United States Patent [19]

Anders

[11] **3,759,046**

[45] **Sept. 18, 1973**

[54] **MOVEMENT OF MARINE STRUCTURES IN SALINE ICE**

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[73] Assignee: **Global Marine, Inc.**, Los Angeles, Calif.

[22] Filed: **Mar. 23, 1972**

[21] Appl. No.: **237,398**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 130,092, April 1, 1971.

[52] **U.S. Cl.** **61/46.5**, 61/63, 114/0.5, 114/41, 165/1

[51] **Int. Cl.** **E02b 15/02**, B63b 35/12

[58] **Field of Search** ..... 61/46.5, 46, 1, 36 A, 61/0.5; 114/40, 41, 42, 0.5 D, 0.5 F; 166/5; 9/8 P

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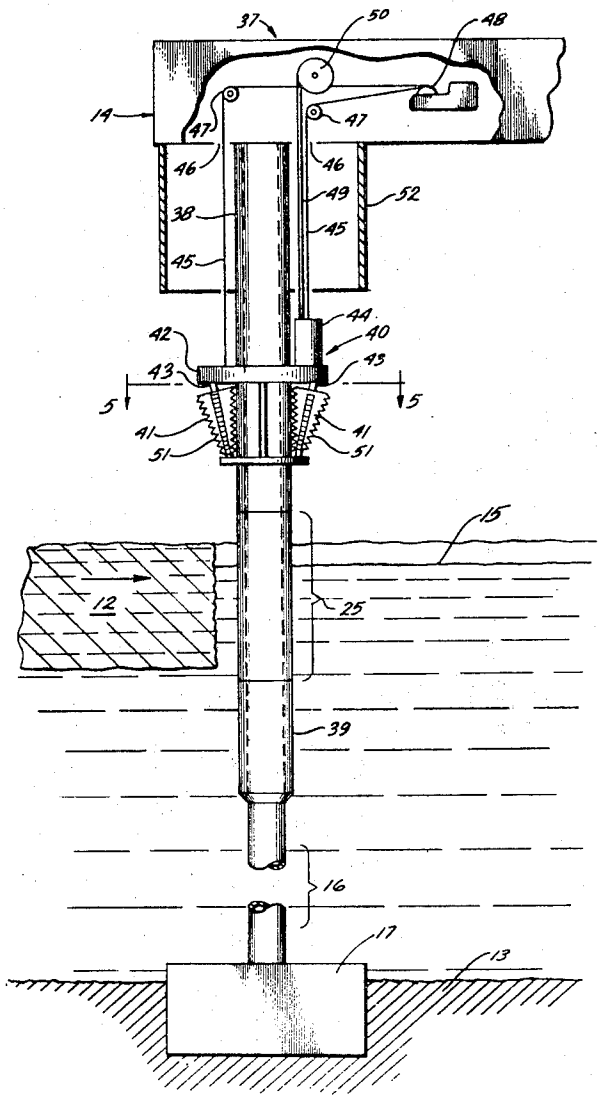
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Primary Examiner—Jacob Shapiro
Attorney—Robert L. Parker et al.

[57] **ABSTRACT**

Relative movement between a surface-piercing marine structure and a sheet of saline ice is enabled by applying heat to the ice from the structure at a rate sufficient to cause ice proximately adjacent the structure to be heated essentially to its melting point, at which temperature the strength of the ice is reduced sufficiently to permit the structure to break through the ice, thus enabling the desired relative motion. Also, the rate of heat transfer from the structure may be sufficient, in terms of the rate of relative motion, to melt the ice adjacent the structure at a rate equal to the rate of relative motion.

18 Claims, 8 Drawing Figures



4 Sheets-Sheet 1

FIG_1

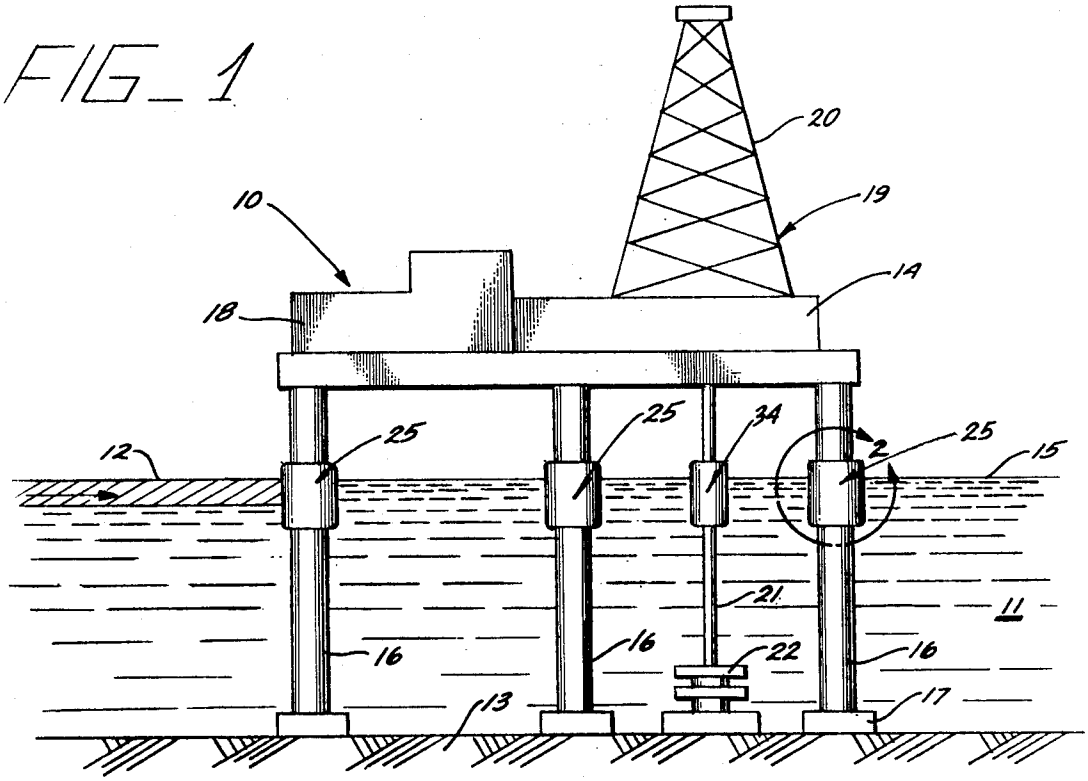


FIG_2

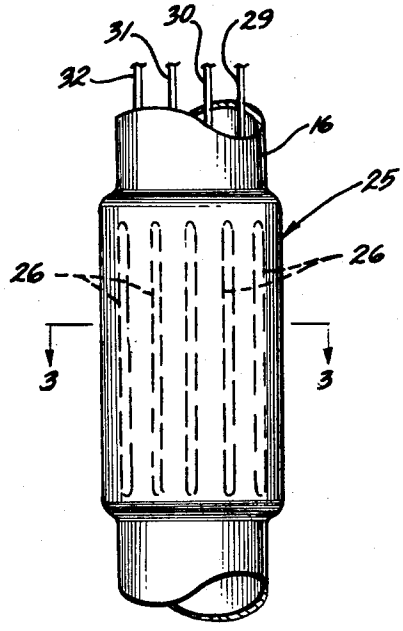


FIG_3

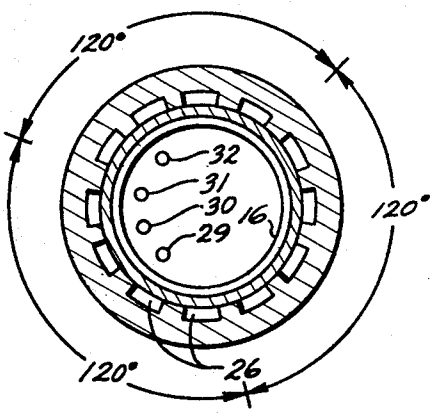


FIG. 4

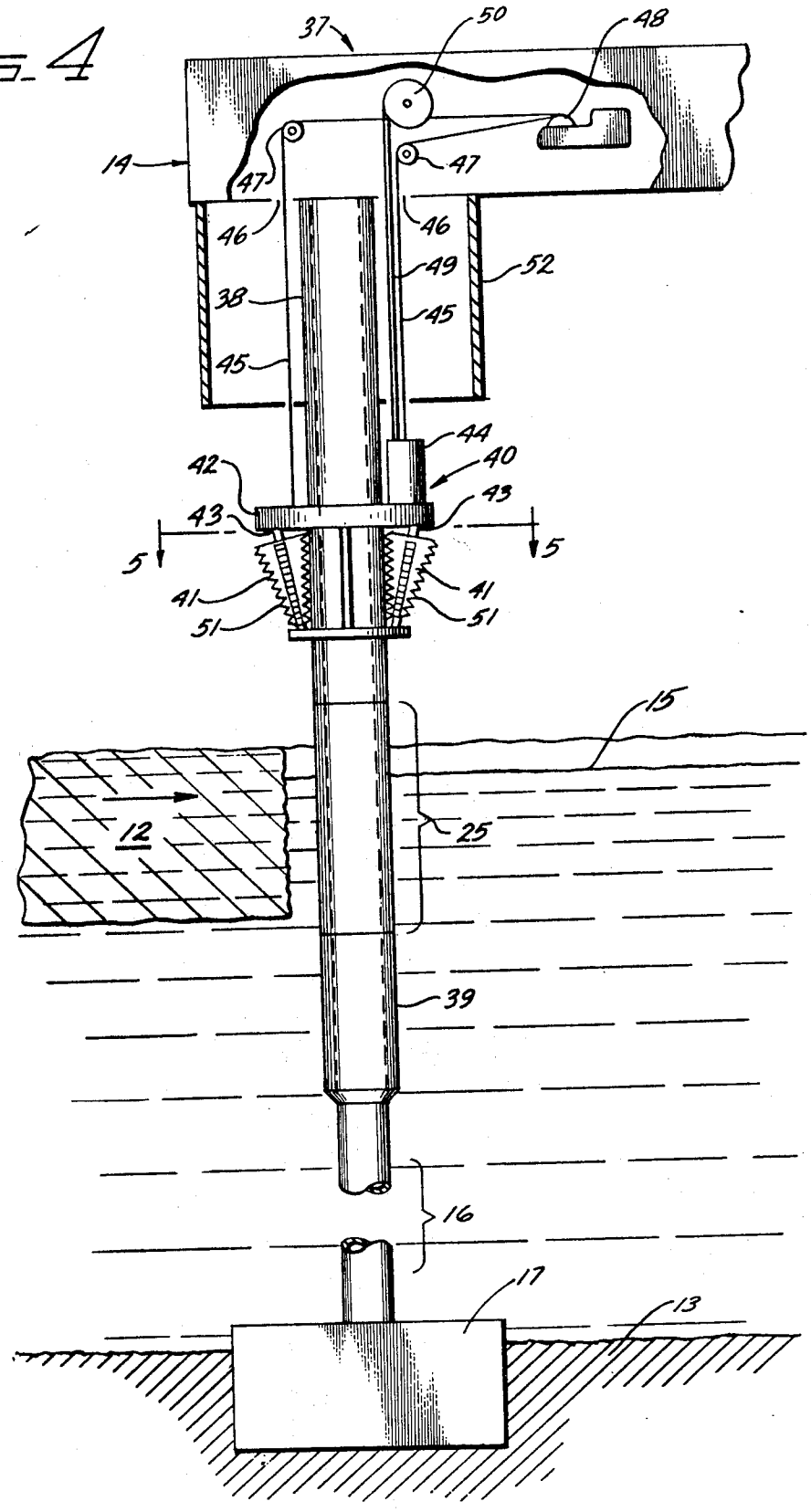

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FIG. 5

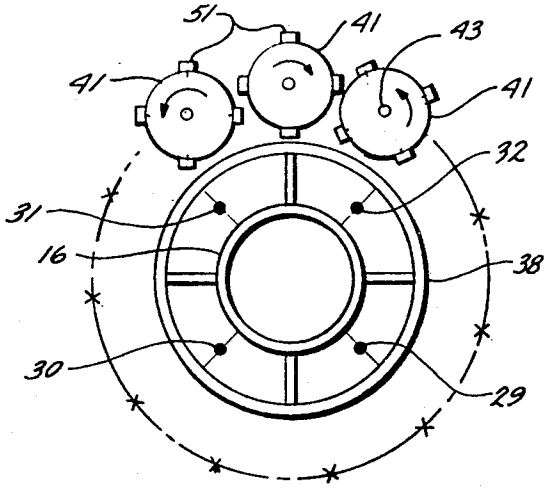

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FIG. 6

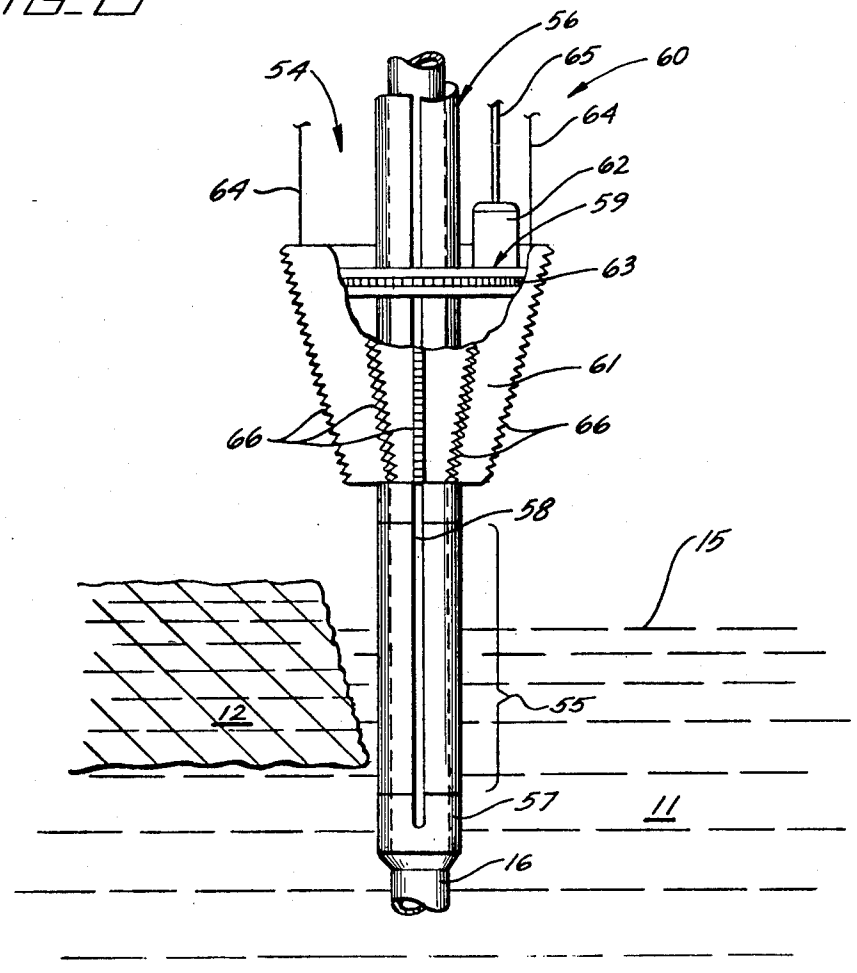

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FIG. 7

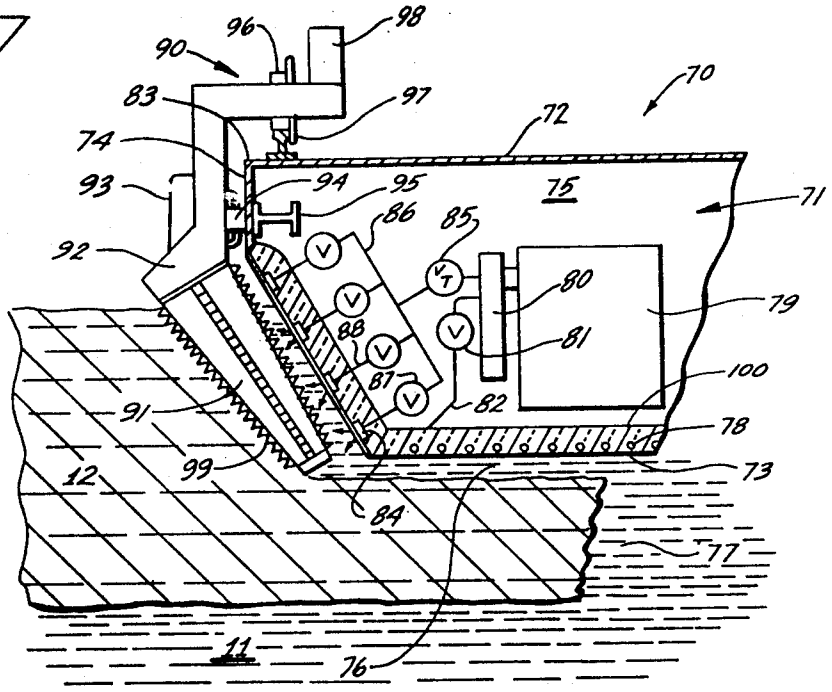
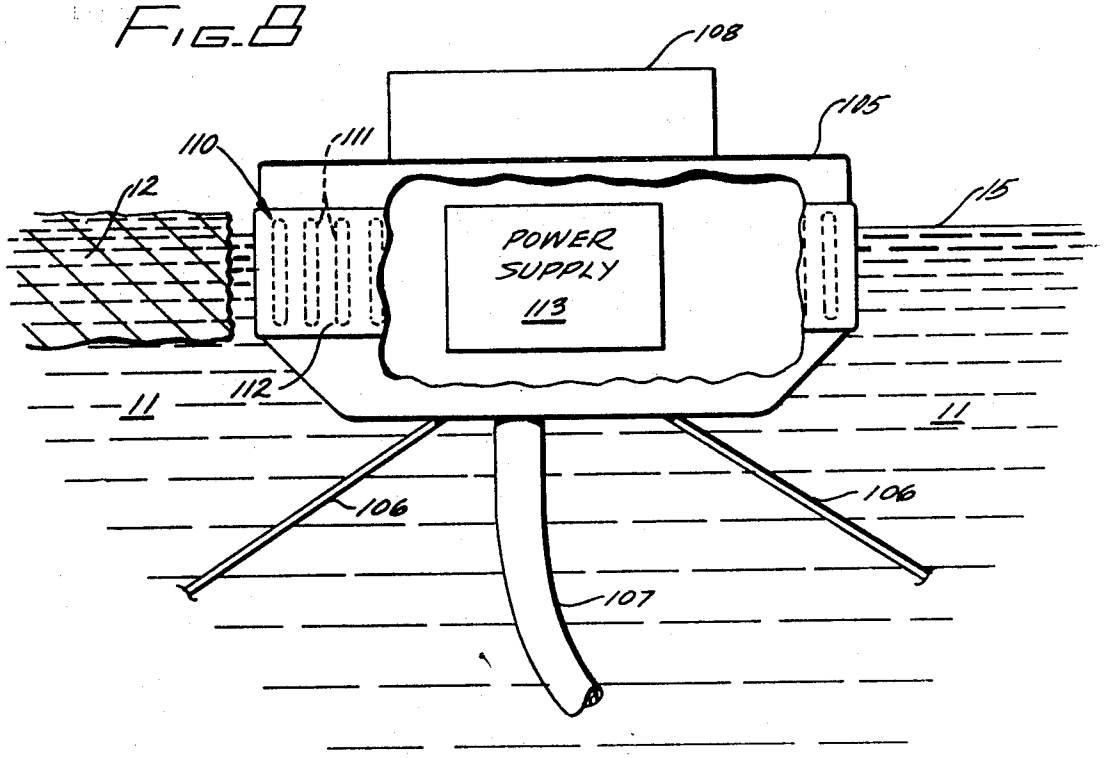

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FIG. 8


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POWER
SUPPLY
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MOVEMENT OF MARINE STRUCTURES IN SALINE ICE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of my earlier application Ser. No. 130,092 filed Apr. 1, 1971 for Arctic Oil and Gas Development.

FIELD OF THE INVENTION

This invention pertains to marine structures in the arctic, for example. More particularly, it pertains to method and apparatus for enabling horizontal relative movement between a surface-piercing marine structure, which may be moored or unmoored, and an ice sheet formed over a body of salt water.

BACKGROUND OF THE INVENTION

My prior application describes an air cushion platform adapted for use as an unmoored oil and gas drilling or production unit on a year-round basis in arctic areas. The platform has a buoyant hull which, during use over ice-covered submerged sites, is floated in a water pool formed in and through the ice sheet. The position of the water pool, and thus the position of the platform, over the submerged site is maintained within appropriate limits during movement of the ice sheet. Platform position is maintained by effectively moving the water pool in the ice sheet in a direction opposite to the direction of ice movement over the submerged site at a rate equal to the rate of ice movement. The water pool is moved by applying energy to the ice sheet from the platform to remove the portions of the ice around the pool which tend to move toward the platform. The necessary energy may be applied as mechanical, chemical, or thermal energy, or as combinations of these energy forms, but thermal energy is the preferred energy form described in my prior application.

Model tests concerning a thermally energized platform according to my prior application have now been completed. The tests were conducted under conditions which carefully simulated operation of a full-scale platform in ice sheets formed over salt water, i.e., ocean water. Quite unexpectedly, it was found that the quantities of thermal energy required to enable the test platform to maintain position within a moving ice sheet were substantially less than initially had been expected. The causative effects of and reasons for the unexpectedly low thermal requirements of the platform described in my prior application are now recognized, and this recognition forms a part of the advance provided by the present invention.

SUMMARY OF THE INVENTION

This invention includes and proceeds from the recognition that the heat transfer methods and apparatus which are described in my prior application in terms of a free-floating stationary body in a moving ice sheet, as a practical matter, can be extended to moored surface-piercing marine structures, and also to unmoored surface-piercing marine structures, considered in the context of a relatively moving sheet of sea ice. This invention makes it possible to economically use marine platforms and other moored marine structures in the Arctic Ocean on a year-round basis despite the presence of a moving ice pack. The fact that the polar ice pack is very close to or in contact with the arctic shoreline for much of the year has previously been thought to make it impossible, as a practical matter, to use moored or bottom-footed marine structures economically in the arctic. It had been thought that there was no way in which to enable such a moored surface-piercing structure to effectively, and at acceptable cost, withstand the enormous lateral loads capable of being applied to such a structure by the ice during the arctic winter.

This invention provides simple and economic procedures and apparatus for enabling a surface-piercing marine structure to move relatively through a sheet of sea water ice without encountering insurmountably high ice forces. According to the structural aspects of the invention, each discrete portion of the marine structure which pierces the water surface on which the ice sheet floats is equipped with heat transfer means. The heat transfer means extend vertically along the structure for selected distances above and below the water surface. Means are provided for energizing the heat transfer means sufficiently to cause the heat transfer means to heat ice moving relatively toward the structure essentially to the melting point of the ice.

According to the procedural aspects of the invention, heat transfer devices are disposed along each portion of the marine structure which pierces the water surface for selected distances above and below the water surface. The heat transfer devices are energized to transfer to those portions of an adjacent sheet of sea ice moving relatively toward the structure sufficient heat to raise the temperature of the ice near the structure essentially to its melting point.

In one such procedure which is presently preferred, the ice is heated sufficiently to cause it to melt adjacent the structure; this procedure is preferred where the marine structure is a moored floating structure such as a single-point mooring and oil transfer buoy.

Where the marine structure is a bottom-footed structure, such as a drilling platform engaged with and extending from the ocean floor, the preferred procedure is to heat the portions of the ice adjacent the platform to within 1° to 2° C or so of its melting point. Such heating lowers the strength of the ice sufficiently that either the platform can break through the ice coming into contact with it, or mechanical ice cutters carried by the platform may be used economically to remove ice moving toward contact with the platform. Also, this procedure may be used advantageously where the structure is an unmoored floating structure such as a platform according to my prior application.

DESCRIPTION OF THE DRAWINGS

The abovementioned and other features of this invention are move fully set forth in the following detailed description of certain presently preferred and illustrative embodiments of the invention, which description is presented with reference to the accompanying drawings, wherein:

FIG. 1 is an elevation view of an offshore drilling platform for arctic use according to this invention;

FIG. 2 is an enlarged elevation view of a portion of the structure shown in FIG. 1;

FIG. 3 is a cross-section view taken along line 3—3 in FIG. 2;

FIG. 4 is a fragmentary elevation view of a portion of another offshore drilling platform according to this invention;

FIG. 5 is a cross-sectional view taken along lines 5—5 in FIG. 4;

FIG. 6 is a fragmentary elevation view of a portion of another drilling platform according to this invention;

FIG. 7 is a cross-sectional elevation view of a floating vessel according to this invention; and

FIG. 8 is an elevation view, with parts broken away, of a moored single-point oil transfer buoy according to this invention.

DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

The low thermal requirements discerned during testing of the platform described in my prior application result from the fact that the amount of thermal energy required to melt a gram of saline ice at its freezing point is less than the amount of thermal energy required to melt a gram of fresh water ice at 0° C, its freezing point. The greater the salinity of the ice, the lower is the heat of fusion of the ice. The heat of fusion of fresh water ice at −0.1° C is approximately 80 calories per gram, whereas the heat of fusion of ice with 1 percent salinity at −0.1° C is approximately 37 calories per gram, and decreases to approximately 8 calories per gram for 5 percent saline ice at −0.3° C. On the other hand, the specific heat of ice (the amount of thermal energy required to raise the temperature of a gram of ice by 1° C) increases with the salinity of the ice from a value of 0.5 calories per gram for 0 percent salinity to a value of about 6.0 calories per gram for 5 percent saline ice at −2° C; the specific heat of saline ice at constant temperature rises rather rapidly with increasing salinity, but decreases rather rapidly with decreasing temperature for ice of constant salinity. Even though the variation of specific heat with changing salinity and temperature is opposite in effect to the variation in heat of fusion with changing salinity and temperature, the net result of these factors is that less thermal energy is required to convert saline ice at a given temperature to a liquid than is required to convert pure ice (ice having no salt content) at the same temperature to a liquid.

The variations of heat of fusion and specific heat of ice with changing temperature and salinity are described in "Specific Heat and Heat of Fusion of Sea Ice" by Nobuo Ono, Contribution No. 789, The Institute of Low Temperature Science, Hokkaido University, Sapporo, Japan, and less extensively in "Physical Oceanography," by Defant, Volume 1, Pergammon Press, 1961, pages 249 et seq.

Another factor involved in this invention is that the physical strength of saline ice decreases as the temperature of the ice approaches its melting point. The flexural modulus of sea ice at several degrees below 0° C is nominally about 12 Kg/cm^2., but within 1° or 2° C of its melting point the flexural modulus drops to about 3 Kg/cm^2.; this reduction in ice strength with increasing temperature is not encountered in the case of fresh water ice.

It has been found that in the ice encountered in the Beaufort Sea, the greatest portion of the ice (i.e., the lower portions of the ice) has been subjected to temperatures of 0° to −1° C for most of the time following formation of the ice. This portion of the ice, in the case of 1-year old ice, has relatively high salinity (about 4 to 6 percent). It is only in the upper portions of the ice layer that temperatures fall significantly below the temperature of the water below the ice. In the case of one-year old ice, it is in the relatively thin upper skin of the ice that the ice has low salinity levels (below about 4 percent) during those periods when ice thickness is greatest. That is, the greatest portion of the ice encountered in those portions of the Arctic Ocean below which oil or gas reserves are believed to exist is warm ice having high salinity levels. Ice of this character can be melted with much less heat than is required to melt equivalent quantities of fresh water ice at the same ambient temperature.

One aspect of the advance provided by this invention is the recognition of the practical interrelation between the separate units of information set forth above. While these units of information have been separately known, they have not previously been assimilated and applied to practical advantage in the context of definite useful procedures and arrangements such as those described below.

Considered in combination with each other, the factors reviewed above mean that a moored or bottom-footed marine structure in arctic sea waters can usefully and economically be installed and maintained on a year-round basis by equipping those portions of the structure susceptible to contact by ice with mechanisms for heating adjacent ice to within 1° or 2° C of the melting point of the ice; if desired, the heating mechanisms may be operated to melt the adjacent ice. The heating mechanisms are operated to raise the temperature of ice moving toward the structure to such an extent that the strength of the ice is lowered sufficiently that the structure itself can break through the ice and not be destroyed or severely damaged by the ice. As an alternative, the structure may also be equipped with mechanisms, such as ice cutters or the like, to remove the thermally weakened ice from around the structure, and thereby prevent contact of the moving ice directly with the structure.

Accordingly, drilling platforms, docks and buoys may be erected and maintained in the Arctic Ocean at suitable locations and used year-round despite the fact that such structures may be in the path of the polar ice pack for several months of the year. Such structures would have to be stronger than similar structures installed in temperate waters, but the added cost of such structures is within the range of economic acceptability. On the other hand, in the absence of use of this invention, if it were possible to build structures strong enough to withstand the expected ice loads, such structures would be so costly as to be far outside the range of economic acceptability.

FIG. 1 is an elevation view of an offshore drilling installation **10** adapted by the procedures and structures of this invention for use in a body of salt water **11** in arctic regions. Such waters are susceptible to being covered during substantial portions of the year by a thick sheet **12** of saline ice which tends to move laterally relative to the geologic formation **13** which forms the bottom of water body **11**. Drilling installation **10** includes a horizontal platform structure **14** which is supported above water surface **15** on a plurality of legs **16** which extend from the underside of the platform into engagement with geologic formation **13**. The legs are sufficiently long that the underside of platform **14** is disposed a desired distance above water surface **15**. Legs **16** preferably are engaged with the geologic formation by a foot structure **17** carried by the lower end of each leg. An accommodation structure **18** for hous-

ing the personnel, supplies and equipment necessary to operate the installation, and a drilling rig **19**, including a derrick **20**, are mounted to platform structure **14**. The drilling rig is used to drill an oil or gas well in geologic formation **13** by conventional processes. A drilling mud riser pipe **21** is connected between platform **14** and a blowout preventer assembly **22** disposed on the bottom of water body **11**. The necessary string of drill pipe is extended from the drilling rig through riser pipe **21** and blowout preventer assembly **22** into the geologic formation.

Platform legs **16** preferably are fabricated of large diameter heavy walled tubular structural elements. To adapt offshore drilling platform **10** for effective and economic use in ice-covered arctic waters by the use of this invention, a heat transfer mechanism **25** is installed around each platform leg **16** at the location where the platform leg pierces water surface **15**. As shown best in FIG. **1**, each heat transfer mechanism extends for a selected distance above and below water surface **15**. The extent of each heat transfer mechanism along each platform leg preferably is sufficient that the upper portion of the heat transfer mechanism lies above the top surface of the ice sheet normally expectable in the vicinity of platform **10** at extreme high tide conditions. The lower portion of each heat transfer mechanism is disposed below the lower surface of the thickest ice sheet normally expectable at the location at extreme low tide conditions.

As shown best in FIG. **3**, heat transfer mechanism **25** is defined by a plurality of electrical resistance heating elements **26** which preferably are of elongate, bar-like configuration and are disposed in alignment with the length of platform leg **16**. The heating elements are disposed on the external surfaces of a layer of thermal insulation material **27** which surrounds the exterior of platform leg **16**. The heating elements have a length at least as great as the above-described effective length of the heating mechanism and are spaced at regular intervals around the circumference of the platform leg. The heating elements are embedded within a protective covering **28** of a thermally conductive material such as aluminum or the like. The protective covering is provided to enable the heating mechanisms to withstand the abrasive effects of warm ice which may move into direct contact with the platform legs, as described below. Preferably, the heating elements are arranged in three separate groups of heating elements, each group subtending an arc of 120° around the circumference of platform leg **16**. Electrical energy is supplied to the heating elements in each group via separate energization conductors **29, 30** and **31**, and via a command return conductor **32**. Preferably conductors **29–32** are disposed within the hollow interior of platform leg **16** and extend to heating mechanism **25** from a suitable electric generator (not shown) disposed in accommodation structure **18**, for example.

The arrangement of heating elements **26** into three groups of heating elements, each group subtending an arc 120° about the circumference of platform leg **16**, makes it possible to energize the heating elements in one or two of the groups, but not in all three groups, for maximum efficiency and economy. Depending upon the direction from which ice sheet **12** moves laterally toward offshore drilling installation **10**, one or two, but not all three, of the heating element groups need be energized to protect the platform from the otherwise overwhelming destructive force of the moving ice sheet.

As shown in FIG. **2**, it is preferred that the protective thermally conductive material **28** disposed around the exterior of heating elements **26** be faired into the exterior of platform legs **16** at the upper and lower ends of the heating mechanism. Those skilled in the art to which this invention pertains, however, will readily appreciate that heating mechanism **25** may be defined within a circumferential recess formed in the exterior of platform leg **16** so that the exterior surfaces of the heating mechanism are coextensive with the exterior surfaces of the platform leg above and below the heating mechanism.

As shown in FIG. **1**, each element of the structure of offshore drilling installation **10** which pierces water surface **15** is surrounded by a heating mechanism **25**. Accordingly, a heat transfer mechanism **25** is provided circumferentially of each platform leg **16** at the location where the platform leg pierces water surface **15**. Also, during use of drilling rig **19** to drill an oil well in geologic formation **13** below the platform, a heat transfer mechanism **34** is disposed around drilling mud riser pipe **21** at the location where the riser pipe pierces water surface **15**. Heat transfer mechanism **34** is similar to heat transfer mechanism **25**, described above, but may be of different overall size. Also, since the interior of riser pipe **21** is used to define a conduit through which drilling mud moves upwardly from blowout preventer assembly **22** to drilling rig **19**, it is preferred that the energization and return conductors for heat transfer mechanism **34** be disposed along the exterior of the riser pipe.

During those periods of the year in which salt water body **11** is covered by a layer of ice, offshore drilling installation **10** is protected from damaging or destructive loads from the ice by energizing heat transfer mechanisms **25** and **34**. The extent to which the several heat transfer mechanisms are energized, and the extent to which one or more groups of heating elements in each heat transfer mechanism are energized, will be dependent upon a number of factors, including the thickness of the ice sheet, the temperature of water body **11**, ambient air temperature, the salinity profile vertically through ice sheet **12**, and the rate at which ice sheet **12** moves laterally toward the installation. Taking cognizance of these factors, the heat transfer mechanisms are energized at a level which is sufficient to cause the heat transfer mechanisms to raise the temperature of the ice proximately adjacent the mechanisms to a temperature within 1° or 2° C of the melting point of the ice. The energy required to heat a saline ice sheet to this temperature level is substantially less than the energy required to produce the same temperature change in a sheet of ice formed of fresh water in view of the considerations set forth above.

As the approaching ice sheet is heated adjacent the legs of installation **10** to a temperature close to, but slightly below the melting point of the ice, the structural strength of the ice is reduced sharply. The temperature to which the ice adjacent the platform is heated by operation of heat transfer mechanisms **25** and **34** is enough to reduce the strength of the ice sheet adjacent the platform sufficiently that the inherent structural strength of the platform and its supporting legs may safely be relied upon to break through the approaching ice close to the platform. In this respect, it is noted that

riser pipe 21 will have substantially less resistance to lateral loads applied to it than platform legs 16; therefore, heating mechanism 34 carried by the riser pipe may normally be energized sufficiently to produce melting of the approaching ice sheet around this heat transfer mechanism. Preferably, the dimensions of the elements of offshore drilling installation 10 which pierce water surface 15 are somewhat greater than the dimensions of a corresponding installation intended for use in temperate or tropical waters.

Another offshore drilling platform 37 according to this invention is illustrated in FIGS. 4 and 5. To the extent that platform 37 includes elements also encountered in installation 10 described above, common reference numerals are used to denote components of platform 37. As shown in FIG. 4, a heat transfer mechanism 25 is disposed circumferentially of platform leg 16 at the location where the platform leg pierces water surface 15 and for a selected distance both above and below the water surface; in this respect, see the preceding description concerning installation 10 for a description of the extent to which mechanism 25 extends vertically along platform leg 16. A shroud 38 is provided circumferentially of the platform leg above heat transfer mechanism 25 so that the effective outer diameter of the platform leg above the heat transfer mechanism is the same as the effective diameter of the leg through heat transfer mechanism 25. A similar shroud 39 is provided around the platform leg immediately below the heat transfer mechanism and extends a short distance downwardly along the leg as shown. The annular space provided between the interior of shroud 38 and the exterior of leg 16 may conveniently be used as a raceway for the disposition of conductors 29, 30, 31 and 32 associated with the adjacent heat transfer mechanism.

Shrouds 38 and 39 are provided in conjunction with heat transfer mechanism 25 in platform 37, to facilitate movement vertically along the platform leg of a mechanical ice removing assembly 40. Ice removing assembly 40, as shown in FIG. 4, is disposed circumferentially of the platform leg and includes a plurality of conical ice removing heads 41, only two of which are illustrated in FIG. 4, but see FIG. 5. Preferably cones 41 are disposed at regular intervals around the circumference of the platform leg as increased in diameter by heating mechanism 25 and shrouds 38 and 39. It is also preferred that an even number of ice removing heads be provided in assembly 40. The ice removing heads preferably are disposed so that their small diameter ends are disposed downwardly and so that the element of each cone which is closest to the centerline of the adjacent platform leg is parallel to such centerline, and is spaced a small distance outwardly from the adjacent shroud or heat transfer mechanism depending upon the vertical position of assembly 40 at any given time. The conical ice removing heads are cooperatively dimensioned and positioned relative to each other so that, as shown in FIG. 5, the upper ends of the heads substantially completely surround platform leg 16. Heads 41 are rotatably mounted in a supporting framework 42 which rotatably mounts a coaxial shaft 43 for each head above and below the upper and lower ends of each head. A weatherproof electrical drive motor for the ice removing heads is mounted to the upper portion of framework 42 and is operatively coupled to the shaft 43 of each head 41 via suitable gearing disposed within the upper portion of support framework 42. It will be appreciated that in lieu of gearing, timing belts, hydraulic motors or the like may be provided within framework 42 for rotation of the several ice removing heads of assembly 40. Framework 42 is movably engaged with the exterior of platform leg 16 via suitable rollers (not shown). Assembly 40 is suspended from the major platform structure 14 of platform 37 by a plurality of suspension cables 45. The cables extend from framework 42 upwardly along the exterior of the platform leg through suitable openings in the lower portion of platform structure 14, and via suitable pulleys or the like to a winch 48 preferably disposed within platform structure 14. Electrical power for operation of motor 44 is supplied to the motor via a suitable electrical cable 49 the upper end of which is connected to an automatic reel 50, also preferably disposed within platform structure 14.

As shown in FIGS. 4 and 5, a plurality of ice cutting teeth 51 are carried by the exterior of each conical head 41. Preferably the teeth are arranged in rows disposed along the linear elements of the concial head.

It will be understood that each leg 16 of platform 37 is provided with an ice removing assembly 40, as described above and shown in FIG. 4.

During intervals in which salt water 11 is covered by a layer of saline ice 12, heat transfer mechanisms 25 are energized sufficiently to heat the ice proximately adjacent the platform legs to a temperature within about 1° or 2° C of the melting point of the ice. As the ice sheet moves relative to the platform so as to tend to move into direct physical contact with the exterior of the heat transfer mechanism, ice removing assembly 40 is activated and lowered from its normal storage position below platform structure 14 within a protective housing 52. Activation of the assembly produces rotation of conical ice removing heads 41. As the assembly is lowered along shroud 38 toward the ice sheet, the lower portions of heads 41 initially engage the ice which has been thermally weakened by the operation of heat transfer mechanism 25. Due to the thermal weakening of the ice, the teeth 51 of assembly 40 are effective to rapidly and effectively remove ice from ice sheet 12 around the circumference of the platform leg. The activated ice removing assembly is lowered along the platform leg until the upper portions of ice cutting heads 41 have cleared the lower portion of the ice sheet. The head is then retracted vertically upwardly along the platform leg to its normal stowed position within housing 52. Such operation of the assembly either completely removes ice from around the platform leg, or reduces the thermally weakened ice to pieces sufficiently small in size to pass readily around leg 16. Assembly 40 is activated and operated in the manner described above at intervals dependent in length upon the rate of movement of ice sheet 12 horizontally relative to platform 37.

It was noted above that is is preferred that an even number of ice cutting heads 41 be provided circumferentially of platform leg 16 in each ice removing assembly. As shown in FIG. 5, it is preferred that adjacent ones of heads 41 be driven to rotate in opposite directions relative to each other. In this manner, the torque imparted to assembly 40 by interaction between the ice cutting teeth on each head and the adjacent ice is counteracted at the adjacent head. Accordingly, operation of the assembly to physically remove ice from laterally adjacent heat transfer mechanism 25 does not result in

the assembly being induced to move angularly about the platform leg.

Shroud **39** is provided around platform leg **16** per se below heat transfer mechanism **25** to provide a guide for assembly **40** in movement below the lower end of heat transfer mechanism **25** for engagement of the upper ends of ice cutting heads **41** with the lower portions of a thick ice sheet.

FIG. **6** is a fragmentary elevation view of a portion of a leg **16** of another offshore drilling platform **54.** A heat transfer mechanism **55** is disposed around platform leg **16** at the location where the platform leg pierces water surface **15** and for a desired distance upwardly and downwardly from such location; see the foregoing description concerning heat transfer mechanism **25** for a more complete exposition on the preferred vertical extent of the heat transfer mechanism. A shroud **56** is provided circumferentially of the platform leg from the upper end of heat transfer mechanism **55** to the underside of a platform structure **14** (now shown in FIG. **6,** but see FIG. **4,** for example). A similar shroud **57** is provided circumferentially of the platform leg from the lower end of the heat transfer mechanism for a desired distance downwardly along the leg. Heat transfer mechanism **55** and shrouds **56** and **57** are essentially identical to mechanism **25** and shrouds **38** and **39** of offshore drilling platform **37** except that, in platform **54,** the heat transfer mechanism and the shrouds define a straight vertical slot **58** which extends along these elements from their upper end to adjacent the lower end of shroud **57.** Slot **58** is provided as a guide keyway for constraining the support framework **59** of an ice removing assembly **60** to move only linearly along platform leg **16** during operation of the assembly.

Framework **59** of ice removing assembly **60** is disposed circumferentially of shroud **56,** for example, for movment vertically along the shroud; such movement is facilitated by a plurality of rollers (not shown) engaged between the framework and the shroud. Also, a suitable key projection (not shown) extends from the framework into registration with keyway slot **58.** Framework **59** is disposed within a unitary ice cutting element **61** which prefereably is provided in the form of a right truncated cone having its minor diameter disposed at its lower end. The ice cutting element is rotatably mounted to framework **59** and is driven relative to the framework about platform leg **16** in response to operation of a drive motor **62.** A driving connection between ice cutting element **61** and motor **62** is provided by an internal ring gear **63** secured to the element and cooperating with a suitable pinion (not shown) driven by motor **62** and rotatably mounted to framework **59.** Ice removing assembly **60** is suspended around shroud **56,** for example, by a plurality of suspension cables **64** which extend from framework **59** to a suitable winch within the offshore drilling platform in the manner described above relative to FIG. **4.** Also, electrical power for operation of motor **62** is supplied to the motor via a suitable electrical cable **65** extended from an automatic reel (not shown) preferably disposed within the platform structure of the offshore drilling platform in the manner previously described.

As shown in FIG. **6,** a plurality of ice cutting teeth **66** are secured to the exterior surface of ice cutting element **61.**

During periods where the presence of a laterally moving ice sheet **12** over water body **11** presents a hazard to offshore drilling platform **54,** the several heat transfer mechanisms **55** of the platform are energized in the same manner as and for the same purposes as energization of heat transfer mechanisms **25** previously described. As the ice moves into close proximity to the exterior of any of the heat transfer mechanisms, or actually engages the exterior of a platform leg **16,** the appropropriate ice removing assembly **60** is activated and lowered toward the ice sheet from its normal stowed position adjacent the upper end of leg **16.** Activation of the ice removing assembly includes operation of motor **62** to drive conical ice cutting element **61** angularly about platform leg **16.** As it is activated, the assembly is moved into engagement with the ice sheet until teeth **66** adjacent the upper rim of element **61** engage the lower portions of ice sheet **12.** Such operation of ice removing assembly **60** is effective to provide an annular space between the exterior of heat transfer mechanism **55** and ice sheet **12.** Preferably the taper of conical ice cutting element **61** is sufficient that when contact exists between the lower portions of ice sheet **12** and heat transfer mechanism **55,** a clearance exists between the upper portion of the ice sheet and the heat transfer mechanism of sufficient dimension to enable insertion of the lower portion of element **61** into position between the ice sheet and the heat transfer mechanism.

In view of the preceding description, it will be apparent that ice removing assembly **60** is activated and operated through the cycle described above at intervals dependent upon the rate of horizontal movement of ice sheet **12** relative to platform leg **16.**

Workers skilled in the art to which this invention pertains will readily appreciate that the structures and procedures described above concerning FIGS. **4, 5** and **6** are useful to convert an existing offshore drilling structure, such as a semisubmersible drilling platform or the like initially intended for use in temperate or tropical water, for use in arctic waters on a year-round basis. In the case of drilling platforms **37** and **54,** the strength of platform legs **16** is not relied upon to break through ice thermally weakened by operation of heat transfer mechanisms **25** and **55.** Instead, in platforms **37** and **54,** heat transfer mechanisms **25** and **55** are provided to thermally weaken the ice sufficiently to enable efficient operation of the mechanical ice removing assemblies **40** and **60,** respectively.

In my prior application Ser. No. 130,092 filed Apr. 1, 1971, there is described a buoyant operations platform which may be used to advantage to conduct drilling operations for oil and gas wells in the arctic. In my prior application, the operations platform is disclosed to incorporate energy transfer mechanisms for applying energy from the platform to an adjacent ice sheet to form and to maintain a pool of water in the ice sheet within which the platform is floated during use. The pool of water is communicated through the ice sheet to the water body over which the ice is formed. This communication of the pool with the underlying water body results in the platform not applying its gross weight to the ice sheet, but rather being buoyantly supported totally independently of the ice sheet.

The operations platform is described in my prior application in the context of the use thereof within a landfast ice sheet, i.e., an ice sheet which is intimately engaged with a shoreline, as in arctic bays and the like, and does not move with the polar ice pack. Landfast ice is susceptible of lateral movement from time to time

primarily due to the influences of tidal action and thermal expansion. Landfast ice sheets move only small distances in random directions and at relatively low velocities within any given period, such as a day or so. Accordingly, my prior application describes the buoyantly supported, energy transferring operations platform in the context of the accommodation of ice sheet movements of low velocity and small magnitude.

The procedures and apparatus of this invention may be used in conjunction with the energy transferring operations platform described in my prior application to make it possible to use the platform in the context of ice sheets, other than landfast ice sheets, such as the arctic ice pack which continually moves within the Arctic Ocean with substantially greater velocities than are encountered in arctic landfast ice sheets. Such an adaptation is illustrated in FIG. 7.

As shown in FIG. 7, a buoyant operations platform 70 has a hull 71 which includes a main deck 72, a substantially flat horizontal bottom 73, and side walls 74 which cooperate with the main deck and bottom to enclose a space 75 within the hull. The hull bottom and side walls are equipped with energy transferring mechanisms which preferably are arranged to transfer thermal energy from the hull to an adjacent ice sheet 12 to form and to maintain a water pool 76 at least in the upper portions of the ice sheet and within which the platform floats. As shown in FIG. 7, water pool 76 preferably communicates with water body 11 below the ice sheet, as at 77.

The thermal energy transfer mechanisms of platform 70 include a plurality of ducts 78 arranged for the circulation of a heated heat transfer fluid therethrough. Ducts 78 are formed of thermally conductive material and are disposed in intimate contact with the inner surfaces of hull bottom 73. Warm heat transfer fluid, such as warm sea water, is supplied to ducts 78 from a suitable heater 79 disposed within hull 71. The connection of the heater to ducts 78 preferably is via a manifold 80 and a control valve 81 installed in a supply conduit 82 between the manifold and the ducting.

Also, as shown in FIG. 7, the side walls 74 of hull 71 slope upwardly and outwardly from their connection to bottom 73 for a major portion of their height. Intermediate their height, but closer to deck 72 than to bottom 73, side walls 74 preferably have a vertical portion which terminates at their upper end at deck 72 to define a gunwale 83 of hull 71. The heat transfer mechanisms of the operations platform, in addition to ducts 78, include a plurality of liquid discharge nozzles 84 installed at selected locations along the sloping portions of each of the side walls 74 of hull 71. At each side wall, nozzles 84 are arranged in columns vertically along the wall and in rows along the wall parallel to hull bottom 73. Each nozzle 84 is capable of being supplied with hot heat transfer fluid, such as warm sea water, under pressure from heater 79 and manifold 80 thereof via a regulating valve 85 interconnected between the manifold and a distribution conduit 86 common to all of the nozzles associated with any given side wall of the hull. Each horizontal row of nozzles is connected to conduit 86 via a valve 87 and by suitable ducts connected from respective ones of valves 87 to the several nozzles in the respective row.

During use of operations platform 70, warm sea water, for example, after having been heated in heater 79, is discharged through nozzles 84 to maintain water pool 76 in ice sheet 12 for buoyant support of the operations platform. In certain circumstances, the heat applied to the water in pool 76 from ducts 78 may be sufficient to maintain water 76 in its liquid state. Normally, operations platform 70 is used over a fixed location at the bottom of water body 11. Accordingly, if ice sheet 12 should move laterally relative to the submerged fixed location, platform 70 is maintained in its desired relation to the submerged location by, in effect, moving the water pool within ice sheet 12 so that the water pool in which the operations platform floats is in turn maintained stationary over the desired submerged loaction. Such relative movement between the operations platform and ice sheet 12 is accommodated by discharging warm heat transfer fluid through those ones of nozzles 84 which are submerged in pool 86 and which face toward those boundaries of the water pool which tend to move toward hull 71 as a result of lateral movement of ice sheet 12. The quantity of water discharged through any one of these nozzles is dependent upon the temperature of the liquid being discharged and the rate of movement of the adjacent portions of the ice sheet perpendicularly toward the nozzle. Depending upon these factors, liquid is discharged from these nozzles toward the approaching boundaries of pool 76 at a rate which is sufficient to cause the ice adjacent the pool to be heated to within a few degrees of the melting point of the ice. The temperature at which the ice will melt is in turn dependent upon several factors, principally the salinity of the ice. The temperature of the ice adjacent water pool 76 is raised to produce thermal weakening of the ice so that an ice removing mechanism 90 may be operated effectively and economically to remove the thermally weakened ice from those portions of the ice sheet which move toward hull 71.

Ice removing mechanism 90, illustrated in FIG. 7, includes an elongate, generally conical ice removing head 91 which is truncated and disposed with its minor diameter adjacent the turn of the bilge of hull 71, i.e., the location where hull bottom 73 is connected to side walls 74. Preferably the lower end of ice removing head 91 is disposed slightly below the bottom of hull 71, as shown. Head 91 is rotatably mounted at its opposite ends in a frame 92 of mechanism 90. Frame 92 mounts a drive motor 93 for rotatably driving ice cutting head 91. The frame is mounted for movement along the gunwale of hull 71 by guide wheels 94 (only one of which is shown) which ride along the exterior of the hull side wall below gunwale 83. The loads applied to hull 71 by engagement of wheels 94 with the exterior portions of the hull are borne by a girder 95 which is secured to the inner surfaces of the hull plating in line with and parallel to the track of wheels 94 along the hull. Frame 92 is also movably supported on hull 71 by flanged wheels 96 (only one of which is shown) similar to railroad wheels which ride along a rail 97, similar to a railroad rail, affixed to main deck 72 parallel to and just inboard from gunwale 83. A motor 98 for rotating wheels 96 is carried by frame 92 adjacent these wheels. A plurality of teeth 99 are carried by the exterior surfaces of ice cutting head 91 and are distributed along the length of the head.

As ice sheet 12 moves laterally toward operations platform 70, those heat transfer mechanisms aboard the platform of which nozzles 84 form a part are operated to thermally weaken those portions of the ice sheet moving toward the platform. Periodically, ice

cutting mechanism **90** is operated to remove or fragment this thermally weakened ice to provide clearance between the exterior of the hull and the adjacent boundaries of water pool **76.** During those intervals in which mechanism **90** is not being operated, it may be stored in the water pool adjacent those portions of the ice sheet which tend to move away from the platform. During operation of the ice cutting mechanism, it is traversed by operation of drive motor **98** across the submerged surfaces of the hull toward which the ice is moving.

It is apparent that the presence of ice cutting mechanism **90** aboard operations platform **70,** which platform is per se generally in accord with the description set forth in my previously filed application, adapts the operations platform for effective and economic use in arctic waters on a year-round basis to carry out the desired operations at a submerged location. Therefore, the same operations platform as may have been designed and equipped for year-round use in landfast ice, and in which the thermal output capabilities of the platform are defined with respect to the movements of landfast ice, may be used effectively in non-landfast ice where greater and higher velocity movements of a surrounding ice sheet may be encountered, and as to which the basic thermal output capacity of the operations platform is inadequate. Further, the combination of a thermal output operations platform and ice removing mechanisms therefor may be used in landfast ice.

To achieve maximum possible thermal efficiency of operations platform **70** during use of the heat transfer mechanisms described above, ducts **78** and discharge nozzles **84** are embedded within a layer of thermal insulation material **100** disposed over the inner surfaces of the hull bottom and side walls.

This invention also provides means whereby an unmanned moored marine structure may be maintained in position at a desired location notwithstanding the presence adjacent the structure of a moving ice sheet. Accordingly, as shown in FIG. **8,** a single-point mooring and oil transfer buoy **105** floats in water **11** to extend above the water surface. The buoy is held in a desired position by mooring cables **106** extended from the lower portions of the buoy to suitable anchors (not shown) engaged with the bed of water body **11.** A flexible oil supply conduit **107** extends downwardly from the buoy through water **11** to extend to an on-shore oil storage facility, for example. Suitable mooring facilities and oil transfer equipment for the buoy are stored in an enclosure **108** provided in the upper surfaces of the buoy.

To enable the buoy to maintain an essentially fixed position within water body **11,** notwithstanding the presence for at least a portion of the year of a moving ice sheet adjacent the buoy, the buoy is equipped with a circumferential heat transfer belt **110.** The heat transfer belt takes the form of a plurality of electrical resistance heating elements **111** disposed around the exterior of the buoy and embedded within a thermally conductive protective material **112.** Preferably heating elements **111** and protective material **112** are similar to elements **26** and material **28** described above concerning heat transfer mechanism **25** shown in FIG. **3.** The several heating elements provided circumferentially of buoy **105** are energized from a power supply **113** disposed within buoy **105.** Power supply **113** may be provided in the form of a bank of storage batteries, or a bank of fuel cells, or, more advantageously, in the form of a nuclear-powered electric generator. It is also within the scope of this invention that the heating elements of the heat transfer belt may be provided in the form of a plurality of heat transfer coils through which a hot heat transfer fluid, such as warm sea water, may be circulated, and in such case, a nuclear-powered heat source may be used to advantage in place of an electrical power supply.

In the case of an unmanned moored marine structure, such as buoy **105,** it is apparent that the heat transfer mechanism provided circumferentially of those portions of the structure which pierce water surface **15** must be energized sufficiently to produce melting of the advancing portions of ice sheet **12;** as a general rule, it is not possible to provide effective mooring, by way of anchors and mooring chains or the like, of strength sufficient to enable the floating moored structure to force its way through ice which has been thermally weakened by operation of the heat transfer mechanisms with which the moored structure is equipped.

The present invention has been set forth above by the description of certain presently preferred and illustrative embodiments of this invention. Workers skilled in the art to which this invention pertains will readily appreciate that modifications and variations in the procedures and structures described above may be pursued without departing from the scope of this invention. For example, in the case of a bottom-footed offshore platform structure, each heat transfer mechanism associated with a surface-piercing component of the structure may be defined to have a vertical extent equal to or about equal to the thickness of a maximum thickness ice sheet expectable at the site of the structure, and such heat transfer means may be movable vertically along the structure by the operation of suitable positioning means such as cables and winches or such as hydraulic rams. Also, the heat transfer mechanism may be disposed along each surface-piercing component of the structure so as to extend around only a portion of the circumference of the surface-piercing component, and such a heat transfer mechanism may be made movable around the component to be effective upon ice moving toward the structure from any direction. Accordingly, the preceding description should not be considered as limiting the scope of this invention.

What is claimed is:

1. Apparatus for facilitating relative motion between an ice sheet overlying a body of salt water and a structure disposed in the water and extending through the surface thereof comprising heat transfer means disposed along each discrete portion of the structure which is adapted to penetrate the water surface at the location on said portion of penetration and extending vertically along the structure for a selected distance above and below said location, and means for energizing the heat transfer means sufficiently to cause the heat transfer means to heat ice disposed proximately adjacent the heat transfer means to within about 2° C of its melting point.

2. Apparatus according to claim **1** wherein the structure is intended for support from the bottom of the body of water at a selected site in the body of water for a selected period, and the maximum thickness of ice to be encountered and the maximum tidal variation at the site during the period are known, and wherein the ex-

tent of the heat transfer means vertically along the structure is sufficient to locate the upper end of the heat transfer means at least adjacent the upper extent of a maximum thickness ice sheet at maximum high tide and to locate the lower end of the heat transfer means at least adjacent the lower extent of a maximum thickness ice sheet at maximum low tide.

3. Apparatus according to claim 1 wherein the structure is intended for use as a floating structure at a selected site in the body of water for a selected period and the maximum thickness of ice to be encountered at the site during the period is known, and wherein the extent of the heat transfer means vertically along the structure is sufficient to locate the upper end of the heat transfer means at least as far above the waterline of the structure as the height of a maximum thickness ice sheet above the water surface and to locate the lower end of the heat transfer means at least as far below the waterline as the depth of a maximum thickness ice sheet below the water surface.

4. Apparatus according to claim 1 wherein the extent of the heat transfer means vertically along the structure is at least equal to the thickness of a maximum thickness ice sheet expectable at a selected site of intended use of the structure during a selected period of use of the structure.

5. Apparatus according to claim 1 wherein each heat transfer mechanism is disposed to surround the adjacent discrete portion of the structure.

6. Apparatus according to claim 5 including means for energizing the heat transfer means about only a part of its extent around the adjacent portion of the structure.

7. Apparatus according to claim 1 including ice removing means movable along the structure adjacent the heat transfer means and operable upon portions of an ice sheet adjacent the structure which are thermally influenced by operation of the heat transfer means to fragment and remove ice from engagement with the structure and from proximate juxtaposition to the structure.

8. Apparatus according to claim 8 wherein the ice removing means includes a rotatable ice cutting head and a plurality of teeth carried thereon operable in response to rotation of the head to comminute ice engaged thereby.

9. Apparatus according to claim 8 wherein the structure is a platform structure adapted for support above the water surface on at least one leg, the leg comprising said discrete portion of the structure, and wherein the ice cutting head is disposed substantially circumferentially of the leg in substantially coaxial alignment therewith and is of inverted truncated conical configuration, a support frame for the head, means cooperating between the frame and the leg for constraining the frame to movement only along the leg, and means cooperating between the frame and the head for rotating the head about the leg.

10. Apparatus according to claim 7 wherein the structure is a platform structure adapted for support above the water surface on at least one leg, the leg comprising said discrete portion of the structure, and wherein the ice removing means includes a plurality of externally toothed rotatable ice cutting heads disposed around the leg, the heads each having an inverted conical configuration, a support frame for mounting the heads for rotation about the cone axes thereof, and means for rotating the heads relative to the frame and arranged so that during operation thereof adjacent ones of the head rotate in opposite directions.

11. Apparatus for facilitating relative motion between an ice sheet overlying a body of salt water and a buoyant hull having a gunwale comprising heat transfer means disposed along the hull at and for a selected distance above and below the load waterline of the hull, means for energizing the heat transfer means sufficiently to cause the heat transfer means to melt ice disposed proximately adjacent the hull at least substantially to the melting point of the ice, ice removing means operable upon said proximately disposed ice to remove said ice from engagement with the hull and from proximate juxtaposition to the hull, and means cooperating between the hull and the ice removing means for supporting the ice removing means on the hull adjacent the gunwale and for movement of the ice removing means along at least a portion of the circumference of the hull.

12. Apparatus according to claim 11, wherein the ice removing means is arranged for operative ice removing engagement with ice extending from above the hull waterline to adjacent the bilge of the hull.

13. A method for maintaining the position of a structure connected to the bottom of a body of water and penetrating the surface of the water in the presence of ice moving across the water surface, the method comprising the step of melting the ice proximate the structure at a rate which is at least equal to the rate of movement of the ice toward the structure.

14. The method according to claim 13 wherein the melting step is performed by applying heat to the ice from the portions of the structure which would be forcefully engaged by the ice in the absence of performance of the melting step.

15. The method according to claim 14 including controlling the rate of heat application to the ice in relation to the rate of movement of the ice toward the structure.

16. A method for maintaining the position of a structure engaged with the bottom of a body of salt water and extending through the water surface in the presence of ice moving across the water surface, the method comprising the step of heating ice proximate the structure to a temperature which approaches the melting point of the ice and which is adequate to weaken the ice sufficiently that the structure is effective to break through the ice by reason of the strength and resistance of the structure to loads applied laterally thereto.

17. A method for producing or accommodating relative lateral motion between an ice layer formed over a body of salt water and a structure disposed in the water and extending through the surface thereof, the method comprising the steps of applying thermal energy from the structure to ice proximate to the structure in quantities and at rates sufficient to heat the ice proximate the structure to a temperature which is within about 2° C of the melting point of the ice, and mechanically reducing the weakened ice to pieces sufficiently small to pass readily around the structure.

18. Apparatus for facilitating relative motion between an ice sheet overlying a body of salt water and a structure disposed in the water and extending through the surface thereof comprising heat transfer means disposed along each discrete portion of the structure which is adapted to penetrate the water surface at the

location on said portion of penetration and extending vertically along the structure for a distance at least equal to the thickness of a maximum thickness ice sheet expectable at a selected site of intended use of the structure during a selected period of use of the structure, means for energizing the heat transfer means sufficiently to cause the heat transfer means to heat ice disposed proximately adjacent the heat transfer means at least substantially to the melting point of the ice, and means for moving the heat transfer means vertically along the structure.

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