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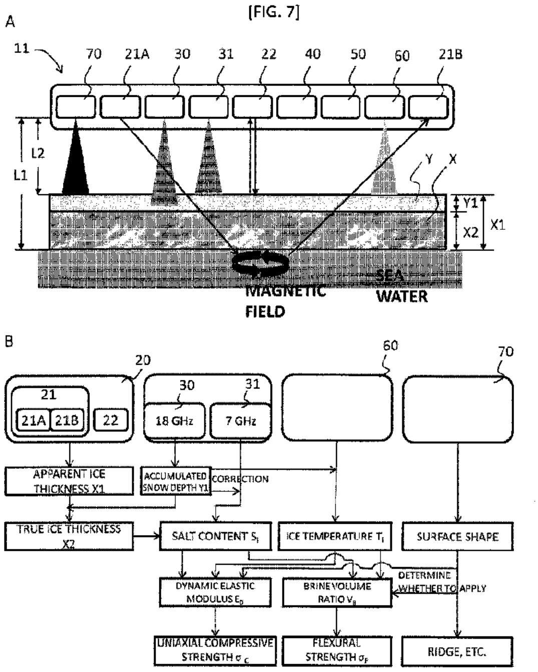
(54) Titre : PROCEDE ET DISPOSITIF DE TELEMESURE DE L'EPAISSEUR DE LA GLACE, PROCEDE ET DISPOSITIF DE TELEMESURE DE LA RESISTANCE DE LA GLACE, PROCEDE DE TELEMESURE ET CORPS DE TELEMESURE

(54) Title: A REMOTE ICE-THICKNESS MEASURING METHOD, A REMOTE ICE-STRENGTH MEASURING METHOD, A REMOTE MEASURING METHOD, A REMOTE ICE-THICKNESS MEASURING DEVICE, A REMOTE ICE-STRENGTH MEASURING DEVICE, AND A REMOTE MEASURING BOD

[FIG. 7]



(57) **Abrégé/Abstract:**
Provided are a remote ice-thickness measurement method, a remote ice-strength measurement method, a remote measurement method, a remote ice-thickness measurement device, a remote ice-strength measurement device, and a remote measurement

(57) Abrégé(suite)/Abstract(continued):
body, whereby the true thickness or strength of ice can be measured without contact therewith at any location by remotely measuring an apparent ice thickness including accumulated snow on the top surface of the ice using an electromagnetic induction sensor, remotely measuring the thickness of the accumulated snow using electromagnetic waves, and calculating the true thickness or strength of the ice on the basis of the apparent ice thickness and the thickness of the accumulated snow.

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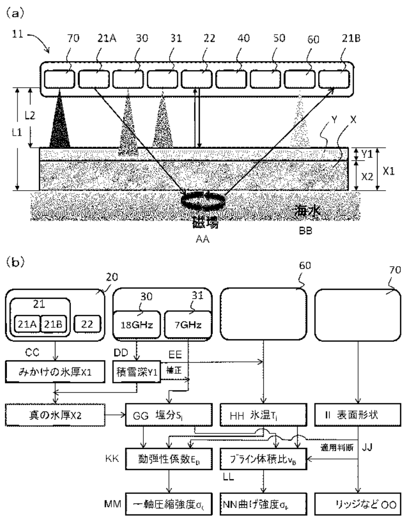
(54) **Title**: REMOTE ICE-THICKNESS MEASUREMENT METHOD, REMOTE ICE-STRENGTH MEASUREMENT METHOD, REMOTE MEASUREMENT METHOD, REMOTE ICE-THICKNESS MEASUREMENT DEVICE, REMOTE ICE-STRENGTH MEASUREMENT DEVICE, AND REMOTE MEASUREMENT BODY

(54) 発明の名称 : 遠隔氷厚測定方法、遠隔氷強度測定方法、遠隔測定方法、遠隔氷厚測定装置、遠隔氷強度測定装置、及び遠隔測定体



AA Magnetic field
BB Seawater
CC Apparent ice thickness
DD Accumulated snow depth
EE Correction
FF True ice thickness
GG Salinity
HH Ice temperature
II Surface shape
JJ Applied determination
KK Dynamic elastic modulus
LL Brine volume ratio
MM Uniaxial compression strength
NN Bend strength
OO Ridges, etc.

(57) **Abstract**: Provided are a remote ice-thickness measurement method, a remote ice-strength measurement method, a remote measurement method, a remote ice-thickness measurement device, a remote ice-strength measurement device, and a remote measurement body, whereby the true thickness or strength of ice can be measured without contact therewith at any location by remotely measuring an apparent ice thickness including accumulated snow on the top surface of the ice using an electromagnetic induction sensor, remotely measuring the thickness of the accumulated snow using electromagnetic waves, and calculating the true thickness or strength of the ice on the basis of the apparent ice thickness and the thickness of the accumulated snow.

(57) 要約: 氷の上面への積雪を含めたみかけの氷厚を遠隔から電磁誘導センサを利用して測定し、積雪の厚みを遠隔から電磁波を用いて測定し、みかけの氷厚と積雪の厚みに基づいて氷の真の氷厚又は強度を求めることにより、任意の地点において、非接触で氷の真の氷厚又は強度を測定できる、遠隔氷厚測定方法、遠隔氷強度測定方法、遠隔測定方法、遠隔氷厚測定装置、遠隔氷強度測定装置、及び遠隔測定体を提供する。

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Description

Title of the Invention :
A REMOTE ICE-THICKNESS MEASURING METHOD, A REMOTE ICE-STRENGTH MEASURING METHOD, A REMOTE MEASURING METHOD, A REMOTE ICE-THICKNESS MEASURING DEVICE, A REMOTE ICE-STRENGTH MEASURING DEVICE, AND A REMOTE MEASURING BODY

Technical field

[0001]

The present invention relates to a remote ice-thickness measuring method, a remote ice-strength measuring method, a remote measuring method, a remote ice-thickness measuring device, a remote ice-strength measuring device, and a remote measuring body, by which a thickness, a strength or the like of ice are measured in a non-contact manner.

Background Art

[0002]

A thickness or a strength of ice is information essential for evaluation of an ice strengthen of structures such as an oil and natural gas production facility operating in ice-covered waters and the like. Furthermore, the thickness or the strength is also information necessary to operate and evaluate safety or economy of a vessel such as a drilling ship, a work barge, and an icebreaker navigating in ice-covered waters.

In a mechanical strength of ice, a flexural strength and a compressive strength are included. Firstly, the ice flexural strength is related with a load generated during flexure fracture caused as a result of an ice plate being pushed up or sunk down. In this fracture mode, the load is relatively low, and hence is effective in fracture. A reason why many structures and vessels for ice-covered waters are shaped to have an inclined lateral wall is to take advantage of flexure fracture. Therefore, when a load is estimated which is imposed on a structure or a vessel for a long period of time to design and evaluate a performance on maintaining a position, propulsion and the like, it is necessary to know the flexural strength of ice.

Furthermore, the compressive strength of ice is related with a load generated during compressive fracture in which ice is crushed. In this fracture mode, generally the highest load is observed. When structures or vessels for ice-covered waters collapse, it is possible to interpret that the compressive strength of the ice exceeds the structural strength of the structures or vessels. Therefore, when designing and evaluating a critical strength of a structure or a vessel, it is necessary to know the compressive strength of ice.

[0003]

Here, Patent Document 1 discloses a method for estimating a thickness of sea ice on the basis of a phase angle of voltage induced around a secondary coil after arranging a primary coil and the secondary coil in an upper portion of the sea ice and passing a high-frequency current of 0.1 to 2 MHz through the primary coil to generate an electromagnetic field.

Furthermore, Patent Document 2 discloses a method for measuring an ice thickness by arithmetically operating a difference between an indicated value of a microwave range finder configured to measure a distance to a bottom surface of sea ice and an indicated value of an ultrasonic range finder configured to measure a distance to a top surface of the sea ice.

Furthermore, Patent Document 3 discloses a method for detecting a frozen condition of a skate rink by detecting, with an infrared camera, infrared energy emitted from the skate rink to obtain, as an infrared thermal image of a surface temperature of the skate rink, the infrared energy, with an infrared thermal image device.

Furthermore, Patent Document 4 discloses an accumulated snow measuring method for arithmetically operating a height and a density of snow by arithmetically operating a measurement result which is obtained as a result of radiating an electromagnetic wave from a transmitting antenna and receiving a reflection from a top surface of snow and a reflection from a ground surface with a receiving antenna.

Furthermore, Patent Document 5 discloses an accumulated snow depth measurement system in which a laser light ray is emitted from a scanner directing a top surface of the accumulated snow, after reciprocal scanning in a fan shape, a distance to an accumulated snow surface is measured while the scanner is moving, and a difference between the data and a stored reference value is arithmetically operated to obtain accumulated snow depth data obtained by eliminating peculiar data within a scanning angle range.

Furthermore, Patent Document 6 discloses a method for evaluating a desired draft value of sea ice by synchronously performing observation of an ice thickness/drifting velocity of sea ice by using an ice thickness measurement sonar of underwater mooring type and a current meter and observation of sea ice by a high-resolution aircraft.

Furthermore, Patent Document 7 discloses a method for depicting, in a drawing format, an accumulated snow depth or the like by flying a flying object over an object to be measured, irradiating the object to be measured with a laser light ray from the flying object, and detecting the reflected laser light ray to obtain three dimensional information of the object to be measured.

Furthermore, Patent Document 8 discloses a technology of mapping and detecting, as a property of ice, an internal crack or a deformation of ice by observing the ice with an interferometric synthetic aperture radar having two bands.

Citation List

Patent Literature

[0004]

Patent Document 1: Japanese Unexamined Patent Application Publication No. S58-223704A
Patent Document 2: Japanese Unexamined Patent Application Publication No. S62-124480A
Patent Document 3: Japanese Unexamined Patent Application Publication No. H05-253333A
Patent Document 4: Japanese Unexamined Patent Application Publication No. H11-014434A
Patent Document 5: Japanese Unexamined Patent Application Publication No. 2011-149894A
Patent Document 6: Japanese Unexamined Patent Application Publication No. 2003-149332A
Patent Document 7: Japanese Unexamined Patent Application Publication No. H10-318743A
Patent Document 8: WO 2014/039267

Summary of the Invention

Problem to be solved by the invention

[0005]

In the methods for measuring the thickness of sea ice in Patent Document 1 and Patent Document 2, a thickness of snow accumulated on ice is not taken into consideration, and thus, it is not possible to comprehend a true ice thickness.

Furthermore, in the method for detecting an ice frozen condition in a skate rink in Patent Document 3, an infrared thermal image of a surface temperature of the skate rink is obtained by using an infrared camera, and thus, the ice thickness is not measured.

Furthermore, in the methods for measuring an accumulated snow depth in Patent Document 4 and Patent Document 5, the snow height is arithmetically operated on the basis of the relationship with the ground surface that is a previously known reference surface; however, in a case of ice floating on water, a shape of ice beneath the accumulated snow is not known and thus it is not possible to obtain the reference surface, and therefore, it is not possible to apply this method to measurement of a thickness of ice on a water surface.

Furthermore, in the method for observing sea ice in Patent Document 6, the sea ice observation is synchronously performed by the ice thickness measurement sonar of underwater mooring type and the high-resolution aircraft, and thus, the sea ice is only observed from the air and the ice thickness is not measured. Furthermore, the method is for measuring the thickness of an accumulated snow.

Furthermore, in the method for measuring an accumulated snow depth in Patent Document 7, laser light is used; however, the laser range finder merely measures the distance to the surface, and it is necessary to calculate the depth as a difference from the reference surface in which the distance is fixed such as a ground surface. In a case of ice floating on water, the shape of the ice beneath the accumulated snow is not known and thus the reference surface is not obtained, and hence, it is not possible to obtain the accumulated snow depth.

Furthermore, in the technology of mapping of sea ice and the property measurement in Patent Document 8, an ice layer is measured with the interferometric synthetic aperture radar by using an electromagnetic wave with two bands. In the EM method by an electromagnetic induction sensor used in the present invention, it is proved that a measured physical amount and an ice thickness are directly correlated, and it is possible to obtain an ice thickness with accuracy. On the other hand, in the technology of Patent Document 8, a backscattering strength obtained by the interferometric synthetic aperture radar is not directly converted into the ice thickness; however, the method requires that the ice thickness is estimated through complicated processes, and thus, there is a disadvantage in terms of accuracy.

Furthermore, in Patent Document 1 to Patent Document 8, the strength of the ice is not measured in a non-contact manner.

Note that another means of measuring the ice thickness in a non-contact manner includes a means of using only a laser range finder and a means of using an underwater sonar. The laser range finder measures, from above, a difference in distance between the water surface and the ice top surface. Furthermore, the underwater sonar measures, from underwater, a distance to an ice bottom surface. A water depth is measured separately with a depth meter. However, in either method, the specific gravity of ice needs to be assumed to calculate the thickness of ice, and in addition, some shapes do not allow for calculation with the specific gravity. Besides, generally, a plane resolution is low.

Furthermore, generally, a means of measuring a temperature in a non-contact manner includes a pyrometer. However, the pyrometer, which is designed to determine from a visible light ray a temperature of an incandescent object, does not have applicability to ice.

Furthermore, another means of measuring a top surface shape of the sea ice in a non-contact manner includes a means of using a 3D camera. However, although the 3D camera provides an optical stereoscopic image, measurement at night is not possible because visible light is used.

Furthermore, in order to digitize height information, post-analysis is needed, and thus, immediacy is not provided.

[0006]

Thus, conventionally, there is no other way to obtain the true ice thickness and strength than limited local observation (direct measuring method). However, such a local observation generally requires a human and monetary cost such as cutting out an ice block and employing a large-scale tester.

[0007]

Therefore, an object of the present invention is to provide a remote ice-thickness measuring method, a remote ice-strength measuring method, a remote measuring method, a remote ice-thickness measuring device, a remote ice-strength measuring device, and a remote measuring body with which it is possible to measure, at any point, a true thickness or strength of ice in a non-contact manner.

Means for solving the problem

[0008]

A remote ice-thickness measuring method corresponding to claim 1 is a remote ice-thickness measuring method for remotely measuring an ice thickness. The method includes: remotely measuring an apparent ice thickness including an accumulated snow onto a top surface of the ice by utilizing an electromagnetic induction sensor; remotely measuring the thickness of the accumulated snow by using an electromagnetic wave; and evaluating a true thickness of the ice on the basis of the apparent ice thickness and the thickness of the accumulated snow.

According to the present invention set forth in claim 1, it is possible to exactly comprehend a true ice thickness obtained by eliminating the thickness of snow (accumulated snow depth) accumulated on ice at any point in a non-contact manner. For example, as a result of a substance having a high electrical conductivity such as sea water residing beneath the ice, it is possible to accurately measure an apparent ice thickness including an accumulated snow by using an electromagnetic induction sensor, and further, it is possible to accurately measure the thickness of an accumulated snow by using an electromagnetic wave.

[0009]

A remote ice-strength measuring method corresponding to claim 2 is a method for remotely measuring a strength of ice. The method includes: remotely measuring an apparent ice thickness including an accumulated snow onto a top surface of the ice by utilizing an electromagnetic induction sensor; remotely measuring the thickness of the accumulated snow by using an electromagnetic wave; evaluating a true thickness of the ice on the basis of the apparent ice thickness and the thickness of the accumulated snow; and calculating the strength of the ice by an ice strength calculation unit on the basis of the true ice thickness.

According to the present invention set forth in claim 2, it is possible to exactly measure the strength of ice in a non-contact manner at any point. Furthermore, the strength of ice is calculated on the basis of a true ice thickness obtained by eliminating the accumulated snow depth that is accurately measured, and thus, it is possible to comprehend the exact strength. For example, as a result of a substance having a high electrical conductivity such as sea water residing beneath the ice, it is possible to accurately measure an apparent ice thickness including an accumulated snow by using an electromagnetic induction sensor, and further, it is possible to accurately measure the thickness of an accumulated snow by using an electromagnetic wave, and thus it is possible to more exactly comprehend the strength of ice.

[0010]

The present invention according to claim 3 includes: remotely measuring a temperature of the ice by utilizing infrared; and calculating the strength while taking a measurement result of the temperature into consideration.

For example, while a bottom-surface temperature of sea ice floating on a sea-level surface stands at a freezing point, from a top-surface temperature as a measurement result and the bottom-surface temperature as a freezing point, a temperature in a center portion of the sea ice is evaluated assuming that a temperature gradient is linear relative to the ice thickness, and the temperature in the center portion is used as a representative value so as to calculate the strength of the sea ice.

According to the present invention set forth in claim 3, the temperature of the ice measured upon calculation of the strength of the ice is also taken into consideration, and thus, it is possible to more exactly comprehend the strength of the ice.

Note that "calculation" means to obtain the strength of ice by using a single parameter or a plurality thereof of an ice thickness, a temperature, a salt content, and the like. These parameters include not only that obtained by measurement, but also that obtained by correcting the above, that obtained by calculation, that obtained by a previously defined table or graph, that obtained by estimation with a rational method, and the like. The same applies hereinafter.

[0011]

The present invention according to claim 4 includes: remotely measuring a salt content of the ice by utilizing an electromagnetic wave; and calculating the strength while taking a measurement result of the salt content into consideration.

For example, when there is an accumulated snow on the sea ice, it is more likely that the calculation comes with a greater error when the accumulated snow is thicker. In this case, a coefficient corresponding to the thickness of the accumulated snow is multiplied to compensate the effect to evaluate a true salt content of the sea ice. In this way, a strength of the sea ice different depending on each salt content is calculated.

According to the present invention set forth in claim 4, the salt content of the ice measured upon calculation of the strength of the ice is also taken into consideration, and thus, it is possible to more exactly comprehend the strength of ice.

[0012]

The present invention according to claim 5 includes: remotely measuring a shape of the ice by utilizing a laser scanner; and calculating the strength while taking a measurement result of the shape into consideration.

For example, when the sea ice is ridged with an internal high pressure, the scale is estimated from a height or a width as a shape of ice, and a coefficient corresponding thereto is multiplied to take the effect into consideration to calculate the strength of the sea ice.

According to the present invention set forth in claim 5, the shape of the ice measured upon calculation of the strength of the ice is also taken into consideration, and thus, it is possible to more exactly comprehend the strength of ice.

[0013]

The present invention according to claim 6 includes: evaluating a dynamic elastic modulus on the basis of the true ice thickness, the temperature, the salt content, and the shape; and further calculating, as the strength, a uniaxial compressive strength from the dynamic elastic modulus.

According to the present invention set forth in claim 6, it is possible to exactly comprehend the uniaxial compressive strength that is one of the mechanical strengths of ice, on the basis of each parameter obtained by remote measurement.

[0014]

The present invention according to claim 7 includes: evaluating a brine volume ratio on the basis of the true ice thickness, the temperature, the salt content, and the shape; and further calculating, as the strength, a flexural strength from the brine volume ratio.

According to the present invention set forth in claim 7, it is possible to exactly comprehend the flexural strength that is one of the mechanical strengths of ice, on the basis of each parameter obtained by remote measurement.

[0015]

A remote measuring method corresponding to claim 8 includes: implementing measurement from a remote location by utilizing a moving body upon implementing the remote ice-thickness measuring method according to claim 1 or the remote ice-strength measuring method according to any one of claims 2 to 7.

According to the present invention set forth in claim 8, it is possible to measure the ice over a wide range by utilizing a moving body, and thus, it is possible to collect more data about the thickness or the strength of the ice.

[0016]

In a remote measuring method corresponding to claim 9, the measurement result obtained by implementing the remote ice-thickness measuring method according to claim 1 or the remote ice-strength measuring method according to any one of claims 2 to 7 is utilized for operation or design of an offshore structure including an oil production facility and a natural gas production facility operating in ice-covered waters, or a vessel including a drilling ship, a work barge, and an icebreaker.

According to the present invention set forth in claim 9, when the thickness or the strength of a measured ice is utilized for operation or design, it is possible to contribute improvement of safety or evaluation of economy of these facilities and vessels.

Note that the range of operation includes operation in which the measured thickness or strength of the ice is utilized in real time, operation that is utilized in a batch processing, and operation in which the both are utilized.

In particular, when the measured thickness or strength is utilized in real time, the thickness or the strength of ice measured by using a vessel may be utilized by the vessel itself, for example.

[0017]

A remote ice-thickness measuring device corresponding to claim 10 is a remote ice-thickness measuring device for remotely measuring an ice thickness. The device includes: an electromagnetic induction sensor unit utilized for remotely measuring an apparent ice thickness including an accumulated snow onto a top surface of the ice; a microwave radiometer for measurement of an accumulated snow thickness configured to remotely measure a thickness of the accumulated snow; and an ice thickness calculation unit configured to calculate a true thickness of the ice on the basis of the apparent ice thickness measured by the electromagnetic induction sensor unit and the thickness of the accumulated snow measured by the microwave radiometer for measurement of an accumulated snow thickness.

According to the present invention set forth in claim 10, it is possible to exactly comprehend a true ice thickness obtained by eliminating an accumulated snow depth at any point in a non-contact manner.

For example, as a result of a substance having a high electrical conductivity such as sea water residing beneath the ice, it is possible to accurately measure an apparent ice thickness including an accumulated snow by using an electromagnetic induction sensor unit, and further, it is possible to accurately measure the thickness of an accumulated snow by using a microwave radiometer for measurement of an accumulated snow thickness.

[0018]

A remote ice-strength measuring device corresponding to claim 11 is a device for remotely measuring a strength of ice. The device includes: an electromagnetic induction sensor unit utilized for remotely measuring an apparent ice thickness including an accumulated snow onto a top surface of the ice; a microwave radiometer for measurement of an accumulated snow thickness configured to remotely measure a thickness of the accumulated snow; an ice thickness calculation unit configured to calculate a true thickness of the ice on the basis of the apparent ice thickness measured by the electromagnetic induction sensor unit and the thickness of the accumulated snow measured by the microwave radiometer for measurement of an accumulated snow thickness; and an ice strength calculation unit of calculating the strength of the ice on the basis of the true ice thickness.

According to the present invention set forth in claim 11, it is possible to exactly measure the strength of ice in a non-contact manner at any point. Furthermore, the strength of ice is calculated on the basis of a true ice thickness obtained by eliminating the accumulated snow depth that is accurately measured, and thus, it is possible to comprehend the exact strength.

For example, as a result of a substance having a high electrical conductivity such as sea water residing beneath the ice, it is possible to accurately measure an apparent ice thickness including an accumulated snow by using an electromagnetic induction sensor unit, and further, it is possible to accurately measure the thickness of an accumulated snow by using a microwave radiometer for measurement of an accumulated snow thickness.

[0019]

According to the present invention set forth in claim 12, the remote ice-strength measuring device includes: an infrared radiometer configured to remotely measure a temperature of the ice. The ice strength calculation unit calculates the strength while taking into consideration the temperature of the ice measured by the infrared radiometer. For example, while a bottom-surface temperature of sea ice floating on a sea-level surface stands at a freezing point, from a top-surface temperature as a measurement result and the bottom-surface temperature as a freezing point, a temperature in a center portion of the sea ice is evaluated assuming that a temperature gradient is linear relative to the ice thickness, and the temperature in the center portion is used as a representative value so as to calculate the strength of the sea ice.

According to the present invention set forth in claim 12, the temperature of the ice measured upon calculation of the strength of the ice is also taken into consideration, and thus, it is possible to more exactly comprehend the strength of the ice.

[0020]

According to the present invention set forth in claim 13, the remote ice-strength measuring device includes: a microwave radiometer for measurement of a salt content configured to remotely measure a salt content of the ice. The ice strength calculation unit calculates the strength while taking into consideration the salt content measured by the microwave radiometer for measurement of a salt content.

For example, when there is an accumulated snow on the sea ice, it is more likely that the measurement comes with a greater error when the accumulated snow is thicker. In this case, a coefficient corresponding to the thickness of the accumulated snow is multiplied to compensate the effect to evaluate a true salt content of the sea ice. In this way, a strength of ice different depending on each salt content is calculated.

According to the present invention set forth in claim 13, the salt content of the ice measured upon calculation of the strength of the ice is also taken into consideration, and thus, it is possible to more exactly comprehend the strength of ice.

[0021]

According to the present invention set forth in claim 14, the remote ice-strength measuring device includes: a laser scanner configured to remotely measure a shape of the ice. The ice strength calculation unit calculates the strength while taking into consideration the shape measured by the laser scanner.

For example, when the sea ice is ridged with an internal high pressure, the scale is estimated from a height or a width as a shape of ice, and a coefficient corresponding thereto is multiplied to take the effect into consideration to calculate the strength of the sea ice.

According to the present invention set forth in claim 14, the shape of the ice measured upon calculation of the strength of the ice is also taken into consideration, and thus, it is possible to more exactly comprehend the strength of the ice.

[0022]

According to the present invention set forth in claim 15, the ice strength calculation unit evaluates a dynamic elastic modulus on the basis of the true ice thickness, the temperature, the salt content, and the shape; and further calculates, as the strength, a uniaxial compressive strength from the dynamic elastic modulus.

According to the present invention set forth in claim 15, it is possible to exactly comprehend the uniaxial compressive strength that is one of the mechanical strengths of ice, on the basis of each parameter obtained by remote measurement.

[0023]

According to the present invention set forth in claim 16, the ice strength calculation unit evaluates a brine volume ratio on the basis of the true ice thickness, the temperature, the salt content, and the shape; and further calculates, as the strength, a flexural strength from the brine volume ratio.

According to the present invention set forth in claim 16, it is possible to exactly comprehend the flexural strength that is one of the mechanical strengths of ice, on the basis of each parameter obtained by remote measurement.

[0024]

In a remote measuring body corresponding to claim 17, a measuring body member includes the remote ice-thickness measuring device according to claim 10 or the remote ice-strength measuring device according to any one of claims 11 to 16. The measuring body member is configured to be attachable by hanging from a moving body.

According to the present invention set forth in claim 17, when the measuring body member is attached by hanging from the moving body, it is possible to measure the ice over a wide range, and thus, it is possible to collect more data about the thickness or the strength of ice.

[0025]

In the present invention according to claim 18, the measuring body member includes a GPS and a storage unit configured to store a measurement result.

According to the present invention set forth in claim 18, when the global positioning system (GPS) is included in the measuring body member, it is possible to exactly comprehend a measurement point. Furthermore, when the storage unit is included in the measuring body member, it is possible to obtain the thickness or the strength of sea ice in any date and time and any latitude and longitude on a movement route after the measurement, and it is also possible to comprehend, through a plurality of times of measurements, a chronological change of the thickness or the strength of ice in the same measurement point.

Effects of the Invention

[0026]

According to the present invention, it is possible to exactly comprehend a true ice thickness obtained by eliminating the thickness of snow (accumulated snow depth) accumulated on ice at any point in a non-contact manner.

[0027]

According to method for remotely measuring strength of ice, it is possible to accurately measure strength of ice at any point in a non-contact manner by remotely measuring an apparent ice thickness including the accumulated snow onto a top surface of the ice by utilizing an electromagnetic induction sensor, remotely measuring the thickness of the accumulated snow by using an electromagnetic wave, evaluating a true thickness of the ice on the basis of the apparent ice thickness and the thickness of the accumulated snow, and calculating the strength of the ice is calculated on the basis of a true ice thickness by using an ice strength calculation unit. It is also possible to comprehend exact strength by calculating the strength of the ice on the basis of a true ice thickness obtained by eliminating the accumulated snow depth that is accurately measured.

[0028]

It is possible to more exactly comprehend the strength of the ice by remotely measuring a temperature of the ice by utilizing infrared, calculating the strength while taking a measurement result of the temperature into consideration and considering temperature of the ice measured upon calculation of the strength of the ice.

[0029]

It is possible to more exactly comprehend the strength of the ice by remotely measuring a salt content of the ice by utilizing an electromagnetic wave, calculating the strength while taking a measurement result of the salt content into consideration, and considering the salt content of the ice measured upon calculation of the strength of the ice.

[0030]

It is possible to more exactly comprehend the strength of the ice by remotely measuring a shape of the ice by utilizing a laser scanner, calculating the strength while taking a measurement result of the shape into consideration, and considering the shape of the ice measured upon calculation of the strength of the ice.

[0031]

It is possible to exactly comprehend uniaxial compressive strength that is one of the mechanical strengths of ice on the basis of each parameter obtained by remote measurement, by evaluating a dynamic elastic modulus on the basis of the true ice thickness, the temperature, the salt content, and the shape, and calculating the uniaxial compressive strength as the strength from the dynamic elastic modulus.

[0032]

It is possible to exactly comprehend flexural strength that is one of the mechanical strengths of ice, on the basis of each parameter obtained by remote measurement, by evaluating a brine volume ratio on the basis of the true ice thickness, the temperature, the salt content, and the shape and further calculating the flexural strength as the strength from the brine volume ratio.

[0033]

It is possible to measure the ice over a wide range by utilizing a moving body, and thus, it is possible to collect more data about the thickness or the strength of the ice by implementing measurement from a remote location by utilizing a moving body upon implementing the remote ice-thickness measuring method according to claim 1 or the remote ice-strength measuring method according to any one of claims 2 to 7.

[0034]

It is possible to contribute improvement of safety or evaluation of economy of these facilities and vessels by utilizing thickness or the strength of a measured ice for operation or design, when utilization is made of the measurement result obtained by implementing the remote ice-thickness measuring method according to claim 1 or the remote ice-strength measuring method according to any one of claims 2 to 7 for operation or design of an offshore structure including an oil production facility and a natural gas production facility operating in ice-covered waters, or a vessel including a drilling ship, a work barge, and an icebreaker.

[0035]

According to a remote ice-thickness measuring device, it is possible to exactly comprehend a true ice thickness obtained by eliminating an accumulated snow depth at any point in a non-contact manner, when the device includes: an electromagnetic induction sensor unit utilized for remotely measuring an apparent ice thickness including an accumulated snow onto a top surface of the ice; a microwave radiometer for measurement of an accumulated snow thickness configured to remotely measure a thickness of the accumulated snow; and an ice thickness calculation unit configured to calculate a true thickness of the ice on the basis of the apparent ice thickness measured by the electromagnetic induction sensor unit and the thickness of the accumulated snow measured by the microwave radiometer for measurement of an accumulated snow thickness.

[0036]

According to a remote ice-strength measuring device, it is possible to exactly measure the strength of ice in a non-contact manner at any point, when the device includes: an electromagnetic induction sensor unit utilized for remotely measuring an apparent ice thickness including an accumulated snow onto a top surface of the ice; a microwave radiometer for measurement of an accumulated snow thickness configured to remotely measure a thickness of the accumulated snow; an ice thickness calculation unit configured to calculate a true thickness of the ice on the basis of the apparent ice thickness measured by the electromagnetic induction sensor unit and the thickness of the accumulated snow measured by the microwave radiometer for measurement of an accumulated snow thickness; and an ice strength calculation unit of calculating the strength of the ice on the basis of the true ice thickness. Furthermore, it is possible to comprehend the exact strength by calculating the strength of the ice on the basis of a true ice thickness obtained by eliminating the accumulated snow depth that is accurately measured.

[0037]

It is possible to more exactly comprehend the strength of the ice by including an infrared radiometer configured to remotely measure a temperature of the ice, calculating the strength while taking into consideration the temperature of the ice measured by the infrared radiometer, and considering the temperature of the ice measured upon calculation of the strength of the ice.

[0038]

It is possible to more exactly comprehend the strength of ice by including a microwave radiometer for measurement of a salt content configured to remotely measure a salt content of the ice and calculating the strength by the ice strength calculation unit while taking into consideration the salt content measured by the microwave radiometer for measurement of a salt content, and considering the salt content of the ice measured upon calculation of the strength of the ice.

[0039]

It is possible to more exactly comprehend the strength of the ice by including a laser scanner configured to remotely measure a shape of the ice, calculating the strength by the ice strength calculation unit while taking into consideration the shape measured by the laser scanner, and considering the shape of the ice measured upon calculation of the strength of the ice.

[0040]

It is possible to exactly comprehend the uniaxial compressive strength that is one of the mechanical strengths of ice, on the basis of each parameter obtained by remote measurement, by evaluating a dynamic elastic modulus on the basis of the true ice thickness, the temperature, the salt content, and the shape, and further calculating, as the strength, uniaxial compressive strength from the dynamic elastic modulus.

[0041]

It is possible to exactly comprehend the flexural strength that is one of the mechanical strengths of ice, on the basis of each parameter obtained by remote measurement, by evaluating a brine volume ratio on the basis of the true ice thickness, the temperature, the salt content, and the shape, and further calculating, as the strength, flexural strength from the brine volume ratio.

[0042]

It is possible to measure the ice over a wide range by hanging a measuring body member from a moving body when a configuration is made to include in a remote measuring body member the remote ice-thickness measuring device according to claim 10 or the remote ice-strength measuring device according to any one of claims 11 to 16, and the measuring body member is configured to be attachable by hanging from a moving body. Thus, it is possible to collect more data about the thickness or the strength of ice, which will be useful as data of the moving body at operating.

[0043]

It is possible to exactly comprehend a measurement point by including GPS (Global Positioning System) in the measuring body member when a GPS and a storage unit for storing a measurement result are provided in the measuring body member. Further, it is possible to obtain the thickness or the strength of sea ice in any date and time and any latitude and longitude on a movement route after the measurement, and it is also possible to comprehend, through a plurality of times of measurements, a chronological change of the thickness or the strength of ice in the same measurement point.

Brief Description of Drawings

[0044]

FIGS. 1A and 1B are a schematic configuration diagram and a flow diagram of a remote ice-thickness measuring device according to one embodiment of the present invention.

FIGS. 2A and 2B are a schematic configuration diagram and a flow diagram of a remote ice-strength measuring device according to another embodiment of the present invention.

FIGS. 3A and 3B are a schematic configuration diagram and a flow diagram of a remote ice-strength measuring device according to yet another embodiment of the present invention.

FIGS. 4A and 4B are a schematic configuration diagram and a flow diagram of a remote ice-strength measuring device according to yet another embodiment of the present invention.

FIG. 5 is a graph showing a relationship between an ice thickness and a salt content.

FIGS. 6A and 6B are a schematic configuration diagram and a flow diagram of a remote ice-strength measuring device according to yet another embodiment of the present invention.

FIGS. 7A and 7B are a schematic configuration diagram and a flow diagram of a remote ice-strength measuring device according to yet another embodiment of the present invention.

FIG. 8 is a graph showing a relationship among a temperature, a salt content, and a dynamic elastic modulus of ice.

FIG. 9 is a graph showing a relationship between a dynamic elastic modulus and a uniaxial compressive strength of ice.

FIGS. 10A and 10B are a schematic configuration diagram and a block diagram of a remote measuring body according to yet another embodiment of the present invention.

Description of Embodiments

[0045]

Below, a remote ice-thickness measuring method, a remote ice-strength measuring method, a remote measuring method, a remote ice-thickness measuring device, a remote ice-strength measuring device, and a remote measuring body according to embodiments of the present invention, will be described.

[0046]

FIGS. 1A and 1B are a schematic configuration diagram and a flow diagram of a remote ice-thickness measuring device according to one embodiment of the present invention, where FIG. 1A is a schematic configuration diagram of the device and FIG. 1B is a flow diagram.

The remote ice-thickness measuring device 10 according to the present embodiment faces approximately parallel to sea ice X in order to measure a thickness of the sea ice X from above the sea ice X which is to be measured and underneath which a sea water resides.

The remote ice-thickness measuring device 10 includes: an electromagnetic induction sensor unit 20 utilized for remotely measuring an apparent ice thickness X1 including an accumulated snow to a top surface of the sea ice X; a microwave radiometer for measurement of an accumulated snow thickness 30 configured to remotely measure a thickness Y1 of an accumulated snow Y; and an ice thickness calculation unit 40 configured to calculate a true ice thickness X2 of the sea ice X on the basis of the apparent ice thickness X1 measured by the electromagnetic induction sensor unit 20 and the thickness Y1 of the accumulated snow Y measured by the microwave radiometer for measurement of an accumulated snow thickness 30.

Note that, here, a portable microwave radiometer (PMR) is used as the microwave radiometer for measurement of an accumulated snow thickness 30.

[0047]

The electromagnetic induction sensor unit 20 includes an electromagnetic induction sensor (EM sensor) 21 and a laser range finder 22.

The electromagnetic induction sensor 21 includes a transmitter (EM Tx) 21A and a receiver (EM Rx) 21B and is configured such that the transmitter 21A emits an electromagnetic wave directed towards the sea ice X. By the emitted electromagnetic wave, a magnetic field is formed in the vicinity of a sea surface, which is received by the receiver 21B, and by using a property that a permittivity of the sea water and a permittivity of the accumulated snow and the sea ice differ largely, it is possible to measure a distance L1 to the bottom surface of the sea ice X (sea ice bottom surface) in contact with the sea water.

Furthermore, the laser range finder 22 irradiates a top surface of the sea ice X with a laser to measure a distance L2 to the top surface of the sea ice X.

The laser range finder 22 irradiates the top surface of the sea ice X approximately vertically with pulsed laser light, receives the reflected light, and measures, on the basis of a time difference and a phase difference, the distance L2 to the top surface of the sea ice X, making it possible to measure accurately the distance L2 to the top surface of the sea ice X.

From the difference between the thus obtained distance L1 to the bottom surface of the sea ice and the distance L2 to the top surface of the sea ice, the apparent ice thickness X1 is obtained.

Note that this apparent ice thickness X1 may include the thickness Y1 of the accumulated snow Y (accumulated snow depth).

Thus, in a case of using the electromagnetic induction sensor 21 for remotely measuring the apparent ice thickness X1, the sea water, which serves as an electric conductor and resides beneath the sea ice X which is an electric non-conductor, efficiently exhibits an electromagnetic effect, making it possible to accurately detect the apparent ice thickness X1 including the thickness Y1 of the accumulated snow Y.

Furthermore, apart from the sea water, the electric conductor may include metals or graphite and the like, and when ice is formed on these conductors, the conductors accumulated with snow on the ice are also to be measured.

The portable microwave radiometer for measurement of an accumulated snow thickness 30 measures, as a brightness temperature, a microwave emission in an 18 GHz band from the top surface of the sea ice X. Due to a correlation between the thickness Y1 of the accumulated snow Y and the microwave emission in the 18 GHz band from the top surface of the sea ice X, it is possible to accurately calculate the thickness Y1 of the accumulated snow Y by measuring the brightness temperature by the portable microwave radiometer 30 used in the 18 GHz band.

The portable microwave radiometer for measurement of an accumulated snow thickness 30, which uses microwaves, which are electromagnetic waves, may utilize millimeter waves or the like.

The ice thickness calculation unit 40 includes an automatic calculation function that accurately calculates the true ice thickness X2 of the sea ice X by eliminating the thickness Y1 of the accumulated snow Y from the apparent ice thickness X1.

[0048]

Thus, when the apparent ice thickness X1, which includes the accumulated snow Y onto the top surface of the sea ice X, is remotely measured by utilizing the electromagnetic induction sensor 21 and the thickness Y1 of the accumulated snow Y is remotely measured by using the electromagnetic wave (microwave) to evaluate the true thickness X2 of the sea ice X on the basis of the apparent ice thickness X1 and the thickness Y1 of the accumulated snow Y, it is possible to comprehend the true thickness X2 of the sea ice X, which is obtained by eliminating the accumulated snow depth Y1, in a non-contact manner in any location.

A measuring method using the present electromagnetic induction sensor 21 is not affected by problems in terms of measurement accuracy related with the resolution unlike in the case of an interferometric synthetic aperture radar, and enables accurate measurement of the distance L1 to the bottom surface of the sea ice X.

Furthermore, in a case of using only the laser range finder 22 for the measurement, for example, a specific gravity of ice needs to be assumed to calculate the thickness of the ice, and in addition, some shapes do not allow for calculation with the specific gravity. However, the present embodiment combines the electromagnetic induction sensor 21 with the laser range finder 22, making the specific gravity of the ice unnecessary for the measurement and allowing for a measurement regardless of the shape, thus making it possible to obtain data with high plane resolution.

Furthermore, the electromagnetic induction sensor 21 does not need to measure the location of the top surface itself of the sea ice X, and thus, the measurement can be conducted regardless of the shape of the ice below the accumulated snow Y.

Note that the laser range finder 22 may be omitted when the distance L2 (distance to the top surface of the accumulated snow Y) between the remote ice-thickness measuring device 10 and the top surface of the sea ice X is known or obtained by another measurement means. The same applies in another embodiment that follows.

[0049]

FIGS. 2A and 2B are a schematic configuration diagram and a flow diagram of a remote ice-strength measuring device according to another embodiment of the present invention, where FIG. 2A is a schematic configuration diagram of the device and FIG. 2B is a flow diagram. Note that the same reference numbers are given to the same functional components as those in the above-described embodiment and the description thereof will be omitted.

The remote ice-strength measuring device 11 according to the present embodiment measures a strength of the sea ice X from above the sea ice X which is to be measured. The remote ice-strength measuring device 11 includes: the electromagnetic induction sensor unit 20, the portable microwave radiometer for measurement of an accumulated snow thickness 30, the ice thickness calculation unit 40, and an ice strength calculation unit 50 configured to calculate the strength of the sea ice X on the basis of the true ice thickness X2.

[0050]

The electromagnetic induction sensor 21 measures the distance L1 to the bottom surface of the sea ice X. Furthermore, the laser range finder 22 measures the distance L2 to the top surface of the sea ice X.

The laser range finder 22 irradiates the top surface of the sea ice X approximately vertically with pulsed laser light, receives the reflected light, and measures, on the basis of a time difference and a phase difference, the distance L2 to the top surface of the sea ice X, making it possible to measure accurately the distance L2 to the top surface of the sea ice X.

From the difference between the thus obtained distance L1 to the bottom surface of the sea ice X and the distance L2 to the top surface of the sea ice X, the apparent ice thickness X1 is accurately obtained. Note that this apparent ice thickness X1 may include the thickness Y1 of the accumulated snow Y (accumulated snow depth).

The portable microwave radiometer for measurement of an accumulated snow thickness 30 measures, as a brightness temperature, a microwave emission in an 18 GHz band from the top surface of the sea ice and calculates the thickness Y1 of the accumulated snow Y from this brightness temperature.

The ice thickness calculation unit 40 accurately calculates the true thickness X2 of the sea ice X by eliminating the thickness Y1 of the accumulated snow Y from the apparent ice thickness X1.

Furthermore, the ice strength calculation unit 50 includes an automatic calculation function that uses previously stored data of a correlation between the thickness and the strength of the ice to exactly calculate the strength of the sea ice X on the basis of the true thickness X2 of the sea ice calculated by the ice thickness calculation unit 40.

Note that, "accurately" and "exactly" refers to measurements of the ice thickness and the ice strength from a remote location, without measuring the ice or the snow directly, while obtaining results that are far more precise and accurate than results obtained by combining the conventional techniques.

[0051]

Thus, from remotely measuring the apparent ice thickness X1, which includes the accumulated snow Y onto the top surface of the sea ice X by utilizing the electromagnetic induction sensor 21, and from remotely measuring the thickness Y1 of the accumulated snow Y by using the electromagnetic wave (microwave); it is possible to evaluate the true thickness X2 of the sea ice X on the basis of the apparent ice thickness X1 and the thickness Y1 of the accumulated snow Y, and further, from calculating accurately the strength of the sea ice X, on the basis of the true ice thickness X2, by the ice strength calculation unit 50, it is possible to exactly measure the strength of the sea ice X in a non-contact manner at any point. Further, the strength of the sea ice X is calculated on the basis of the accurately measured true ice thickness X2 obtained by eliminating the accumulated snow depth Y1, and thus, it is possible to comprehend the exact strength.

[0052]

FIGS. 3A and 3B are a schematic configuration diagram and a flow diagram of a remote ice-strength measuring device according to yet another embodiment of the present invention, where FIG. 3A is a schematic configuration diagram of the device and FIG. 3B is a flow diagram. Note that the same reference numbers are given to the same functional components as those in the above-described embodiment and the description thereof will be omitted.

The remote ice-strength measuring device 11 according to the present embodiment measures a strength of the sea ice X from above the sea ice X which is to be measured. The remote ice-strength measuring device 11 includes: the electromagnetic induction sensor unit 20, the portable microwave radiometer for measurement of an accumulated snow thickness 30, the ice thickness calculation unit 40, the ice strength calculation unit 50, and an infrared radiometer 60 configured to remotely measures a temperature of the sea ice X.

[0053]

The electromagnetic induction sensor 21 measures the distance L1 to the bottom surface of the sea ice X. Furthermore, the laser range finder 22 measures the distance L2 to the top surface of the sea ice X. From the difference between the thus obtained distance L1 to the bottom surface of the sea ice X and the distance L2 to the top surface of the sea ice X, the apparent ice thickness X1 is accurately obtained. Note that this apparent ice thickness X1 may include the thickness Y1 of the accumulated snow Y (accumulated snow depth).

The portable microwave radiometer for measurement of an accumulated snow thickness 30 measures, as a brightness temperature, a microwave emission in an 18 GHz band from the top surface of the sea ice and calculates the thickness Y1 of the accumulated snow Y from this brightness temperature.

The ice thickness calculation unit 40 accurately calculates the true thickness X2 of the sea ice X by eliminating the thickness Y1 of the accumulated snow Y from the apparent ice thickness X1.

The ice strength calculation unit 50 uses previously stored data of a correlation between the thickness and the strength of the ice to exactly calculate the strength of the sea ice X on the basis of the true thickness X2 of the sea ice calculated by the ice thickness calculation unit 40.

Furthermore, the infrared radiometer 60 measures and directly quantifies the top-surface temperature of the accumulated snow Y. Furthermore, in order to eliminate the effect of the accumulated snow Y, the ice strength calculation unit 50 uses the accumulated snow depth Y1, measured by using the portable microwave radiometer for measurement of an accumulated snow thickness 30, to correct the top-surface temperature of the accumulated snow Y, measured by using the infrared radiometer 60, and thus evaluates the top-surface temperature of the sea ice X. Furthermore, on the basis of the top-surface temperature of the sea ice X evaluated as a result of the correction, the temperature of the sea ice X is estimated, and thus the strength of the sea ice X is calculated more exactly.

For example, while a bottom-surface temperature of the sea ice X floating on a sea-level surface stands at a freezing point, from the top-surface temperature of the sea ice X, estimated on the basis of measurement results, and the bottom-surface temperature as a freezing point, a temperature in a center portion of the sea ice X is evaluated assuming that a temperature gradient is linear relative to the true ice thickness X2, and the true ice thickness X2 and the temperature in the center portion are used as representative values so as to calculate the strength of the sea ice X.

Further, in a case in which no accumulated snow Y is present on the sea ice X or in a case in which the accumulated snow depth Y1 is very small, a value measured by the infrared radiometer 60 is used as the top-surface temperature of the sea ice X to estimate the temperature of the sea ice X, and on the basis of the thus estimated temperature of the sea ice X, the strength of the sea ice X is calculated more exactly.

[0054]

Thus, when the temperature of the sea ice X is remotely measured by utilizing infrared and the strength of the sea ice X is calculated with taking a measurement result of the temperature into consideration, it is possible to more exactly comprehend the strength of the sea ice X while taking the temperature into consideration.

[0055]

FIGS. 4A and 4B are a schematic configuration diagram and a flow diagram of a remote ice-strength measuring device according to yet another embodiment of the present invention, where FIG. 4A is a schematic configuration diagram of the device and FIG. 4B is a flow diagram. Note that the same reference numbers are given to the same functional components as those in the above-described embodiment and the description thereof will be omitted.

The remote ice-strength measuring device 11 according to the present embodiment measures a strength of the sea ice X from above the sea ice X which is to be measured. The remote ice-strength measuring device 11 includes: the electromagnetic induction sensor unit 20, the portable microwave radiometer for measurement of an accumulated snow thickness 30, the ice thickness calculation unit 40, the ice strength calculation unit 50, and a microwave radiometer for measurement of a salt content 31 configured to remotely measure a salt content of the sea ice X. Note that, here, a portable microwave radiometer (PMR) is used as the microwave radiometer for measurement of a salt content 31.

[0056]

The electromagnetic induction sensor 21 measures the distance L1 to the bottom surface of the sea ice X. Furthermore, the laser range finder 22 measures the distance L2 to the top surface of the sea ice X. From the difference between the thus obtained distance L1 to the bottom surface of the sea ice X and the distance L2 to the top surface of the sea ice X, the apparent ice thickness X1 is accurately obtained. Note that this apparent ice thickness X1 may include the thickness Y1 of the accumulated snow Y (accumulated snow depth).

The portable microwave radiometer for measurement of an accumulated snow thickness 30 measures, as a brightness temperature, a microwave emission in an 18 GHz band from the top surface of the sea ice and calculates the thickness Y1 of the accumulated snow Y from this brightness temperature.

The ice thickness calculation unit 40 accurately calculates the true thickness X2 of the sea ice X by eliminating the thickness Y1 of the accumulated snow Y from the apparent ice thickness X1.

The ice strength calculation unit 50 uses previously stored data of a correlation between the thickness and the strength of the ice to exactly calculate the strength of the sea ice on the basis of the true thickness X2 of the sea ice calculated by the ice thickness calculation unit 40.

Furthermore, the portable microwave radiometer for measurement of a salt content 31 measures, as a brightness temperature, a microwave emission in a 7 GHz band from the top surface of the sea ice X. Due to a correlation between the salt content of the top surface of the sea ice X and the microwave emission in the 7 GHz band from the top surface of the sea ice X (where an emissivity of microwaves is changed by the salt content), it is possible to measure the brightness temperature by the portable microwave radiometer for measurement of a salt content 31 used in the 7 GHz band to calculate the salt content of the top surface of the sea ice X. Note that a microwave radiometer for measurement of a salt content used in a 6 GHz band, which measures microwaves in the 6 GHz band, may also be used. Furthermore, in order to eliminate the effect of the accumulated snow Y, the ice strength calculation unit 50 uses the accumulated snow depth Y1, measured by using the portable microwave radiometer for measurement of an accumulated snow thickness 30, to correct the salt content of the sea ice X, measured by using the portable microwave radiometer for measurement of a salt content 31, and takes the corrected salt content into consideration to more exactly calculate the strength of the sea ice X.

For example, when the accumulated snow Y is present on the sea ice X, it is more likely that the measurement comes with a greater error when the accumulated snow Y is thicker. In this case, a coefficient corresponding to the thickness of the accumulated snow Y is multiplied to compensate the effect to evaluate a true salt content of the sea ice X. The true ice thickness X2 and the true salt content are used to calculate more exactly the strength of the sea ice X while taking the salt content into consideration.

Furthermore, in a case in which no accumulated snow Y is present on the sea ice X or in a case in which the accumulated snow depth Y1 is very small, the result measured by using the portable microwave radiometer for measurement of a salt content 31 is used as the salt content of the sea ice X to calculate more exactly the strength of the sea ice X.

Note that FIG. 5 is a graph showing a relationship between an ice thickness and a salt content (Kovacs, A., The Bulk Salinity of Arctic and Antarctic Sea Ice Versus Thickness. Proc. OMAE/POAC Joint Convention, Vol. IV, pp. 271-281. 1997). As shown in FIG. 5, since the ice thickness and the salt content are correlated in a wide range of ice-covered waters, it is desirable to obtain a salt content of high reliability, which is achieved by cross-verification of the salt content calculated from the true thickness X2 of the sea ice, calculated by using the ice thickness calculation unit 40, and the salt content measured by using the portable microwave radiometer for measurement of a salt content 31.

[0057]

Thus, when the salt content of the sea ice X is remotely measured by utilizing the electromagnetic wave (microwave) and the strength of the sea ice X is calculated with taking the salt content into consideration, it is possible to more exactly comprehend the strength of the sea ice X.

[0058]

FIGS. 6A and 6B are a schematic configuration diagram and a flow diagram of a remote ice-strength measuring device according to yet another embodiment of the present invention, where FIG. 6A is a schematic configuration diagram of the device and FIG. 6B is a flow diagram. Note that the same reference numbers are given to the same functional components as those in the above-described embodiment and the description thereof will be omitted.

The remote ice-strength measuring device 11 according to the present embodiment measures a strength of the sea ice X from above the sea ice X which is to be measured. The remote ice-strength measuring device 11 is provided with: the electromagnetic induction sensor unit 20, the portable microwave radiometer for measurement of an accumulated snow thickness 30, the ice thickness calculation unit 40, the ice strength calculation unit 50, and a laser scanner 70 configured to remotely measure a shape of the sea ice X.

[0059]

The electromagnetic induction sensor 21 measures the distance L1 to the bottom surface of the sea ice X. Furthermore, the laser range finder 22 measures the distance L2 to the top surface of the sea ice X. From the difference between the thus obtained distance L1 to the bottom surface of the sea ice X and the distance L2 to the top surface of the sea ice X, the apparent ice thickness X1 is obtained. Note that this apparent ice thickness X1 may include the thickness Y1 of the accumulated snow Y (accumulated snow depth).

The portable microwave radiometer for measurement of an accumulated snow thickness 30 measures, as a brightness temperature, a microwave emission in an 18 GHz band from the top surface of the sea ice and calculates the thickness Y1 of the accumulated snow Y from this brightness temperature.

The ice thickness calculation unit 40 accurately calculates the true thickness X2 of the sea ice X by eliminating the thickness Y1 of the accumulated snow Y from the apparent ice thickness X1.

The ice strength calculation unit 50 uses previously stored data of a correlation between the thickness and the strength of the ice to exactly calculate the strength of the sea ice X on the basis of the true thickness X2 of the sea ice calculated by the ice thickness calculation unit 40.

Furthermore, the laser scanner 70 measures the top surface shape of the sea ice on which the accumulated snow Y is present. Note that, here, the top surface shape of the sea ice means a roughness, an unevenness of the surface, and the like. These correlate with a degree of deformation and an age of the ice and the like, and are clues in the classification of types of ice (ice classes) such as flat ice, deformed ice or other peculiar, not foreseen shapes, for example. Depending on the surface shape or the ice type, it is possible to select algorithms for calculating parameters such as a thickness, a strength, a temperature, and a salt content of the ice, and it is possible to automatically identify places where the degree of deformation is strong, such as ice ridges, which needs to be handled separately in terms of strength. Furthermore, the ice strength calculation unit 50 estimates the shape of the sea ice X by using the thickness Y1 of the accumulated snow Y, from the top surface shape of the sea ice on which the accumulated snow Y is present, calculated by the laser scanner 70, to calculate more exactly the strength of the sea ice X, while taking the estimated shape of the sea ice X into consideration.

The strength of the sea ice X obtained from the temperature and the salt content is assumed to be that of sea ice of, in theory, approximately average and homogeneous shape. Therefore, in a case of a peculiar shape, a correction using an appropriate method is necessary. For example, when the sea ice X is ridged due to an internal high pressure, the scale is estimated from a height or a width as the shape of the ice, and a coefficient corresponding thereto is multiplied to take the effect into consideration, and, together with the true ice thickness X2, is used to calculate the strength of the sea ice X.

Furthermore, in a case in which no accumulated snow Y is present on the sea ice X or in a case in which the accumulated snow depth Y1 is very small, the result obtained by measurement by the laser scanner 70 is used as the shape of the sea ice X to calculate more exactly the strength of the sea ice X.

[0060]

Thus, when the shape of the sea ice X is remotely measured by utilizing the laser scanner 70 and the strength of the sea ice X is calculated with taking the measurement result of the shape into consideration, it is possible to more exactly comprehend the strength of the sea ice X.

Note that, it is possible to operate the laser scanner 70 even at night, because no visible light is required for the measurement. Furthermore, measurement data is automatically recorded, in a digital form, as height information, and thus, it is possible to immediately use the measurement data as a surface shape.

[0061]

FIGS. 7A and 7B are a schematic configuration diagram and a flow diagram of a remote ice-strength measuring device according to yet another embodiment of the present invention, where FIG. 7A is a schematic configuration diagram of the device and FIG. 7B is a flow diagram. Note that the same reference numbers are given to the same functional components as those in the above-described embodiment and the description thereof will be omitted.

The remote ice-strength measuring device 11 according to the present embodiment measures a strength of the sea ice X from above the sea ice X which is to be measured. The remote ice-strength measuring device 11 includes: the electromagnetic induction sensor unit 20, the portable microwave radiometer for measurement of an accumulated snow thickness 30, the portable microwave radiometer for measurement of a salt content 31, the ice thickness calculation unit 40, the ice strength calculation unit 50, the infrared radiometer 60, and the laser scanner 70. Furthermore, while the sea ice X is to be measured, the remote ice-strength measuring device 11 remotely measures the ice strength of the sea ice X.

[0062]

The electromagnetic induction sensor 21 measures the distance L1 to the bottom surface of the sea ice X. Furthermore, the laser range finder 22 measures the distance L2 to the top surface of the sea ice X. From the difference between the thus obtained distance L1 to the bottom surface of the sea ice X and the distance L2 to the top surface of the sea ice X, the apparent ice thickness X1 is obtained. Note that this apparent ice thickness X1 may include the thickness Y1 of the accumulated snow Y (accumulated snow depth).

The portable microwave radiometer for measurement of an accumulated snow thickness 30 measures, as a brightness temperature, a microwave emission in an 18 GHz band from the sea ice top surface. From the measured brightness temperature, the thickness Y1 of the accumulated snow Y is obtained.

The portable microwave radiometer for measurement of an accumulated snow thickness 30 measures, as a brightness temperature, a microwave emission in an 18 GHz band from the top surface of the sea ice and calculates the thickness Y1 of the accumulated snow Y from this brightness temperature.

The infrared radiometer 60 measures and directly quantifies the top-surface temperature of the accumulated snow Y.

The laser scanner 70 measures the top surface shape of the sea ice on which the accumulated snow Y is present.

The ice thickness calculation unit 40 accurately calculates the true thickness X2 of the sea ice X by eliminating the thickness Y1 of the accumulated snow Y from the apparent ice thickness X1.

In order to eliminate the effect of the accumulated snow Y, the ice strength calculation unit 50 uses the measured accumulated snow depth Y1 to correct the result obtained by measurement by the infrared radiometer 60 and the portable microwave radiometer for measurement of a salt content 31, and thus evaluates the top-surface temperature and the salt content of the sea ice X.

Furthermore, in a case in which no accumulated snow Y is present on the sea ice X or in a case in which the accumulated snow depth Y1 is very small, there is no need to correct the measurement results of the infrared radiometer 60, the portable microwave radiometer for measurement of a salt content 31, and the laser scanner 70, with the accumulated snow depth Y1.

[0063]

Here, FIG. 8 is a graph showing a relationship among a temperature, a salt content, and a dynamic elastic modulus of ice; and FIG. 9 is a graph showing a relationship between a dynamic elastic modulus and a uniaxial compressive strength of ice (Saeki et al., Estimation method for sea ice strength from dynamic elastic modulus tests, Proceedings of Coastal Engineering, Vol. 37, pp. 689-693. 1990). Note that, in FIG. 8, a vertical axis represents a dynamic elastic modulus E_D (kgf/cm^2), a horizontal axis represents a temperature (°C), and S (‰) in the figure represents a salt content. In FIG. 9, a vertical axis represents a uniaxial compressive strength σ_C (kgf/cm^2), a horizontal axis represents a dynamic elastic modulus E_D (kgf/cm^2), and S (‰) in the figure represents a salt content S.

The ice strength calculation unit 50 evaluates the dynamic elastic modulus E_D of the sea ice X from an average temperature T_i and a salt content S_i of the sea ice X, corrected according to the accumulated snow depth Y1. Upon evaluation of the dynamic elastic modulus E_D, an algorithm to be applied is selected automatically, taking into consideration the top surface shape of the sea ice measured by the laser scanner 70, for the relationship illustrated in FIG. 8, and the dynamic elastic modulus E_D is automatically calculated by this algorithm.

Furthermore, the ice strength calculation unit 50 calculates the uniaxial compressive strength σ_C from the evaluated dynamic elastic modulus E_D.

Thus, when the dynamic elastic modulus E_D is evaluated on the basis of the true ice thickness X2, the temperature, the salt content, and the shape, and further, the uniaxial compressive strength σ_C is calculated as the strength from the dynamic elastic modulus ED, it is possible to exactly comprehend, on the basis of each parameter obtained by remotely measuring, the uniaxial compressive strength σ_C that is one of the mechanical strengths of the sea ice X.

[0064]

Furthermore, the ice strength calculation unit 50 evaluates a brine volume ratio v_B from the average temperature T_i and the salt content S_i of the sea ice X, in accordance with the following Equation (1) (Frankenstein, G.E., Equations for determining the brine volume of sea ice from -0.5 to -22.9°C. Journal of Glaciology, Vol.6, Num. 48, pp.943-944. 1967.).

[Equation 1]

$$v_B = \frac{S_i}{100}\left(\frac{49.185}{|T_i|} + 0.532\right) \quad \cdots (1)$$

Furthermore, the evaluated brine volume ratio v_B and the following Equation (2) are used to evaluate a flexural strength σ_F (Timco, G.W. and S. O'Brien. Flexural strength equation for sea ice. Cold Regions Science and Technology, Vol. 22, pp. 285-298. 1994.).

[Equation 2]

$$\sigma_F = 1.76exp(-5.88\sqrt{v_B}) \quad \cdots (2)$$

Note that upon evaluation of the brine volume ratio v_B, an algorithm to be applied is selected automatically, with taking into consideration the top surface shape of the sea ice measured by the laser scanner 70, for the Equation (1), and the brine volume ratio v_B is automatically calculated by the algorithm.

Thus, when the brine volume ratio v_B is evaluated on the basis of the true ice thickness X2, the temperature, the salt content, and the shape, and further, the flexural strength σ_F is calculated as the strength from the brine volume ratio v_B, it is possible to exactly comprehend, on the basis of each parameter obtained by remotely measuring, the flexural strength σ_F that is one of the mechanical strengths of the sea ice X.

[0065]

FIGS. 10A and 10B are a schematic configuration diagram and a block diagram of a remote measuring body according to yet another embodiment of the present invention, where FIG. 10A is a schematic configuration diagram and FIG. 10B is a block diagram. Note that the same reference numbers are given to the same functional components as those in the above-described embodiment and the description thereof will be omitted.

[0066]

A remote measuring body 110 according to the present embodiment includes: a measuring body member 111 and is configured such that the measuring body member 111 is attachable by hanging from a moving body, such as a helicopter 120.

The measuring body member 111 includes therein: the electromagnetic induction sensor unit 20 (the electromagnetic induction sensor 21, the laser range finder 22), the portable microwave radiometer for measurement of an accumulated snow thickness 30, the portable microwave radiometer for measurement of a salt content 31, the infrared radiometer 60, the laser scanner 70, and a GPS (Global Positioning System) 80. Furthermore, the measuring body member 111 includes a computer 100 which includes: the ice thickness calculation unit 40, the ice strength calculation unit 50 and a storage unit 90 configured to store a measurement result.

[0067]

The measuring body member 111 is attached by hanging to a helicopter 120 that is a moving body via a hoisting equipment 112 such as a sling. Note that it is desirable for the measurement that the measuring body member 111 is attached by hanging such that a distance between the measuring body member 111 and the sea ice X that is to be measured, is about 15 m.

Furthermore, in order for the helicopter 120 to fly stably, the measuring body member 111 is of an elongated, cylindrical shape with one end tapering, like a missile, but other shapes are possible.

Furthermore, in order that the microwave radiometers 30 and 31 are built into the measuring body member 111, a horn shape of a transmission path is formed of a bent path for reduction in size.

Moreover, the sensitivity of the electromagnetic induction sensor 21 is easily affected by metals and the like. Therefore, in order to minimize the effect on the electromagnetic induction sensor 21, a housing and a fixing equipment of the measuring body member 111 are made of resin, where possible.

Furthermore, a network hub is built into the measuring body member 111 which is constructed therein to include a small-scale local area network (LAN) by using a connection device or the like with RS-232C and USB interfaces. As a result, it is possible for a whole control device including a signal cable and various sensors to achieve reduction in weight, hence decrease in manufacturing costs.

[0068]

The electromagnetic induction sensor 21 measures the distance L1 to the bottom surface of the sea ice X. Furthermore, the laser range finder 22 measures the distance L2 to the top surface of the sea ice X. From the difference between the thus obtained distance L1 to the bottom surface of the sea ice X and the distance L2 to the top surface of the sea ice X, the apparent ice thickness X1 is understood. Note that this apparent ice thickness X1 may include the thickness Y1 of the accumulated snow Y (accumulated snow depth).

The portable microwave radiometer for measurement of an accumulated snow thickness 30 measures, as a brightness temperature, a microwave emission in an 18 GHz band from the top surface of the sea ice and calculates the thickness Y1 of the accumulated snow Y from this brightness temperature.

The portable microwave radiometer for measurement of a salt content 31 measures, as a brightness temperature, a microwave emission in a 7 GHz band from the top surface of the sea ice X and calculates the salt content of the sea ice X from the brightness temperature.

The infrared radiometer 60 measures and quantifies directly or after providing a correction by using the accumulated snow depth Y1, the top-surface temperature of the sea ice X.

The laser scanner 70 measures the top surface shape of the sea ice to obtain directly or after providing a correction by using the accumulated snow depth Y1, the shape of the sea ice X.

[0069]

The computer 100 includes the ice thickness calculation unit 40 and the ice strength calculation unit 50, and, on the basis of each measured parameter, conducts: a calculation of the true ice thickness X2, a correction of the temperature and the salt content of the sea ice X, a calculation of the uniaxial compressive strength σ_C, and a calculation of the flexural strength σ_F.

Furthermore, the computer 100 includes the storage unit 90, such as a magnetic disk and a flash memory, configured to store, together with a measurement value, the uniaxial compressive strength σ_C, the flexural strength σ_F, and the like from various sensors, positional information received from the GPS 80.

Furthermore, an external computer 130 is installed in a command and control room of a vessel or an offshore structure, for example. The external computer 130 can get various types of information stored on the storage unit 90, and thus, it is possible to immediately give orders, as necessary, from the command and control room to a related section or the like.

[0070]

Thus, upon conducting measurements of the ice thickness and the strength of the sea ice X by utilizing the helicopter 120 to conduct to remotely measuring, it is possible to change the point to measure the ice over a wide range, and thus, it is possible to collect more data related with the ice thickness or the strength of the sea ice X. Further, since the data is digitally processed, it is possible to perform immediate automatic calculation.

Note that in the present embodiment, the helicopter 120 is given as an example of a moving body, however, various types of moving bodies including an aircraft such as an airplane, an airship, and a drone, or a vehicle such as a vessel and a snowmobile, may be used.

Moreover, for example, in a case of the moving body such as the vessel or the vehicle, the measured ice thickness or strength of ice may be utilized by the moving body itself.

Furthermore, an application of the measurement results of the ice thickness and the strength of the sea ice X includes both an application in which the measured thickness or strength of ice is utilized in real time and an application utilized in a batch processing.

Moreover, by including the GPS 80 in the measuring body member 111 of the remote measuring body 110, it is possible to exactly comprehend a measurement point. Furthermore, by including the storage unit 90 in the measuring body member 111 of the remote measuring body 110, it is possible to obtain the ice thickness or strength of the sea ice X, after the measurement, at any date and time, and in any latitude and longitude on a moving route.

Moreover, from a plurality times of measurements, it is also possible to comprehend a temporal change of the ice thickness or the strength of the sea ice X at the same measurement point.

[0071]

Furthermore, when the obtained ice thickness and strength of the sea ice X is utilized for operation or design of an offshore structure operating in ice-covered waters including an oil production facility and a natural gas production facility, or a vessel including a drilling ship, a work barge, and an icebreaker, it is possible to contribute improvement of safety or evaluation of economy of these facilities and vessels.

Industrial Applicability

[0072]

According to the present invention, it is possible to provide a remote ice-thickness measuring method, a remote ice-strength measuring method, a remote measuring method, a remote ice-thickness measuring device, a remote ice-strength measuring device, and a remote measuring body with which it is possible to comprehend a true ice thickness and strength of ice obtained by eliminating a thickness of snow accumulated on ice (accumulated snow depth), at any point, such as an ocean, a lake, and rivers, in a non-contact manner. Furthermore, when a moving body such as a helicopter, a vessel, or a vehicle including a snowmobile vehicle is used for measurement, a measurement available range is wide and it is thus possible to collect data related with a thickness and a strength of ice over a wide range.

Therefore, it is possible to provide an immediate operation support and a systematic design support for an oil and natural gas production facility operating in ice-covered waters such as the Arctic Ocean and the Sea of Okhotsk or a vessel such as a drilling ship and a work barge. Note that the immediate operation support means to quantitatively evaluate the risk due to an ice load when an operator makes a decision to secure a safety for a device operation, and the systematic design support means to accumulate design data through monitoring ice conditions for a long period of time in a particular sea area to quantitatively evaluate the ice strengthen in device design.

Reference Numeral

[0073]

10 Remote ice-thickness measuring device

11 Remote ice-strength measuring device

20 Electromagnetic induction sensor unit

21 Electromagnetic induction sensor

22 Laser range finder

30 Microwave radiometer for measurement of an accumulated snow thickness

31 Microwave radiometer for measurement of a salt content
40 Ice thickness calculation unit
50 Ice strength calculation unit
60 Infrared radiometer
70 Laser scanner
80 GPS
90 Storage unit
110 Remote measuring body
111 Measuring body member
120 Moving body

Claims

[Claim 1]

A remote ice-thickness measuring method for remotely measuring a thickness of ice, comprising:

remotely measuring an apparent ice thickness including an accumulated snow onto a top surface of the ice by utilizing an electromagnetic induction sensor;

remotely measuring a thickness of the accumulated snow by using an electromagnetic wave; and

evaluating a true thickness of the ice on the basis of the apparent ice thickness and the thickness of the accumulated snow.

[Claim 2]

A remote ice-strength measuring method for remotely measuring a strength of ice, comprising:

remotely measuring an apparent ice thickness including an accumulated snow onto a top surface of the ice by utilizing an electromagnetic induction sensor;

remotely measuring a thickness of the accumulated snow by using an electromagnetic wave;

evaluating a true thickness of the ice on the basis of the apparent ice thickness and the thickness of the accumulated snow; and

calculating the strength of the ice by an ice strength calculation unit on the basis of the true ice thickness.

[Claim 3]

The remote ice-strength measuring method according to claim 2, comprising:

remotely measuring a temperature of the ice by utilizing infrared; and

calculating the strength while taking a measurement result of the temperature into consideration.

[Claim 4]

The remote ice-strength measuring method according to claim 2 or claim 3, comprising:

remotely measuring a salt content of the ice by utilizing an electromagnetic wave; and

calculating the strength while taking a measurement result of the salt content into consideration.

[Claim 5]

The remote ice-strength measuring method according to any one of claims 2 to 4, comprising:

remotely measuring a shape of the ice by utilizing a laser scanner; and

calculating the strength while taking a measurement result of the shape into consideration.

[Claim 6]

The remote ice-strength measuring method according to claim 5, comprising:

evaluating a dynamic elastic modulus on the basis of the true ice thickness, the temperature, the salt content, and the shape; and

further calculating, as the strength, a uniaxial compressive strength from the dynamic elastic modulus.

[Claim 7]

The remote ice-strength measuring method according to claim 5, comprising:

evaluating a brine volume ratio on the basis of the true ice thickness, the temperature, the salt content, and the shape; and

further calculating, as the strength, a flexural strength from the brine volume ratio.

[Claim 8]

A remote measuring method, comprising:

implementing remote measurement by utilizing a moving body upon implementing the remote ice-thickness measuring method according to claim 1 or the remote ice-strength measuring method according to any one of claims 2 to 7.

[Claim 9]

A remote measuring method, the measurement result obtained by implementing the remote ice-thickness measuring method according to claim 1 or the remote ice-strength measuring method according to any one of claims 2 to 7 being utilized for operation or design of an offshore structure including an oil production facility and a natural gas production facility operating in ice-covered waters, or a vessel including a drilling ship, a work barge, and an icebreaker.

[Claim 10]

A remote ice-thickness measuring device for remotely measuring a thickness of ice, comprising:

an electromagnetic induction sensor unit utilized for remotely measuring an apparent ice thickness including an accumulated snow onto a top surface of the ice;

a microwave radiometer for measurement of an accumulated snow thickness configured to remotely measure a thickness of the accumulated snow; and

an ice thickness calculation unit configured to calculate a true thickness of the ice on the basis of the apparent ice thickness measured by the electromagnetic induction sensor unit and the thickness of the accumulated snow measured by the microwave radiometer for measurement of an accumulated snow thickness.

[Claim 11]

A remote ice-strength measuring device for remotely measuring a strength of ice, comprising:

an electromagnetic induction sensor unit utilized for remotely measuring an apparent ice thickness including an accumulated snow onto a top surface of the ice;

a microwave radiometer for measurement of an accumulated snow thickness configured to remotely measure a thickness of the accumulated snow;

an ice thickness calculation unit configured to calculate a true thickness of the ice on the basis of the apparent ice thickness measured by the electromagnetic induction sensor unit and the thickness of the accumulated snow measured by the microwave radiometer for measurement of an accumulated snow thickness; and

an ice strength calculation unit configured to calculate the strength of the ice on the basis of the true ice thickness.

[Claim 12]

The remote ice-strength measuring device according to claim 11, comprising:

an infrared radiometer configured to remotely measure a temperature of the ice, wherein

the ice strength calculation unit calculates the strength while taking the temperature of the ice measured by the infrared radiometer into consideration.

[Claim 13]

The remote ice-strength measuring device according to claim 11 or claim 12, comprising:

a microwave radiometer for measurement of a salt content configured to remotely measure a salt content of the ice, wherein

the ice strength calculation unit calculates the strength while taking the salt content measured by the microwave radiometer for measurement of a salt content into consideration.

[Claim 14]

The remote ice-strength measuring device according to any one of claims 11 to 13, comprising:

a laser scanner configured to remotely measure a shape of the ice, wherein

the ice strength calculation unit calculates the strength while taking the shape measured by the laser scanner into consideration.

[Claim 15]

The remote ice-strength measuring device according to claim 14, wherein the ice strength calculation unit evaluates a dynamic elastic modulus on the basis of the true ice thickness, the temperature, the salt content, and the shape, and further calculates, as the strength, a uniaxial compressive strength from the dynamic elastic modulus.

[Claim 16]

The remote ice-strength measuring device according to claim 14, wherein the ice strength calculation unit evaluates a brine volume ratio on the basis of the true ice thickness, the temperature, the salt content, and the shape, and further calculates, as the strength, a flexural strength from the brine volume ratio.

[Claim 17]

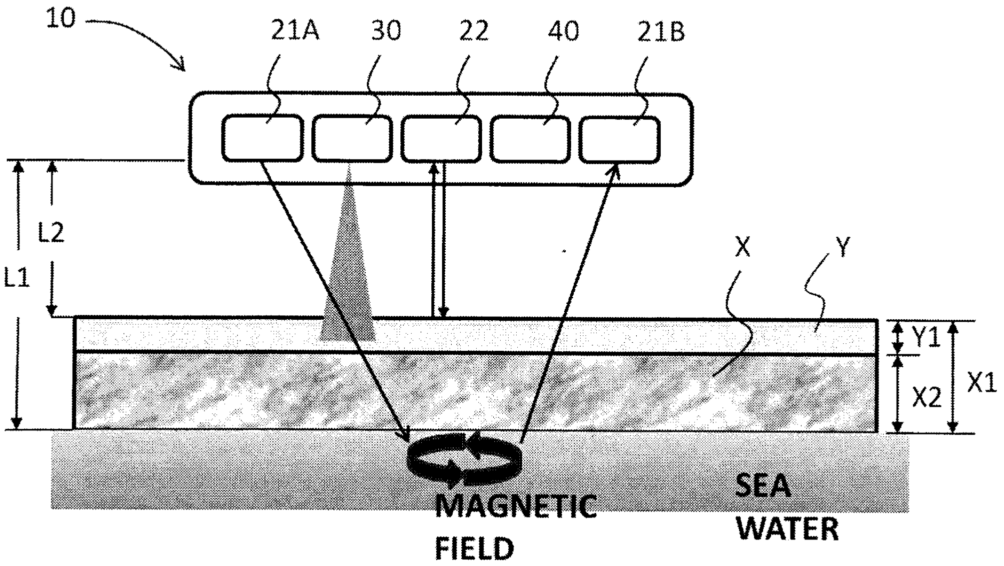
A remote measuring body, comprising: in a measuring body member, the remote ice-thickness measuring device according to claim 10 or the remote ice-strength measuring device according to any one of claims 11 to 16, the measuring body member being configured to be attachable by hanging from a moving body.

[Claim 18]

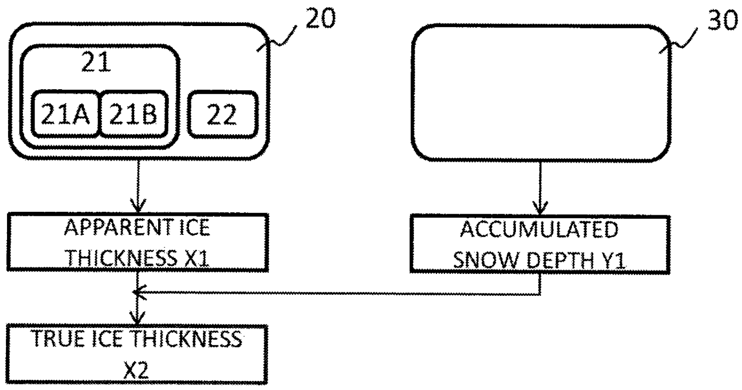
The remote measuring body according to claim 17, wherein the measuring body member comprises a GPS and a storage unit configured to store a measurement result.

[FIG. 1]

A

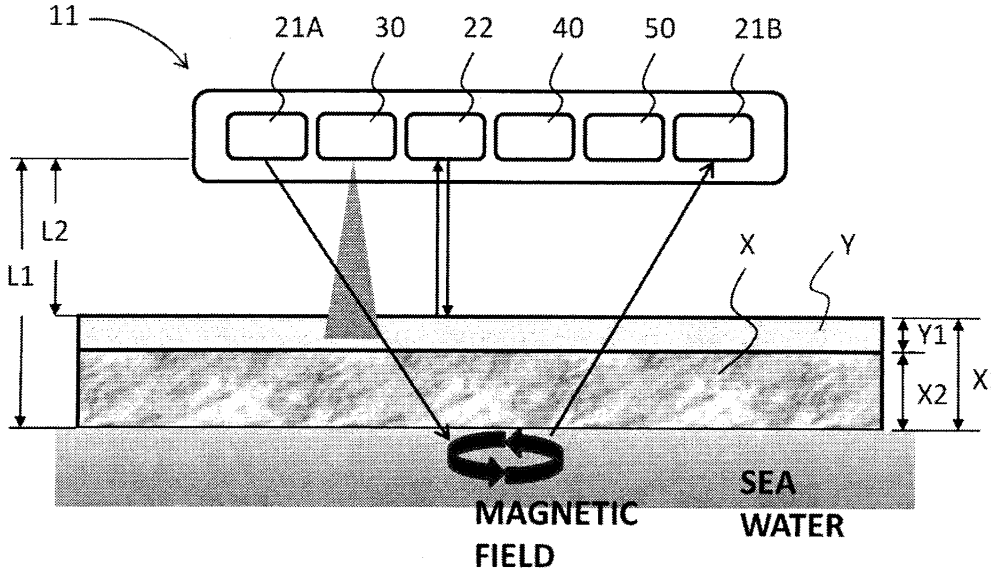

10
21A
30
22
40
21B
L2
L1
X
Y
Y1
X2
X1
MAGNETIC FIELD
SEA WATER

B

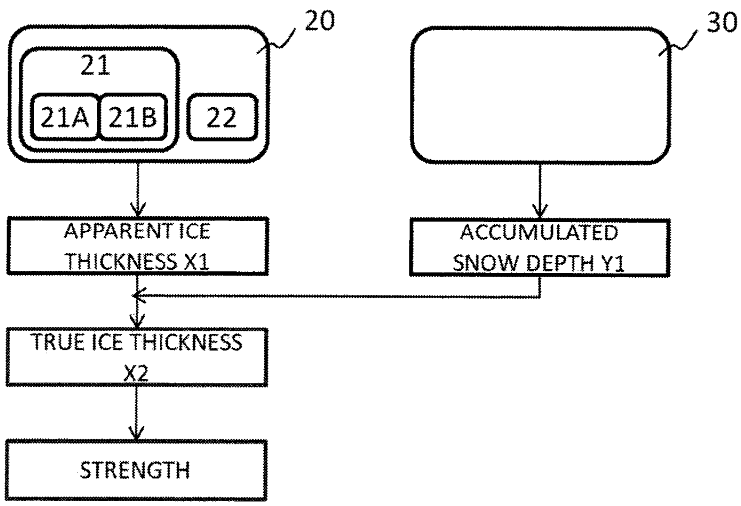

20
21
21A
21B
22
30
APPARENT ICE THICKNESS X1
ACCUMULATED SNOW DEPTH Y1
TRUE ICE THICKNESS X2

[FIG. 2]

A

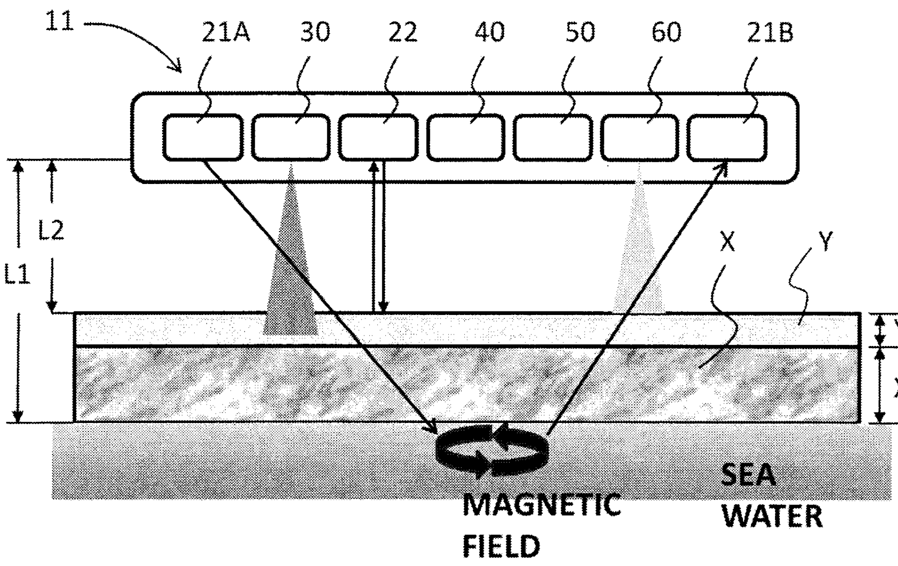

11
21A
30
22
40
50
21B
L2
L1
X
Y
Y1
X1
X2
MAGNETIC FIELD
SEA WATER

B

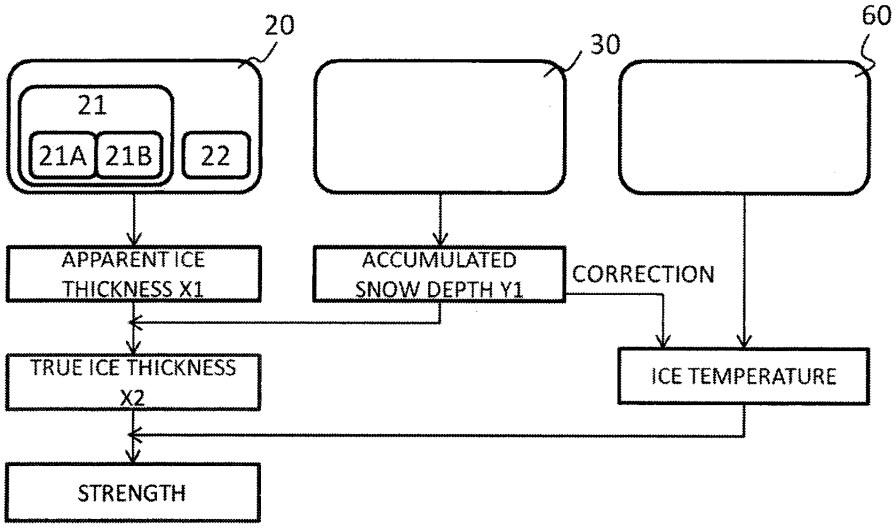

20
21
21A
21B
22
30
APPARENT ICE THICKNESS X1
ACCUMULATED SNOW DEPTH Y1
TRUE ICE THICKNESS X2
STRENGTH

[FIG. 3]

A

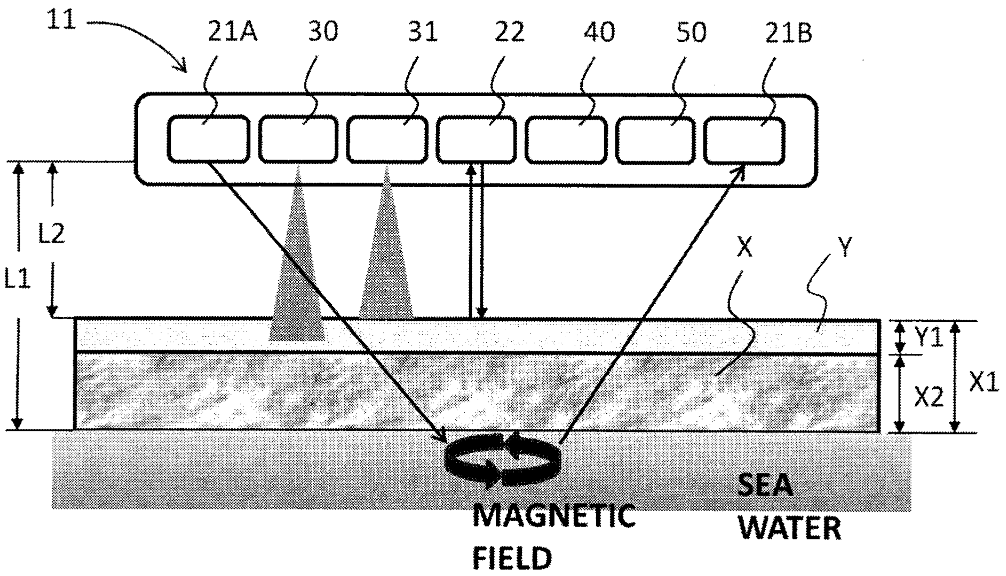

11
21A
30
22
40
50
60
21B
L1
L2
X
Y
Y1
X2
X1
MAGNETIC FIELD
SEA WATER

B

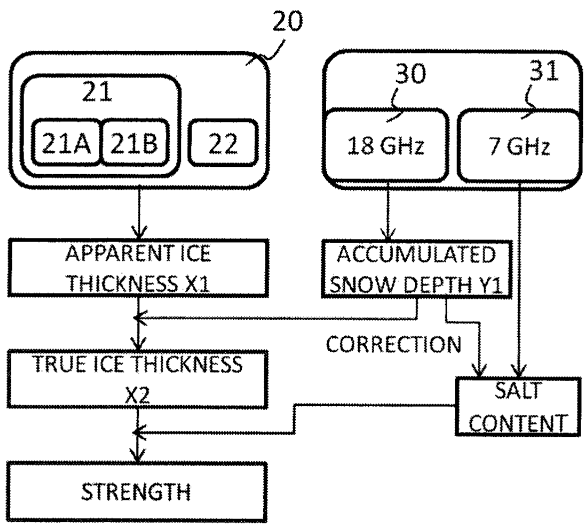

20
21
21A
21B
22
30
60
APPARENT ICE THICKNESS X1
ACCUMULATED SNOW DEPTH Y1
CORRECTION
TRUE ICE THICKNESS X2
ICE TEMPERATURE
STRENGTH

[FIG. 4]

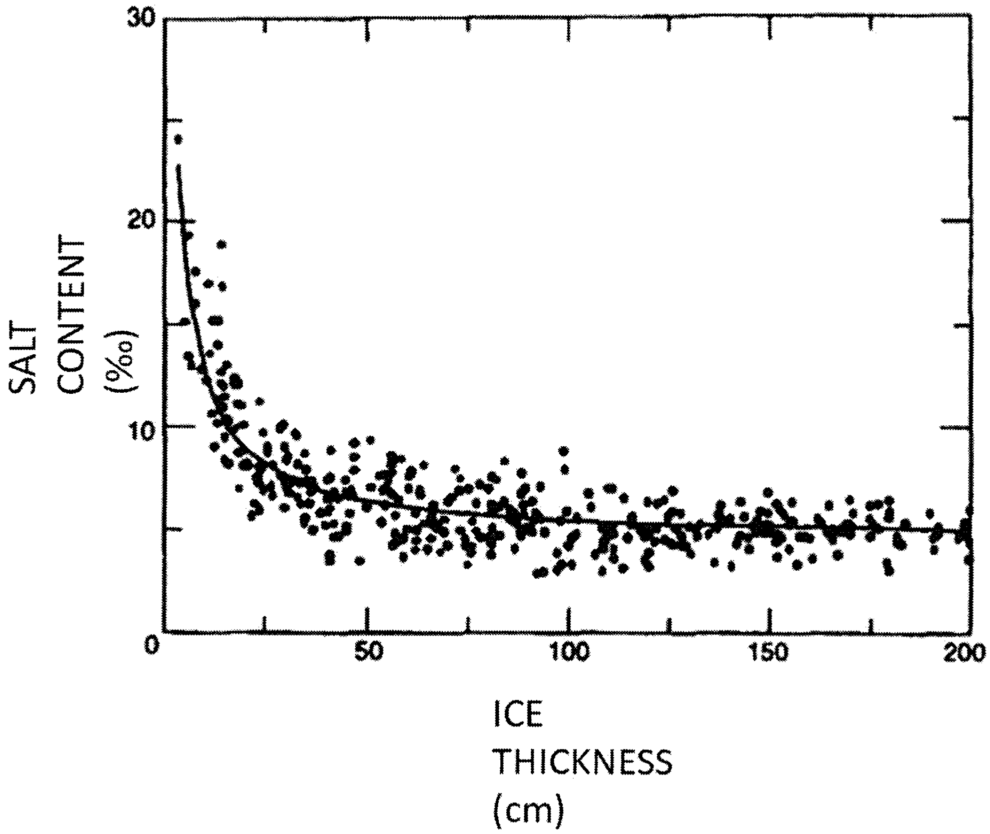
A


11
21A
30
31
22
40
50
21B
L1
L2
X
Y
Y1
X2
X1
MAGNETIC FIELD
SEA WATER

B

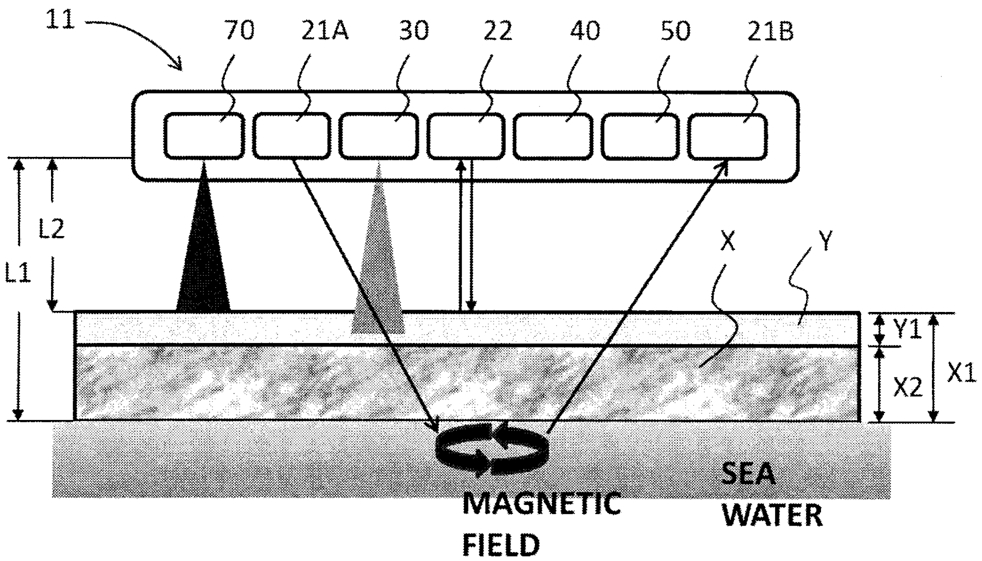

20
21
21A
21B
22
30
31
18 GHz
7 GHz
APPARENT ICE THICKNESS X1
ACCUMULATED SNOW DEPTH Y1
CORRECTION
TRUE ICE THICKNESS X2
SALT CONTENT
STRENGTH

[FIG. 5]

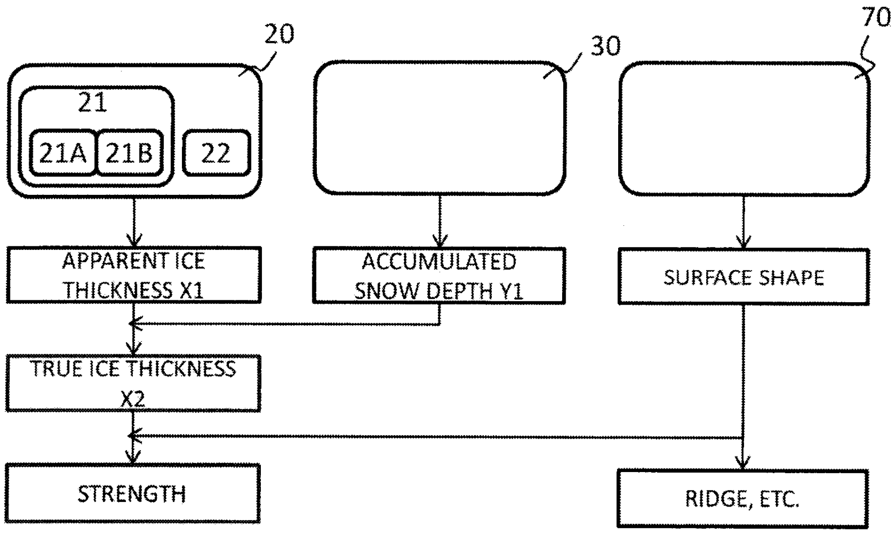


[FIG. 6]

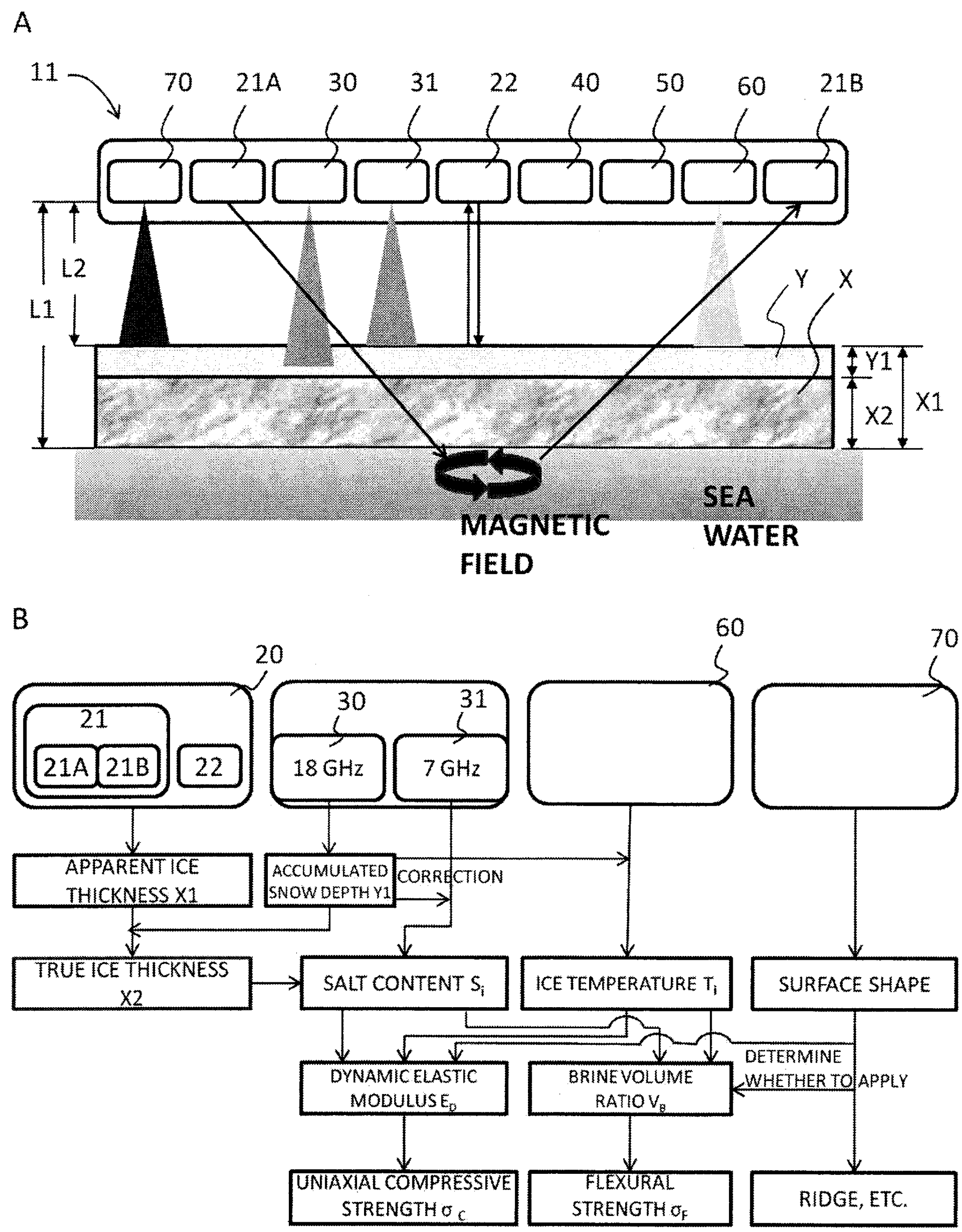
A


11
70
21A
30
22
40
50
21B
L2
L1
X
Y
Y1
X2
X1
SEA
WATER
MAGNETIC
FIELD

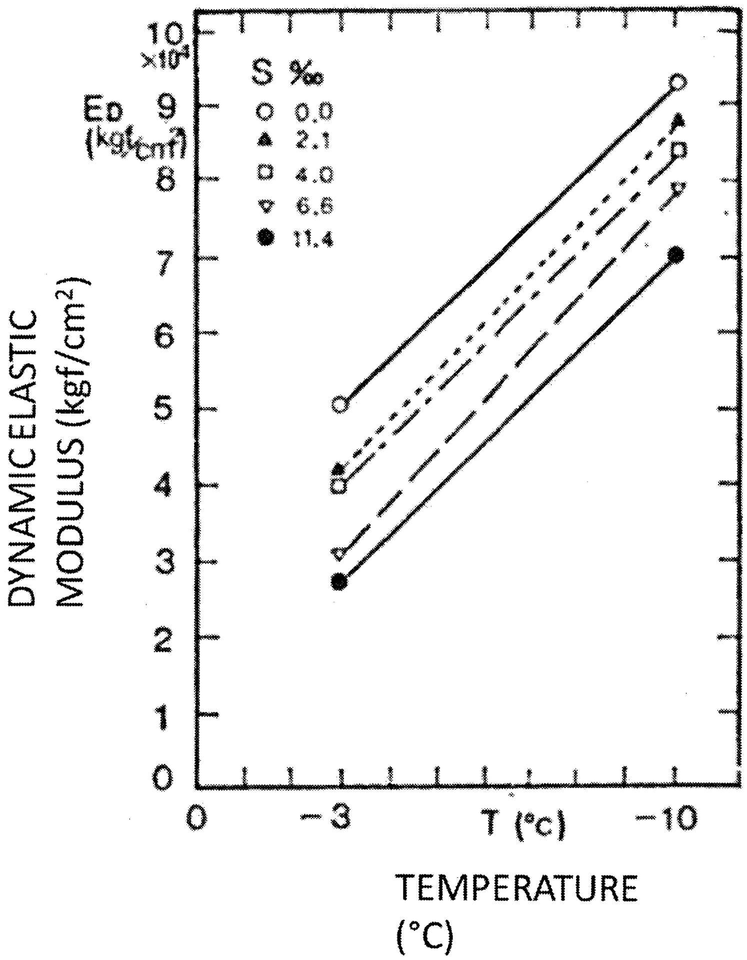
B


20
21
21A
21B
22
30
70
APPARENT ICE THICKNESS X1
ACCUMULATED SNOW DEPTH Y1
SURFACE SHAPE
TRUE ICE THICKNESS X2
STRENGTH
RIDGE, ETC.

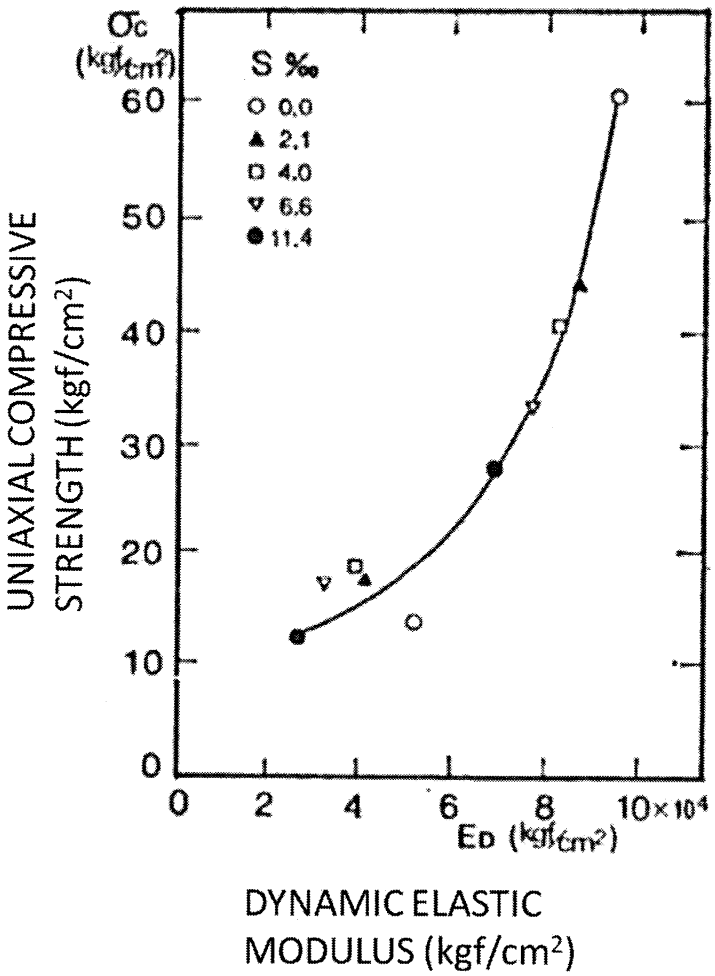
[FIG. 7]


A
11
70
21A
30
31
22
40
50
60
21B
L1
L2
Y
X
Y1
X2
X1
MAGNETIC FIELD
SEA WATER
B
20
21
21A
21B
22
30
31
18 GHz
7 GHz
60
70
APPARENT ICE THICKNESS X1
ACCUMULATED SNOW DEPTH Y1
CORRECTION
TRUE ICE THICKNESS X2
SALT CONTENT S_i
ICE TEMPERATURE T_i
SURFACE SHAPE
DETERMINE WHETHER TO APPLY
DYNAMIC ELASTIC MODULUS E_D
BRINE VOLUME RATIO V_B
UNIAXIAL COMPRESSIVE STRENGTH σ_C
FLEXURAL STRENGTH σ_F
RIDGE, ETC.

[FIG. 8]

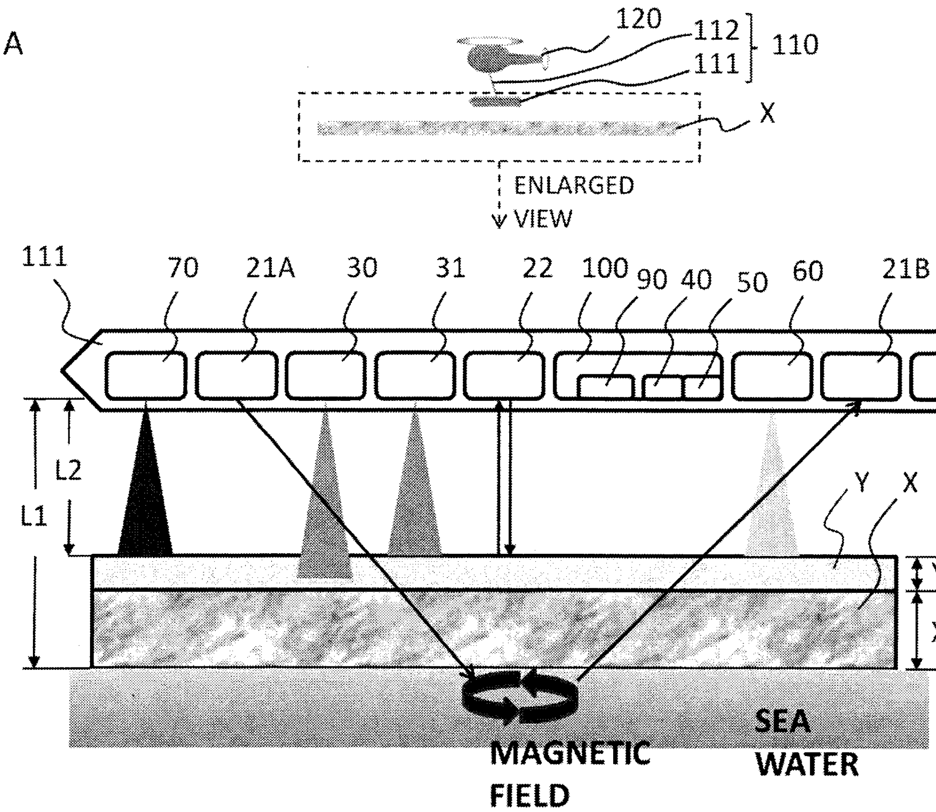

S ‰
0.0
2.1
4.0
6.6
11.4
Ed (kgf/cm²)
×10⁴
DYNAMIC ELASTIC MODULUS (kgf/cm²)
0
1
2
3
4
5
6
7
8
9
10
0
−3
T (°c)
−10
TEMPERATURE (°C)

[FIG. 9]

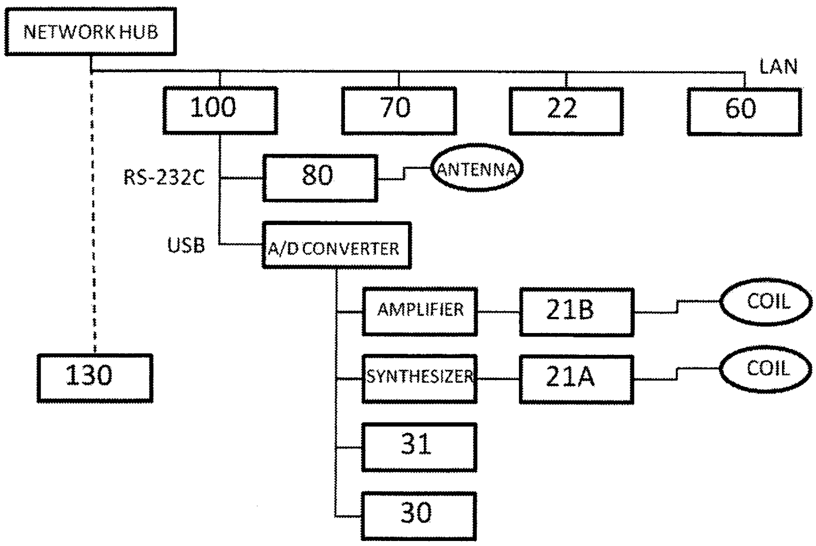

σc
(kgf/cm²)
S ‰
0.0
2.1
4.0
6.6
11.4
60
50
40
30
20
10
0
0
2
4
6
8
10×10⁴
ED (kgf/cm²)
UNIAXIAL COMPRESSIVE STRENGTH (kgf/cm²)
DYNAMIC ELASTIC MODULUS (kgf/cm²)

[FIG. 10]

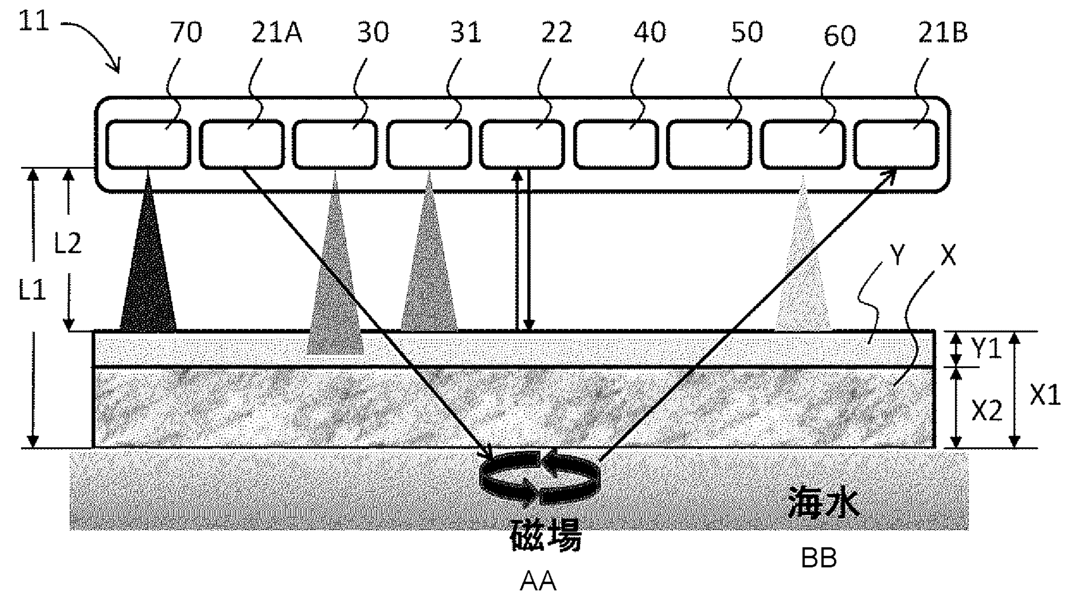
A


120
112
111
110
X
ENLARGED
VIEW
111
70
21A
30
31
22
100
90
40
50
60
21B
80
L2
L1
Y
X
Y1
X1
X2
SEA
WATER
MAGNETIC
FIELD

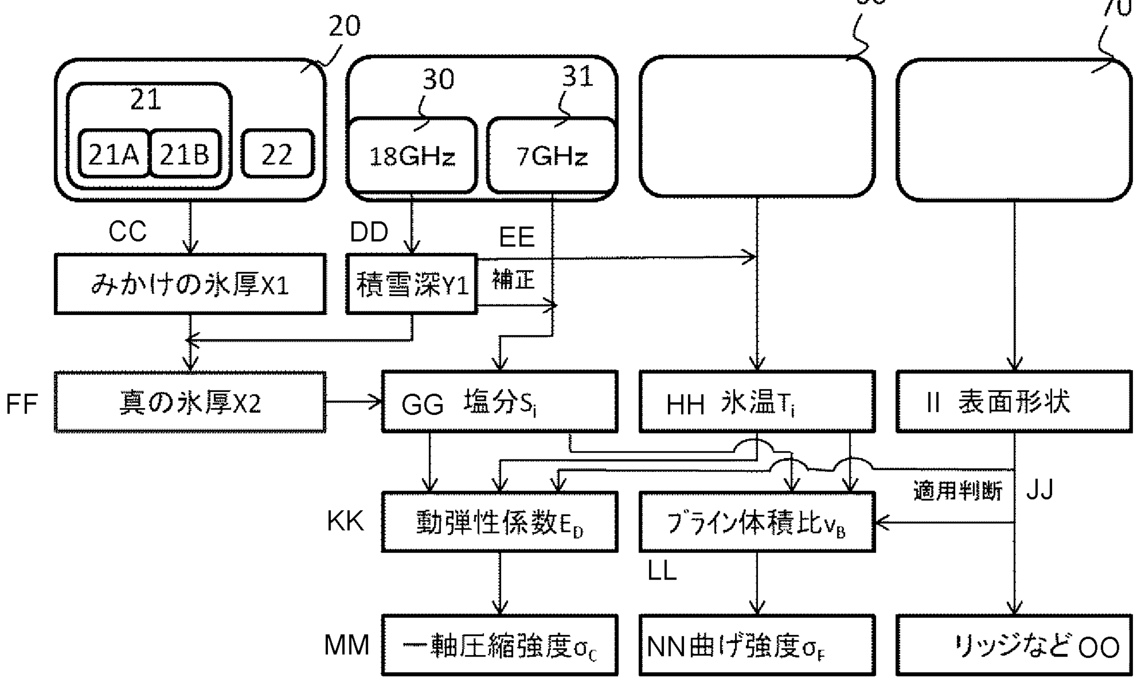
B


NETWORK HUB
LAN
100
70
22
60
RS-232C
80
ANTENNA
USB
A/D CONVERTER
AMPLIFIER
21B
COIL
SYNTHESIZER
21A
COIL
130
31
30

(a)



(b)



AA Magnetic field
BB Seawater
CC Apparent ice thickness
DD Accumulated snow depth
EE Correction
FF True ice thickness
GG Salinity
HH Ice temperature
II Surface shape
JJ Applied determination
KK Dynamic elastic modulus
LL Brine volume ratio
MM Uniaxial compression strength
NN Bend strength
OO Ridges, etc.