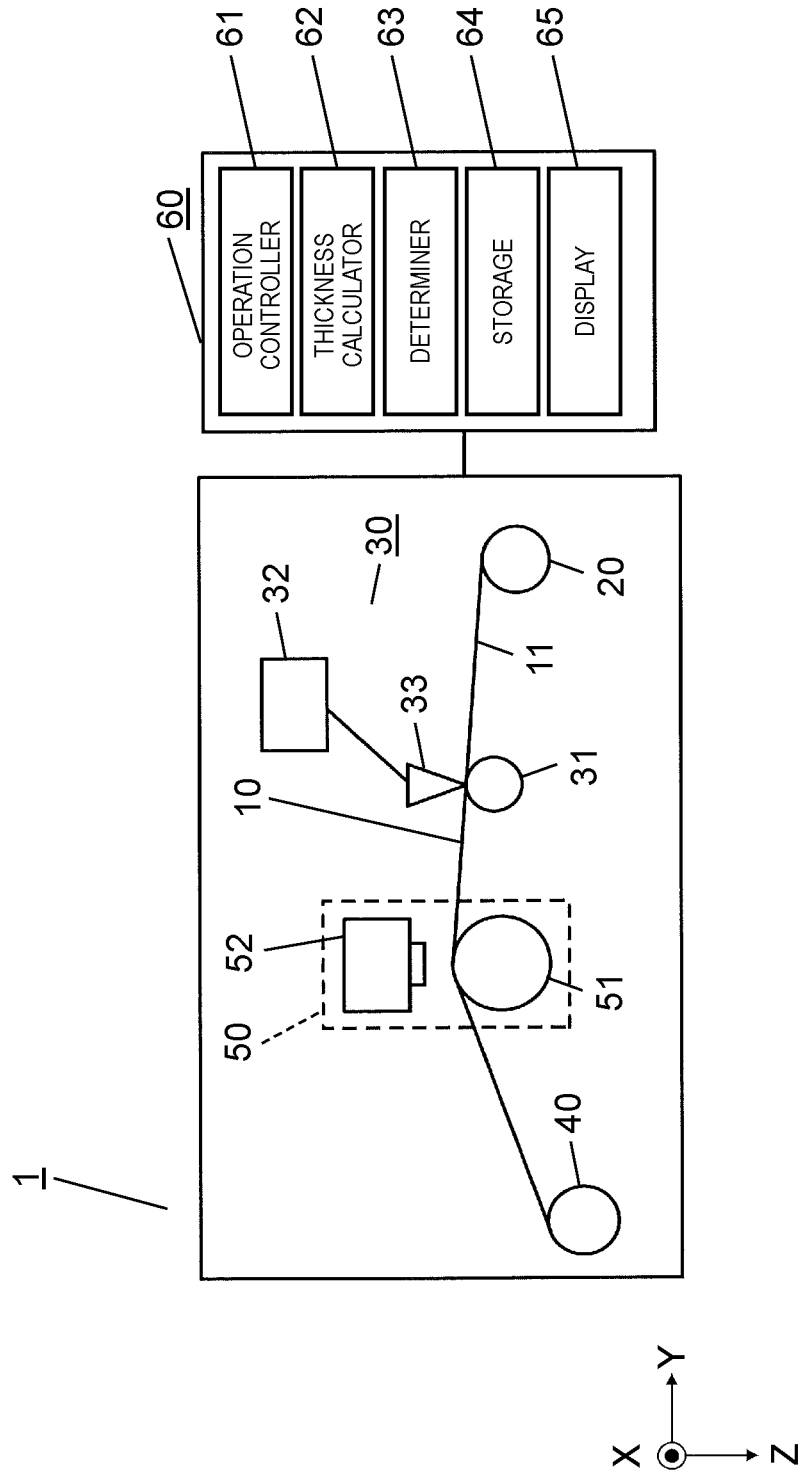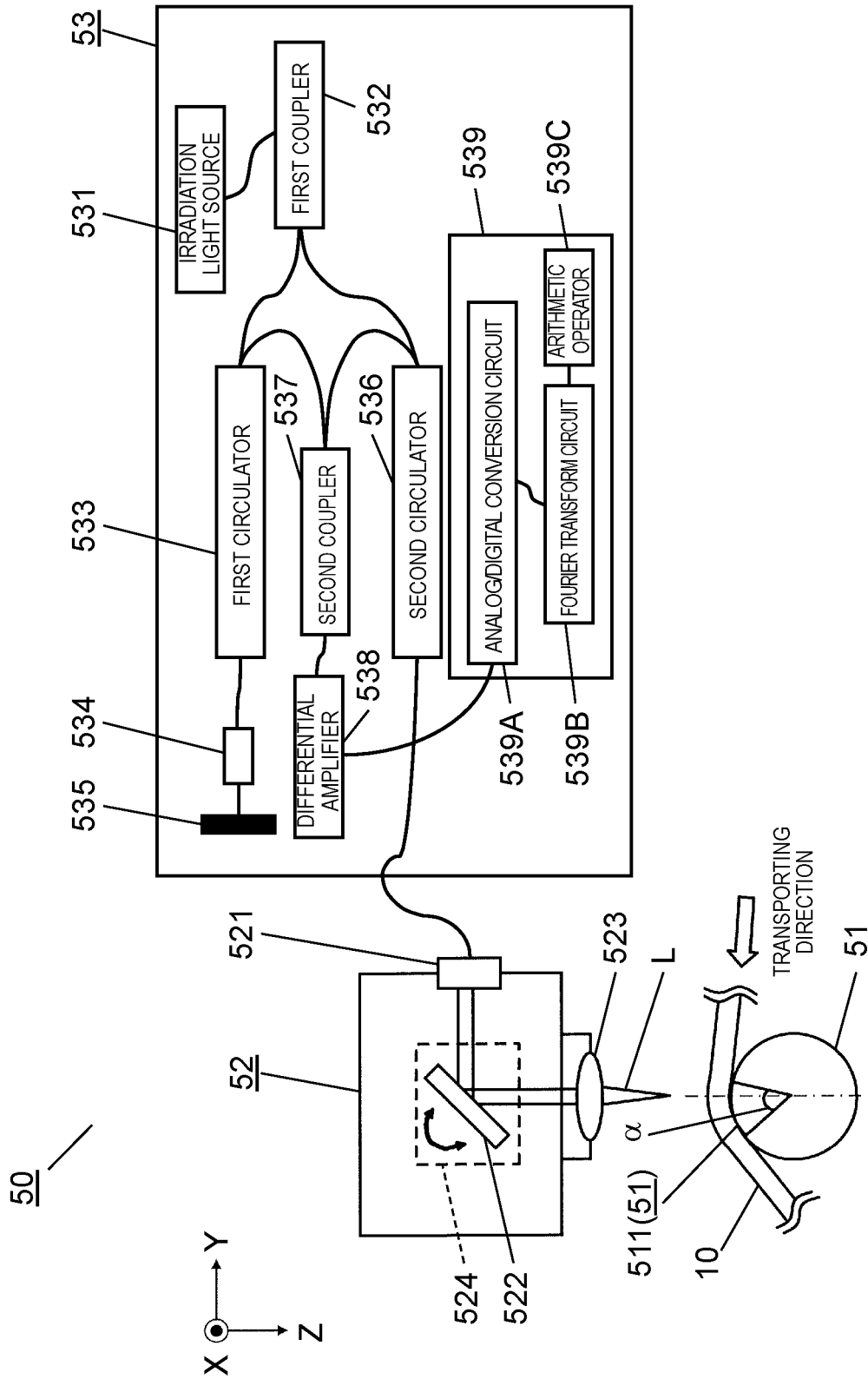
9 Claims, 10 Drawing Sheets

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FIG. 1

OPERATION CONTROLLER — 61

THICKNESS CALCULATOR — 62

DETERMINER — 63

STORAGE — 64

DISPLAY — 65

60

30

32

33

10

31

11

20

52

50

51

40

1

X Y Z

FIG. 2

50

53

531 IRRADIATION LIGHT SOURCE

532 FIRST COUPLER

533 FIRST CIRCULATOR

537 SECOND COUPLER

536 SECOND CIRCULATOR

534

535

538 DIFFERENTIAL AMPLIFIER

539

539A ANALOG/DIGITAL CONVERSION CIRCUIT

539B FOURIER TRANSFORM CIRCUIT

539C ARITHMETIC OPERATOR

521

52

524

522

523

L

511(51)

10

51

α

TRANSPORTING DIRECTION

X Y Z

FIG. 3

START

INSTALL SHEET MATERIAL — S1

GENERATE MULTI-LAYER SHEET — S2

PERFORM SS-OCT MEASUREMENT FOR MULTI-LAYER SHEET — S3

CALCULATE THICKNESS OF SHEET MATERIAL AND THICKNESS OF COATING MATERIAL — S4

S5

IS THICKNESS OF SHEET MATERIAL AND COATING MATERIAL WITHIN OK RANGE?

NO

YES

OUTPUT NG SIGNAL — S6

DISPLAY FACT THAT MULTI-LAYER SHEET IS NG — S7

STORE SERIAL NUMBER OF MULTI-LAYER SHEET IN ASSOCIATION WITH INFORMATION INDICATING FACT THAT IT IS NG — S8

S9

IS MULTI-LAYER SHEET COMPLETED?

NO

YES

STOP GENERATION OF MULTI-LAYER SHEET AND CUT SHEET MATERIAL — S10

END

FIG. 4A

FIG. 4B

FIG. 5A

θ1   θ2

X → Y

Z

L1(L)

L2(L)

10

TRANSPORTING
DIRECTION

FIG. 5B

θ1   θ2

X → Y

Z

L1(L)

L2(L)

10

TRANSPORTING
DIRECTION

FIG. 5C

X → Y

Z

L1(L)

L2(L)

10

TRANSPORTING
DIRECTION

FIG. 6A

X ⊙ → Y
↓
Z

12

51D

51C

11

10

TRANSPORTING
DIRECTION

FIG. 6B

Z ⊗ → Y
↓
X

10

511

51D

51C

51   M

TRANSPORTING
DIRECTION

FIG. 6C

Z ⊗ → Y
↓
X

P   θz

θs

D

11

TRANSPORTING
DIRECTION

FIG. 7A

FIG. 7B

FIG. 8

1A

60A

OPERATION CONTROLLER	61
THICKNESS CALCULATOR	62
DETERMINER	63
STORAGE	64
DISPLAY	65
FEEDBACK CONTROLLER	66A

32

30

33

11

20

10

31

70A

71A

71A

72A

50

52

51

40

X

Y

Z

FIG. 9

START

INSTALL SHEET MATERIAL — S1

GENERATE MULTI-LAYER SHEET — S2

PERFORM SS-OCT MEASUREMENT FOR MULTI-LAYER SHEET — S3

CALCULATE THICKNESS OF SHEET MATERIAL AND THICKNESS OF COATING MATERIAL — S4

S5

IS THICKNESS OF SHEET MATERIAL AND COATING MATERIAL WITHIN OK RANGE?

NO

YES

S22

EXECUTE FEEDBACK

S21

CALCULATE AMOUNT OF FEEDBACK

S6

OUTPUT NG SIGNAL

S7

DISPLAY FACT THAT MULTI-LAYER SHEET IS NG

S8

STORE SERIAL NUMBER OF MULTI-LAYER SHEET IN ASSOCIATION WITH INFORMATION INDICATING FACT THAT IT IS NG

S9

IS MULTI-LAYER SHEET COMPLETED?

NO

YES

STOP GENERATION OF MULTI-LAYER SHEET AND CUT SHEET MATERIAL — S10

END

FIG. 10

SHEET PRODUCING DEVICE AND SHEET PRODUCING METHOD

BACKGROUND

1. Technical Field

The present disclosure relates to a sheet producing device and a sheet producing method.

2. Description of the Related Art

For a band-shaped laminated sheet constituted by a plurality of layers, it is important to inspect the thickness of the laminated sheet due to its characteristics. As a device for inspecting the thickness of the laminated sheet, a device as illustrated in FIG. 10 is disclosed, for example, in Japanese Patent Unexamined Publication No. H5-185022 (hereinafter referred to as "Patent Literature 1").

The device for inspecting the thickness of the laminated sheet described in Patent Literature 1 includes knife 92 that is provided more transporting destination side of metal plate 91 than a coating position of resin 90 and controls the thickness of coated resin 90. The device includes X-ray thickness meter 93 provided more transporting destination side of metal plate 91 than the coating position of resin 90. First, the device in Patent Literature 1 measures the thickness of metal plate 91 by using X-ray thickness meter 93. Arithmetic operation device 94 advances and retreats knife 92 with respect to metal plate 91 according to the deviation of the measured thickness of metal plate 91. As a result, the non-uniformity of the thickness of the film of resin 90 applied to metal plate 91 is reduced.

However, in the technique of Patent Literature 1, the thickness of the laminated sheet after applying resin 90 is not inspected. Therefore, there is a possibility that a laminated sheet having a desired thickness cannot be manufactured. Therefore, a configuration is conceivable in which X-ray thickness meter 93 is provided more transporting destination side of metal plate 91 than the coating position of resin 90, and the thickness of the laminated sheet is inspected by using X-ray thickness meter 93. However, in such a configuration, it is necessary to interpose the laminated sheet from the front and back by an X-ray irradiator and a detector of X-ray thickness meter 93. The above device also requires a cover or the like to prevent an explosion. Therefore, an installation place of X-ray thickness meter 93 is limited. That is, a coating position and an inspection position of the resin are physically separated. As a result, there is a possibility that the tact time from the application of the resin to the acquisition of the thickness of the laminated sheet is long.

SUMMARY

The present disclosure provides a sheet producing device and a sheet producing method capable of shortening the tact time from the start of producing a multi-layer sheet to the end of calculating the thickness.

A sheet producing device of the present disclosure is a sheet producing device for producing a multi-layer sheet by applying a coating material to a sheet material that is transported. The sheet producing device includes a radiation light source that emits radiation light, a division part that divides the radiation light into measurement light to be incident on the multi-layer sheet and reference light with which a reference surface is to be irradiated, and an optical

member that emits the measurement light onto the multi-layer sheet and receives the measurement light reflected by the multi-layer sheet. The sheet producing device further includes an interference detector that detects interference light in which the measurement light reflected by the multi-layer sheet and the reference light reflected by the reference surface interfere with each other, and a thickness calculator that calculates a thickness of the sheet material and a thickness of the coating material of the multi-layer sheet based on the detected interference light.

A sheet producing method of the present disclosure is a sheet producing method for producing a multi-layer sheet by applying a coating material to a sheet material that is transported. The sheet producing method includes a step of emitting radiation light from a radiation light source, a step of dividing the radiation light into measurement light and reference light, and a step of causing an optical member to emit the measurement light onto the multi-layer sheet and making the measurement light reflected by the multi-layer sheet incident on the optical member. The sheet producing method further includes a step of irradiating a reference surface with the reference light, a step of detecting interference light in which the measurement light reflected by the multi-layer sheet and the reference light reflected by the reference surface interfere with each other, and a step of calculating a thickness of the sheet material and a thickness of the coating material of the multi-layer sheet based on the detected interference light.

According to the present disclosure, it is possible to provide a sheet producing device and a sheet producing method capable of shortening the tact time from the start of producing a multi-layer sheet to the end of calculating the thickness of the multi-layer sheet.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view illustrating a schematic configuration of a sheet producing device according to Exemplary Embodiment 1 of the present disclosure;

FIG. 2 is a schematic view illustrating a configuration of an SS-OCT device according to Exemplary Embodiment 1 and Exemplary Embodiment 2 of the present disclosure;

FIG. 3 is a flowchart illustrating a sheet producing method according to Exemplary Embodiment 1;

FIG. 4A is a YZ plan view illustrating a positional relationship between objective lens of the SS-OCT device and a multi-layer sheet according to Exemplary Embodiment 1 and Exemplary Embodiment 2;

FIG. 4B is an XY plan view illustrating a positional relationship between an inspection roll of the SS-OCT device and the multi-layer sheet according to Exemplary Embodiment 1 and Exemplary Embodiment 2;

FIG. 5A is a schematic view illustrating a positional relationship between measurement light when a B scan is performed and the multi-layer sheet at a B scan position that is different on the inspection roll and the same on the multi-layer sheet according to Exemplary Embodiment 1 and Exemplary Embodiment 2;

FIG. 5B is a schematic view illustrating a positional relationship between the measurement light when the B scan is performed and the multi-layer sheet at the B scan position that is different on the inspection roll and also different on the multi-layer sheet according to Exemplary Embodiment 1 and Exemplary Embodiment 2;

FIG. 5C is a schematic view illustrating a positional relationship between the measurement light when the B scan is performed and the multi-layer sheet at the B scan position

that is the same on the inspection roll and different on the multi-layer sheet in a state in which a transporting speed of the multi-layer sheet is reduced according to Exemplary Embodiment 1 and Exemplary Embodiment 2;

FIG. **6A** is a cross-sectional view of a YZ plane illustrating a periodic structure of a sheet material of the multi-layer sheet according to Exemplary Embodiment 1 and Exemplary Embodiment 2;

FIG. **6B** is an XY plan view illustrating a positional relationship between the inspection roll of the SS-OCT device and the multi-layer sheet according to Exemplary Embodiment 1 and Exemplary Embodiment 2;

FIG. **6C** is an XY plane view illustrating a periodic structure of the sheet material in the multi-layer sheet according to Exemplary Embodiment 1 and Exemplary Embodiment 2;

FIG. **7A** is a schematic view illustrating a refraction state of the measurement light in the multi-layer sheet according to Exemplary Embodiment 1 and Exemplary Embodiment 2;

FIG. **7B** is an explanatory view of a calculation method of the thickness of the multi-layer sheet according to Exemplary Embodiment 1 and Exemplary Embodiment 2;

FIG. **8** is a schematic view illustrating a schematic configuration of a sheet producing device according to Exemplary Embodiment 2;

FIG. **9** is a flowchart illustrating a sheet producing method according to Exemplary Embodiment 2; and

FIG. **10** is an explanatory view of the description in Patent Literature 1 in the related art.

DETAILED DESCRIPTION

Each exemplary embodiment of the present disclosure will be described with reference to the drawings.

Exemplary Embodiment 1

Hereinafter, a sheet producing device according to Exemplary Embodiment 1 of the present disclosure will be described separately in terms of items.

Schematic Configuration of Sheet Producing Device

First, a schematic configuration of sheet producing device **1** according to Exemplary Embodiment 1 of the present disclosure will be described with reference to FIG. **1**.

FIG. **1** is a schematic view of sheet producing device **1** according to Exemplary Embodiment 1 of the present disclosure. In the following, a direction may be described with reference to the XYZ axes illustrated in FIG. **1**. Specifically, the Y-axis corresponds to a length direction or a transporting direction of sheet material **11** or multi-layer sheet **10**. The X-axis corresponds to a width direction of sheet material **11** or multi-layer sheet **10** or a direction orthogonal to the transporting direction.

Sheet producing device **1** is a device that produces multi-layer sheet **10** in which coating material **12** (see FIG. **6A**) is applied to sheet material **11** and performs inspection of multi-layer sheet **10**.

Specifically, as illustrated in FIG. **1**, sheet producing device **1** of Exemplary Embodiment 1 includes sheet supply reel **20**, coater **30**, winding roll **40**, SS-OCT device **50**, sheet generation controller **60**, and the like. The SS-OCT is an abbreviation for swept-source optical coherence tomography.

Sheet supply reel **20** is provided such that the rotation axis is parallel to the X-axis. Sheet material **11** wound in a roll shape is installed on sheet supply reel **20**. Sheet supply reel

20 supplies sheet material **11** to coater **30**. Sheet material **11** is a base material of multi-layer sheet **10**, for example, a resin sheet such as cellophane resin or polyimide resin, or cotton, resin fibers, fabric woven with fiberglass, or non-woven fabric.

Coater **30** includes coating roll **31**, coating supply device **32**, coating device **33**, and the like.

Coating roll **31** is provided such that the rotation axis is parallel to the X-axis, at a position more transporting direction side (on the side in the −Y direction) of sheet material **11** than sheet supply reel **20**.

Coating supply device **32** supplies coating material **12** to coating device **33**. Coating material **12** is, for example, an adhesive made of a resin such as epoxy or acrylic, or a filler applied for the purpose of reinforcing mechanical intensity against fibers and improving weather resistance.

Coating device **33** is provided an upper side of coating roll **31** (on the side in the −Z direction). Coating device **33** applies coating material **12** supplied from coating supply device **32** to sheet material **11** transported on coating roll **31**. As a result, coating material **12** is laminated on sheet material **11** and multi-layer sheet **10** is formed. Multi-layer sheet **10** is an example of a measurement target. Specifically, multi-layer sheet **10** is, for example, an adhesive tape.

The method of applying coating material **12** to sheet material **11** is not limited to the method of using coating device **33**. For example, coating material **12** may be applied to sheet material **11** by passing sheet material **11** through a tank filled with coating material **12**. Alternatively, coating material **12** may be applied to sheet material **11** by contacting the roll, in which coating material **12** is applied, with sheet material **11** separately. Coating material **12** may be applied to both surfaces of sheet material **11**.

In the above description, the configuration in which multi-layer sheet **10** is configured with two layers of a base material and a resin layer has been described as an example, but the present disclosure is not limited to this. For example, multi-layer sheet **10** may be configured with a multi-layer structure constituted by a plurality of coating layers and a plurality of base materials. When forming multi-layer sheet **10**, a step of drying coating material **12** with a heater, warm air, or the like may be provided after coating material **12** is applied on sheet material **11** which will be described later.

Winding roll **40** of sheet producing device **1** is provided such that the rotation axis is parallel to the X-axis at a position more supply direction side (on the side in the −Y direction) of sheet material **11** than coating device **33**. Winding roll **40** is rotated by being driven by a motor or the like and winds multi-layer sheet **10**. In the above description, the example in which the step of winding multi-layer sheet **10** with winding roll **40** is provided has been described, but the present disclosure is not limited to this. For example, a cutting step for cutting into a sheet of a certain length may be provided without providing a winding step. Multi-layer sheet **10** may be continuously connected to the subsequent steps without providing the winding step.

SS-OCT device **50** of sheet producing device **1** outputs various information used for calculating the thickness of sheet material **11** and the thickness of coating material **12** constituting multi-layer sheet **10** to sheet generation controller **60**. The detailed configuration of SS-OCT device **50** will be described later.

Sheet generation controller **60** includes operation controller **61**, thickness calculator **62**, determiner **63**, storage **64**, display **65**, and the like, and controls the operation of entire sheet producing device **1**.

Operation controller **61** controls a generation operation of multi-layer sheet **10**.

Thickness calculator **62** calculates the thickness of sheet material **11** and the thickness of coating material **12** based on the information from SS-OCT device **50**.

Determiner **63** determines the quality of multi-layer sheet **10** (whether it is a product with OK status or a product with NG status) based on the thickness calculation result by thickness calculator **62**.

Storage **64** stores the fact that multi-layer sheet **10** is a product with NG status in association with a serial number or the like that is attached to multi-layer sheet **10**.

Display **65** displays whether multi-layer sheet **10** is a product with OK status or a product with NG status based on the determination result by determiner **63**.

Regarding SS-OCT Device

Next, the configuration of SS-OCT device **50** will be described with reference to FIG. **2**. FIG. **2** is a schematic view illustrating a configuration of the SS-OCT device.

SS-OCT device **50** is an example of an inspection device. SS-OCT device **50** is an optical interference signal measurement device using a wavelength scanning type swept source-optical coherence tomography (SS-OCT).

An optical coherence tomography (OCT) is a measurement method using an optical interference phenomenon. Specifically, the OCT divides the radiation light from the light source into reference light and measurement light L, makes the reference light incident on the reference surface, and makes measurement light L incident on the measurement target. The interference signal is detected by interfering with the reference light that is reflected by the reference surface with measurement light L that is reflected by the measurement target. The OCT detects a position of the measurement target based on the detected interference signal.

There are roughly two types of OCT: time domain OCT (TD-OCT: time domain optical coherence tomography), which requires scanning of the reference surface, and frequency domain OCT (FD-OCT: Fourier domain optical coherence tomography), which does not require scanning of the reference surface. There are two types of FD-OCT, a spectrometer type and a wavelength scanning type. In particular, the wavelength scanning type FD-OCT is referred to as the SS-OCT described above. The SS-OCT detects the interference light while changing the frequency of light emitted from the light source over time.

SS-OCT device **50** includes inspection roll **51**, measurement head **52**, optical fiber interferometer **53**, and the like.

Inspection roll **51** is provided between coating roll **31** and winding roll **40** such that the rotation axis is parallel to the X-axis. Inspection roll **51** is provided such that multi-layer sheet **10** is in contact with inspection roll **51** at holding angle α. Therefore, a contact surface between inspection roll **51** and multi-layer sheet **10** is arc surface **511**.

Measurement head **52** functions as an example of an optical member. Measurement head **52** includes irradiation collimating lens **521**, galvanometer mirror pair **522**, objective lens **523**, driver **524**, and the like. The galvanometer mirror pair means a pair of galvanometer mirrors, and the same applies hereinafter.

Irradiation collimating lens **521** is connected to second circulator **536** of optical fiber interferometer **53**, which will be described later. Irradiation collimating lens **521** converts measurement light L entered from second circulator **536** into parallel light. The parallel light is emitted to galvanometer mirror pair **522**.

Galvanometer mirror pair **522** is disposed an upper side of inspection roll **51**. Galvanometer mirror pair **522** includes a first mirror having a rotation axis that is parallel to the X-axis and a second mirror having a rotation axis that is parallel to the Y-axis. Galvanometer mirror pair **522** reflects the parallel light entered from irradiation collimating lens **521** and emits the reflected parallel light to objective lens **523**.

Objective lens **523** is provided between galvanometer mirror pair **522** and inspection roll **51**. Objective lens **523** collects the parallel light entered from galvanometer mirror pair **522** and irradiates multi-layer sheet **10** with the collected parallel light. Objective lens **523** is provided so as to configure a telecentric optical system in combination with galvanometer mirror pair **522**. Therefore, the incident position of measurement light L changes in the XY plane (horizontal plane) depending on the movement of the first mirror and the second mirror of galvanometer mirror pair **522**, but the incident angle of measurement light L on the incident position is configured so as not to change.

Driver **524** moves the first mirror and the second mirror of galvanometer mirror pair **522** to adjust the incident position of measurement light L with respect to multi-layer sheet **10**.

With the above configuration of measurement head **52**, measurement light L is incident on irradiation collimating lens **521** from second circulator **536**. As described above, the entered measurement light L passes through galvanometer mirror pair **522**, is collected by objective lens **523** and is incident on the front surface of multi-layer sheet **10**. Measurement light L incident on the front surface of multi-layer sheet **10** is reflected (or back scattering) by the front surface, the inside, and the back surface of multi-layer sheet **10** and inspection roll **51**. Reflected measurement light L is emitted to second circulator **536** via objective lens **523**, galvanometer mirror pair **522**, and irradiation collimating lens **521**.

Optical fiber interferometer **53** functions as an example of the light source unit. Optical fiber interferometer **53** includes radiation light source **531**, first coupler **532**, first circulator **533**, reference collimating lens **534**, reference surface **535**, second circulator **536**, second coupler **537**, differential amplifier **538**, OCT arithmetic operation processor **539**, and the like.

Radiation light source **531** emits the radiation light. Radiation light source **531** is configured such that the wavelength of the radiation light can be changed. A light emitting port of radiation light source **531** is connected to a light receiving port of first coupler **532**.

First coupler **532** functions as an example of a division part that divides the light entered from radiation light source **531** into two at a fixed ratio of, for example, 50:50. First coupler **532** has a first light sending port and a second light sending port (not illustrated). The first light sending port is connected to first circulator **533**. The second light sending port is connected to second circulator **536**. With this configuration, the radiation light incident on first coupler **532** from radiation light source **531** is divided into the reference light and measurement light L. The reference light is emitted to first circulator **533**, and measurement light L is emitted to second circulator **536**.

First circulator **533** is connected to the light receiving port of second coupler **537**. First circulator **533** emits the reference light entered from first coupler **532** to reference collimating lens **534**. The reference light incident on reference collimating lens **534** is reflected by reference surface **535** and emitted to first circulator **533** via reference collimating

lens **534**. First circulator **533** emits the reference light reflected by reference surface **535** to second coupler **537**.

Second circulator **536** is connected to the light receiving port of second coupler **537** and the light receiving port of irradiation collimating lens **521** of measurement head **52**. As a result, second circulator **536** emits measurement light L entered from first coupler **532** to measurement head **52** and emits measurement light L from measurement head **52** to second coupler **537**.

Second coupler **537** is connected to differential amplifier **538**. Second coupler **537** forms the interference light by the reference light from first circulator **533** and measurement light L from second circulator **536**. That is, second coupler **537** functions as an example of a multiplexer of the reference light and measurement light L.

Differential amplifier **538** differentially transmits an optical beat signal of the interference light formed by second coupler **537** to OCT arithmetic operation processor **539**. At this time, the frequency of the radiation light that is emitted from radiation light source **531** changes with the passage of time. Therefore, in second coupler **537**, a frequency difference is generated between the interfering reference light and measurement light L according to the amount of time delay. This frequency difference becomes the optical beat signal of the interference light.

OCT arithmetic operation processor **539** includes analog/digital conversion circuit **539A** (analog/digital converter), Fourier transform circuit (Fourier transform portion) **539B**, arithmetic operator **539C**, and the like. Fourier transform circuit **539B** functions as an interference detector, and arithmetic operator **539C** functions as a profile acquisition portion.

Analog/digital conversion circuit **539A** is connected to differential amplifier **538**. Analog/digital conversion circuit **539A** converts, from analog to digital, a time waveform of the optical beat signal of the interference light that is formed by differential amplifier **538**.

Fourier transform circuit **539B** is connected to analog/digital conversion circuit **539A**. Fourier transform circuit **539B** detects the optical beat signal of the interference light from analog/digital conversion circuit **539A**. Fourier transform circuit **539B** fourier-transforms the detected optical beat signal and performs a frequency analysis. As a result, Fourier transform circuit **539B** obtains an SS-OCT signal that represents the intensity distribution of the interference light.

An input of arithmetic operator **539C** is connected to Fourier transform circuit **539B**. Arithmetic operator **539C** calculates a reflected signal intensity profile, which is an intensity profile of the interference light, at the incident position of measurement light L, based on the information (SS-OCT signal) input from Fourier transform circuit **539B**. Hereinafter, a process of acquiring the one-dimensional reflected signal intensity profile in the incident direction at the position of one point where measurement light L is entered will be described as an "A scan".

An output of arithmetic operator **539C** is connected to radiation light source **531**, driver **524** such as galvanometer mirror pair **522** of measurement head **52**, and sheet generation controller **60** (see FIG. **1**). Arithmetic operator **539C** controls driver **524** to operate galvanometer mirror pair **522**. Specifically, arithmetic operator **539C** performs the above-mentioned A scan while changing the incident position of measurement light L. As a result, arithmetic operator **539C** acquires the reflected signal intensity profile at the incident position of measurement light L that is changed linearly and creates a two-dimensional image. Hereinafter, a process of acquiring the reflected signal intensity profile at the incident positions of a plurality of measurement lights, which are made into a two-dimensional image, will be described as a "B scan", and the obtained two-dimensional image will be described as a "B scan image".

Sheet generation controller **60** that is illustrated in FIG. **1** performs a predetermined operation such as calculating the thickness of multi-layer sheet **10** based on the information obtained by the A scan or the B scan under the control of arithmetic operator **539C**.

The above-mentioned TD-OCT may be adopted in the above-described Exemplary Embodiment 1 and Exemplary Embodiment 2 described later. However, when TD-OCT is adopted, it is desirable to use SS-OCT or SD-OCT, which can be performed at, for example, 10 kHz or higher, as the one-dimensional scan called A scan described above. As a result, the speed of measuring the thickness of multi-layer sheet **10** can be increased.

Regarding Measurement Head Installation Position and Scanning Direction

Next, an installation position and a scanning direction of measurement head **52** will be described with reference to FIG. **2**.

As described above, multi-layer sheet **10** is in contact with an outer peripheral surface of inspection roll **51** at holding angle α. Measurement head **52** is installed such that measurement light L is able to be perpendicularly incident on arc surface **511** in which inspection roll **51** and multi-layer sheet **10** are in contact with each other within an operating range of galvanometer mirror pair **522**. With this configuration, the refraction of measurement light L between the air and multi-layer sheet **10** can be suppressed. Therefore, the thickness of multi-layer sheet **10** can be measured more accurately.

The rotation axis of the second mirror of galvanometer mirror pair **522** is disposed parallel to the Y-axis. With this configuration, the incident position of measurement light L can be moved in the axial direction of inspection roll **51**, that is, in the X-axis direction, and the B scan can be performed.

Sheet Producing Method

Next, the sheet producing method by sheet producing device **1** will be described by using FIG. **3** with reference to FIGS. **1** and **2**. FIG. **3** is a flowchart illustrating a sheet producing method.

First, as illustrated in FIG. **3**, sheet material **11** is installed on winding roll **40**, for example, by extending an end portion of the winding of sheet material **11** that is wound around sheet supply reel **20** illustrated in FIG. **1** (step S1). Step S1 may be configured to be performed by a worker or automatically performed by a grip portion after providing the grip portion that grips sheet material **11**. As a method of installing sheet material **11** on the winding roll **40**, for example, a method of providing an open and close type slit in winding roll **40** and holding sheet material **11** in the slit can be exemplified.

Next, multi-layer sheet **10** is generated (step S2). Specifically, operation controller **61** of sheet generation controller **60** rotates winding roll **40** in the counterclockwise direction. At this time, operation controller **61** transports sheet material **11** and at the same time sends coating material **12** from coating supply device **32** to coating device **33**. As a method of sending coating material **12**, for example, pressure sending by compressed air or the like, or a pump such as a diaphragm pump may be used. As a result, coating material **12** is applied to the front surface of sheet material

11 and multi-layer sheet **10** is generated. The generated multi-layer sheet **10** is continuously wound on winding roll **40**.

Next, SS-OCT device **50** performs the SS-OCT measurement with respect to multi-layer sheet **10** while transporting multi-layer sheet **10** (step S**3**).

The details of SS-OCT device **50** will be specifically described.

First, SS-OCT device **50** measures the thickness of multi-layer sheet **10** while changing the wavelength of the radiation light emitted from radiation light source **531**. At this time, the range in which the wavelength is changed is, for example, a range of 1550 nm±100 nm. Within this range, the transmittance of radiation light with respect to sheet material **11** and coating material **12** can be enhanced. The operation of radiation light source **531** is controlled by arithmetic operator **539**C. The radiation light from radiation light source **531** enters the front surface of multi-layer sheet **10** from the −Z direction.

The wavelength of the radiation light emitted from radiation light source **531** may be a wavelength outside the range of 1550 nm±100 nm. As a result, when the center wavelength is shortened, the resolution is high, and when the center wavelength is lengthened, the effect of being less susceptible to scattering from the measurement target can be obtained. Radiation light source **531** may emit the radiation light including light having a plurality of wavelengths within the range of 1550 nm±100 nm. In this case, one light source may emit the radiation light including light having a plurality of wavelengths, or a plurality of light sources capable of emitting light having different wavelengths may be used. As a result, it becomes easier to select the wavelength to be used.

Measurement light L incident on multi-layer sheet **10** is reflected (or backscattered) by the front surface, the inside, and the back surface of multi-layer sheet **10** and inspection roll **51**. Measurement light L reflected by multi-layer sheet **10** proceeds to second coupler **537**. In second coupler **537**, measurement light L reflected by multi-layer sheet **10** and the reference light reflected by reference surface **535** interfere with each other to form the interference light. The optical beat signal of the formed interference light is detected by Fourier transform circuit **539**B of OCT arithmetic operation processor **539** via differential amplifier **538**.

Arithmetic operator **539**C of OCT arithmetic operation processor **539** frequency-analyzes the optical beat signal of the interference light detected by Fourier transform circuit **539**B to acquire the SS-OCT signal. Arithmetic operator **539**C calculates the B scan image based on the acquired SS-OCT signal. The calculated B scan image is a two-dimensional imaged reflected signal intensity profile as described above.

The B scan image calculated by arithmetic operator **539**C is output to sheet generation controller **60** together with the information about the incident position of measurement light L. At this time, as described above, the incident position of measurement light L on multi-layer sheet **10** is in contact with inspection roll **51**. Therefore, the incident position of measurement light L is stable against vibration and the like. As a result, highly accurate inspection (measurement) of the thickness of multi-layer sheet **10**, for example, becomes possible.

In the OCT device, when the infrared light having a wavelength of 1550 nm±100 nm is used as measurement light L (radiation light) as described above, measurement light L can pass through the resin. When measurement light L passes through the resin, scattered light is generated inside

the resin due to additives such as fillers inside the resin or non-uniformity of the refractive index inside the resin. The generated scattered lights strengthen each other, and a random speckle pattern is generated. This speckle pattern is not desirable because it affects the calculation of thickness ΔZs and thickness ΔZt in step S**4** described later.

Therefore, in the process of step S**3**, thickness calculator **62** of sheet generation controller **60** emits measurement light L from at least a plurality of angles with respect to multi-layer sheet **10** to perform the B scan. Thickness calculator **62** obtains a plurality of B scan images having different generation patterns of speckle and averages the B scan images. As a result, an averaged image from which speckles are removed is obtained. The averaging process will be described later.

Next, as illustrated in FIG. **3**, thickness calculator **62** of sheet generation controller **60** calculates thickness ΔZs of sheet material **11** and thickness ΔZt of coating material **12** based on the averaged image obtained above (step S**4**). A specific description of the calculation of thickness ΔZs and thickness ΔZt will be described later.

Next, determiner **63** determines whether or not thickness ΔZs and thickness ΔZt calculated in step S**4** are within an OK range (step S**5**). The OK range is a range in which the product can be regarded as a non-defective product. Specifically, the OK range is a range of thickness ΔZs and thickness ΔZt that does not cause a problem in product quality. The OK range is stored in advance in storage **64**. The details of the OK range stored in advance will be described later.

At this time, when it is determined that thickness ΔZs and thickness ΔZt are not within the OK range (NO in step S**5**), determiner **63** outputs an NG signal to display **65** (step S**6**). Based on the NG signal, display **65** displays the fact that the formed multi-layer sheet **10** is NG (step S**7**). Determiner **63** associates the serial number and the like attached to multi-layer sheet **10** with the information indicating that it is NG, and stores the information in storage **64** (step S**8**). As a result, in the subsequent step, the information stored in storage **64** can be compared with the serial number of multi-layer sheet **10** and the like, and the NG product can be more reliably discarded.

On the other hand, when determiner **63** determines that thickness ΔZs and thickness ΔZt are within the OK range (YES in step S**5**), operation controller **61** determines whether or not multi-layer sheet **10** is completed (step S**9**). In this case, operation controller **61** determines whether or not multi-layer sheet **10** is completed based on the information from the encoder or the like connected to winding roll **40**. Specifically, for example, first, operation controller **61** obtains the number of rotations of winding roll **40** from the information from the encoder. Thereafter, it is determined whether or not the obtained number of rotations reaches the number of times stored in storage **64** in advance. The number of times stored in advance is, for example, 10 times.

At this time, when it is determined that multi-layer sheet **10** is not completed (for example, less than 10 times) (NO in step S**9**), operation controller **61** does not end the generation of multi-layer sheet **10**, returns to step S**3** and performs the SS-OCT measurement again.

On the other hand, when it is determined that multi-layer sheet **10** is completed (YES in step S**9**), or when the process of step S**8** is performed, operation controller **61** ends the coating operation of coating device **33**. Thereafter, sheet material **11** from sheet supply reel **20** to coating roll **31** is cut by a cutting part (not illustrated) (step S**10**), and the sheet producing operation of multi-layer sheet **10** is ended.

When step S7 or step S8 is performed, step S10 may be performed at the same time. As a result, the range of NG of the multi-layer sheet can be minimized.

The above steps S3 to S5 are examples of inspection steps. That is, in Exemplary Embodiment 1, the inspection step is performed at the same time while multi-layer sheet 10 is being generated. As a result, the time required from the start of the generation of multi-layer sheet 10 to the end of the inspection can be shortened.

Regarding the Position of the Measurement Light in the Y Direction in the Averaging Process of a Plurality of B Scan Images

Next, the position of the measurement light in the Y direction in the averaging process of the plurality of B scan images in step S3 illustrated in FIG. 3 will be described with reference to FIGS. 4A to 5C.

FIG. 4A is a YZ plan view illustrating a positional relationship between objective lens 523 of SS-OCT device 50 and multi-layer sheet 10. FIG. 4B is an XY plan view illustrating a positional relationship between inspection roll 51 of SS-OCT device 50 and multi-layer sheet 10. FIG. 5A is a schematic view illustrating a positional relationship between measurement light L when a B scan is performed and multi-layer sheet 10 at a B scan position that is different on inspection roll 51 and the same on multi-layer sheet 10. FIG. 5B is a schematic view illustrating a positional relationship between measurement light L when a B scan is performed and multi-layer sheet 10 at a B scan position that is different on inspection roll 51 and also different on multi-layer sheet 10. FIG. 5C is a schematic view illustrating a positional relationship between measurement light L when the B scan is performed and multi-layer sheet 10 at the B scan position that is the same on inspection roll 51 and different on multi-layer sheet 10 in a state in which a transporting speed of multi-layer sheet 10 is reduced.

In a case where a plurality of B scan images are averaged, when there is a variation in the thickness inside the surface of multi-layer sheet 10, the different the B scan position corresponding to the B scan image, the different the generation pattern of speckle. In this case, unlike the above-mentioned averaging of the same part, B scan images of different parts are averaged. Therefore, the calculation accuracy of thickness ΔZs and thickness ΔZt performed in step S4 becomes low.

Hereinafter, a positional relationship between measurement light L and multi-layer sheet 10 in FIGS. 5A to 5C will be specifically described by dividing them into terms (A, B, C).

(A: Averaging B scan images, which can be obtained by B scans, at different B scan positions on the inspection roll and the same B scan position on the multi-layer sheet (front surface))

In Exemplary Embodiment 1 and Exemplary Embodiment 2 described later, as illustrated in FIG. 5A, the B scan position on inspection roll 51 is shifted by a predetermined amount in parallel with the transporting direction of multi-layer sheet 10, that is, the Y direction. From the viewpoint of multi-layer sheet 10, a B scan image is acquired by performing a B scan with respect to the same B scan position on the front surface of multi-layer sheet 10 under the same condition. The amount of shifting is determined by thickness calculator 62 of sheet generation controller 60 based on the transporting speed of multi-layer sheet 10.

As illustrated in FIGS. 4A and 4B, the radius of inspection roll 51 is defined as r, and the line passing through the center of inspection roll 51 and extending in the gravity direction is defined as center line C. An angle formed by a line, which connects a position on inspection roll 51 in which measurement light L is incident on during a first B scan and a center of inspection roll 51, and the gravity direction that is parallel to the Z-axis (center line C) is defined as $\theta 1$. Further, a distance along the horizontal direction (Y direction) from a first B scan position 51A, which is first interference light at a first position, to center line C is defined as X1. Hereinafter, the position may be referred to as "first B scan position 51A".

In this case, radius r, angle $\theta 1$, and distance X1 satisfy the following Equation (1).

$$X1 = r \times \cos \theta 1 \tag{1}$$

At this time, since distance X1 is a known value if the positional relationship between inspection roll 51 and measurement head 52 is fixed, angle $\theta 1$ is also a known value.

A rotation angle of the inspection roll at a time interval in which the B scan is performed is defined as AO, and a distance along the horizontal direction (Y direction) from a position on inspection roll 51, in which measurement light L is entered during a second B scan, to center line C is defined as X2. Hereinafter, the above position may be referred to as "second B scan position 51B" which is second interference light at a second position.

In this case, radius r, angle $\theta 1$, angle AO, and distance X2 satisfy the following Equation (2).

$$X2 = r \times \cos(\theta 1 + \Delta\theta) \tag{2}$$

Therefore, thickness calculator 62 controls driver 524 to operate galvanometer mirror pair 522 such that first B scan position 51A becomes a position satisfying Equation (1) and second B scan position 51B becomes a position satisfying Equation (2).

In this case, the two B scan images obtained by the first B scan and the second B scan are images illustrating different B scan positions on inspection roll 51.

That is, as illustrated in FIG. 5A, when viewed from multi-layer sheet 10, the images have the same incident position of measurement light L on multi-layer sheet 10 (front surface) but different incident angles. Due to the effect that multi-layer sheet 10 is bent along arc surface 511 of inspection roll 51, the incident angle of measurement light L1 in the first B scan is $\theta 1$, and the incident angle of measurement light L2 in the second B scan is $\theta 2$. Therefore, the generation patterns of speckle of the two B scan images are different. Two different B scan images are averaged. As a result, the speckle can be removed. Further, since the same measurement position is maintained on multi-layer sheet 10, the calculation accuracy of thickness ΔZs and thickness ΔZt performed in step S4 illustrated in FIG. 3 is not lowered.

On the other hand, with respect to a part of multi-layer sheet 10 (for example, the part positioned between inspection roll 51 and coating roll 31) which is linearly transported without bending along inspection roll 51, when the first and second B scans are performed under the same condition as above, the incident angles of the measurement lights in the two B scan images are equal to each other. Therefore, the generation patterns of speckle are also the same. As a result, even when the obtained two B scan images are averaged, the speckle cannot be removed. That is, the configuration for obtaining a B scan image at the part of multi-layer sheet 10 is not desirable.

The movement of the B scan position can be performed by changing the angle of galvanometer mirror pair 522, but the present disclosure is not limited to this. Instead of using galvanometer mirror pair 522, for example, a mechanism such as a stepping motor may be provided to move mea-

surement head **52** itself. As a result, the same effect can be obtained without using an expensive galvanometer mirror.

(B: Averaging B scan images, which can be obtained by B scans, at different B scan positions on the inspection roll and also different B scan positions on the multi-layer sheet (front surface))

When there is no variation in the thickness of multi-layer sheet **10** in the plane, the incident positions of the measurement light in the plurality of B scans may be significantly different. In this case, it is more desirable that the incident position of the measurement light is largely shifted by, for example, equal to or larger than the spot diameter of the measurement light. Thereby, the effect of removing the speckle can be enhanced.

At that time, as illustrated in FIG. **5B**, with respect to the incident position (corresponding to the first position) of measurement light L1 of the first B scan on multi-layer sheet **10**, the incident position (corresponding to the second position) of measurement light L2 of the second B scan is set to be positioned on the rear side of multi-layer sheet **10** in the transporting direction. As a result, it is possible to generate a large difference in the position of the measurement light while suppressing the amount of change in the angle of the galvanometer mirror pair **522**. Further, it is possible to surely prevent measurement light L1 and measurement light L2 from being incident on the same part. As a result, it is more desirable because it can make a large difference in the generation patterns of speckle.

With respect to the incident position (corresponding to the first position) of measurement light L1 of the first B scan, the incident position (corresponding to the second position) of measurement light L2 of the second B scan may be set to be positioned on the front side of multi-layer sheet **10** in the transporting direction. With this configuration, the same part of multi-layer sheet **10** can be measured by using the measurement light entered from different angles.

An interval between the incident position of measurement light L1 of the first B scan and the incident position of measurement light L2 of the second B scan is desirably the same as a distance at which multi-layer sheet **10** is transported from the start of the incident of measurement light L1 of the first B scan to the start of the incident of measurement light L2 of the second B scan. With this configuration, measurement light can be incident on the same part during the transportation of multi-layer sheet **10** to make the B scan position the same. Thereby, the B scan images of the same part can be averaged. As a result, it is possible to suppress a decrease in the calculation accuracy of thickness ΔZs and thickness ΔZt, which is performed in step S4 illustrated in FIG. **3**.

As described above, when the first B scan and the second B scan are performed, in the case illustrated in FIG. **5A**, the incident angle of the measurement light is different but the incident position is the same, in multi-layer sheet **10**. On the other hand, in the case illustrated in FIG. **5B**, both the incident angle of the measurement light (incident angle θ1 of measurement light L1 in the first B scan incident angle θ2 of measurement light L2 in the second B scan) and the incident position are different.

(C: Averaging B scan images, which can be obtained by B scans, at the same B scan position on the inspection roll and different B scan positions on the multi-layer sheet (front surface))

In general, even when there is no variation in the thickness of multi-layer sheet **10** in the plane, it is not desirable to continue the B scan at the same position on inspection roll

51 because the speckle may not be sufficiently removed due to the following situations and the like.

For example, there is a case where multi-layer sheet **10** momentarily stops or the transporting speed decreases during the transportation because of the slack of multi-layer sheet **10** due to disturbance or fluctuation of tension. In this case, the incident positions of the measurement lights may be the same or extremely close to each other. Therefore, there is a possibility that the speckle cannot be sufficiently removed, which is not desirable.

In the above situation, as illustrated in FIG. **5C**, the incident angle of measurement light L1 of the first B scan and the incident angle of measurement light L2 of the second B scan on multi-layer sheet **10** become the same. Therefore, the difference between the incident positions of measurement light L1 and measurement light L2 becomes the length obtained by multiplying the transporting speed by the time interval of each of the B scans. That is, when the transporting speed becomes close to 0 (zero) due to fluctuations in tension or the like since the same speckle pattern occurs in the first B scan and the second B scan, it is not desirable in the averaging process of the B scan image.

In A, B, and C described above, an example of averaging two B scan images has been described, but the present disclosure is not limited to this. For example, two or more B scan images may be averaged. As a result, the measurement tact is increased, and the speckle pattern can be removed more strongly.

Regarding the Position of the Measurement Light in the Y Direction in the Averaging Process of a Plurality of B Scan Images of the Multi-Layer Sheet Having a Structure that is not Uniform in the X Direction

Next, in the averaging process of the plurality of B scan images in step S3 illustrated in FIG. **3**, a position of the measurement light in the Y direction in the averaging process of the B scan image of multi-layer sheet **10** having a structure that is not uniform in the X direction (width direction) will be described with reference to FIGS. **6A** to **6C**.

FIG. **6A** is a cross-sectional view of a YZ plane illustrating a periodic structure of sheet material **11** in multi-layer sheet **10**. FIG. **6B** is an XY plan view illustrating a positional relationship between inspection roll **51** of SS-OCT device **50** and multi-layer sheet **10**. FIG. **6C** is an XY plane view illustrating a periodic structure of sheet material **11** in multi-layer sheet **10**.

That is, even when the positions in the Y direction of multi-layer sheet **10** are the same, there is a case where different B scan images are obtained depending on the positions in the X direction.

Therefore, as illustrated in FIG. **6A**, a case where the front surface of sheet material **11** is provided with a periodic uneven structure in the X direction in order to improve the adhesion with coating material **12** will be considered below.

Specifically, as illustrated in FIG. **6B**, it is conceivable that a B scan image is obtained at first B scan position **51C** and second B scan position **51D** along a line parallel to the X direction and at different positions in the Y direction. In this case, when the phase of the periodic structure of sheet material **11** in the X direction is always constant regardless of the position in the Y direction, the periodic structure of the B scan image in the X direction is also constant regardless of the measurement position (first B scan position **51C** and second B scan position **51D**).

However, in general, the transporting direction of sheet material **11** is not a direction such that a specific phase portion (for example, the mountain portion having the

periodic structure) having the periodic structure exists along the transporting direction unless a device such as an edge position controller (EPC) is used. That is, as illustrated in FIG. **6**C, there is a case where specific phase portion P having the periodic structure becomes a direction that exists in the θz direction at inclined angle θs with respect to the transporting direction.

In this case, even when the averaging process may be performed by using the B scan images at first B scan position **51**C and second B scan position **51**D as they are, the speckle can be removed because the incident positions of the measurement light are different. However, since the periodic structures of sheet materials **11** in the two B scan images are different, the image that is obtained by the averaging process becomes unclear. Therefore, the calculation accuracy of thickness ΔZs and thickness ΔZt is lowered.

Therefore, the correction in the Y direction is performed based on the transporting distance of sheet material **11** and angle θs. Specifically, second B scan position **51**D is offset in the Y direction with respect to first B scan position **51**C by distance M satisfying the following Equation (3) based on transporting distance D and angle θs of the sheet material **11** between the two B scans so that the same position can be measured. As a result, it is possible to eliminate the phase shift of the periodic structure in the two B scan images.

$$M = D \times \tan \theta s \tag{3}$$

Angle θs may be acquired based on the phase difference between the two B scan images in the X direction. Angle θs may be acquired based on the result of detecting the position of sheet material **11** in the X-direction edge with a displacement meter (not illustrated).

In the above description, the case where the phase in the front surface structure of sheet material **11** is taken into consideration has been described as an example, but the present disclosure is not limited to this. For example, first B scan position **51**C and second B scan position **51**D may be adjusted as described above in consideration of the phase of the fiber structure of sheet material **11** itself. Even when the front surface of sheet material **11** has a non-periodic structure instead of a periodic structure, first B scan position **51**C and second B scan position **51**D may be adjusted as described above. The averaging process may be performed by combining the adjustment of the measurement light in the plurality of B scans described based on FIGS. **4**A to **4**B and **5**A to **5**B, and the adjustment of the measurement light in the plurality of B scans described based on FIGS. **6**A to **6**C. As a result, the effect of suppressing blurring of the image can be obtained while removing the speckle.

Regarding the Correction of B Scan Image Based on the Height of B Scan Position

Next, the correction of the B scan image based on the height of the B scan position will be described with reference to FIGS. **4**A and **4**B.

That is, an offset may occur in the height in the Z direction between first B scan position **51**A and second B scan position **51**B. This is because the shape of multi-layer sheet **10** along the Y direction is not a straight line. When the B scan images obtained at first B scan position **51**A and second B scan position **51**B having different heights are averaged, the accuracy of calculating thickness ΔZs and thickness ΔZt performed in step S**4** illustrated in FIG. **3** will be reduced.

Therefore, the B scan image is corrected and then averaged. Thereby, the calculation accuracy of thickness ΔZs and thickness ΔZt can be improved.

Specifically, in the case illustrated in FIG. **4**A, difference H between the height of first B scan position **51**A and the

height of second B scan position **51**B is obtained based on the following Equation (4). Therefore, the B scan image at second B scan position **51**B is offset in the Z direction by the obtained difference H.

$$H = r \times \{\sin \theta 1 - \sin(\theta 1 + \Delta \theta)\} \tag{4}$$

For example, in the first B scan image among the 100-pixel image in the height direction (Z direction), it is assumed that multi-layer sheet **10** is captured at the 50th pixel in the height, and in the second B scan image, it is assumed that multi-layer sheet **10** is captured at the 55th pixel in the height, shifted in the Z direction by height difference H.

In this case, as an offset, 5 pixels in the Z direction of the second B scan image are deleted. Thereby, the heights of multi-layer sheets **10** in the first B scan image and the second B scan image can be aligned. As a result, the calculation accuracy of thickness ΔZs and thickness ΔZt can be improved.

In addition to the above method, the first B scan image may be provided with extra 5 pixels in the height direction, and the heights of the multi-layer sheets **10** in the first B scan image and the second B scan image may be aligned. As a result, the same effect as described above can be obtained.

Regarding the Correction of B Scan Image Based on the Incident Angle of the Measurement Light

Next, the correction of the B scan image based on the incident angle of the measurement light will be described with reference to FIG. **7**A. FIG. **7**A is a schematic view illustrating a refraction state of measurement light L in multi-layer sheet **10**.

That is, when the incident angle of the measurement light with respect to multi-layer sheet **10** is not perpendicular, and when the refractive index of multi-layer sheet **10** is high with respect to air, the refraction generation of measurement light L is corrected. To be precise, the refractive indexes of coating material **12** and sheet material **11** of multi-layer sheet **10** are slightly different but are much smaller as compared with the difference in the refractive indexes of the air and the resin material.

Therefore, for the sake of simplicity, multi-layer sheet **10** will be described below assuming that multi-layer sheet **10** has a uniform refractive index n.

For example, as illustrated in FIG. **7**A, measurement light L entered at an angle $\theta 3$ from the vertical direction, which is the thickness direction of multi-layer sheet **10**, enters inside multi-layer sheet **10** at angle $\theta 4$ due to refraction by multi-layer sheet **10**. The optical path length of the refracted light is defined as D**4**.

At this time, angle $\theta 3$ and angle $\theta 4$ have a relationship of the following Equation (5).

$$\sin \theta 3 = n \times \sin \theta 4 \tag{5}$$

In Equation (5), angle $\theta 3$ is known from the relationship between the B scan position and the position of inspection roll **51**, as illustrated in FIG. **7**A. The refractive index n is also known. Therefore, angle $\theta 4$ can be obtained by Equation (5).

Therefore, by using the above-mentioned refractive index n and angle $\theta 4$, the Z-axis of the B scan image of SS-OCT measurement is multiplied by coefficient **8** shown below. Thereby, the thickness of multi-layer sheet **10** can be converted into the actual thickness T.

That is, with respect to the obtained optical path length D**4**, the actual thickness T of multi-layer sheet **10** can be

obtained based on the following Equation (6). At this time, coefficient **8** becomes a value obtained by the following Equation (7).

$$T=(D4/n)\times\cos\theta4 \tag{6}$$

$$\beta=1/n\times\cos\theta4 \tag{7}$$

In the above, the amount of correction of the B scan image based on the height of the B scan position and the incident angle of the measurement light is calculated on the assumption that inspection roll **51** has a cylindrical shape, but the present disclosure is limited to this. It may be stored as a table in advance by using the actual measured values, for example, the pixel values of the front surface position and the back surface position of multi-layer sheet **10** at each B scan position in the depth direction, or the like. The amount of correction may be calculated based on the stored table. As a result, the same effect can be obtained even when the shape of inspection roll **51** is unknown.

Regarding the Calculation Method of Thickness Z

Next, a calculation method of the thickness of the multi-layer sheet will be described with reference to FIG. 7B. FIG. 7B is an explanatory view of a calculation method of the thickness of multi-layer sheet **10**.

Thickness calculator **62** of sheet generation controller **60** measures boundary position Z1, boundary position Z2, and boundary position Z3 illustrated in the left figure in FIG. 7B based on the obtained B scan image. Boundary position Z1 is a boundary position between the air and coating material **12**. Boundary position Z2 is a boundary position between coating material **12** and sheet material **11**. Boundary position Z3 is a boundary position between sheet material **11** and the back surface air or inspection roll **51**.

Regarding the measurement of boundary positions Z1, Z2, and Z3, for example, the measurement may be performed by using the peak position of the signal intensity in the Z direction, or the measurement may be performed by using another signal processing method such as edge detection with respect to the SS-OCT signal. At this time, in the X direction and the Y direction, for example, a filter such as integration may be applied to improve the measurement accuracy of the boundary position.

In Exemplary Embodiment 1 and Exemplary Embodiment 2, since thickness ΔZs and thickness ΔZt may be calculated, boundary position Z1, boundary position Z2, and boundary position Z3 may be known. Therefore, for example, it is not necessary to distinguish whether the SS-OCT signal corresponding between boundary position Z2 and boundary position Z3 is the SS-OCT signal from sheet material **11** or coating material **12**. However, both signals may be distinguished by using the fact that the intensity of the scattered light with respect to the measurement light is different inside sheet material **11** and coating material **12**.

Specifically, when the inside of sheet material **11** is uniform and the inside of coating material **12** contains mixed objects, the scattering of the measurement light inside coating material **12** is large. In that case, as illustrated in the right figure in FIG. 7B, the signal intensity between boundary position Z1 and boundary position Z2 is stronger than the signal intensity between boundary position Z2 and boundary position Z3. Therefore, both sheet material **11** and coating material **12** may be distinguished by using the difference in the obtained signal intensities.

From the obtained boundary positions Z1, Z2, and Z3, (Z2–Z1) becomes the optical thickness including the refractive index of coating material **12**. Further, (Z3–Z2) becomes

the optical thickness including the refractive index of sheet material **11**. Therefore, these optical thicknesses are divided by the known refractive indexes of sheet material **11** and coating material **12**. As a result, the respective physical thickness ΔZs and physical thickness ΔZt are obtained. Physical thickness ΔZs and physical thickness ΔZt here are the average thicknesses in the X direction obtained by the two B scans. For example, the minimum or maximum thickness may be set for each part of the B scan in the X direction. As a result, not the average in the X direction, the minimum value or maximum value of the thicknesses in that range can be adopted as the "physical thickness".

Sheet generation controller **60** drives coating device **33** while rotationally driving winding roll **40**, and continuously performs the above measurement while changing rotation angle θ of winding roll **40**. Thereby, thickness ΔZs and thickness ΔZt are measured at all rotation angles θ until the completion of the production of multi-layer sheet **10**.

From the above, thickness ΔZs and thickness ΔZt of multi-layer sheet **10** can be calculated.

Regarding the Quality Determination of the Multi-layer Sheet Next, the quality determination of generated multi-layer sheet **10** will be described.

First, when multi-layer sheet **10** is used as an adhesive sheet, the function as the multi-layer sheet may not be achieved unless thickness ΔZt and thickness ΔZs are equal to or larger than a certain size. Specifically, for example, when thickness ΔZs of sheet material **11** is thin, the intensity is insufficient. On the other hand, when thickness ΔZt of coating material **12** that is an adhesive is thin, the adhesive force may be insufficient.

Therefore, in Exemplary Embodiment 1 and Exemplary Embodiment 2, the quality determination of the multi-layer sheet is performed by using a first threshold value as a threshold value having a certain size. Specifically, the quality determination of the multi-layer sheet is performed by comparing the first threshold value with thickness ΔZs and thickness ΔZt by determiner **63**. At this time, for example, the first threshold value is set to 50 μm.

On the other hand, when the values of thickness ΔZs and thickness ΔZt are too large, a problem may occur. Therefore, thickness ΔZs and thickness ΔZt need to be equal to or less than a certain size. The quality determination of the multi-layer sheet is further performed by using a second threshold value as a threshold value of a certain size. At this time, for example, the second threshold value is set to 100 μm.

That is, a value equal to or larger than the first threshold value and equal to or less than the second threshold value is stored in advance in storage **64** as an OK range of the multi-layer sheet. Based on the stored OK range, determiner **63** performs the quality determination of multi-layer sheet **10**.

Actions and Effects of Exemplary Embodiment 1

According to Exemplary Embodiment 1, thickness ΔZs of sheet material **11** and thickness ΔZt of coating material **12** are measured by using SS-OCT device **50** in which the interference light is used. Therefore, it is not necessary to provide measurement head **52** constituting SS-OCT device **50** with a cover for preventing explosion such as X-ray thickness meter **93** in Patent Literature 1. That is, the installation place of measurement head **52** can be set near the position where coating material **12** is applied to sheet material **11**. As a result, sheet producing device **1** can perform an inspection of the thickness of multi-layer sheet **10** immediately after producing multi-layer sheet **10** while producing multi-layer sheet **10**. Therefore, the tact time from

the start of the production of multi-layer sheet **10** to the end of the inspection of the thickness of multi-layer sheet **10** can be shortened.

Exemplary Embodiment 2

Hereinafter, a sheet producing device **1A** according to Exemplary Embodiment 2 of the present disclosure will be described separately in terms of items.

Schematic Configuration of Sheet Producing Device

First, a schematic configuration of sheet producing device **1A** according to Exemplary Embodiment 2 of the present disclosure will be described with reference to FIG. **8**.

FIG. **8** is a schematic view of sheet producing device **1A** according to Exemplary Embodiment 2 of the present disclosure. The same components as those in Exemplary Embodiment 1 may be given the same reference numerals and the same names, and the description thereof may be omitted.

As illustrated in FIG. **8**, sheet producing device **1A** of Exemplary Embodiment 2 is different from sheet producing device **1** of Exemplary Embodiment 1 in that thickness adjustor **70A** is further included, and sheet generation controller **60A** is provided instead of sheet generation controller **60**.

Thickness adjustor **70A** of sheet producing device **1A** includes a pair of rollers **71A** that interpose multi-layer sheet **10** and movement device **72A** that controls the positions of the pair of rollers **71** to change the thickness of multi-layer sheet **10**.

The pair of rollers **71A** are provided so as to interpose multi-layer sheet **10** between coating roll **31** and winding roll **40**. Movement device **72A** is driven so as to change the gap between the pair of rollers **71A**. As a result, the thickness of multi-layer sheet **10** is configured to be changed.

Sheet generation controller **60A** is different from sheet generation controller **60** of Exemplary Embodiment 1 in that feedback controller **66A** is further provided.

Specifically, feedback controller **66A** feeds back the amount of control, which is based on thickness ΔZs and thickness ΔZt obtained by using SS-OCT device **50**, to movement device **72A** of thickness adjustor **70A**. The relationship between thickness ΔZs and thickness ΔZt, and the amount of control is stored in advance in storage **64** as a relational equation or a table. That is, feedback controller **66A** determines the amount of control by using the relational equation or the table stored in advance, and feeds back the amount of control to movement device **72A**.

Sheet Producing Method

Next, a sheet producing method by sheet producing device **1A** will be described by using FIG. **9** with reference to FIG. **8**. FIG. **9** is a flowchart illustrating a sheet producing method. The same steps as those in Exemplary Embodiment 1 may be designated by the same reference numerals and the description thereof may be omitted.

First, as illustrated in FIG. **9**, the processes of steps S1 to S9 of Exemplary Embodiment 1 illustrated in FIG. **3** are performed.

In step **9**, operation controller **61** determines whether or not multi-layer sheet **10** is completed. At this time, when operation controller **61** determines that multi-layer sheet **10** is completed (YES in step S9), the process in step S10 is performed.

On the other hand, when operation controller **61** determines that multi-layer sheet **10** is not completed (NO in step S9), feedback controller **66A** calculates the amount of con-

trol (amount of feedback) of the pair of rollers **71A** based on the calculation results of thickness ΔZs and thickness ΔZt in step S4 (step S21).

Feedback controller **66A** causes movement device **72A** to execute feedback (step S22).

Next, movement device **72A** adjusts the gap between the pair of rollers **71A** based on the amount of feedback.

Thereafter, the process returns to step S3, and the SS-OCT measurement by SS-OCT device **50** is performed again.

Next, as in Exemplary Embodiment 1, sheet material **11** from sheet supply reel **20** to coating roll **31** is cut by a cutting part (not illustrated) (step S10), and the sheet producing operation of multi-layer sheet **10** is ended.

Modification Example

Needless to say, the present disclosure is not limited to the exemplary embodiments described above, and various modifications can be made without departing from the spirit of the present disclosure.

For example, in Exemplary Embodiment 1 and Exemplary Embodiment 2, the following configurations may be applied.

Specifically, threshold values of an upper limit and a lower limit may be set for each of sheet material **11** and coating material **12** as criteria for determining the quality of multi-layer sheet **10**. As a result, for example, when the thickness of sheet material **11** fluctuates as a material characteristic, by making the threshold value of coating material **12** stricter than the threshold value of the upper and lower limits of sheet material **11**, the effect of maintaining the thickness accuracy of the coating material can be obtained.

In the above description, although it has been described in the example of obtaining the actual thickness ΔZs and thickness ΔZt by dividing the optical thickness by the refractive index, but the present disclosure is not limited to this. For example, the obtained optical thickness may be used as it is as the respective thickness ΔZs and thickness ΔZt, and a threshold value corresponding to thickness ΔZs and thickness ΔZt may be set. As a result, the accuracy can be maintained even when the refractive index of object is unknown.

Thickness ΔZs and thickness ΔZt may be calculated based on the result of one B scan (one B scan image), and thickness ΔZs and thickness ΔZt may be calculated based on the result of at least one A scan. The measurement light may be incident on both surfaces of multi-layer sheet **10**, in other words, sheet material **11** side and coating material **12** side, and thickness ΔZs and thickness ΔZt may be measured by using the measurement light. At this time, the above configuration can be implemented by using two SS-OCT devices **50**. As a result, a good image can be obtained on the back surface side of sheet material **11** even when the transmittance is insufficient.

In the above description, the configuration in which sheet supply reel **20**, coating roll **31**, and inspection roll **51** are not individually provided with a drive source for rotating each of them has been described as an example, but a rotation drive device such as a motor may be provided individually. Thereby, as compared with a case driven by a single motor, it is easier to control the travel speed.

In Exemplary Embodiment 2, a configuration in which a mechanism for adjusting the gap between the pair of rollers **71A** is adopted as thickness adjustor **70A** has been described as an example, but the present disclosure is not limited to this. Another mechanism having a function of adjusting the

thickness of multi-layer sheet **10** in the Z-axis direction, for example, a mechanism for adjusting the thickness of multi-layer sheet **10** by heating may be adopted. For example, a mechanism for adjusting the thickness of only coating material **12** by a peeling off action such as a scraper may be adopted. As a result, the effect of being able to adjust the thickness can be obtained regardless of the physical characteristics of the coating material.

In Exemplary Embodiment 2, thickness adjustor **70A** has been described as an example of a configuration in which the thickness of multi-layer sheet **10** is changed by interposing multi-layer sheet **10**, but the present disclosure is not limited to this. For example, a configuration in which the thickness of sheet material **11** is changed by interposing only sheet material **11**, may be used. Further, a configuration in which only the thickness of a coating by coating device **33** is changed may be used. At this time, a configuration in which the thickness of both sheet material **11** and coating material **12** is changed at the same time may be used.

Any exemplary embodiment or modification example may be combined as appropriate among the above-described exemplary embodiments or modification example. As a result, the effects of each can be achieved.

In Exemplary Embodiment 1 and Exemplary Embodiment 2, when infrared light, which is the measurement light, passes through the resin, speckle is generated, and the accuracy of the detected thickness is lowered. Therefore, as described above, it is more desirable, but not limited to, to measure the thickness of sheet material **11** and coating material **12** on inspection roll **51** during the production of the multi-layer sheet. For example, after multi-layer sheet **10** is completed, it is possible to measure the thickness by using SS-OCT measurement. As a result, the measurement can be performed in a statically indeterminate environment as compared with inspection roll **51**.

What is claimed is:

1. A sheet producing device for producing a multi-layer sheet by applying a coating material to a sheet material that is transported, the sheet producing device comprising:

a radiation light source that emits radiation light;

a division portion that divides the radiation light into measurement light to be incident on the multi-layer sheet and reference light with which a reference surface is to be irradiated;

an optical member that emits the measurement light onto the multi-layer sheet and receives the measurement light reflected by the multi-layer sheet;

an interference detector that detects interference light in which the measurement light reflected by the multi-layer sheet and the reference light reflected by the reference surface interfere with each other;

a thickness calculator that calculates a thickness of the sheet material and a thickness of the coating material of the multi-layer sheet based on the detected interference light;

a coating device for forming the multi-layer sheet by applying the coating material to the sheet material transported on a coating roll;

an inspection roll that is provided on an opposite side of the optical member with the multi-layer sheet interposed therebetween so as to contact with the multi-layer sheet;

a winding roll for winding the multi-layer sheet; and

a profile acquisition portion that acquires an intensity profile of the interference light, which is obtained by moving an incident position of the measurement light in a width direction of the multi-layer sheet, at a predetermined position in a length direction of the multi-layer sheet by controlling the optical member, wherein

the inspection roll is provided such that a central axis of the inspection roll is parallel to the width direction of the multi-layer sheet,

the optical member is configured to emit the measurement light toward an arc surface of the inspection roll, the arc surface being in contact with the multi-layer sheet,

the multi-layer sheet is positioned to be in contact with the inspection roll at a predetermined holding angle on the arc surface of the inspection roll,

the profile acquisition portion acquires the intensity profile of the interference light at a plurality of positions in the length direction of the multi-layer sheet,

the thickness calculator calculates the thickness of the sheet material and the thickness of the coating material based on a result of averaging a plurality of the intensity profiles,

the profile acquisition portion acquires an intensity profile of first interference light at a first position in the length direction of the multi-layer sheet and then acquires an intensity profile of second interference light at a second position behind the first position in a transporting direction of the multi-layer sheet, and

when a time at which the measurement light is emitted to the first position is defined as a first time point, and a time at which the measurement light is emitted to a second position is defined as a second time point, a distance between the first position and the second position is the same as a distance that the multi-layer sheet is transported during an elapsed time between the first time point and the second time point.

2. The sheet producing device of claim **1**, wherein the optical member is configured such that the measurement light is incident on the arc surface perpendicularly.

3. The sheet producing device of claim **1**, wherein the optical member is configured to emit the measurement light onto the multi-layer sheet positioned between the coating device and the winding roll.

4. The sheet producing device of claim **1**, further comprising:

a thickness adjustor that adjusts at least one of the thickness of the sheet material and the thickness of the coating material based on the thickness of the sheet material and the thickness of the coating material.

5. The sheet producing device of claim **1**, wherein the radiation light source emits infrared light as the radiation light.

6. The sheet producing device of claim **1**, wherein the radiation light source emits the radiation light in which a wavelength changes periodically in a range of 1550 nm±100 nm.

7. The sheet producing device of claim **1**, wherein the radiation light source emits the radiation light that contains light having a plurality of wavelengths within a range of 1550 nm±100 nm.

8. The sheet producing device of claim **1**, further comprising:

a determiner that determines a quality of the multi-layer sheet based on the thickness of the sheet material and the thickness of the coating material, wherein

the determiner is configured to determine an OK range when the thicknesses of the sheet material and the coating material are 50 μm or more and 100 μm or less, respectively.

9. A sheet producing method for producing a multi-layer sheet by applying a coating material to a sheet material that is transported by using the sheet producing device of claim **1**, the sheet producing method comprising:

emitting the radiation light from the radiation light source;

dividing the radiation light into the measurement light and the reference light;

causing, with the multi-layer sheet being in contact with the arc surface of the inspection roll at the predetermined holding angle, the optical member to emit the measurement light onto the multi-layer sheet and making the measurement light reflected by the multi-layer sheet incident on the optical member;

irradiating the reference surface with the reference light;

detecting the interference light in which the measurement light reflected by the multi-layer sheet and the reference light reflected by the reference surface interfere with each other; and

calculating the thickness of the sheet material and the thickness of the coating material of the multi-layer sheet based on the detected interference light.

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